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Current Status and Development Trend of Research on The Interaction Mechanism Between Large Building Foundations in Goaf Sites

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Abstract: With the acceleration of urban development and industrialization, the construction of large buildings in goaf sites is becoming increasingly common. The goaf site has characteristics such as underground cavities and weak soil layers, which pose significant challenges to the safety and stability of the foundation of large buildings. This article aims to systematically explore the interaction mechanism between goaf sites and large-scale building foundations, analyze the current research status, and look forward to future development trends. Through a comprehensive literature review and case analysis, this article summarizes the influencing factors of goaf sites on the foundation of large-scale buildings, while elaborating on the challenges currently faced by research and proposing possible future research directions.

Keywords: Large scale building; Foundation interaction in goaf.

1. Introduction

1.1. Background Introduction

With the acceleration of urbanization, more and more large-scale construction projects are starting to be built on goaf sites. Due to the characteristics of underground cavities and weak soil layers, the goaf site poses significant challenges to the safety and stability of the foundation of large buildings. Therefore, the importance of studying the interaction mechanism between large building foundations in goaf sites is self-evident. This article will elaborate on the importance of studying this issue from the perspectives of practical needs, economic benefits, personnel safety, and engineering sustainability.

1.2. Related definitions

The interaction mechanism between the foundation of large buildings in goaf refers to the mechanical, geological, hydrological and other aspects that occur between the foundation of large buildings and the surrounding goaf site in urban construction. A goaf is usually a void area formed by mineral mining or other human activities, and its geological characteristics and soil structure are significantly different from naturally formed surfaces. The foundation of a large building is the structural foundation that supports the building, and its load and structural characteristics directly affect the safety and stability of the building.

The study of this interaction mechanism is of great significance for universal urban construction and engineering design. Firstly, the presence of goaf sites may have varying degrees of impact on the foundations of buildings, such as foundation settlement, tilting, and other issues. Secondly, the goaf site may alter the mechanical properties of the surrounding soil, thereby affecting the stress situation of the building foundation. In addition, changes in groundwater levels may also create complex interactions between goaf and building foundations, affecting the stability of buildings.

The definition of the interaction mechanism between the foundation of large buildings in goaf is helpful for a deeper understanding of the soil structure interaction mechanism in this special situation. By exploring these mechanisms, scientific basis can be provided for urban planning and the design of large buildings to ensure their safety and stability under goaf site conditions. In addition, with the continuous advancement of urbanization, more and more construction projects may face the situation of goaf sites. Therefore, in-depth research in this field will help provide more reliable technical support for future engineering design and construction.

1.3. Research meaning

In terms of practical needs, large-scale construction projects on goaf sites are not uncommon, such as factories, sports arenas, commercial centers, etc. Studying the interaction mechanism between the foundation of large buildings in goaf sites can provide technical support and guidance for practical engineering, ensuring project quality and safety, avoiding deformation or tilting of buildings during use, and improving the reliability and stability of the project.

In terms of economic benefits, due to the special nature of the goaf site, targeted technical measures are required in the engineering design and construction process. By studying the interaction mechanism between the foundation of large buildings in goaf sites, reasonable design and construction plans can be developed based on their characteristics, effectively reducing engineering investment and construction costs, and improving the sustainability and economic benefits of buildings.

From the perspective of personnel safety, there are various hidden dangers in the construction of large buildings in goaf sites, such as foundation settlement, earthquakes, water inrush, and other issues. By conducting in-depth research on the interaction mechanism between large building foundations in goaf sites, we can better understand the properties and behavioral patterns of underground media, predict and prevent geological disasters in a timely manner, and protect the safety of workers.

In summary, studying the interaction mechanism between large building foundations in goaf sites has important practical significance and far-reaching impact. It can not only improve the safety and stability of large buildings, reduce engineering investment and construction costs, protect the safety of workers, but also help promote the sustainable development of cities. Therefore, research in this field has important theoretical and practical value, and is worthy of further exploration and study.

2. Interaction Mechanism Between Goaf Site and Large Building Foundation

2.1. Characteristics of goaf sites

The hydrogeological characteristics of goaf sites are mainly influenced by their formation background and geological structure, which are of great significance in studying the interaction between large building foundations and goaf sites. The following are the common hydrogeological characteristics of goaf sites:

Loose geological structure: The site of goaf is often prone to loose geological structure due to mineral mining and other activities. The voids and cracks formed after the mining of the original ore body reduce the compactness of the soil, affecting its bearing capacity and deformation resistance.

Complex hydrological conditions: Due to the presence of goaf, the groundwater level may exhibit complex changes in these areas. The voids in the goaf may become channels for groundwater, leading to instability of water levels. This complex hydrological condition has a direct impact on the stability of large building foundations.

Soil composition differences: The soil composition in the goaf site may differ significantly from the surrounding areas. During the process of ore mining, different types of soil or slag may be mixed in, resulting in soil heterogeneity within the site and increasing soil heterogeneity.

A deep understanding of the hydrogeological characteristics of goaf sites can help to understand the mechanism of interaction between large building foundations and goaf sites. This provides important information for engineering design, helping to develop a reasonable foundation design plan to ensure the safety and stability of buildings under the conditions of goaf sites.

2.2. Characteristics of Large Building Foundation

The structure and load of large building foundations have some unique characteristics when interacting with goaf sites, which directly affect the performance and stability of the foundation under special geological conditions.

Adaptability of infrastructure: Due to the geological characteristics of the goaf site, the foundation structure of large buildings needs to have certain adaptability to cope with the irregularity of underground space and changes in geological conditions. Flexible infrastructure design is the key to ensuring uniform force distribution at different locations on the foundation.

The challenge of bearing capacity: The soil in the goaf site may be loose or uneven due to ore mining, which poses a certain challenge to the bearing capacity of large building foundations. Reasonable engineering methods must be used to enhance the bearing capacity of the foundation and ensure the safety of the building.

Uneven distribution of loads: The irregular surface morphology of the goaf site may lead to uneven distribution of foundation loads. This uneven load distribution may cause local settlement or deformation of the foundation, so it is necessary to solve this problem through accurate load analysis and reasonable foundation design.

The influence of hydrological conditions on loads: The groundwater level may undergo drastic changes within the goaf site, directly affecting the stability of the foundation. The load characteristics of the foundation under different hydrological conditions need to be fully considered to ensure that the foundation can remain stable under both wet and dry conditions.

In the process of studying the interaction between large building foundations and goaf sites, it is necessary to fully consider the characteristics of these structures and loads in order to develop scientifically reasonable engineering design schemes, ensuring the safety and long-term stability of buildings under complex geological conditions. This is also an important research conducted to adapt to the increasingly common situation of goaf sites in urban construction.

2.3. Interaction mechanism

The relationship between the goaf site and the foundation of large buildings is a complex problem involving multiple disciplines such as geology, structural engineering, and hydrogeology. Here are some important aspects of the relationship between the two:

Adaptation of foundation to goaf characteristics: The design of large building foundation needs to consider the special characteristics of the goaf site, including loose geological structure, complex hydrological conditions, irregular surface morphology, etc. The infrastructure should have adaptability to cope with changes in the geological environment of the goaf.

The relationship between basic bearing capacity and geological characteristics: The soil in goaf sites may become loose and heterogeneous due to mining, posing challenges to the bearing capacity of the foundation. Through in-depth geological surveys and foundation design, it is necessary to ensure that the foundation has sufficient bearing capacity at different locations.

Changes in groundwater level and foundation stability: The groundwater level in goaf sites may undergo drastic changes due to the influence of surface and underground space. This hydrological condition has a direct impact on the stability of large building foundations, which may lead to settlement or uneven deformation of the foundation.

The correlation between foundation load and surface morphology: The surface morphology of the goaf site may be irregular, which affects the distribution of foundation load. In the design, it is necessary to consider the changes in surface morphology to ensure uniform distribution of foundation loads and avoid local overload or excessive settlement.

Underground space affects building structure: The existence of goaf may lead to changes in underground space, directly affecting the stability of building structure. The basic structure design must consider the potential impact of underground space changes on the building structure and adopt corresponding design methods to ensure the stability of the structure.

The dynamic nature of interaction: The interaction between the goaf site and the building foundation is a dynamic process that involves multiple aspects such as soil deformation and groundwater flow. In design and construction, continuous monitoring and adjustment are necessary to adapt to changes in geological conditions.

Overall, understanding the interrelationship between the goaf site and the foundation of large buildings is key to ensuring the success and safety of the project. This involves collaborative efforts across multiple disciplines to fully consider geological conditions, structural characteristics, and hydrogeological factors, ensuring the reliability and stability of buildings in complex geological environments.

2.4. Analysis of influencing factors

Geological features: The geological features of the goaf site have a significant impact on the foundation of large buildings. Factors such as soil type, geological structure, and underground rocks directly affect the bearing capacity and stability of the foundation.

Groundwater level: Groundwater level is a key hydrological factor. The goaf may affect groundwater flow and water level distribution, thereby directly affecting the stability of the foundation. The changing groundwater level may lead to the risk of foundation settlement or uneven settlement.

Soil deformation: Soil deformation caused by mining activities is an important factor affecting foundation stability. The settlement, shrinkage, or expansion of soil directly affect the performance of the foundation, so these deformation characteristics need to be considered in the design.

Surface morphology: The surface morphology of the goaf site may exhibit irregular features, such as pits, hills, etc. This change in surface morphology will affect the distribution of foundation loads and needs to be reasonably considered in the design to prevent local overload or uneven settlement.

Basic structural characteristics: The structural characteristics of building foundations, including form, type, and material selection, directly affect their adaptability and stability in goaf sites. The flexibility and strength of the structure need to meet the requirements of geological conditions.

Load transfer mechanism: The goaf site may cause changes in the load transfer mechanism, including the interaction between the foundation and soil. Understanding the mechanism of load transfer is crucial for proper design and strengthening of foundations to ensure that loads can be effectively transmitted to stable geological formations.

By considering these factors comprehensively, we can gain a more comprehensive understanding of the interrelationship between the goaf site and the foundation of large buildings, providing guidance for scientific and rational engineering design and implementation.

3. Current Situation Analysis

3.1. Domestic research status

The main research results on the interaction between goaf sites and large building foundations include in-depth analysis of geological characteristics, groundwater levels, soil deformation, surface morphology, foundation structural characteristics, load transfer mechanisms, monitoring and adjustment, environmental factors, and risk management. This provides comprehensive guidance for scientific and rational engineering design and implementation. Research results in related fields in China mainly cover geological exploration, hydrological impact analysis, structural adaptability, exploration of load transfer mechanisms, real-time monitoring and risk management, and engineering case analysis. These achievements provide effective solutions for construction projects under complex geological conditions.

Professors Chen Shaojie, Chang Xikun, and others have conducted specific research on large-scale building technology in goaf areas and have achieved important results. Coal is the main energy source in China, and while ensuring China's energy supply, it has also formed a large number of goaf areas. With the rapid development of China's economy, there is a need for sufficient construction land supply. At the same time, the pressure on farmland protection in China is very prominent, and the construction utilization of coal mining subsidence land has become an effective way to alleviate the contradiction between construction land shortage and farmland protection in China. The construction of new buildings (such as natural gas pipelines, factories, bridges, dams, high-rise buildings, etc.) above the goaf may cause "secondary activation" of the old goaf due to factors such as surface building loads, overburden mechanical strength damage, and other external disturbances or their coupling effects, resulting in additional movement and deformation of the surface, leading to disasters such as settlement, local cracking, tilting, and collapse of surface buildings (structures), seriously affecting and endangering the planning, construction, and safe operation of buildings (structures) above the goaf.

Qian Minggao focused on analyzing the balance relationship of key blocks based on the research of masonry beam structures, and proposed the "S-R" stability condition for the sliding and rotational deformation instability of key blocks in masonry beams; Miao Xiexing analyzed the stability of the first pressure on the roof of the mining area and provided the instability criteria for the first pressure on the roof; Hou Zhongjie provided a more accurate size of the angular contact surface at the turning end of the rock block in the old roof fracture, and calculated the type judgment curves for sliding instability and turning instability respectively. Huang Qingxiang et al. established a "short masonry beam" and "step rock beam" structural model for the periodic pressure on the old roof of shallow buried coal seam mining sites, analyzed the stability of the roof structure, and revealed that the mechanism of obvious pressure on the shallow buried working face and the sinking of the roof steps is the sliding instability of the roof structure. They provided a calculation formula for the support force to maintain the stability of the roof structure: there are two important parameters in the stability criterion of the old roof structure of the mining site, namely the end angle friction coefficient between the key block of the old roof and the rock mass in front, and the end angle compression coefficient between the rock blocks. The size of these two parameters directly affects the stability of the roof structure and the judgment of the instability form. Quantitative analysis of the control of the roof rock layer in the mining site is crucial. Huang Qingxiang et al. We conducted block experiments, similarity simulations, and computational simulations to study the characteristics of end angle friction and end angle compression of old roof rock blocks, The end angle friction angle of the old roof rock block is determined as the residual friction angle of the rock, and the friction coefficient is determined as the end angle compression strength, which is significantly affected by the weak surface; In addition, Zhong Xingu used mutation theory to analyze the initial conditions for the deformation and instability of the coal mine longwall working face roof, derived the bifurcation set of deformation and instability, pointed out the condition that the roof does not undergo large-scale compression, analyzed the stability of the hard roof of the mining area using the elastic stability theory of the roof, and proposed a critical stability parameter model for the roof of the mining area when subjected to large-scale roof compression. With the help of structural stability theory, the deformation and instability mechanism of the "three hinged arch" structure and "masonry beam" structure of the working face roof were analyzed. The geometric and load parameter conditions for roof deformation and instability were established, and the standard and calculation formula for determining the reasonable support stiffness were proposed. At the same time, it was pointed out that the rheological behavior of the roof rock layer would reduce the bearing capacity of the roof structure and promote deformation and instability.

Based on the movement characteristics of overlying rock blocks in top coal caving mining, Run Shaohong and Jia Guangsheng introduced the theory of finite deformation mechanics and proposed a quantitative discrimination formula for the stability of upper rock structural planes. On the basis of the "masonry beam" and "transmission rock beam" theories, Jiang Fuxing proposed the "rock mass index method" for quantitatively diagnosing the structural form of the old roof based on the viewpoint that "quantitative changes in rock mass cause qualitative changes in the structural form of the old roof". On this basis, the principle of expert system was adopted to achieve computer automatic analysis of bar charts to obtain the form of the old roof structure and the motion parameters of the direct roof, thereby realizing quantitative design of roof control; Hao Qinxia et al. proposed a method for predicting mine pressure manifestation using multi model soft sensing. The pressure prediction model based on EEMD-SVM-ARIMA soft sensing has high accuracy and can well reflect the deformation law of pressure, meeting the needs of safety production. With the development of computer network technology, more and more intelligent algorithms are being applied to mine safety systems, such as using wavelet and chaos optimization processing to predict roof pressure, which has achieved good prediction results, but the time cost consumption is too high. Some scholars have proposed using a grey model to predict working face pressure, and using particle swarm optimization algorithm for parameter selection in the grey model, thus achieving good prediction results.

Starting from the study of surface subsidence control, the Gao Yan method proposed the "four zones" model of rock movement. Ma Qingyun considered the system engineering of mining pressure control, special mining, and surface control from the perspective of the movement process of rock layers and the structural characteristics after the completion of rock movement. He divided the overlying rock layers after destruction and movement into five zones or the "five zones" model. Wu Lixin and Wang Jinzhuang established the theory of support plate for overburden failure in strip mining. Su Zhongjie and Yu Guangming applied fractal and damage mechanics to study the nonlinear effects of rock strata on surface subsidence during mining subsidence. Based on the mechanical model of composite plate deformation, Yang Lun et al. derived a formula for quantitatively calculating the separation position according to the overlying strata layer, thickness, and physical and mechanical properties, and proposed the theory of secondary compression of rock layers; Guo Weijia divided the layered composite rock mass of coal seams into rock groups based on hard rock layers, and applied elastic theory to provide the stratigraphic, constraint boundary, and spatial development characteristic equations of the subsidence, bending, and separation layers of overlying strata; Liu Limin used factor analysis and regression model optimization methods to obtain the optimal regression equation and corresponding regression coefficients between the height of the water conducting fracture zone in the roof of gently inclined coal seam mining and the weighted average of the coal seam mining thickness and the unidirectional compressive strength of the roof rock layer; Zhang Dingli conducted an in-depth analysis of the activity characteristics and processes of the overlying rock strata on the longwall mining face of coal mines based on the structural characteristics of layered rock masses in coal bearing strata. He proposed three basic modes of overlying layered rock mass movement and also analyzed the types and control characteristics of delamination; Wu Kan, Wang Yuehan, and others conducted research on the subsidence characteristics of overlying strata under repeated mining conditions, and derived calculation formulas for the subsidence coefficients of the surface and internal rock mass under repeated mining conditions. In addition, grey system theory, fuzzy mathematics methods, fractal theory, and neural network methods have achieved some results in this field. Zhang Wenyi, Zeng Bing, and others conducted research on the method of classifying and predicting the height of overlying rocks using fuzzy mathematics and artificial neural networks; Jiang Fuxing established a rock quality index characterization system using fuzzy mathematical methods from the perspective of overburden structure and roof control. On the basis of summarizing the experience of predecessors, Xu Yanchun et al. proposed using the comprehensive evaluation coefficient of overlying rock mass properties - the 'P' coefficient method to predict fracture height. This method is still based on the empirical formula of predecessors and further considers the lithology of overlying rock, using modern mathematical methods, and has not yet been widely applied.

3.2. Current Status of International Research

Foreign scholars' existing research results mainly use physical (mechanical) methods to complete pressure numerical calculations by constructing pressure space structure models. Bienkiewic et al. used an orthogonal decomposition method for pressure reconstruction to analyze the pressure part, calculate the pressure space related parameters, and complete the construction of the mechanical model. Bilim et al. established a time-dependent relationship between the hardness of the working face and the roof pressure by analyzing the hardness and mining efficiency of coal and calculating the pressure values exerted on the working face by the mining pressure. Based on the results of these analyses, the optimal waiting time before mining has been determined in terms of supporting safety and mining productivity. Szurgacz et al. designed a wireless system for continuous monitoring of bracket pressure installed on a power roof bracket. For the first time, long wall wireless multi-channel signal transmission has been achieved, in which data archiving enables continuous access to study recorded waveforms and support inference and prediction under certain conditions.

After coal seam mining, the overlying rock is damaged and moved. At present, there is a relatively consistent understanding of the state of overburden failure and movement, that is, overburden failure and displacement have obvious zoning characteristics, and the characteristics of each zone are closely related to geological, mining and other conditions. In the working face where the full collapse method is used for mining, as long as the mining depth reaches a certain depth (about 100m), there will be three representative parts of the overlying rock failure movement: the collapse zone, the fracture zone, and the bending zone, which is the viewpoint proposed in the typical "upper three zones" theory.

4. Development Trends and Prospects

4.1. Future research directions and prospects

Firstly, we can start with the definition and characteristics of large buildings in goaf areas to understand their unique problems on the foundation. The goaf usually refers to the hollow area formed after underground coal mines or other mineral deposits are mined. In this context, large buildings may need to establish foundations on these goaf areas, but this will pose a series of challenges.

Unstable geological conditions: The geological conditions of goaf areas are usually affected by mining activities, which may lead to uneven and unstable underground structures. This makes it more difficult to build foundations for large buildings in these areas.

Environmental impact: Large buildings in goaf areas may have certain impacts on the surrounding environment, including groundwater level, soil stability, and other aspects. Therefore, it is necessary to consider the potential impact of construction activities on the surrounding environment in order to develop appropriate environmental protection measures.

In summary, addressing the challenges of the interaction mechanism between the foundations of large buildings in goaf areas requires in-depth engineering geological and structural engineering research to ensure that buildings can exist safely and stably under such geological conditions.

5. Conclusion

This article introduces the relevant definitions of the interaction mechanism between the foundation and ground of large buildings in goaf to discuss the content of the renovation. Through specific descriptions of the background, research status, research results, current limitations, and future research prospects, readers can have a better understanding of the research content of the interaction mechanism between the foundation and ground of large buildings in goaf.

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