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Research Status and Prospect of Fan Foundation in Goaf Site

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Abstract: With the development of wind energy resources, wind power has become one of the important clean energy. However, the stability and bearing capacity of wind turbine foundation directly affect the long-term operation of wind power projects, especially in complex geological conditions such as goaf. The goaf refers to the cavity area left after underground mining. The geological structure of these areas is unstable, and there may be phenomena such as settlement and displacement, which poses a serious challenge to the safety of the wind turbine foundation. Therefore, it is the key to ensure the successful implementation and operation of wind power projects to study the design and stability of wind turbine foundation in goaf. At present, the research on the fan foundation in the goaf mainly focuses on the foundation treatment, foundation design and structural optimization. The foundation treatment technology includes soil reinforcement, settlement compensation and other methods to improve the bearing capacity and stability of the soil in the goaf. In terms of foundation design, according to the geological characteristics of the goaf, the researchers proposed a variety of wind turbine foundation forms, such as shallow foundation, pile foundation and deep foundation, to adapt to different geological conditions. However, there are still some challenges in the current research, including how to predict the settlement law of the foundation in the goaf more accurately, how to optimize the design of the wind turbine foundation to improve the seismic resistance and tilt resistance, and how to improve the long-term stability of the foundation. With the development of artificial intelligence, big data and intelligent monitoring technology, future research is expected to further improve the design accuracy and reliability of fan foundation in goaf by combining advanced calculation methods and material technologies.

Keywords: Goaf management; wind turbine foundation; goaf foundation; form of foundation failure.

1. Introduction

With the transformation of the global energy structure and the increasing demand for clean energy, the development and utilization of wind energy as a green renewable energy has received extensive attention[1]. Especially in China, due to the large-scale exploitation of coal resources and the continuous expansion of goaf area, the development of wind energy resources in these areas has become a new research direction. The particularity of the goaf site lies in its complex geological conditions and poor ground stability, which puts forward higher requirements for the stability and safety of wind turbines. In recent years, researchers have devoted themselves to the development of wind turbine infrastructure suitable for goaf sites to adapt to their special geological and environmental conditions. These studies not only involve the basic design of wind turbines, but also include correction techniques, structural health monitoring, and impact assessment on the stability of mined-out area sites.The development of these technologies is of great significance for improving the reliability of wind turbines, extending the service life and reducing maintenance costs. Therefore, it is of great practical significance to analyze the research status of wind turbines in goaf site for promoting the progress of wind power technology and the rational utilization of goaf resources.

2. Factors Affecting the Stability of Goaf Site

The stability of the goaf is affected by many factors[2], which can be divided into geological factors, mining methods, external loads and environmental factors. These factors are different in different mines and different geological conditions. Therefore, various influencing factors must be considered comprehensively when analyzing the stability of goaf.

2.1. Geological conditions

Geological conditions are the most direct factors affecting the stability of goaf. The structural characteristics of the ore body (such as layers, faults, joints, fracture zones, etc.) and the properties of the surrounding rock (such as rock strength, elastic modulus, rock dip angle, etc.) directly determine the stability of the goaf. In areas with relatively hard rock strata, the stability of the goaf is usually better, but in areas with broken rock strata and complex faults, the goaf is prone to collapse and cause instability.

In addition, the distribution of groundwater and hydrogeological conditions will also affect the stability of the goaf. Groundwater immersion will reduce the strength of rock strata, resulting in expansion or fracture of rock strata, thus affecting the stability of goaf.

2.2. Mode of mining

Mining method is an important factor affecting the stability of goaf. Different mining methods (such as open-pit mining, underground mining, long-wall mining, etc.) will have different effects on the shape and stability of the goaf. For example, in underground mining, the mining and supporting methods of ore bodies directly determine the deformation and stability of goaf.

The longwall mining method is widely used because of its high efficiency, but in the process of mining, a large goaf is often produced, which makes the stability of the goaf poor.

Other methods such as 'roof support ' or 'short wall mining ' can reduce the size of the goaf to a certain extent and improve its stability.

2.3. External load

The external load refers to the additional stress caused by the ground buildings, roads and other loads acting on the goaf during the mining activities. These external loads often generate additional deformation pressure on the goaf, which in turn affects the stability of the goaf. With the deepening of mining, the influence of external load is gradually increasing, and the stability of goaf is becoming more and more fragile.

2.4. Environmental factors

Environmental factors, especially climate change and groundwater flow, are also one of the factors affecting the stability of goaf. For example, natural disasters such as rainstorm and strong wind may lead to the instability of surrounding rock in goaf, resulting in collapse or settlement. In addition, fluctuations in the groundwater level, especially in arid areas, water infiltration may also have an adverse effect on the mined-out area and reduce its stability.

3. Analysis Method of Goaf Site Stability

The stability analysis of goaf site is a complex process, involving mechanics, geology, computer simulation and other disciplines. Commonly used stability analysis methods include theoretical analysis, numerical simulation, and experimental methods. These methods have their own advantages and disadvantages and are often used in combination.

3.1. Theoretical analysis

The theoretical analysis method mainly evaluates the stability of goaf through mechanical model and theoretical derivation. Common analysis methods include limit equilibrium method, static equilibrium method and mechanical model method. By assuming the stress conditions and failure modes of the goaf, the safety factor of the goaf is calculated, and then its stability is evaluated.

Based on the classical theory of geomechanics, the limit equilibrium method is used to judge the stability of the goaf by assuming the equilibrium state of the force in the goaf. This method is simple and easy to use, and is suitable for general goaf analysis. However, for the complex ore body structure and uneven geological conditions, the applicability of the limit equilibrium method is poor.

3.2. Numerical simulation method

With the development of computer technology, numerical simulation method has become an important means of goaf stability analysis. Common numerical simulation methods include finite element method (FEM), discrete element method (DEM) and boundary element method (BEM). These methods simulate the stress, deformation and failure process of goaf under different working conditions by establishing numerical models of goaf and surrounding rock mass.

The finite element method divides the goaf into multiple finite elements, calculates the stress, strain and displacement of each element, and obtains the overall stability of the goaf. The discrete element method is suitable for studying the failure process of the goaf by simulating the interaction between particles and analyzing the particle fracture and slip in the goaf.

The numerical simulation method can deal with complex geological conditions and irregular ore body structure, which provides a more accurate evaluation tool for the stability analysis of goaf.

3.3. Experimental method

The experimental method mainly evaluates the stability of the goaf through physical model tests in the field or laboratory. By simulating the actual mine

The wind turbine foundation is an important part of the wind turbine, and its stability directly affects the efficiency and safety of wind power generation. With the increasing scale of wind turbines, the failure mechanism of wind turbine foundation has gradually become an important factor affecting the safety and long-term operation of wind power generation projects. Based on the stress analysis of wind turbine foundation and combined with practical engineering cases, this paper discusses the main mechanism of wind turbine foundation failure, analyzes the foundation stress mode, common failure modes, influencing factors and failure mechanism, and puts forward the protective measures in the design and construction of wind turbine foundation, which provides a theoretical basis for the optimal design of wind power generation foundation.

4. Control Technology of Goafs

The governance of goaf should first determine the governance requirements and carry out functional design, which mainly includes two aspects[3] : structural governance requirements and strength governance requirements. Both of them are determined by the shape of goaf and the conditions of proposed buildings (structures). The shape of the mined-out area generally includes the overlying rock conditions, coal mining methods, development stages, etc. The conditions of the building (structure) are generally the use requirements, foundation forms, load conditions, etc.

4.1. Filling treatment technology

After ascertaining the scope of the known goaf, combined with the importance of the ground protection object, whether it is a mine under construction or an abandoned mine, filling treatment is an effective means to effectively control the deformation of the goaf and prevent the surface displacement caused by the instability of the goaf. For the coal mines that are being produced, there are various filling methods in the goaf, which can be filled by ground grouting in combination with mining layout and mining methods. It can also be combined with the roadway layout, and the underground filling can be carried out while producing. The filling material can give priority to the surrounding rock and coal gangue produced in the mine construction or production process. For abandoned mines, regional full filling or partial filling can be selected according to the relative position and important grade of surface buildings (structures), highways, railways and goafs. The filling treatment method is to use existing boreholes or re-boreholes to goafs, and then use materials such as cement, sand or fly ash to fill goafs.

4.2. Roof blasting control technology

Roof blasting is to use caving surrounding rock and roof to fill the goaf and form a buffer protection cushion to prevent the danger caused by the sudden collapse of the roof. This is a pretreatment method. If the buried depth of the goaf is shallow, it is easy to cause surface cracking and collapse. This method is suitable for the surface without important protection objects. In the short term, it is not used as a development or construction area.

5. Common Failure Forms of Wind Turbine Foundation

The damage of wind turbine foundation is mainly manifested in the following forms :

Foundation settlement : Foundation settlement is one of the most common forms of wind turbine foundation damage[4]. The reason for the settlement of the foundation is mainly due to the insufficient bearing capacity of the soil or the excessive deformation of the foundation soil, which leads to the settlement of the foundation and affects the stability of the fan. The settlement of the foundation not only affects the overall level of the fan, but also may lead to the tilt of the fan tower, increase the load of the fan, and even lead to the overall collapse of the fan.

Foundation tilt : When the foundation is unevenly stressed, it will cause the foundation to tilt. The inclination of the fan foundation will not only affect the operation accuracy of the fan, but also may cause structural instability, which may lead to the damage of the fan. The reason of foundation tilt is usually due to the unreasonable design of foundation, the change of geological conditions or improper construction.

Pile foundation damage : Pile foundation damage is a common form of damage in wind turbine foundations using pile foundations. The failure of the pile foundation is usually manifested as the fracture, deformation or settlement of the pile body, which will lead to the instability of the whole wind turbine foundation in severe cases. The failure of pile foundation is often related to the bearing capacity of pile, the friction between pile and stratum, the construction quality of pile and so on.

Fatigue failure : During the operation of the wind turbine, the foundation will undergo periodic dynamic loads due to the influence of wind load and mechanical vibration. Long-term periodic load will lead to fatigue failure of foundation materials, especially in the case of large dynamic load, the risk of foundation failure is higher.

Soil liquefaction : Under the action of earthquake or other vibration load, some soil layers may be liquefied. Soil liquefaction causes the foundation to lose its supporting force, which is an important reason for the failure of wind turbine foundation, especially in areas with frequent vibration or high water level.

6. Influencing Factors of Foundation Damage of Wind Turbine

The failure mechanism of wind turbine foundation is affected by many factors, including the following aspects:

6.1 Load factor : The load of wind turbine foundation includes static load and dynamic load[5]. The static load is mainly caused by the weight and prestress of the wind turbine itself, while the dynamic load is caused by the periodic changes of wind and rotation. Long-term exposure to these loads, especially dynamic loads, can lead to fatigue of the base material and eventually damage.

6.2 Geological conditions : The stability of wind turbine foundation is closely related to geological conditions[6]. The bearing capacity, compressibility, permeability and groundwater level of the soil will affect the stability of the foundation. Poor geological conditions may lead to uneven settlement of the foundation and increase the risk of damage.

6.3 Design defects : Failure to fully consider all possible load and environmental factors in the design, or the use of inappropriate materials and structural forms, may cause the foundation to fail to withstand the expected load in actual use, resulting in damage[7].

6.4 Extreme weather : Extreme weather events, such as strong winds, earthquakes, etc., may cause sudden and huge impacts on the wind turbine foundation, exceeding the load range considered in the design, resulting in foundation damage.

7. Conclusion

The research status of wind turbine foundation in goaf site shows that this field is facing a series of challenges and progress. First of all, the geological conditions of the goaf are complex, which has a significant impact on the stability of the wind turbine foundation. The research shows that the goaf may induce ground collapse or cracking, which poses a threat to the safe operation of wind turbines. In terms of theoretical analysis, researchers have conducted in-depth discussions on the impact of goafs on the stability of wind farm sites, including the development characteristics of coal seam goafs and the impact of mining on the site. These theoretical studies provide a scientific basis for the design and construction of wind turbine foundation.

In summary, the research status of wind turbine foundation in goaf site shows the progress in design, construction method and correction technology. These studies not only improve the stability and safety of wind turbines in the goaf site, but also provide technical support for the long-term stable operation of wind farms. With the continuous development and innovation of technology, it is expected that more solutions will be developed in the future to meet the special requirements of the goaf site.

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