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Ventilation Simulation and Gas Safety Risk Assessment for Non Coal on Gas Tunnel Construction

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Abstract: The construction of underground tunnels generally includes characteristics such as large scale, difficult conditions, long construction period, and strong concealment. Therefore, in the construction of subway tunnels, there are often safety issues that affect the quality of the entire project. In the process of underground tunnel construction, various factors that affect its safety should be carefully analyzed based on engineering practice, and scientifically and reasonably selected to ensure the safety and quality of the entire project. At the junction of tunnels and gas tunnels, it is necessary to correctly apply safety management measures for gas tunnel construction, prevent gas accidents, strengthen the effectiveness of safety management measures, and enhance ventilation stability during construction. This article aims to address the above issues and construct a gas safety risk assessment system based on the NCM (normal cloud model). The experiment has proven that the safety risk assessment and discrimination results of gas leakage in the system are III-IV, which is consistent with the reality of high oil and gas content at the construction site, susceptibility to gas overflow, and high risk of tunnel excavation.

1. Introduction

To ensure that the gas concentration in the mine does not exceed the safety limit, corresponding measures must be taken to minimize the actual ventilation time. It can not only reduce ventilation costs, but also improve ventilation efficiency, improve building environmental hygiene, and ensure the safety of workers' lives and property. During the construction of gas tunnels, the gas monitoring and warning system should be fully utilized to strengthen ventilation safety management. This article establishes a safety prevention and control system for harmful gases such as gas to prevent gas accidents, strengthen the effectiveness of safety control measures, and enhance the stability of tunnel construction ventilation. On this basis, combined with specific engineering examples, it deeply analyzed the ventilation optimization and safety control technology in gas tunnel construction.

Experts have conducted relevant research on ventilation and safety risk assessment techniques for gas tunnel construction. Due to insufficient data to explain the causes of pipeline failures and a lack of knowledge about the safety and security of offshore oil companies, these have hindered efforts to reduce these risks. To this end, Kraidi L proposed a complete risk management system that identifies, analyzes, and ranks potential risks, and evaluates them. His research utilized qualitative literature analysis methods to conduct semi-structural research on the current security risk factors and risk mitigation methods in Iraq's oil and gas pipeline project, and collected opinions from relevant parties on the project. On this basis, a computer risk assessment model is established based on probability and severity. At the same time, he proposed a method based on fuzzy comprehensive evaluation to evaluate the occurrence probability and result level of various risk factors in engineering. The investigation results indicate that terrorism, official corruption, and unstable regions are at risk [1]. Ping X I E conducts research on the exchange of existing mixed hydrogen natural gas in pipeline transportation systems, the adaptability of mixed hydrogen technology systems, and the safety issues of mixed hydrogen transportation pipeline equipment internationally. He proposed to improve the online/offline chromatography of gas phase composition in response to the current situation of China's natural gas pipeline network and the impact of hydrogen content, hydrogen and methane stratified flow. He studies the leakage and diffusion laws of mixed hydrogen gas in pipelines, arranges and sets up gas leakage detection devices under various leakage conditions, and establishes corresponding emergency plans [2]. Song Z has studied a new type of SINGOR (self-powered integrated nanostructured gas sensor) system with autonomous power supply function, and combined it with SINGOR wireless communication network. SINGOR, which operates at room temperature, is a silicon based solar cell based on indoor light sources. It has extremely high detection limits for gases such as hydrogen, formaldehyde, toluene, and acetone, with detection limits of 10, 2, 1, and 1 ppb, respectively. On this basis, a SINGOR system based on multiple Nano scale sensors is proposed. In addition, he wirelessly formed a sensor network with multiple SINGOR systems to detect and warn of combustible gases. Research has shown that even in a separate room, good leak detection accuracy can be achieved [3]. The above research only focuses on testing different gases and lacks an accurate risk warning and evaluation system. It is not enough to prevent the leakage of toxic gases and reduce the casualties of workers.

The safety construction of gas tunnels has always been highly concerned by the engineering community, and precise monitoring and timely prediction and treatment are important means to ensure their safety. This article conducts in-depth research on the safety risk management system for gas tunnel construction, exploring how to construct a ventilation simulation and gas safety risk assessment system for gas tunnel construction. The experiment verified the feasibility of the system by analyzing its scalability, interoperability, interactivity, and data process ability.

2. Gas Safety Risk Assessment and Ventilation Simulation for Gas Tunnel Construction

2.1 Current Status of Tunnel Construction Ventilation Technology

There are generally two types of ventilation during tunnel construction: tunnel ventilation and pipeline ventilation, which are ideal methods. Pipeline ventilation can be divided into three types according to its ventilation form: positive pressure, discharge, and mixing [4]. In positive pressure ventilation, a ventilation device is installed near the entrance to transport fresh air to the surface of the foundation pit through a ventilation pipe, thereby forcibly discharging the contaminated gas [5]. The advantages of this invention are that the installation position of the fan is fixed, the length of the pipeline is long, but there are problems such as slow smoke exhaust rate and high ventilation energy consumption. The method of pipeline ventilation is to set a ventilation hole near the front of the drilling hole that passes through the ventilation pipe, in order to discharge the unclean gas in the drilling hole into the front end of the drilling hole [6]. This method has the advantage of good smoke exhaust effect, but there is a need to move the position of the roadway and ventilation device forward, which affects engineering construction. In general, composite ventilation systems are only suitable for long-distance and highly ventilated passages [7].

Currently, the ventilation technology level of tunnels in China is relatively low, resulting in the ventilation effect of tunnels not meeting safety requirements [8]. If the safety requirements cannot be met, it would bring greater harm to tunnel construction. The most important issue in tunnel construction, especially in large-scale tunnel construction, is the quality of ventilation design [9]. The design of tunnel ventilation should consider both the environmental protection issues inside the tunnel and the environmental protection issues outside the tunnel. However, due to the fact that most tunnels are currently underground, how to provide safety protection has become a top priority in tunnel ventilation and environmental protection work [10].

2.2 NCM Model

The Normal Cloud Model (NCM) is currently the most widely used cloud model. A large number of studies have shown that under natural conditions, the average curves of many qualitative cloud models basically follow a normal distribution [11-12]. Normal clouds are a gas hazard level prediction method based on hyper entropy, which mainly uses numerical eigenvalues to predict E_x and E_n [13-14]. Among them, the expected value of domain E_x represents the intermediate value of the evaluation criteria for coal mine safety risk level; E_n is the fuzzy margin used to measure the strength level of rock burst when evaluating the strength level of rock burst. It is the range within which the evaluation index value can be accepted by the intensity level of rock burst when evaluating the level of rock burst, representing the condensation of clouds [15].

Definition of normal cloud (NCM): Suppose X is a discourse domain represented by a quantitative value, C is a qualitative concept on X. For x∈X, and X is a random realization of qualitative concept C. If there is: $x \sim N(E_x, E_n^{'2})$, where $E_n^{'} \sim N(E_n, H_e^2)$ and x have a certainty of C: $\mu = e^{-(x-E)^2/(2E_n^{'2})}$, the distribution of x on the discourse domain x is called a normal cloud [16].

For element x in the domain, the cloud model forward generator generates the certainty cloud of x versus qualitative C, which is a cloud model forward generator. The forward cloud generator utilizes the digital characteristic (E_x, E_n, H_e) of the cloud body to generate cloud droplets [17]. The calculation method and steps of the forward cloud generator are as follows:

(1) According to mathematical methods, the normal random number $E_n^{'}$ with E_x as expectation and H_e as variance was generated by programming in Matlab software.

(2) According to mathematical methods, a program was programmed in Matlab to generate a normal random number x with E_x as expectation and $E_n^{'}$ as variance.

(3) A cloud droplet can be obtained by calculating the degree of certainty $\mu = e^{-(x-E_n)^2/(2E_x^{'2})}$.

(4) Cycle the above steps to generate enough cloud droplets.

2.3 EAHP

The Enhanced Analytic Hierarchy Process (EAHP) was proposed by a Chinese expert in the

1980s. After more than 30 years of development, it has now formed a relatively complete system, and has played a great role in promoting practical applications. Object topological analysis is an organic combination of object analysis and cluster topological analysis. Its basic idea is to identify objects by using the three elements of "name, attribute and magnitude", and to describe the relationship between objects and classes through the degree of correlation between objects and classes. This model describes the interrelationships between groups, conducts in-depth analysis and exploration, and applies it to solve incompatible complex watershed management problems. EAHP addresses the compatibility issue of multiple indicators, inconsistent and incompatible evaluation results of a single indicator in the process of watershed governance, and addresses the compatibility issue of single indicator evaluation through methods such as object to object transformation [18].

2.4 Necessity of Establishing a Security Risk Control System

According to the major safety accidents that have occurred in the construction of gas tunnels in China in recent years, most of them are caused by inadequate safety risk management in construction projects. During the construction of gas tunnels, there are various risk factors, including the impact on worker safety. Among them, the construction environment is the most critical, and strict monitoring of it is a more favorable method to solve the major problems existing in the construction of gas tunnels. The gas content and blasting limit values in the mine are shown in Figure 1 [19].

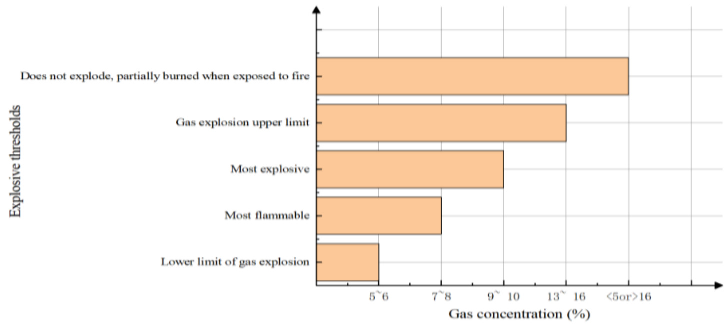

Figure 1: Tunnel Gas Concentration and Explosion Limits

With the development of tunnel mining technology, gas concentration monitoring technology has also achieved good development. This technology is no longer limited to gas concentration monitoring, but is organically integrated with geological exploration, prediction and other technologies to effectively control the safety risks throughout the entire process of gas tunnel construction. The risk monitoring system for gas tunnel construction can effectively integrate relevant parameters and ratios of gas concentration, achieving comprehensive, multi-angle, and three-dimensional monitoring. It is an important means to achieve safety in gas tunnel construction [20].

3. Risk Assessment Model for Gas Tunnel Construction

3.1 Construction of Evaluation Model

This article adopts a modified normal cloud to construct a fuzzy evaluation model for the construction risk of gas tunnels. According to equation (1), determine the expected value E_{xj}, entropy value E_{nj}, and super entropy H_{ej} of the evaluation indicators. ξ is the super entropy coefficient, taken as 0.1.

$$\begin{cases} E_{xj} = (C_{j\max} + C_{j\min})/2 \\ E_{nj} = (C_{j\max} + C_{j\min})/3 \\ H_{ej} = xE_{nj} + \xi \end{cases} \tag{1}$$

In the formula, $C_{j\max}$ and $C_{j\min}$ are the upper and lower limits of the evaluation interval for the jth indicator. Based on literature and construction experience, explore the classic and nodal domains of evaluation indicators.

Using MATLAB/EXCEL software to generate a normally distributed random number $E_{nj}^{'}$ as equation (2).

$$E_{nj}^{'} \sim N(E_{xj}, E_{nj}^{'2}) \tag{2}$$

In the formula, E_{xj} is the expected value; $E_{nj}^{'\,2}$ is the variance.

Calculate the uncertainty $u(x_j)$ of the variable x_j within the domain and form a cloud droplet $[x_j, u(x_j)]$.

$$u[x_j = e^{-\frac{(x_j - E_{xj})^2}{2E_{nj}^{'\,2}}}] \tag{3}$$

Calculate the combined weight $\delta(x_j)$ of the joint indicators, and calculate the comprehensive certainty U of the j indicators in each domain as equation (4).

$$U = \sum_{j=1}^{m} \delta(x_j) \cdot gu(x_j) \tag{4}$$

Using equations (1) to (4), combined with EXCEL and ORGIN software, calculate and draw a membership cloud model.

3.2 Calculation method for gas emission

During the construction process, the gas emission quantity q of the gas tunnel is the sum of the gas emission quantity q_1 of the unclosed section, the gas emission quantity q_2 of the closed section, and the gas emission quantity q_3 of the coal block waste during the excavation process.

(1) Gas emission from unclosed section

The amount of gas emission from newly exposed and unclosed sections during tunnel excavation can be calculated using the following formula:

$$q_1 = AQ_0 f(t) \tag{5}$$

In the formula: A is the area of newly exposed unsupported sections (m^2) every day, and $A = A_0 + SV$ when the same gas escapes from the rock wall and coal wall on the tunnel wall. In the formula, A_0 represents the area of the exposed excavation face (m^2), and S represents the perimeter of the tunnel section (m); V is the excavation footage (m). Q_0 is the initial intensity of gas escape per unit time and area. $f(t)$ is the time decay function.

$$f(t) = \exp(-\alpha t) \tag{6}$$

In the formula: α is the attenuation coefficient, which can be measured. When it cannot be measured, it can be calculated as $\alpha = 0.0047\lambda + 0.026d^{-1}$, and λ is the permeability coefficient of coal; T is the calculation time (d) of coal wall exposure.

(2) Gas emission from closed section

During tunnel excavation, fast closure and early lining should be achieved, but gas can still seep into the tunnel through small voids in the sprayed concrete or lining. The gas permeability is closely related to the gas content and pressure difference (i.e. the difference between air pressure and air pressure in the roadway) of the coal body (or coal seam). It is closely related to factors such as the permeability of surrounding rock and cementitious materials, as well as the airflow velocity in the channel. So, in gas tunnels, the commonly used method is to use the permeability coefficient method.

$$q_2 = [kA(P_1^2 - P_2^2)] \times 10^5 / (2h\gamma P_2) \tag{7}$$

Among them, K is the permeability coefficient of the sprayed concrete or secondary lining in this experiment, measured in meters per second; P_1 is the closed zone after gas pressure; P_2 represents the gas pressure inside the tunnel, in MPa; γ represents the gas volume in kilograms per cubic meter; A is the permeability in m2.

4. Engineering Practical Application

4.1 Project Overview

A certain tunnel is a 5005 meter long, 2-lane, and maximum depth of 384 meters tunnel on the Xinjiang Expressway. The tunnel is located in Suining, Penglai Town, and Shashimiao Jurassic. The construction strata are Qz~Qs sandy clay, gravel soil, and clay, with good geological conditions. The tunnel is an asymmetric inverted slope type, with inclined ends, open excavation faces, developed surrounding rock fractures, and strong groundwater. There are multiple sets of Jurassic heterogeneous gas reservoirs developed horizontally. In the field drilling, the average value of combustible gas measured in the borehole is 620 ppm, and the gas pressure test value is 186 MPa.

The experiment used cloud normal (NCM) and matter element extension (EAHP) to conduct risk assessment on the standard layer, and obtained consistency between the two methods. The gas geological environment of a certain gas tunnel belongs to four categories and is classified as a "serious" unsafe condition. The tunnel construction environment (R2) belongs to level 2 and is classified as "abnormal". The risk level for project construction projects (R3) and equipment projects (R4) is' attention to anomalies'.

4.2 Calculation Results

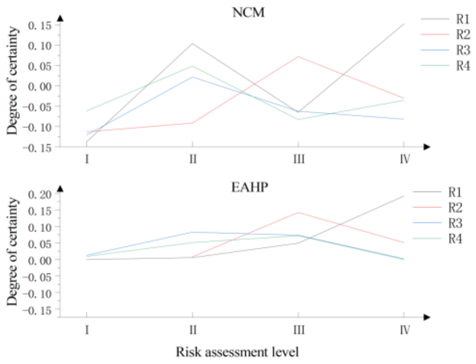

Figure 2: Determination of the evaluation level for the risk criteria layer of a certain gas tunnel construction

From Figure 2, it can be seen that the highest degree of certainty in the risk assessment level is the final discrimination result. The results of the discrimination criteria layers R1 and R2 for both algorithms are the same. When discriminating criterion layer R1, both results are IV. When determining the criterion layer R2, both results are III. However, in the discrimination criteria layer R3 and R4, there are differences between the two, as shown in Table 1.

Table 1: Discriminant results of different algorithms

Standardized layer	Algorithms	Discrimination results
R1	NCM	IV
	EAHP	IV
R2	NCM	III
	EAHP	III
R3	NCM	II
	EAHP	II~III
R4	NCM	II
	EAHP	II~III

Table 2: Results of Risk Assessment for a Gas Tunnel Construction

	Level of certainty of objectives				Results
	I	II	III	IV	
NCM	0.01214	0.05811	0.09124	0.08121	III~IV
EAHP	-0.11567	-0.03971	0.08124	0.071545	III~IV
BPNN	BP Projected results=3.5712				
Construction site	The site has a high oil and gas content and is susceptible to gas spills, making tunnelling a high risk.				

This article relies on Matlab software and combines sample parameters to construct a Backpropagation Neural Network (BPNN) prediction model for gas tunnel construction risk. It verifies the reliability of NCM and EAHP model algorithms. After constructing a BPNN prediction model for risk assessment of gas tunnel construction, this article performs inverse prediction on each sample in the experiment. The inversion calculation results are consistent with the actual results, verifying the reliability of the BPNN prediction model in this paper.

Table 2 is an analysis of the risk assessment for the construction of a gas tunnel. From Table 2, it can be seen that the prediction results of various methods have good consistency and can well reflect the risk level of the construction site. Among them, the evaluation obtained by NCM mode is

III-IV, the evaluation obtained by EAHP method is III-IV, and the evaluation value obtained by BPNN is 3.5712, reflecting the safety status of the tunnel as "abnormal to severe".

5. Conclusions

Therefore, in order to facilitate the construction of highway tunnels in construction projects, targeted treatment must be carried out and the entire construction process must be monitored in order to identify and eliminate dangerous factors, or to control the losses caused within a controllable range. This article explores the ventilation simulation and gas safety risk assessment of non coal based gas tunnel construction based on the above issues, constructs a gas safety risk assessment based on the NCM model, and verifies the operability of the risk assessment system through experiments, which can provide research directions for future research.

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