

Resilience Assessment of Deep Excavation Engineering Systems Based on Bayesian Network

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Abstract: As a key component of infrastructure, the construction safety of deep excavation is particularly important. In order to improve the safety and stability of Deep excavation construction, research on the risk resistance and rapid recovery capabilities of Deep excavation projects is carried out. By introducing the concept of resilience, we analyze the key factors that affect the safety and resilience of Deep excavation projects, use Bayesian networks to establish a resilience model that expresses the causal relationship between factors, and learn the parameters of the network model through data samples collected through surveys; by adjusting the network Analyze the relationship between each factor and system resilience at each node, and clarify the measures that should be taken and key control objects, thereby improving the system resilience and ensuring that normal construction can be carried out safely and orderly. Research shows that this model can be used to quantify the safety toughness value of deep excavation and reason and analyze the impact of various factors on the toughness value, thereby improving risk management and decision support capabilities.

Keywords: Infrastructure; Resilience; Deep Excavation; Bayesian Network.

1. Introduction

With the continuous advancement of urbanization and the increasing shortage of land resources, Deep excavation engineering, as an important underground space development method, has been widely used [1]. As a complex underground structure system, Deep excavation engineering system plays an important role in urban construction and underground space utilization [2]-[4]. However, due to the uncertainty of the complex underground environment and the influence of external factors, Deep excavation engineering systems face various risks and challenges in the design, construction and operation, such as geological disasters, groundwater seepage, soil instability, etc., which Factors may cause damage or even collapse of Deep excavation engineering systems, posing a threat to the safe and stable operation of urban infrastructure [5]-[7].

Therefore, it is particularly important to evaluate and improve the toughness of Deep excavation engineering systems [8]. Resilience, as the ability of a system to resist external shocks, maintain functional integrity, and quickly return to normal conditions, is crucial to ensuring that Deep excavation engineering systems have the ability to cope in the face of various uncertainties and risks [9]-[11]. In recent years, many scholars have studied the construction safety of foundation pits. Ling Shen[12] et al. analyzed the collaborative relationship of each subsystem in the face of internal interference and influence through the composition of the Deep excavation construction safety system; ugli Makhmudov [13] proposed a matrix to determine the hazard level by excavations in the soft soils of Bogotá, whose data provide a prior assessment that contributes to promoting resilience and sustainability of already developed areas; Huang H[14] proposed a general conceptualized framework to assess the resilience of UI in cities under multi-hazards impact. However, the current research on the resilience assessment of Deep excavation engineering systems lacks systematicness and scientificity, which results in certain

limitations in research and practice in related fields[15]-[17].

As a probabilistic graphical model, Bayesian network can effectively handle uncertainty and complexity, and is widely used in fields such as reliability analysis and risk assessment of engineering systems [18]. Therefore, introducing Bayesian network into the field of toughness assessment of Deep excavation engineering systems is expected to provide new ideas and methods for the toughness assessment of Deep excavation engineering systems. This article aims to construct a toughness assessment model for Deep excavation engineering systems based on Bayesian network, and explore the key indicator system and evaluation methods for the toughness assessment of Deep excavation engineering systems, so as to improve the response of Deep excavation engineering systems in complex underground environments. capabilities to promote the safe and sustainable development of urban underground spaces.

2. Resilience of Deep Excavation Engineering System

2.1. Deep Excavation Engineering System

Deep excavation engineering is an engineering form that excavates deeper pit walls above the ground to develop underground space [19]. It is usually used in urban construction projects, such as the development of underground spaces such as subway stations, underground shopping malls, and underground parking lots.

According to the engineering system elements and actual operational systems, the Deep excavation engineering system can be divided into geological and groundwater systems, structural support systems, drainage systems, monitoring and control systems, and emergency response systems. By abstracting the Deep excavation engineering into the corresponding Deep excavation engineering system, the Deep excavation engineering system can be understood as a complex system formed by the joint action of 5 subsystems.

2.2. The Meaning and Measurement of Resilience

The concept of resilience was first proposed by Canadian biologist Holling [20] in 1973 and applied to ecosystems. Subsequently, different disciplines intervened in research. The concept of resilience emphasizes that the system should have the ability to maintain or quickly recover its functions when disturbed, and to better cope with uncertainty through self-adaptation. This concept is in line with the systematic and complex characteristics of engineering.

The resilience of a Deep excavation engineering system refers to its ability to maintain stable structure and function and quickly return to normal status in the face of external shocks and uncertain factors. Specifically, it is the ability to withstand unfavorable factors such as geological disasters,

drainage system failure, and support system damage, ensuring the safe and stable operation of Deep excavation engineering systems.

As a complex comprehensive project, the Deep excavation project is affected by the combined effects of personnel, technology, environment and other factors during the entire construction process. When the Deep excavation engineering system is impacted and disturbed by many risk factors, the system will be affected due to its Different levels of resilience, including differences in reliability, stability and recovery capabilities, will also lead to different system security states after responding to risk disturbances. The process of recovering the resilience of Deep excavation engineering systems when encountering risk disturbances is shown in Figure 1.

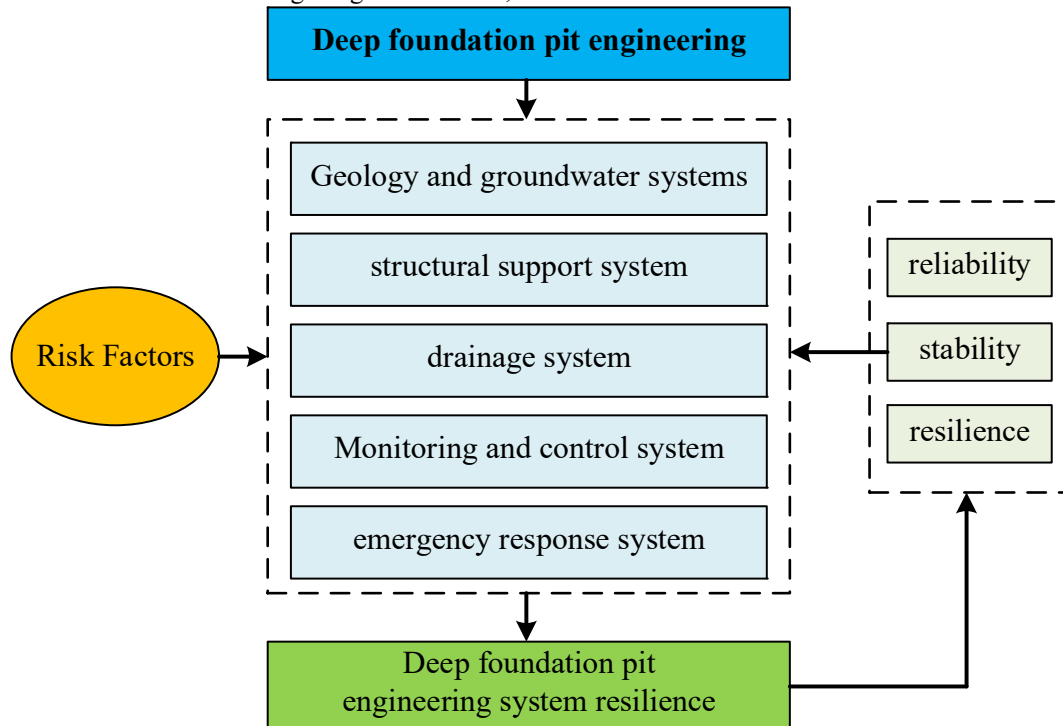


Figure 1. Risk disturbance and recovery process of Deep excavation engineering

The reliability, stability and recovery ability of the Deep excavation engineering system after encountering risk disturbance are used to quantify the toughness. The toughness of the Deep excavation engineering system is expressed in the form of Equation (1), that is, the determination of the toughness value needs to consider three types at the same time. capabilities, and use Bayesian network related algorithms to determine three capability values through conditional probability calculations of various factors that affect reliability, stability and recovery capabilities, and finally determine the resilience value.

$$\Phi = \beta + \lambda + \varepsilon \quad (1)$$

In the formula: β is the stability of the system; λ is the reliability of the system; ε is the recovery capability of the system; Φ is the resilience value of the system.

3. System Resilience Model Based on Bayesian Network

3.1. Bayesian Network

The Bayesian network probability model was first fully proposed by Professor Pearl in 1986. As a probabilistic graphical model, the Bayesian network provides a convenient

framework for the representation of causal relationships because of its ability to handle uncertainty data. Ability to graphically represent the relationship between variables, intuitive and clear, easy to understand and apply, and has become a research tool used in many fields.

Suppose the variables in the network are $X_1, X_2, \dots, X_n$, then multiply the conditional probability distributions attached to each variable to get the joint distribution, that is

$$P(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P(X_i | \text{Parents}(X_i)) \quad (2)$$

In the formula: n is the total number of indicators; b is the parent node set of the i -th element X_i . Equation (2) shows that the Bayesian network effectively expresses the conditional independence between devices by assuming that each node is independent of its non-descendant nodes.

A framework suitable for the resilience assessment of Deep excavation systems is constructed using Bayesian networks, which can describe the system's resilience level in a quantitative manner. The structure of the Bayesian network is determined based on empirical knowledge, and the parameter table of each variable is obtained by learning the sample data. Subsequently, this network can be applied to the reasoning and prediction of actual engineering events, thereby enabling

quantitative observation, estimation and inference of system engineering resilience indicators.

3.2. Variable Factor Identification

Taking the Sanya Estuary Channel Engineering Project as an example, by analyzing the five subsystems that make up the Deep excavation engineering system, combined with national specifications and corporate standards, accident cases and journal literature, we screened out the variable

factors that affect the resilience of the Deep excavation system, including the constituent systems factors and the interrelationships between factors. Based on the above identification principles and methods, 32 influencing factors were initially identified. In order to simplify the analysis, the expert consultation method was used to classify the factors into 10 categories and code them. All variable factors are shown in Table 1.

Table 1. Factors affecting the toughness of Deep excavation engineering systems

type	Node Name	coding	consequences of failure
Stability S	Geological conditions	S1	Deterioration of underground soil stability, collapse of foundation pits, and damage to supporting structures
	Design Parameters	S2	Leading to foundation pit instability, support structure failure, and poor drainage.
	environmental factor	S3	Damage to surrounding buildings and underground pipelines, and damage to the foundation pit structure
Reliability D	Construction Quality	D1	The construction quality of supporting structures is not up to standard and the construction quality of drainage system is poor.
	Human Factors	D2	Construction safety accidents and improper maintenance of engineering facilities
	Safety management level	D3	Construction safety accidents occur frequently and project quality suffers
	Maintenance level	D4	Aging facilities, declining functions, and increased safety hazards
Recovery Capability C	Engineering monitoring	D5	Monitoring data is inaccurate, not timely, and problems cannot be discovered in a timely manner
	Repair time	C1	Project shutdowns and increased losses affect project progress and costs
	Repair cost	C2	Tight project funds and cost overruns affect project operations and investment returns

3.3. Construction of Resilience Model for Deep Excavation Engineering

Based on the causal relationships of the factors screened in

Table 1, a network result diagram is established, and finally a resilience structural model based on Bayesian network is established, as shown in Figure 2.

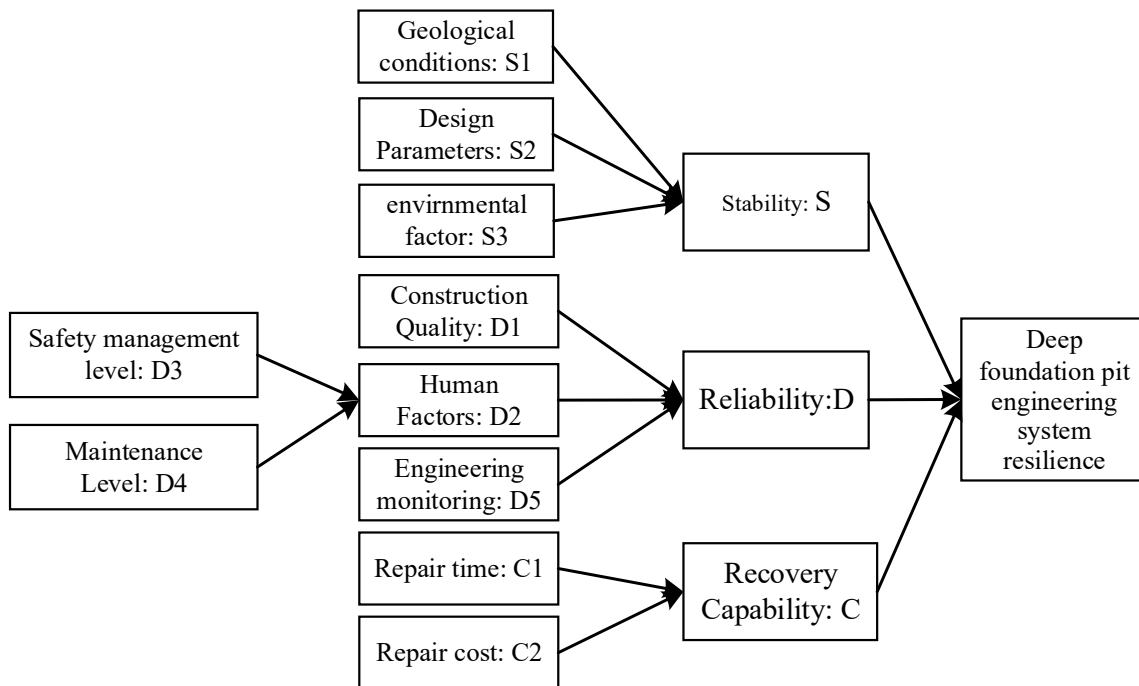


Figure 2. Bayesian network structure

3.4. Probability Calculation

By sorting out the on-site construction logs of the Deep

excavation of the Sanya Estuary Channel Project, issuing relevant questionnaires, and consulting with experts, a total of

362 groups of samples were collected and processed uniformly into binary values. There are only two statuses of Yes and No. In this article In the study, all variables only have two states: "failure" and "not failure". The Bayesian network toolbox Fullbnt-1.0.4 developed based on Matlab is used to process the data samples and calculate the prior and posterior probabilities of the Bayesian network nodes.

3.5. Establishment of Quantitative Evaluation Model for Resilience

In order to facilitate analysis and visually view the changes

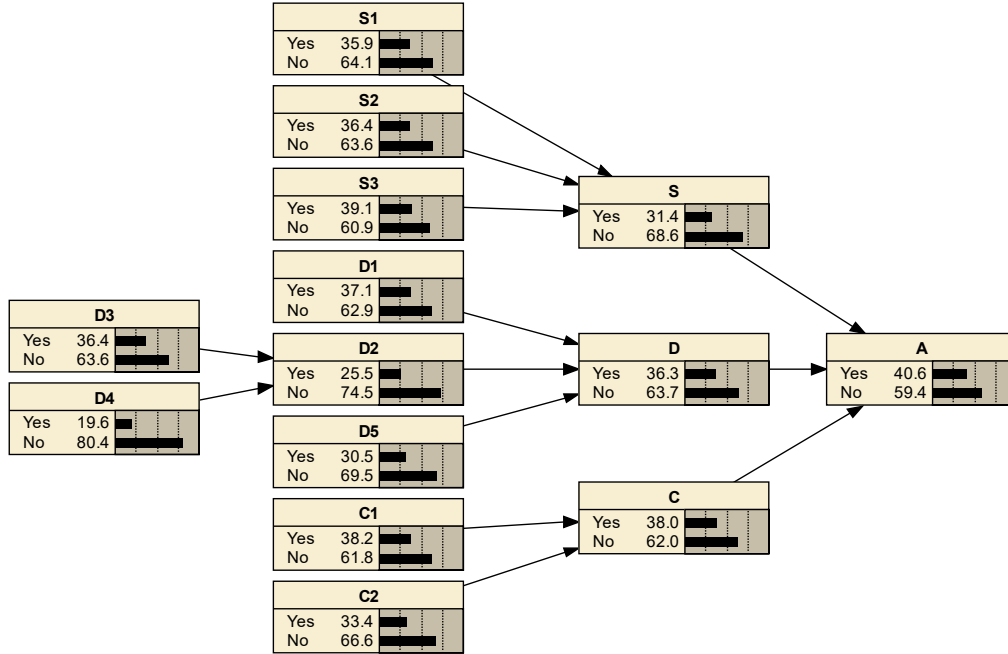


Figure 3. Quantitative model of Resilience of Deep excavation engineering system

3.6. Resilience Assessment

In the Netica software, the probability value of the node taking No is used as the embodiment of the final toughness value. The calculation results obtained using Netica software are shown in Figure 3, and the toughness value of the Deep excavation system of the Sanya Estuary Channel Project is 59.4%. By comparing the model results with the actual construction and monitoring data of the Sanya Estuary Channel Project, it is confirmed that the probability that the construction progress of the Deep excavation engineering system will not be affected in the process of responding to risks and disasters is highly consistent with the toughness value calculated by the model, verifying that Bei Accuracy and predictive performance of Bayesian network models.

In order to facilitate the analysis of sensitive factors that affect the toughness value, forward or reverse inference can be performed by adjusting the occurrence of factors at each node in the network structure. For example, when the toughness value is increased, it is observed that the values of reliability, stability, and recovery ability all become larger, and it can be inferred that the speed of recovery ability has the greatest impact on toughness based on the phenomenon that the change value of recovery ability is the largest. Therefore, the entire Bayesian network can use the above-mentioned forward and backward reasoning to analyze the sensitive factors that affect resilience, and apply control measures of corresponding intensity through the changes in the values of each variable factor to achieve the purpose of improving

in the probability of network nodes, the calculation results are filled in the network node table established by Netica software. Netica software is used to quantify the factors affecting the resilience of the engineering system in Table 1, and the results are obtained based on Bayesian network The quantitative evaluation model of Deep excavation engineering system toughness is shown in Figure 3. This model can quantitatively and effectively analyze the influence and relationship between various factors by adjusting the probability of occurrence of each node and observing the changing trends of other nodes.

resilience.

4. Conclusion

Combined with resilience theory, national norms and enterprise standards, accident cases and journal literature, 10 evaluation indicators were screened out, and it was concluded that the resilience of Deep excavation systems is jointly determined by reliability, stability and recovery capabilities. Only by focusing on the three capabilities at the same time Only by controlling it can the target toughness value be achieved in an optimal way.

Based on the actual situation of the Sanya Estuary Channel Engineering Project, the toughness of the Deep excavation system of the Sanya Estuary Channel was evaluated. The results showed that the toughness value of the Deep excavation project was 0.594, indicating that the Deep excavation was resistant to interference from external risk factors during the construction process. Good, the evaluation results are consistent with the actual project conditions.

Factors affecting system resilience changes at different stages are often different. In practical applications, the probabilities of observed nodes need to be dynamically updated based on actual events during the construction process to obtain more accurate predicted node probabilities. This can provide more precise quantitative guidance so that timely measures can be taken to ensure the resilience of engineering systems. For example, the repair cost, that is, the response speed of the system after a disaster, has a greater

impact on the resilience value. It can be seen that the emergency budget should be enhanced during the construction and production process to prepare for timely recovery after intervention.

How to better handle uncertainty is a key issue when building Bayesian networks. Follow-up research could focus on improving modeling methods, including introducing more flexible distribution assumptions, developing more accurate parameter estimation algorithms, and taking into account correlations between different data types and features.

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