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Research on Safety Risk Assessment of Limited Space Operations in Construction

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Abstract

In order to improve the safety risk assessment method and risk assessment system for limited space operations in construction, combined with the current safety management status of limited space operations in construction, a safety risk assessment index system for limited space operations in construction is established. The risk coupling evaluation method is used to obtain the risk assessment results. The results indicate that risk coupling evaluation can obtain the actual risk status of engineering operations and provide risk warnings, improve the effectiveness of risk assessment work, strengthen job safety management, and ensure the safety of construction work in confined spaces.

Keywords

Risk Assessment; Working in Confined Spaces; Risk Coupling.

1. Introduction

Construction work in confined underground spaces is a complex and systematic task, and its safety is influenced by four aspects: human, machine, environment, and management[1]. In previous related accidents, the frequency of incidents such as poor equipment reliability, inadequate safety management, and chaotic personnel rescue has been relatively high[2]. If risks are identified and controlled before project operations, it will greatly reduce the probability of accidents and improve system safety. Therefore, a reliable risk assessment method is crucial for risk warning of limited space operations in construction.

Domestic and foreign scholars have conducted extensive research on the analysis and evaluation of safety risks in confined space operations, and have achieved a large number of research results[3-5]. Research has found that the safety of limited space operations in construction is affected by multiple factors. Most scholars consider the impact of each factor on the system when conducting risk assessments, but do not consider the interaction between various factors, lacking comprehensiveness and systematicity[6]. Therefore, when studying the safety risk assessment method for construction limited space operations, it is necessary to consider both the comprehensiveness and systematicity of the system, and the relationship between various factors, in order to make the evaluation method universal, the evaluation work efficient, and the management work convenient.

2. Establish an Evaluation System

2.1 Risk Identification for Confined Space Operations

The common risks of working in confined spaces include poisoning, hypoxia, suffocation, and explosion, while the common risks include drowning, falling from heights, and burning. In a job, there may be a phenomenon of multiple risks coexisting, and risks have characteristics such as suddenness and concealment. For the three common safety risks mentioned above, their identification

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can be mainly divided into three dimensions: generated within a limited space, generated during operation, and generated by the external environment. The specific safety risk identification is shown in Figure 1.

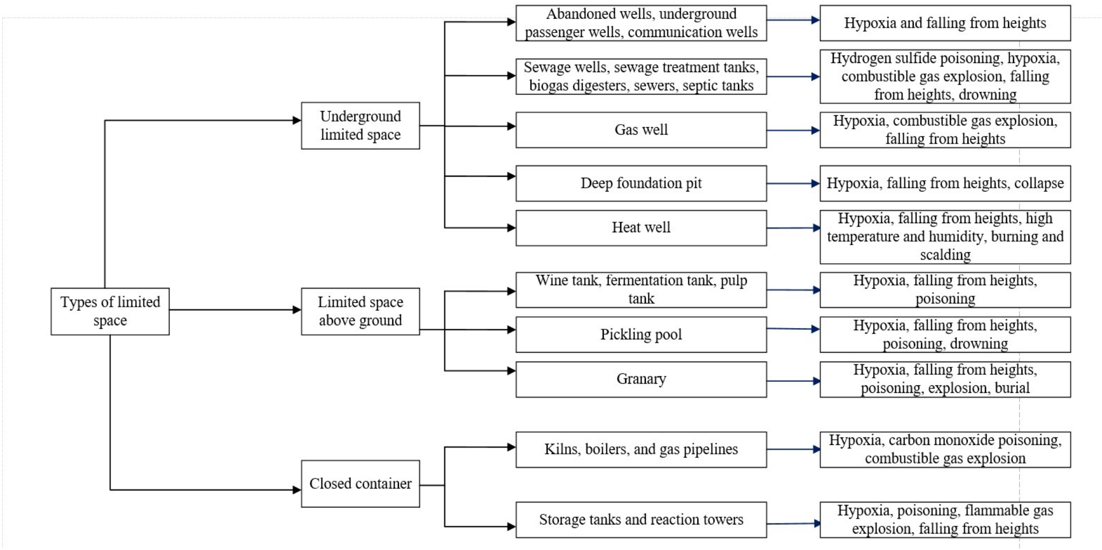

Figure 1. Identification of Main Safety Risks for Common Limited Space Operations

2.2 Construction of Risk Assessment Indicator System

Referring to the relevant content of the 2022 version of the "Standard for Judging Major Safety Hazards in Production Safety of Housing and Municipal Engineering" and the "Technical Specification for Safety of Limited Space Operations", combined with the accident investigation report of limited space operations, taking into account the real environment and personnel situation during the operation, and inviting experts to provide professional opinions, a safety risk assessment system for construction limited space operations is constructed, which includes four primary indicators of operators, equipment and facilities, operating environment, and safety management, and 17 secondary indicators. The specific content of the indicator system is shown in Figure 2.

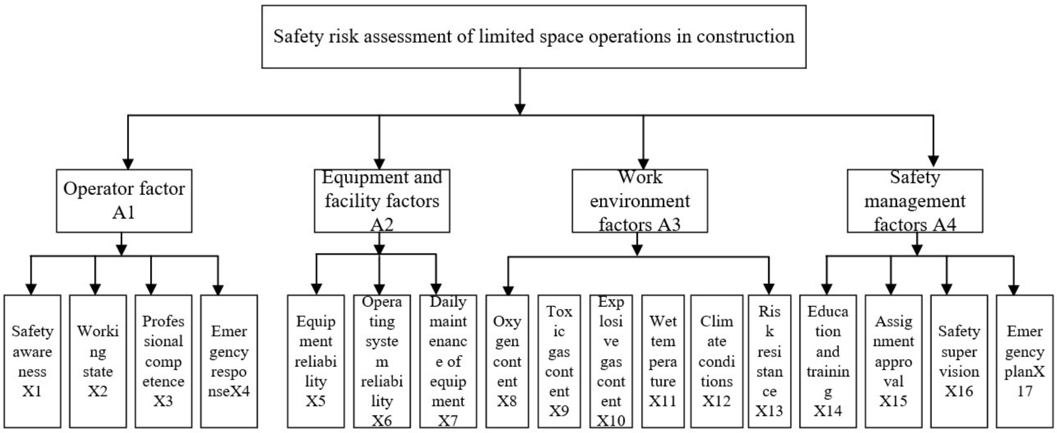

Figure 2. Safety Risk Assessment System for Limited Space Operations in Construction

3. Risk Assessment of Confined Space Operations

The safety risk assessment of construction limited space operations is a complex task, and the safety of operations is influenced by multiple factors. Therefore, this article selects a multi factor coupled risk assessment method for comprehensive analysis.

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Using multi factor coupling for evaluation, firstly, risk identification is carried out for limited space operations in construction, and a risk evaluation index system is established based on four aspects: human, machine, environment, and management; Secondly, analyze and evaluate the impact of various factors to form an interaction matrix, and obtain results based on the matrix data; Finally, a comprehensive analysis is conducted to determine the risk values of each factor, and the main risk factors are identified through comparison.

3.1 Interaction Matrix

The interaction matrix can compensate for the shortcomings of traditional evaluation methods, which comprehensively consider two aspects: a single factor and the coupling effect between various factors[7]. It can solve the problem of the complexity of construction limited space operation systems, obtain more scientific evaluation results, and have comprehensiveness and systematicity.

For the interaction matrix, matrix assignment is more important. In this article, the C-OWA operator is used to determine the matrix assignment, which is used to calculate the numerical values of the effects of each factor on the system. The numerical value corresponds to the magnitude of the impact of the factor on the system. The larger the value, the greater the mutual relationship between the factors, and the greater the impact on the safety performance of the system. The impact and weight of risk factors on the system[8] are shown in equations (1) to (3).

$$C_i = \sum_{j=1}^{n} X_{ij} \qquad \text{(Equation 1)}$$

$$E_i = \sum_{j=1}^{n} X_{ji} \qquad \text{(Equation 2)}$$

$$K_i = \frac{C_i + E_i}{2\sum_{i=1,j=1}^{n} X_{ij}} \qquad \text{(Equation 3)}$$

Among other, $i, j = (1,2,\cdots,n)$, n--Number of homework risk factors; C_i-The impact of the i-th risk factor on other factors is equal in magnitude to the sum of the i-th line; E_i-The i-th risk factor is influenced by other factors, and its magnitude is equal to the sum of the i-th column; K_i--The weight of the i-th risk factor.

3.2 C-OWA Operator Determines Matrix Assignment

In the face of safety evaluation of limited space operations in construction, the coupling relationship between various factors is crucial to the safety of the system. Choosing a reasonable assignment method to reflect the coupling relationship between various factors is of utmost importance. In previous assignment methods, such as Analytic Hierarchy Process and Entropy Method, their strong subjectivity directly affects the evaluation results. In order to weaken this subjective influence, this article uses the C-OWA operator for assignment.

Professor Yager Ronald R proposed the Ordered Weighted Average (OWA) method [9], which rearranges the values in descending or ascending order and then performs weighted calculations, effectively reducing the interference of subjective scoring. The C-OWA operator used in this article is an improvement on the OWA operator by ranking and weighting expert ratings. The specific steps are as follows [10]:

(1) Invite m experts to work hard on each indicator, with a scoring range of 0-10. The larger the score, the higher the danger of the risk factor.

(2) Sort the scores given by experts on indicators$(a_1, a_2, \cdots, a_j, \cdots, a_m)$ at the same level. This article adopts a descending processing method, with a starting number of 0, $b_0 \geq b_1 \geq b_2 \geq \cdots \geq b_j \geq b_{m-1}$.

(3) Weight of ω_{i+1} determine b_i, as shown in Equation 4.

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$$\omega_{j+1} = \frac{C_{m-1}^{j}}{\sum_{j=0}^{m-1} C_{m-1}^{j}} = \frac{C_{m-1}^{j}}{2^{m-1}} \quad \text{(Equation 4)}$$

Among other, j=(0,1,2,…,m-1).

By using data b_i and weight ω_{i+1}, the weighted risk value p_i is obtained, as shown in Equation 5.

$$p_i = \sum_{j=0}^{m-1} \omega_{j+1} \cdot b_j \quad \text{(Equation 5)}$$

Among other, i=(1,2,…,n), j=(0,1,2,…,m-1), n--Number of evaluation indicators; p_i-The values on the main diagonal of the interaction matrix.

(4) The assignment method for element X_{ji} on non main diagonal is the same as above.

3.3 Risk Assessment Coefficient R Value and Risk Assessment Level Classification

Importance refers to the importance of a factor to the safety performance of the system, taking into account both a single risk value and the weight of risk factors. The calculation of the importance weight Z_i is shown in Equation 6.

$$Z_i = K_i \times \frac{p_i}{\max(a)} \quad \text{(Equation 6)}$$

Among other, i=(1,2,…,n),a is the scoring range for experts.

The risk assessment coefficient R can indicate the safety of limited space operations in construction. The larger the R value, the greater the risk of limited space operations in construction. The calculation of the R value is shown in Equation 7.

$$\mathrm{R} = \sum_{i=1}^{n} Z_i \quad \text{(Equation 7)}$$

Among other, i=(1,2,…,n).

According to the R value of the risk assessment coefficient, the risk of limited space operations in construction is divided into four levels [11]. The R value, risk level, and risk degree are shown in Table 1.

Table 1. Safety Risk Grading Standards

Risk assessment coefficient	Risk level	Risk level of homework
[0.75~1.00]	I	Major risk
[0. 5~0.75)	II	Significant risk
[0. 25~0. 5)	III	General risk
[0. 00~0.25)	IV	Low risk

After calculating the R value, corresponding control measures will be taken based on the risk level in Table 1. If at low risk (risk level IV), there is no need for too many decisive changes; For potential risks with high levels of danger (risk level III), measures can be taken according to the actual situation to reduce operational risks; For high-risk situations (risk levels of I and II), it is necessary to focus on controlling the main risk factors, re evaluate after taking measures, and confirm that the risk will be low before proceeding with the operation.

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4. Example Analysis

In order to better verify the evaluation results of the risk coupling evaluation method and identify the main risk factors, a risk assessment was conducted using a limited space engineering operation at a construction site in Nanjing as an example, in order to identify potential risk factors and provide reference for actual engineering operations and make scientific treatments.

Invite 7 experts to rate the constructed evaluation indicators. Taking the main diagonal factor X_1 as an example, the seven experts rated X_1 in order of a = [5,5,6,6,7,8,6]. Rank the expert scoring vectors in descending order of a b = [8,7,6,6,6,5,5]. Calculate the weight vector corresponding to vector b using equation (20) ω = $\left[\frac{1}{64},\frac{6}{64},\frac{15}{64},\frac{20}{64},\frac{15}{64},\frac{6}{64},\frac{1}{64}\right]$, Calculate the comprehensive weight risk score of X_1 using equation (21) again$p_1 = b \cdot \omega^T = 5.671$. A total of 289 risk values were obtained using the same method on other main and non main diagonals.

To study the coupling effect of safety risk factors in the limited space operation of the power plant, identify key risk factors that affect operation safety, and improve the targeted risk management. According to the interaction matrix formula and its principle, the P matrix is solved through equations (17-22) to calculate the degree of influence (C_i), degree of influence (E_i), weight (K_i) and its ranking, importance (Z_i) and its ranking of job safety risk factors, as shown in Table 2.

According to equation (23), the risk assessment coefficient R is calculated to be 0.5582. According to Table 1, the safety risk level for the limited space engineering operation of this project is level II, with a relatively high level of risk. Targeted measures should be taken to reduce the risk of operation and prevent personnel safety accidents.

Table 2. Weight, Importance, and Ranking of Job Safety Risk Impact

Risk indicators	p_i	K_i	K_i ranking	Z_i	Z_i ranking
X1	5.17	0.0966	3	0.04994	4
X2	4.91	0.1117	1	0.05485	1
X3	3.87	0.0296	16	0.01146	16
X4	4.87	0.0425	14	0.02070	14
X5	4.78	0.0536	9	0.02562	10
X6	4.45	0.0211	17	0.00940	17
X7	4.44	0.0536	9	0.02380	12
X8	6.98	0.0441	12	0.03078	8
X9	7.86	0.0471	11	0.03702	7
X10	6.02	0.0439	13	0.02643	9
X11	4.11	0.0526	8	0.02162	13
X12	4.23	0.0570	7	0.02411	11
X13	5.47	0.0327	15	0.01789	15
X14	7.30	0.0738	4	0.05387	2
X15	7.57	0.0680	5	0.05148	3
X16	4.48	0.1080	2	0.04838	5
X17	7.49	0.0641	6	0.05010	6

According to the importance ranking in Table 2, the five main risk factors that have the greatest impact on the safety of limited space operations in construction are work status (X2), safety education and training (X14), operation approval system (X15), safety awareness (X1), and on-site supervision situation (X16). Before starting the project, it is necessary to focus on preventing and controlling the main risk factors to reduce operational risks.

5. Conclusion

This article identifies the safety risk factors of construction limited space operations, constructs a safety risk assessment system for construction limited space operations, and verifies the coupling evaluation method of safety risk for underground space operations through examples. The following conclusions can be drawn:

(1) By constructing an interaction matrix, the influence of expert scoring preferences and extreme values on the results was weakened. The C-OWA operator was introduced to scientifically weight the interaction matrix, and the interaction matrix was analyzed to solve the problem of complex systems under the coupling effect of multiple risk factors.

(2) By using the safety risk coupling evaluation method, five main risk factors affecting limited space operations can be identified, which can be focused on prevention and control to reduce operational risks.

The actual risk assessment results obtained by verifying the limited space operation of construction under the coupling effect of multiple factors through examples are relatively high and consistent with the actual situation.

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