Current Science
CS 5 (3), 2829-2840 (2025)
Received 15 March 2025 | **Revised** 18 April 2025 | **Accepted** 18 May. 2025 | **Online Available** 04 June 2025
https://doi.org/ 10.52845/CS/2025-5-3-59

Current Science

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OPEN ACCESS **ISSN(O)2795-8639**

Original Article

Construction and Application of Safety Risk Assessment Model for Inclined (Vertical) Well Construction Based on Process Method

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Abstract:
In order to scientifically evaluate the construction safety risk of inclined (vertical) wells, a systematic identification of project construction process risks was conducted based on the methodology employed. Subsequently, a safety management model for inclined (vertical) well construction was established by integrating actual project conditions. Using this model, the composition of the safety evaluation index system was analyzed. An inclined (vertical) well construction safety risk evaluation index system was constructed, encompassing five key dimensions: technical support, operational control, risk prevention and mitigation, management efficiency, and personnel quality. Leveraging C-OWA operator theory, sequence relationship analysis methods, and cloud model theory, a comprehensive construction safety risk assessment model for inclined (vertical) wells was developed. Finally, a pumped storage power station project was utilized as a case study. The results indicate that A (technical support) and D (risk prevention and control) represent the primary risk factors within the first-level indices. The indices were ranked in terms of risk severity as follows: risk prevention and control, technical measures, management efficiency, operational control, and personnel quality. The evaluation outcomes align closely with the actual construction scenarios. This model provides robust theoretical support for assessing construction risks in inclined (vertical) wells and holds practical significance in enhancing the level of construction risk management.
Keywords: inclined (vertical) well construction; Process method; Evaluation system; C-OWA operator; G1 method

1. Introduction

Pumped storage power station has a variety of functions such as peak loading, valley filling and energy storage. With the vigorous promotion of policies in the field of new energy, pumped storage power project has ushered in new development opportunities. The construction of inclined (vertical) well is an important link of pumped storage power station project. In the construction process, it is constrained by complex geological conditions, harsh construction environment and high-precision process requirements, which leads to systematic challenges in safety risk management and control. For example, in the "5·29" large explosion accident of Sinan Hydropower Station, the abnormal condensation of combustible gas under the action of canyon wind led to the increasing concentration of gas in the studio, which eventually led to the explosion accident. Therefore, it is of great significance to scientifically evaluate and improve the safety risk control ability of inclined (vertical) well construction project to ensure the safety of construction personnel and ensure the quality of the project.

In terms of construction of inclined (vertical) well construction safety risk index system, Li et al. constructed a safety assessment index system based on Fisher discriminant method, and revealed the dynamic safety assessment process and risk quantification method [1] of reversible Francis hydraulic turbine pumped storage power generation system. Wu et al. established the tunnel collapse risk index system [**Error! Reference source not found.**] by identifying key risk factors affecting tunnel collapse; Liang et al. proposed a risk assessment system based on pressure-state-response (PSR) model to solve the risk assessment problem of crossing goaf in tunnel construction, and conducted feasibility test [3]. Jiang Hui et al. improved the traditional construction index system of high slope excavation in water conservancy engineering, which has higher sensitivity of risk index and is more suitable for the construction management [4] of high slope excavation in water conservancy engineering. Liu Kang et al. analyzed and evaluated the structural safety of diversion tunnel, built a dynamic Bayesian network model, and evaluated [5] the structural safety of diversion tunnel. Li Meng et al. built an evaluation index system based on construction site risk, taking into account the risk of disaster causing factors, stability of disaster-prone environment, vulnerability of disaster bearing body and resilience of disaster reduction ability, and verified [**Error! Reference source not found.**] it with a construction site in Wuhan City. Zhou Shijie et al. established a multi-evidence comprehensive evaluation system based on the multi-evidence fusion fuzzy comprehensive evaluation method of the importance of accident causation, and deter-mined the main causes [7] of construction safety accidents in hydropower projects. Jia Jianqing et al. built a risk index system for shield construction of the underpass Yellow River tunnel and conducted an empirical study [8] after considering the mechanical risk, manual operation risk, engineering geological risk and other factors.

In summary, at present, scholars have constructed inclined (vertical) well construction risk assessment systems from different perspectives, but most of them focus on environmental or management factors, and have not yet built assessment models from the perspective of the overall construction stage, and the indicators are not based on sufficient evidence, unclear positioning and lack of comprehensiveness. In view of this, the process method of quality management is introduced into the construction of inclined (vertical) well, the whole process of "input-operation-output" of construction operation is analyzed, the risk factors in the whole construction process are systematically identified, and the evaluation results are visualized by constructing the construction safety risk assessment index system of inclined (vertical) well construction and combining with the cloud model. In order to provide a basis for improving the risk management and control ability of inclined (vertical) well construction.

2 Construction of safety management model of inclined (vertical) well construction based on process method

The process approach is one of the 8 principles of quality management, defined in the ISO 9001 standard as "process": refers to a group of interrelated or interacting activities that utilize inputs to achieve a desired result [9]. The basic idea of using process method to study the safety risk identification in the construction process of inclined (vertical) well is to treat the construction work as a system, the enterprise provides external resources, and controls the safety risks by carrying out hazard source identification and formulating management system. However, in different stages of inclined (vertical) well construction, The excavation method, mechanical equipment, application facilities and personnel fac-tors are different, so it is difficult to directly take the construction of inclined (vertical) well as the whole object for safety assessment, and it must be divided into different units for assessment according to its construction stage.

Based on the actual production of inclined (vertical) well and referring to the standards of water conservancy and hydropower industry, to master the construction technology and methods of different construction projects, to clarify the difficulties and out-standing problems of risk control of different projects, the construction stage of inclined (vertical) well is divided into six stages: pilot well construction, expansion auxiliary facilities construction, inclined well expansion construction, shaft expansion construction, lining construction and TBM construction. Safety management stage and construction preparation and environment two links will be involved in each construction stage, so they are taken as independent units for overall analysis. The process method is applied to analyze the whole process of "input-operation-output" of construction activities, and the construction safety management model of inclined (vertical) well based on process meth-od is established. It is shown in **Figure 1**.

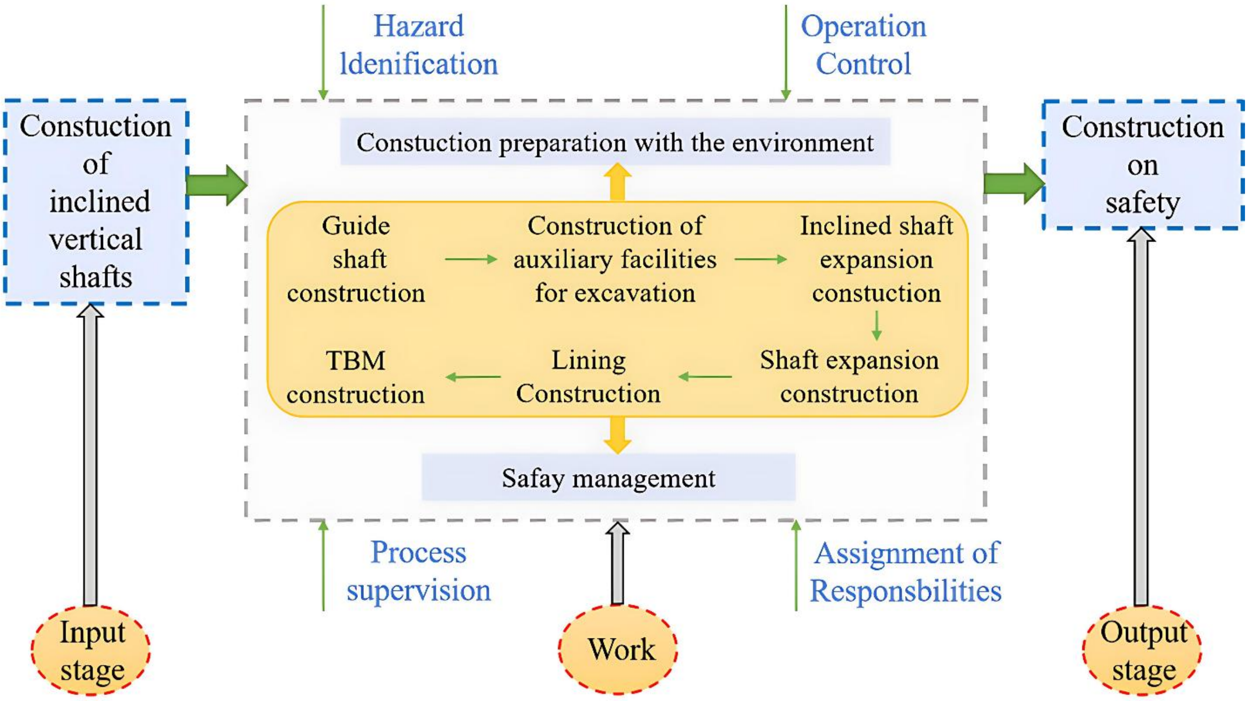


Figure 1 Construction safety management model of inclined (vertical) well based on process method

3 Construction of Safety Risk Assessment Index System of Inclined (Vertical) Well Construction

3.1 Analysis of Influencing Factors

1) Technical support. As the basic support for the safe construction of inclined (vertical) well, the core of technical support lies in the adaptability of construction technology, the reliable application of construction equipment and the compliance of special technical approval. By combining the characteristics of engineering geological conditions and construction environment, reasonable selection of driving technology and mechanized sup-porting equipment, and establishment of equipment condition monitoring and maintenance system, can effectively improve the essential safety level of construction process.

2) Quality of personnel. The quality of personnel directly affects the implementation of safety norms, mainly including professional skills, safety awareness, emergency response ability and other dimensions. Through the establishment of a stepped training system, the operators' ability to operate in a standard manner under complex geological conditions is strengthened, focusing on high-risk processes such as excavation and sup-port. Build a safety behavior-oriented performance appraisal mechanism, incorporate the implementation rate of safety procedures and the effectiveness of self-inspection of hidden dangers into the performance appraisal, form a safety culture atmosphere with full participation, and provide personnel quality guarantee for the essential safety of inclined (vertical) well construction.

3) Operation control. Operation control runs through the whole process of construction, and its key lies in special operation management, operation site supervision, operation code of conduct and process connection control. Through the strict implementation of dynamic qualification review of key positions and regular re-training and assessment, to ensure that the professional skills of blasting, lifting and other special operations personnel continue to meet the standards. Formulate safety operation specifications for the whole process and strengthen the awareness of operators. Implement standardized transfer procedures for the connection of processes, eliminate the blind area of connection through the implementation of the operation disclosure system, and comprehensively improve the essential safety level of construction operations.

4) Risk prevention and control. Risk prevention and control is the prerequisite for the construction safety of inclined (vertical) well, which can be measured by the advance pre-diction of geological risks and the accurate control of construction dynamics. According to the hydrogeological characteristics, the rock stability and groundwater activity law are clearly defined through preliminary exploration and dynamic monitoring, and differentiated construction strategies are formulated according to the geological risk level. In terms of construction environment control, standardized construction specifications for the whole process have been established, multi-level dynamic inspection mechanisms have been implemented simultaneously, and a whole-chain management system covering investigation and design, construction execution and monitoring feedback has been formed to ensure the dynamic matching of construction technology and geological conditions and reduce safety risks.

5) Management efficiency. Management efficiency is the core driving force of safety management of inclined (vertical) well construction, and its importance is reflected in the implementation of responsibility system, hidden danger investigation and management and emergency response. The implementation of the main responsibility needs to clarify the safety management responsibilities at all levels to ensure that the safety decision is effectively implemented to the first line of operation. Hidden danger investigation and management should improve the dynamic investigation mechanism, focusing on strengthening the normal supervision of weak links such as hidden projects and cross-work. The emergency response system should focus on the preparation of hierarchical plans and actual combat exercises to improve the efficiency of handling emergencies.

3.2 Index System Construction

Based on the process method, the construction safety management model of inclined (vertical) well is analyzed, and 5 key influencing factors of inclined (vertical) well construction risk assessment are determined; Sort out and summarize the operation specifications and typical accident cases related to the construction of inclined (vertical) well, find out the secondary indexes in the index system, and then build the construction safety risk evaluation index system of inclined (vertical) well, as shown in **Figure 2**.

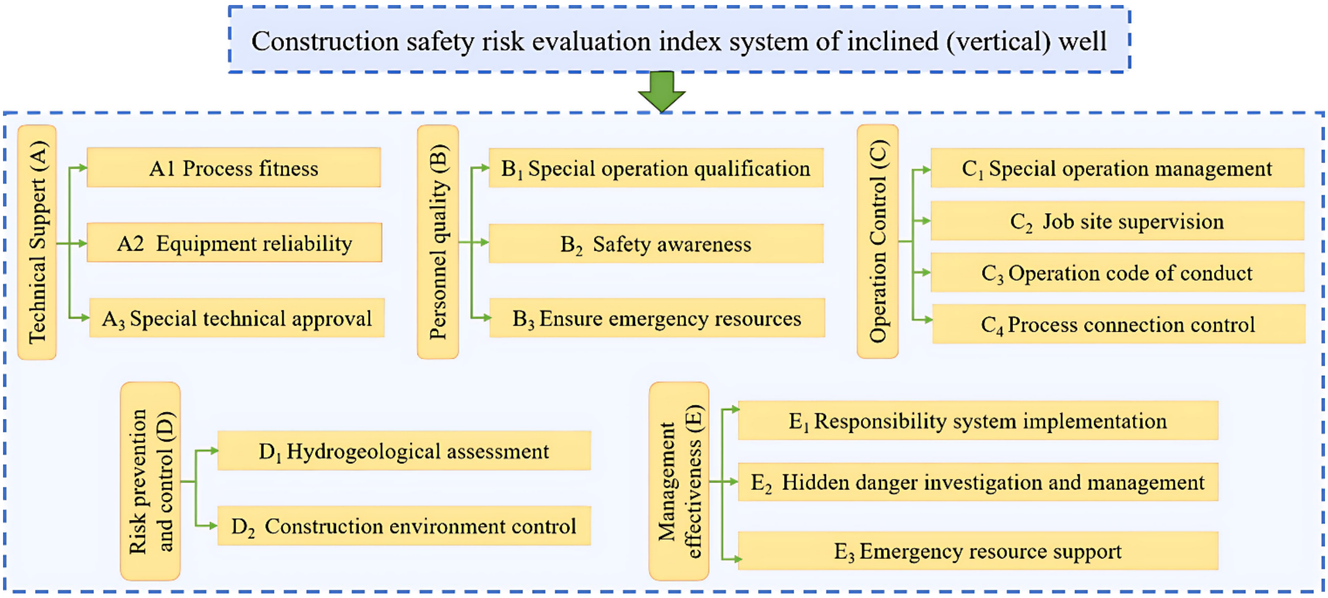


Figure 2 Construction safety risk evaluation index system of inclined (vertical) well

4 Construction of Inclined (Vertical) Well Construction Risk Assessment Model

4.1 C-OWA Operator Theory

The combination-number ordered weighting operator (C-OWA) was proposed by Professor Yager [10]. By organically combining weights and sample data, it can effectively weaken the influence of extreme values judged by experts' subjective experience, and obtain a more scientific and reasonable evaluation of index weights. The specific steps are as follows:

1) Invite p experts in the field of tunnel and underground engineering to score the indicators (the score range is 1-10). The greater the score, the greater the risk, and the initial decision index matrix A= [a_1, a_2, ⋯, a_p] is obtained;

2) The initial index data are sorted from largest to smallest, numbered from 0, and a new index set B= [b_0, b_1, ⋯b_{p-1}] is obtained, where $b_0 \geq b_1 \geq \cdots \geq b_{p-1}$;

3) Using combination number to weight the decision data, and according to the nature of combination number can be obtained weighted vector:

$$w_{j+1} = \frac{C_{n-1}^{j}}{2^{n-1}} \quad (1)$$

In formula, j= 0,1,2... C_{n-1}^{j} is the number of combinations of j data from n-1 data.

4) According to the weighted vector w, the decision data is weighted to obtain the absolute weight value of the index; $\overline{w} = \sum_{i=1}^{n} w_j \cdot b_j$ (2)

In formula, The value range of w_j is from 0 to 1, j=1, 2,... n.

5) Calculate the relative weight value of the indicator w_i;

$$w_i = \frac{\overline{w}}{\sum_{i=1}^{m} \overline{w}_i}, i = 1, 2, \ldots m \quad (3)$$

4.2 Sequential Relation Analysis

G1 method is a subjective weighting method, which was proposed by Guo Yajun to improve the analytic hierarchy process [11] Its main point of view is to compare the indicators of each layer in the index system to determine the importance degree, and avoid the disadvantage of failing the consistency test.

First of all, the order relationship of each index is determined, and the experts sort the importance of different elements in the same index layer. Secondly, experts assign importance values to adjacent indicators. The importance ratio formula is as follows:

$$r_k = \frac{w_{k-1}}{w_k}, k = m, m-1, m-2, \ldots, 2 \quad (4)$$

In the formula, w_{k-1} and w_k respectively represent the weight values of k-1 and k indicators, and the assignment of r_k is shown in **Table 1**.

Table 1 Description of the assignment r_k

r_k	Assignment instructions
1	Indicators are equally important than indicators F_t^* F_{t-1}^*
1.2	Indicators are slightly more important than indicators F_t^* F_{t-1}^*
1.4	Indicators are slightly more important than indicators F_t^* F_{t-1}^*
1.6	Indicators are very important than indicators F_t^* F_{t-1}^*
1.8	Indicators are extremely important F_t^* F_{t-1}^*
1.1, 1.3, 1.5, 1.7	Is the median of the two adjacent judgements above

Finally, the weight coefficient of each index is calculated, and the formula is as follows:

$$W_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \quad (5)$$

In formula, $W_{k-1} = r_{k*} w_k$, k=m-1,m-2,..3,2.The weight value of the hierarchy index can be calculated by the formula.

3.3 Cloud model theory

The cloud evaluation idea proposed by Li Deyi makes use of the digital characteristics of cloud, such as expected Ex, entropy En and super entropy He, to realize the comprehensive evaluation of the certainty and uncertainty description of qualitative evaluation [12]. The numerical features of cloud represent the mathematical properties of qualitative linguistic values, and the comprehensive evaluation of qualitative evaluation and uncertainty description is realized [13].

(1) Determine the evaluation level of cloud digital feature values and cloud maps

According to the experts' description of the qualitative language affecting the construction safety risk factors of inclined (vertical) well, the weight grade range is divided into five levels, and the index weight size is described as natural language, namely: low risk, general risk, high risk, high risk, and major risk. The specific conversion formula for converting expert scoring data into cloud digital characteristic values of each evaluation level is as follows:

$$E_x = (V_{\max} + V_{\min})/2 \quad (6)$$

$$H_e = k \quad (7)$$

$$E_x = (V_{\max} + V_{\min})/2 \quad (8)$$

In formula, V_{max} is the upper limit of the evaluation scoring interval, V_{min} is the lower limit of the evaluation scoring interval, and the k of each evaluation level is 0.01.

(2) Determine the digital characteristic value of the underlying index cloud

The scoring data of the bottom index by n experts in the field of tunnel and underground engineering are sorted out. The specific calculation formula of the bottom index cloud digital characteristic value is shown as follows.

$$E_n = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n}\left|x_i - Ex\right| \quad (9)$$

$$E_x = \bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (10)$$

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{X}\right) \quad (11)$$

$$H_e = \sqrt{\left|S^2 - E_n{}^2\right|} \quad (12)$$

(3) Calculate the cloud digital characteristic value and cloud map of the superior index

In the calculation of oblique (vertical) well construction safety risk factors at the bottom

After the cloud digital characteristic value corresponding to the index, the cloud digital characteristic value corresponding to the superior index of the construction safety risk factor of inclined (vertical) well is obtained. The specific calculation formula is as follows.

$$\begin{aligned} E_x &= \frac{W_1}{W_1 + W_2 + \cdots W_n} E_{x_1} + \cdots + \frac{W_1}{W_1 + W_2 + \cdots W_n} E_{x_n} \\ E_n &= \frac{W_1^2}{W_1^2 + W_2^2 + \cdots W_n^2} E_{n_1} + \cdots + \frac{W_1^2}{W_1^2 + W_2^2 + \cdots W_n^2} E_{n_n} \\ H_e &= \frac{W_1^2}{W_1^2 + W_2^2 + \cdots W_n^2} H_{e_1} + \cdots + \frac{W_1^2}{W_1^2 + W_2^2 + \cdots W_n^2} H_{e_n} \end{aligned} \quad (13)$$

In formula, $W_1 \ldots W_n$ is the weight value.

(4) Generate an evaluation cloud map

After obtaining the digital characteristic value of the upper index and even the whole cloud, the corresponding evaluation cloud map is drawn, and compared with the evaluation cloud of the evaluation level, and the evaluation result is intuitively obtained according to the proximity degree. If the corresponding cloud image of the evaluation object is closer to the corresponding cloud image of each evaluation level, it will be determined which evaluation level it belongs to.

5 Example Application

5.1 Project Overview

A pumped storage power station is located in a city of Shaanxi Province. The project mainly consists of upper reservoir, lower reservoir, water transmission system, underground workshop and switch station. The upper reservoir uses the gully terrain to build a dam, the normal storage water level of the reservoir 1392 meters, at present, the project reservoir is in the construction stage, the lower inclined shaft is in the civil construction and metal structure safety pressure steel pipe installation stage, the power plant in the installation of pumps and turbines.

5.2 Index Empowerment Based on C-OWA Operator and G1 Method

Ten tunnel and underground engineering experts are invited to score and assign values to various risk indicators of the project. Full score is 10 points. The lower the expert score is, the smaller the risk of the index, the better the risk control, the lower the possibility of causing accidents, and the higher the vice versa. The initial data set Q was collected. Due to space reasons, this paper takes the weight determination of each evaluation element of index layer A (technical support) in the risk evaluation index system of inclined (vertical) well construction as an example.

(1) According to experts

Score indicator A1 to get initial decision data:

Q_{A1}=[8, 7, 9, 7, 8, 7, 8, 6, 8, 7];

(2) The decision data is sorted according to the principle from largest to smallest to get a new indicator set.

E_{A1}=[9, 8, 8, 8, 8, 7, 7, 7, 7, 6];

(3) Calculate the corresponding weight vector of the index.

W = (0.0020, 0.0176, 0.0703, 0.01641, 0.2461, 0.2461, 0.1641, 0.0703, 0.0176, 0.0020)

(4) Calculate the assignmentw_{A1} =7.074.

The expert scores of each indicator in layer A are shown in **Table 2**.

Table 2 Scores of indicators experts of Layer A

Indicators	Expert rating 1	Expert Rating 2	Expert rating 3	Expert Rating 4	Expert rating 5	Expert rating 6	Expert rating 7	Expert score 8	Expert rating 9	Expert rating 10
A_1	9	8	8	8	8	7	7	7	7	6
A_2	9	9	9	8	8	8	8	8	7	7
A_3	7	7	7	6	6	6	6	5	5	5

Calculate A total of 5 index values for layer A, as shown in **Table 3**

Table 3 Index weight table of layer A

Indicators	Absolute weights	Relative weights
A_1	7.502	0.348
A_2	8.072	0.374
A_3	6.001	0.278

According to the expert, the indexes A_1（process suitability), A_2 (equipment reliability) and A_3 (special technical approval) are sorted according to their importance. The sorted indexes are set as B1*<B2*<B3*, and the importance of adjacent indexes are assigned according to the r_j assignment table. The importance of indexes is quantified, the weights of the least important indexes are obtained, and the weights of other indexes are calculated. **Table 4** shows the adjacency importance of indexes in layer D and the weight of indexes in layer D.

Table 4 Adjacency importance of indicators at layer A and weight of indicators at layer A

Expert	G1 Method	r_2	r_3	W_1	W_2	W_3
1	$A_3 < A_1 < A_2$	1.4	1.2	0.258	0.361	0.433
2	$A_3 < A_2 < A_1$	1.5	1.3	0.235	0.353	0.459
3	$A_1 < A_3 < A_2$	1.4	1.2	0.258	0.361	0.433
4	$A_3 < A_1 < A_2$	1.3	1.2	0.266	0.346	0.415
5	$A_2 < A_3 < A_1$	1.4	1.2	0.258	0.361	0.433
6	$A_1 < A_2 < A_3$	1.3	1.3	0.251	0.326	0.424
7	$A_3 < A_2 < A_1$	1.3	1.2	0.266	0.346	0.415
8	$A_2 < A_1 < A_3$	1.2	1.1	0.292	0.351	0.386
9	$A_3 < A_1 < A_2$	1.3	1.2	0.266	0.346	0.415
10	$A_1 < A_3 < A_2$	1.4	1.2	0.258	0.361	0.433

Because of the different knowledge level and work experience of experts, there will be differences in judging the order relationship of evaluation indicators, so the arithmetic average method is used to correct the evaluation results of different experts, so as to get a more reasonable weight. In summary, the weight of the secondary index of layer A is *w*= (0.348, 0.370, 0.282). Similarly, the weight coefficients of other index layers can be calculated, as shown in **Table 5**.

Table 5 Index weight summary table of indicator layer

Tier 1 Weights		Secondary weights	
A	0.148	A_1	0.384
		A_2	0.370
		A_3	0.282
B	0.149	B_1	0.324
		B_2	0.364
		B_3	0.312
C	0.258	C_1	0.220
		C_2	0.252
		C_3	0.277
		C_4	0.251
D	0.269	D_1	0.520
		D_2	0.480
E	0.176	E_1	0.284
		E_2	0.365
		E_3	0.361

5.3 Calculation of Construction Safety Risk Level Based on Cloud Model

(1) Determine the evaluation grade standard cloud digital characteristics

According to the experts' description of the qualitative language affecting the construction safety risk factors of inclined (vertical) well, the weight range is divided into five levels, and the indicator weight size is described as natural language, namely: Low risk, general risk, high risk, high risk and major risk, the higher the level indicates the stronger the influence of the factor. The cloud model is used to map the five levels equally to the interval [0,10], as shown in **Table 6**.

Table 6 Value range of weight levels and qualitative language description table.

Weight range	[0,2]	[2,4]	[4,6]	[6,8]	[8,10]
Verbal description	Low Risk	Average risk	Higher risk	High risk	Significant risk
Expected value *(Ex)*	1	3	5	7	9
Entropy (*En*)	0.33	0.33	0.33	0.33	0.33
Superentropy *(He)*	0.01	0.01	0.01	0.01	0.01

Use the forward cloud generator to generate a standard cloud map, as shown in **Figure 3**.

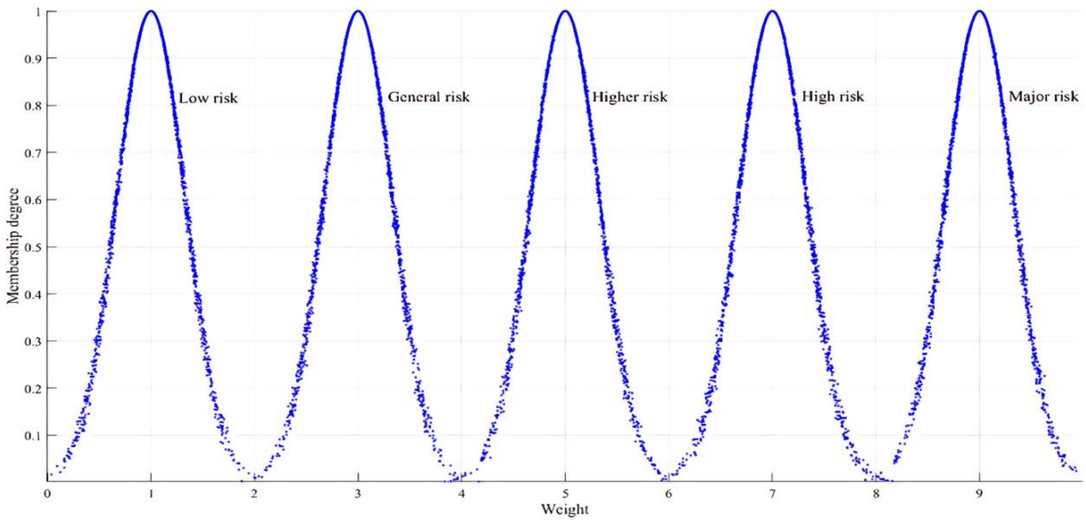


Figure 3 Weight comment standard cloud

(2) Determine the digital characteristic values of indicator clouds at all levels

According to the scores of 10 tunnel and underground engineering experts on the bottom indicators, the cloud digital characteristic values corresponding to the bottom indicators in the technical support index layer are obtained according to formulas 9 ~ 12. According to formulas 13, the cloud digital characteristic values of the upper indexes in each level are obtained, as shown in **Table 7** and **Table 8**.

Table 7 Technical assurance A Cloud digital characteristics

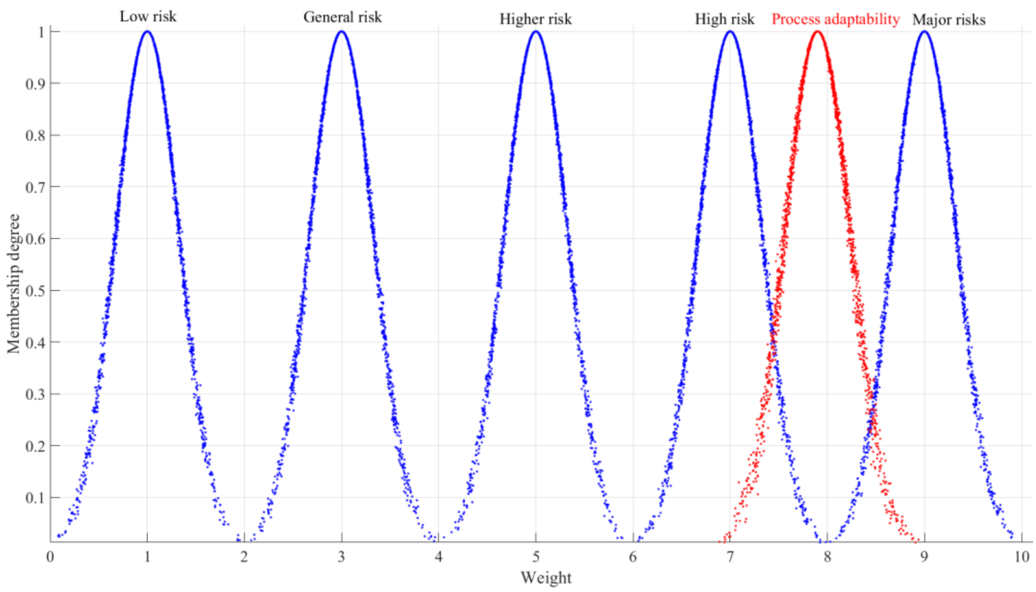
First-level indicators	Ex	En	He	Secondary indicators	Ex	En	He
Technical Support A	8.226	0.331	0.0155	A_1 process suitability	7.900	0.330	0.0174
				A_2 Equipment Reliability	8.400	0.355	0.0168
				A_3 Special technical approval	7.400	0.334	0.0158

Table 8 First level index cloud digital characteristic values

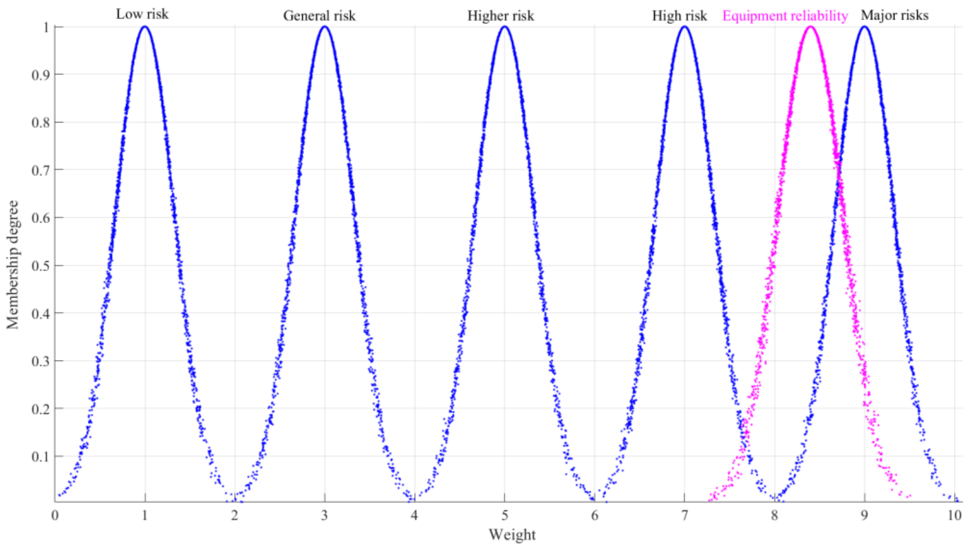
Primary index layer	Ex	En	He
A (Technical support)	8.226	0.331	0.016
B (Quality of personnel)	6.855	0.360	0.012
C (Operation Control)	7.659	0.363	0.018
D (Risk Prevention and Control)	8.434	0.319	0.015
E (Management effectiveness)	7.841	0.320	0.013

(3) Evaluation results

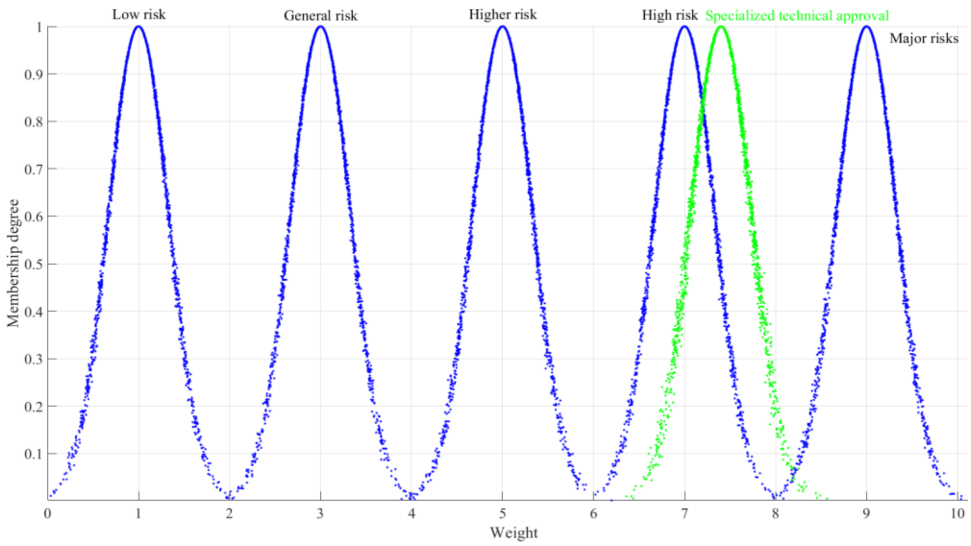
After obtaining the digital characteristic value of the upper index and even the whole cloud, the corresponding evaluation cloud map is drawn, and compared with the evaluation cloud of the evaluation level, and the evaluation result is intuitively obtained according to the proximity degree. It is shown **in Figure 3 and Figure 4.**



(a) Cloud diagram of A1 process adaptability evaluation



(b) Cloud diagram for reliability evaluation of A2 equipment



(d) Cloud map of A3 Special Technology Approval and Evaluation

Figure 4 Cloud diagram of technical support A bottom index

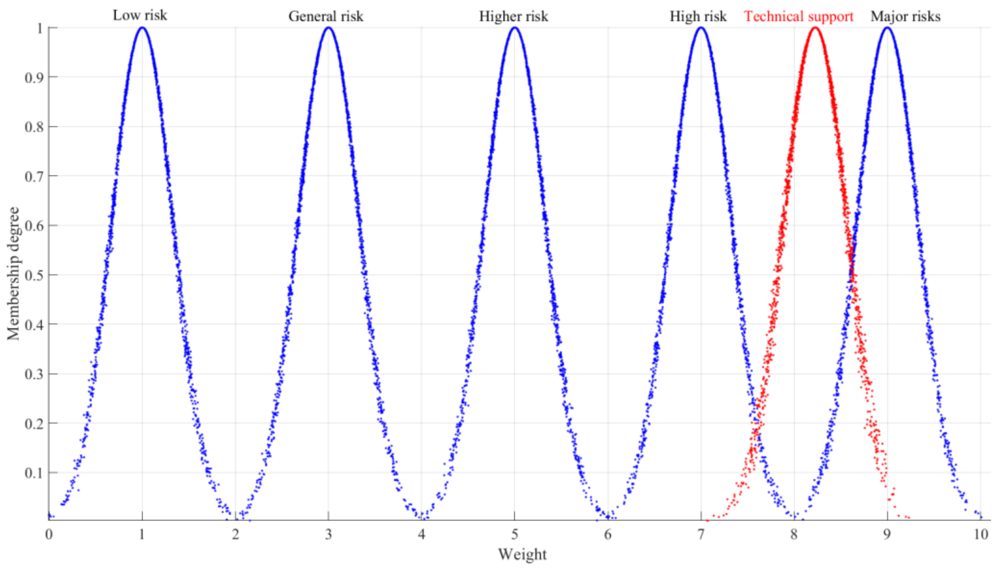


Figure 5 Cloud map of technical support A index

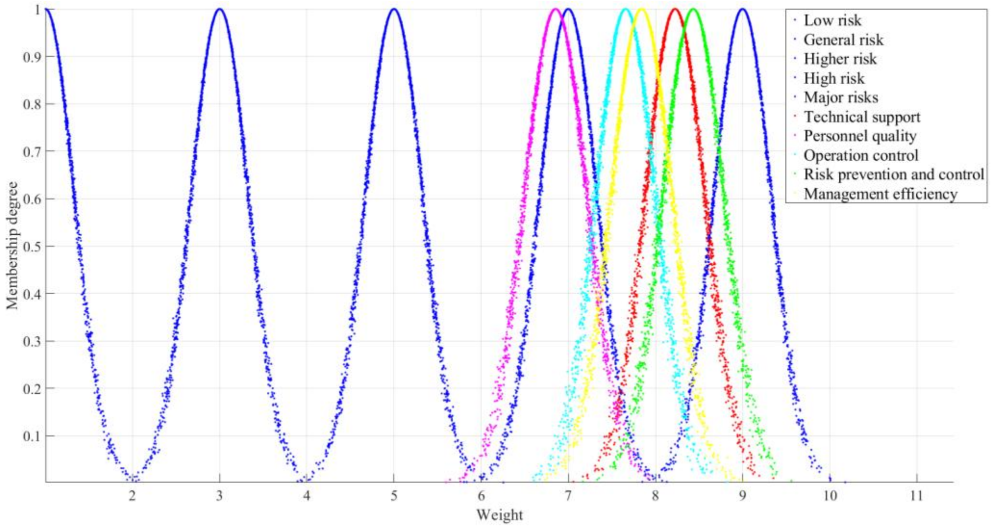


Figure 6. Cloud map of the first level index of inclined (vertical) well construction

As can be seen from Figure 4 and Figure 5, index A (technical support) is at A major risk during shaft construction, and the lower index A_2 (equipment reliability) has A_1 higher risk degree than A_3 (process reliability) and A (special technical approval). Among them, index A_1 (process reliability) has a higher risk degree than index A_3 (special technical approval). As can be seen from the analysis of Figure 6, index D (risk prevention and control) and index A (technical support) are at major risks, while the rest indicators are high risks. The dynamic prevention and control mechanism of major risks throughout the whole cycle should be implemented in the above key links to realize the pre-intervention of risk sources.

4 Analysis of Construction Risk Assessment Results of Inclined (Vertical) Well

The comparison results of the comprehensive cloud map show that the distribution of each risk factor has certain characteristics. Index A (technical support) and index D (risk prevention and control) are in the major risk link in the construction project of inclined (vertical) well. It is necessary to improve the special technical measures of the construction project, and implement the accurate control system according to the characteristics of each construction link; Index B (personnel quality), index C (operation control) and index E (management efficiency) are all high risk levels. Multi-level safety training mechanism should be used to strengthen personnel skills, establish a standardized operation guidance system, and optimize the responsibility system in the construction organization design to jointly reduce the risk degree, ensure construction safety and quality, and comprehensively improve project efficiency and reliability.

5. Conclusion

(1) The "input-operation-output" of inclined (vertical) well construction activities was analyzed by introducing process method, and the construction safety management model of inclined (vertical) well construction based on process method was divided into 6 construction stages and 2 independent units based on the actual project. The risk factors were analyzed and extracted, and five first-level indicators were constructed through systematic integration. 15 secondary indexes of slanted (vertical) well construction risk evaluation index system.

(2) The weight of risk factors at each level is determined by the combination of C-OWA operator and sequential relationship analysis method. Based on the cloud model theory, the construction safety risk assessment model of inclined (vertical) well is constructed. By comparing the cloud map results of primary indicators, index A (technical support) and index D (risk prevention and control) are at major risks, indicating that priority should be given to and key prevention and control should be carried out in the process of risk assessment of inclined (vertical) well construction. The risk degree of other indicators is still high. On the basis of prioritizing the control of major risks, it is necessary to prevent the escalation of risks through standardized operation constraints and other measures, and finally form a management model of "strictly preventing major risks and

systematically controlling high risks" to ensure the control of construction safety risks in the whole area.

(3) Taking a hydropower station as an example, the example application verification shows that the model can accurately evaluate the key risk links of the project, confirm the feasibility of the model, and the application results are basically in line with the actual construction situation. It provides a methodological paradigm and practical reference for improving the construction of inclined (vertical) well to cope with sudden risk accidents and the construction of risk prevention and control system of inclined (vertical) well projects in the same type of water conservancy project.

Author Contributions: Conceptualization, M.P. and X.B.; methodology, Y.M. and W.Z; software, W.Z.; validation, J.L. All authors have read and agreed to the published version of the manu-script.

Funding: This research received no external funding.

Informed Consent Statement: This study did not involve humans.

Data Availability Statement: Date are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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