Risk Assessment on Constructors during Over-water Riprap Based on Entropy Weight and FAHP

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Abstract. Being aimed at waterway regulation engineering, there exist risks of over-water riprap for constructors which keeps uncertainty and complexity. For the purpose of evaluating the possibility and consequence, this paper utilizes fuzzy analytic hierarchy process with abbreviation of FAHP to do empowerment on the related risk indicators, constructs FAHP under entropy weight and establishes relevant evaluation factor set and evaluation language for constructors during over-water riprap construction process. Through doing risk probability estimation and risk consequence size evaluation on the factor of constructors, this paper introduces this model into risk analysis on constructors during over-water riprap of Ching River waterway regulation project. Results show that evaluation of this method is so credible that it could be utilized in practical engineering.

1. Introduction

Under the strategic guidance of Yangtze River economic zone, comprehensive transportation network has been constructed around Yangtze River which has already achieved initial success through doing integration on waterway, highway, railway and airline. However, much potential in Yangtze River shipping still remains to be fulfilled. It is particularly reflected in obstruction of upper and middle reaches of channel, which seriously hinders promotion of effective gathering and transferring system and improvement of proportion of high-level channel [1]. “Intestinal obstruction” of Jingjiang River channel is so serious that development of Yangtze River economic zone is greatly restricted. Therefore our government invested 4.3 billion yuan to dredge the “nine-bend and eighteen-curve” waterway of Jingjiang River. Meanwhile flood control is also taken into consideration whose main construction technologies include paving, rip-rapping, permeable frame flipping and slope protection with gabion mesh, etc. However, its construction quality may be influenced by multiple factors which keep various uncertainties. Therefore, it seems particularly important to make rational analysis on typical qualitative indexes.

Analytic hierarchy process is adopted for quantitative analysis on qualitative elements. However, the analysis needs frequent adjustment and consistency examination which increases calculation workload. Then FAHP is established to do improvement. Li Fawen[2] takes rural drinking water system as example and utilizes FAHP to do calculation on weights of dominant factors in brittle hierarchy structure thus evaluating safety of rural drinking water system from brittleness angle. Aiming at one tunnel collapse, Chen Jiejin [3] utilizes FAHP to construct one risk assessment model thus acquiring construction risk level of this section and comparing it with practical condition of
construction site, whose conditions are identical. Jin Lianghai[4] constructs the comprehensive assessment model FAHP to do comprehensive evaluation and analysis on all involved indexes, which exempts deficiency of much adjustment and consistency examination of AHP and improves computational efficiency. The model is introduced in XiaoWan hydro-power project of Yunnan Province, whose reliability acquires verification. However, subjective factors of experts during its analysis process greatly influence the final results thus decreasing the credibility of analyzing results.

For the purpose of overcoming the subjectivity and uncertainty in the determination of risk assessment index proportion, entropy coefficient is introduced into fuzzy comprehensive evaluation to implement abundant research. For example, Gu Yujiong [5] introduces entropy weight, combines it with AHP and does scientific analysis on equipment maintenance mode of power station through considering objectification of experts’ opinions. Researchers like Wu Dingyong [6] adopt matter-element entropy coefficient model to do safety evaluation on navigational environment of five shipping lanes. In a practical engineering project, researchers like Zhang Lingwan [7] compared the entropy coefficient fuzzy comprehensive evaluation with fuzzy comprehensive safety evaluation which verifies the rationality of model. In the assessment on flood risk degree of Chongqing-Guizhou expressway, researchers like Chen Hongkai adopted the method and got an accurate assessment. Luo Jungang [9] constructed entropy coefficient fuzzy comprehensive evaluation model and did evaluation analysis on risk of water shortage. Yang Yuzhong[10] adopted entropy coefficient fuzzy comprehensive evaluation method to assess and analyze safety of coal transportation.

Focusing on the complicity and uncertainty of risks for constructors in rip-rapping of Jingjiang River Waterway regulation project, this paper adopts entropy coefficient method to analyze risk indexes of constructors in rip-rapping of waterway regulation project, constructs FAHP under entropy coefficient and establishes relevant evaluation factor set and evaluation markers on constructors in rip-rapping to assess and analyze the risk level which accurately reflects risk level of constructors, makes assessment results keep reliability and has certain application value in physical engineering.

2. Method

2.1. Fuzzy analytic hierarchy process
Analytic Hierarchy Process (AHP) sets out all factors which are involved in analyses and decisions and divides them into levels of objective, principle, scheme, etc. On the basis of it, “qualitative analysis and quantitative analysis” could be realized. Decisions or assessment process can be quantified according to ideal and psychological rules. Since the method is especially pragmatic and effective for complicated assessment problems, it is widely used in risk assessment in various fields.

The key to AHP is the construction of assessment matrix. For sake of meeting requirements of adjustment and consistency examination, the matrix should be adjusted repeatedly, which is quite time-wasting and inefficient. If analysis keeps many layers and high complicity, it would be rather difficult to modify the judgment matrix. Therefore the idea of introduction of fuzzy math is utilized to determine assessment results during construction of judgment matrix. Generally speaking, there are reciprocal judgment matrix, complementary judgment matrix and mixed judgment matrix [11]. This paper adopts fuzzy complementary judgment matrix. That is, if matrix $A = (a_{ij})_{mn}$, for any $i, j$, there are $a_{ij} = 0.5$, $i = 1, 2, \ldots, n, 0 < a_{ij} < 1, a_{ij} + a_{ji} = 1$; for matrix $A = (a_{ij})_{mn}$, if there is a $k (1 < k < n)$, then $a_{ij} = a_{ik} - a_{jk} < 0.5$, it is a fuzzy complementary judgment matrix.

2.2. Entropy and entropy coefficient
In information science, there exists information entropy which presents the uncertainty or the probability an object may occur. It is a measurement of the disorder degree of a system. From the practical use of a piece of information, the size of entropy stands for the amount of information. If the information amount is very large, then the event will be of great certainty and the entropy value will
be small; on the contrary, if the information amount is quite small, then the event will be uncertain and the entropy value will be big.

Suppose that the system is under multiple conditions and the probability varies in each condition \( p_i (i = 1, 2, \ldots, m) \), then the entropy of the system can be defined as \( H = -k \sum_{i=1}^{m} p_i \ln p_i \), in the formula, there are \( m \) conditions to be assessed and \( n \) indexes already assessed. Then a matrix of \( m \times n \) is constructed. That is, if \( Q = (q_{ij})_{mn} \), for any \( q_{ij} \) the information entropy can be:

\[
H_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}
\]

(1)

In the above-mentioned formula, \( p_{ij} \) is the normalization of \( q_{ij} \). That is \( p_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}} \), \( k \) is the coefficient and there is \( k = \frac{1}{\ln n} \); if \( p_{ij} = 0 \), then \( H_j = 0 \). The entropy coefficient of \( j \) index can be defined as:

\[
w_j^p = \frac{1 - H_j}{\sum_{j=1}^{n} (1 - H_j)}
\]

(2)

From above, the priority vector of assessment index should be: \( W^p = (w_{1^p}, w_{2^p}, \ldots, w_{n^p}) \). Here, the entropy coefficient stands for the fierce degree of competition among all indexes.

3. Construction of Fuzzy Analytic Hierarchy Process Assessment Model-Entropy Coefficient

For sake of lowering the risks, hydro geological conditions, raw materials, shipping equipment and construction site during rip-raping process of waterway realignment are all strictly controlled. However, it is complicated and difficult to control worker element in the process. As it could not be ignored, it would be necessary to make risk assessment for constructors. Therefore, AHP is adopted and fuzzy math is introduced to “obfuscate” the judgment matrix. After that a fuzzy comprehensive judgment matrix is constructed and entropy coefficient is utilized to make the result be more objective.

3.1. Index factor set of risk assessment for constructors in rip-raping

According to relevant materials and field research, risk carriers in rip-raping can be divided into six types including raw materials, shipping equipment, hydro geological conditions, constructors, environment inside and outside the construction site. This paper focuses on the risk assessment on constructors in rip-raping and makes a risk factor set \( U \), which analyses the probability and consequences of risks for constructors in the construction. It is shown in figure 1.

3.2. Risk assessment markers

Risk assessment on workers in rip-raping is aimed at highlighting constructors. The probability and consequences of the risks are put into five grades. For the probability, there are extremely low, low, medium, high and extremely high. The formula is \( v_i = \{v_{i1}, v_{i2}, v_{i3}, v_{i4}, v_{i5}\} \) and the degree increases from \( v_{i1} \) to \( v_{i5} \); for the consequences, there are extremely low, low, medium, serious and extremely serious. The formula is \( v_i = \{v_{21}, v_{22}, v_{23}, v_{24}, v_{25}\} \) and the degree increases from \( v_{21} \) to \( v_{25} \).

3.3. Calculation and judgment on overall weight

In the entropy coefficient comprehensive assessment model, there are subjective weight in FAHP and objective entropy coefficient in fuzzy comprehensive assessment as well as entropy coefficient process.
3.3.1 Subjective and objective weight. If \( U = \{u_1, u_2, \ldots, u_n\} \) is the assemblage of \( n \) factors on assessment object, then the judgment matrix is \( U^{(i)} = \begin{bmatrix} r_{i1} & r_{i2} & \cdots & r_{in} \\ r_{i2} & r_{i2} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{in} & r_{in} & \cdots & r_{nn} \end{bmatrix} \). The rule for the value of \( r_{ij} \) is

\[
  r_{ij} = \begin{cases} 
    0.5 & t(i) = t(j) \\
    1 & t(i) > t(j) \ i, j = 1, 2, \ldots, n \\
    0 & t(i) < t(j)
  \end{cases}
\]

where \( t(i) \) and \( t(j) \) stands for the relative importance of factor \( u(i) \) and factor \( u(j) \) respectively.

Fuzzy consistency judgment matrix is transferred through \( r: R = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ R_{n1} & R_{n2} & \cdots & R_{nn} \end{bmatrix} \). In the formula,

\[
  R_{ij} = \frac{k_i - k_j}{2n} + 0.5, \quad k_i = \sum_{j=1}^{n} r_{ij}, \quad i, j = 1, 2, \ldots, n.
\]

“Addition” is adopted to calculate relative weight. That is subjective weight and the result is \( A = \{a_1, a_2, \ldots, a_n\} \); the ideas of all experts are integrated into a fuzzy comprehensive assessment matrix. Based on the system and the calculation procedure in 1.2, the objective weight is \( W = \{w_1, w_2, \ldots, w_n\} \).

3.3.2 Overall weight. From above, we can know that subjective weight is \( A = \{a_1, a_2, \ldots, a_n\} \) and objective weight is \( W = \{w_1, w_2, \ldots, w_n\} \). Then the overall weight of \( i \) index is:

\[
  t_i = \frac{a_i \times w_i}{\sum_{i=1}^{n} a_i \times w_i}
\]

the overall weight: \( T = \{t_1, t_2, \ldots, t_n\} \) (3).

3.3.3 Overall assessment result. For single-level result of overall assessment, fuzzy comprehensive evaluation is adopted based on formula: \( B_i = T_i^T \cdot R_i \) (4).
That is: \((b_1, b_2, ..., b_n) = (t_1, t_2, ..., t_n)\). In the formula \(B_i\) stands for single-level comprehensive assessment result; \(R\) stands for fuzzy comprehensive evaluation matrix; \(T_i\) stands for weight vector; "\(\circ\)" stands for fuzzy operator.

Among all sub-assessment factors, all formulas above can work out their fuzzy comprehensive judgments whose results are \(B_1, B_2, ..., B_m\). Therefore, the fuzzy comprehensive evaluation matrix of the factor assemblage is:

\[
\begin{bmatrix}
B_1 \\
B_2 \\
\vdots \\
B_m
\end{bmatrix}
= 
\begin{bmatrix}
\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\
\vdots & \vdots & & \vdots \\
\end{bmatrix} \\
\begin{bmatrix} b_{21} & b_{22} & \cdots & b_{2n} \\
\vdots & \vdots & & \vdots \\
\end{bmatrix} \\
\vdots \\
\begin{bmatrix} b_{m1} & b_{m2} & \cdots & b_{mn} \\
\vdots & \vdots & & \vdots \\
\end{bmatrix}
\end{bmatrix}
.\]

So forth, the fuzzy comprehensive evaluation result of the top layer is \(B\). This study focuses on the importance of a factor and processes the fuzzy evaluation result with the maximum subordination principle. That is: \(V = \left\{ V_i \middle| V_L \rightarrow \max_{j=1} b_j \right\} \).

### 4. Applications of Living Examples

#### 4.1. Determination of Assessment indexes

In order to issue management document of strong pertinence to prevent risks and guide workers, factors influencing the safety of workers must be collected and analyzed through entropy coefficient-FAHP. All risk factor indexes can be seen in figure 1 whose assessment markers are in 2.2.

Ideas of experts on the probability and consequences of the risks are collected to form the second layer of fuzzy comprehensive assessment model. \(B_1\) stands for possibility and \(B_2\) stands for consequences. \(B_{1i}\) and \(B_{2i}\) represent the assessment matrix:

\[
Q_{11} = 
\begin{bmatrix}
0.16 & 0.24 & 0.34 & 0.2 & 0.06 \\
0.12 & 0.12 & 0.32 & 0.32 & 0.12 \\
0.10 & 0.2 & 0.32 & 0.2 & 0.18 \\
0.12 & 0.28 & 0.2 & 0.10 \\
\end{bmatrix}
,
\]

\[
Q_{12} = 
\begin{bmatrix}
0.18 & 0.2 & 0.32 & 0.24 & 0.06 \\
0.18 & 0.2 & 0.32 & 0.24 & 0.06 \\
0.2 & 0.28 & 0.2 & 0.28 & 0.04 \\
0.08 & 0.24 & 0.38 & 0.1 \\
\end{bmatrix}
,
\]

\[
Q_{13} = 
\begin{bmatrix}
0.12 & 0.16 & 0.3 & 0.34 & 0.08 \\
0.16 & 0.24 & 0.24 & 0.26 & 0.1 \\
0.14 & 0.22 & 0.3 & 0.26 & 0.08 \\
\end{bmatrix}
,
\]

\[
Q_{21} = 
\begin{bmatrix}
0.12 & 0.24 & 0.22 & 0.18 & 0.24 \\
0.16 & 0.3 & 0.34 & 0.14 & 0.06 \\
0.1 & 0.26 & 0.28 & 0.26 & 0.1 \\
0.16 & 0.18 & 0.24 & 0.26 & 0.16 \\
\end{bmatrix}
,
\]

\[
Q_{22} = 
\begin{bmatrix}
0.08 & 0.24 & 0.24 & 0.34 & 0.1 \\
0.10 & 0.36 & 0.22 & 0.2 & 0.12 \\
0.10 & 0.26 & 0.24 & 0.26 & 0.14 \\
0.14 & 0.22 & 0.32 & 0.26 & 0.06 \\
\end{bmatrix}
,
\]

\[
Q_{23} = 
\begin{bmatrix}
0.02 & 0.2 & 0.22 & 0.38 & 0.18 \\
0.04 & 0.2 & 0.36 & 0.32 & 0.08 \\
0.08 & 0.26 & 0.22 & 0.34 & 0.1 \\
\end{bmatrix}
.
\]

Based on the assessment matrix \(Q_i\), \(Q_i\) \((i = 1, 2, 3)\) above and formula (1) and (2), the entropy coefficient is calculated: \(W_1^i = (0.31, 0.31, 0.16, 0.22)\); \(W_2^i = (0.19, 0.22, 0.27, 0.32)\); \(W_3^i = (0.49, 0.19, 0.32)\); \(W_1^2 = (0.10, 0.50, 0.32, 0.08)\); \(W_2^2 = (0.31, 0.25, 0.15, 0.29)\); \(W_2^3 = (0.36, 0.41, 0.23)\).

Assessment matrix in FAHP model is:
Assessment matrix of the first layer: \( P = \begin{bmatrix} 0.5 & 1 & 1 \\ 0 & 0.5 & 1 \\ 0 & 0 & 0.5 \end{bmatrix} \)

Assessment matrix of the second layer:

\[
P_1 = \begin{bmatrix} 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 \\ 0 & 0 & 0.5 \end{bmatrix}
, \quad P_2 = \begin{bmatrix} 0.5 & 1 & 0.5 & 0 \\ 0 & 0.5 & 0 & 0 \\ 0.5 & 1 & 0.5 & 0.5 \\ 1 & 1 & 0.5 & 0.5 \end{bmatrix}
, \quad P_3 = \begin{bmatrix} 0.5 & 1 & 0.5 \\ 0 & 0.5 & 0 \\ 0.5 & 1 & 0.5 \end{bmatrix}
\]

All the weight coefficients are worked out through “addition”: the first layer \( \rightarrow \) the second layer: \( A = (0.454, 0.333, 0.213) \); The second layer \( \rightarrow \) the third layer: \( A_1 = (0.283, 0.283, 0.151, 0.283), A_2 = (0.250, 0.151, 0.283, 0.316), A_3 = (0.392, 0.216, 0.392) \).

Based on formula (3), the overall weight of the second layer is \( T_2^i = (0.335, 0.335, 0.092, 0.238) \), \( T_2^j = (0.184, 0.128, 0.296, 0.392) \), \( T_2^k = (0.536, 0.114, 0.350) \), \( T_2^l = (0.118, 0.588, 0.201, 0.094) \), \( T_2^m = (0.311, 0.151, 0.17, 0.368) \), \( T_2^n = (0.441, 0.277, 0.282) \).

Last, overall assessment can be worked out through formula (4) and the Fuzzy Comprehensive Assessment matrix in the second layer:

\[
B_{11} = T_{11} \circ R_{11} = (0.132, 0.210, 0.317, 0.240, 0.101), B_{12} = T_{12} \circ R_{12} = (0.147, 0.224, 0.253, 0.307, 0.070),
B_{13} = T_{13} \circ R_{13} = (0.132, 0.190, 0.293, 0.303, 0.082), B_{21} = T_{21} \circ R_{21} = (0.143, 0.274, 0.305, 0.180, 0.099),
B_{22} = T_{22} \circ R_{22} = (0.109, 0.254, 0.266, 0.276, 0.095), B_{23} = T_{23} \circ R_{23} = (0.043, 0.217, 0.259, 0.352, 0.130).
\]

The fuzzy comprehensive assessment matrix of the first layer is:

\[
R_i = \begin{bmatrix} 0.132 & 0.210 & 0.317 & 0.240 & 0.101 \\ 0.147 & 0.224 & 0.253 & 0.307 & 0.070 \\ 0.132 & 0.190 & 0.293 & 0.303 & 0.082 \end{bmatrix}
, \quad R_2 = \begin{bmatrix} 0.143 & 0.274 & 0.305 & 0.180 & 0.099 \\ 0.109 & 0.254 & 0.266 & 0.276 & 0.095 \\ 0.043 & 0.217 & 0.259 & 0.352 & 0.130 \end{bmatrix}
\]

It is seen from the matrix above that overall weight of the first layer \( T_i = (0.280, 0.353, 0.367) \) and \( T_j = (0.236, 0.272, 0.492) \). By \( B_i = T_i \circ R_i = (0.137, 0.210, 0.286, 0.287, 0.083), B_j = T_j \circ R_j = (0.085, 0.241, 0.272, 0.291, 0.113) \) and the maximum subordination principle, which tells that the probability of risks is “high” and the consequence of risks is “serious”. The results agree with the actual situations. The workers are easily influenced by the factors above. The risks will cause severe loss in both aspects of property and personal security, which shows that assessment result is quite reliable.

4.2. MATLAB programming

To make it more easily for construction managers to control the project and to simplify the calculation process, MATLAB is adopted to build in all the formulas above and GUI programming is used to make the interface more friendly and clear for operators to get risk grade.

5. Conclusions

Aiming at complicity and uncertainty of risks on workers in rip-raping during Jingjiang River waterway regulation process, this paper adopts FAHP to analyze the risk indexes of the workers in rip-raping. Entropy coefficient method is also introduced during fuzzy evaluation to objectively deal with experts’ ideas and constructs entropy coefficient-FAHP model. Based on entropy coefficient fuzzy comprehensive assessment model, this paper constructs relevant assessment factor set and assessment markers for the risks of workers in rip-raping. Through doing
risk probability estimation and risk consequence size evaluation, this paper does programming
MATLAB and introduces it into physical engineering, which is in accordance with field investigation.
It shows strong adaptability of this model in assessment on Jingjiang River waterway regulation,
which also keeps simple and convenient calculation operation. This would provide handy, scientific
and reliable thoughts for other similar construction processes during the waterway regulation project.

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