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Geotechnical Risks Assessment During the Second part of Emamzadeh Hashem (AS) Tunnel Using FDAHP-PROMETHEE

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ABSTRACT: Nowadays, the tunnels based on the public's needs may be built in unfavorable geological conditions. In most of these situations, the use of mechanized excavation technology is unavoidable to improve the performance and safety. Mechanized tunneling in difficult conditions with many risks, including the fault zones, water inflow and squeezing that tunneling operations could stop for a long time. It is very important to predict and assess the hazards because of the large volume of investment in such projects. In this study, it was tried to investigate the stability and convergence of environment and water inflow in seven section of the second part of the Emamzadeh Hashem (AS) tunnel using analytical and numerical methods after identification of the geological characteristics and geotechnical risks. Then, the most risky section was investigated and introduced using Fuzzy Delphi Analytical Hierarchy Process (FDAHP) and PROMETHEE methods. Thus, after selecting criteria, including the instability of the tunnel, water inflow and squeezing, the weighting of each criterion was determined using FDAHP method according to the severity, rate and probability of disaster. Finally, the most risky section of the second part of Emamzadeh Hashem (AS) tunnel was evaluated using the PROMETHEE method. Thus the H-3 section was introduced and selected as the most risky section based on geotechnical properties. The results of this study showed that a combination of multiple criteria decision making, analytical, numerical and fuzzy methods can be used to predict and evaluate the geotechnical risks and doing disaster risk reducing actions to reduce the risk.

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1- Introduction

With population growth and development of cities in recent years, convenient and fast intercity moving and transportation has become important. All of construction projects such as tunneling projects have risk. The most important excavation hazards are geotechnical risks such as water inflow, squeezing and instability of tunnel. Geological and geotechnical risks are the risk to construction work created by the site ground conditions. These risks are as varied as the geologic and geomechnical conditions that create the hazards that are the source of the risks, and the types of construction. [1]. In This research will try to assessment and evaluation the second part of Emamzadeh Hashem (AS) tunnel from the standpoint of geotechnical risks using multi-criteria decision-making methods and Fuzzy Delphi Analytical Hierarchy.

2- Geotechnical Risks of second part of the Emamzadeh Hashem (AS) tunnel

According to geological studies carried out in the second part of Emamzadeh Hashem (AS) tunnel and investigation route profile, three possible outcomes geotechnical risk was identified. These risks include the instability of the tunnel, the water inflow and squeezing. Table 1 shows the results of a critical strain, the influx of water and squeezing for each section.

Table 1. Geotechnical properties of studied sections

Section	Squeezing ((cm	Water inflow (lit/s)	Instability of the tunnel (critical strain)
H-4	1.34	0.045	0.006
H-1	0.5	2.6	0.0027
H-3	3.2	504	0.004
H-16	1.38	0.45	0.0035
H-2	0.83	44.7	0.003
H-11	0.86	8.65	0.004
H-15	0.33	0.007	0.0042

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3- Determination of criteria's weights using FDAHP method

At first to enter data, Fuzzy Delphi Hierarchical Analysis method was used to determine the weight of effective criteria. For this purpose, three pair-wise comparison matrix for the occurrence, severity and likelihood of risk criteria were established. Then fuzzy numbers were calculated by the following equations [2].

$$a_{ij} = \left(\alpha_{ij}, \delta_{ij}, \gamma_{ij}\right) \quad (1)$$

$$\alpha_{ij} = Min\left(\beta_{ijk}\right), k = 1, \ldots, n \quad (2)$$

$$\delta_{ij} = \left(\prod_{k=1}^{n} \beta_{ijk}\right)^{1/n}, k = 1, \ldots, n \quad (3)$$

$$\gamma_{ij} = Max\left(\beta_{ijk}\right), k = 1, \ldots, n \quad (4)$$

In addition, by using fuzzy numbers obtained from the previous stage and Equation 5, fuzzy pairwise matrix was obtained [2]. Fuzzy pairwise matrix is shown in Table 2.

$$\begin{aligned} &\tilde{A} = \left[\tilde{a}_{ij}\right] \\ &\tilde{a}_{ij} \times \tilde{a}_{ij} \approx 1, \forall i, j = 1, 2, \ldots, n \end{aligned} \quad (5)$$

Table 2. Fuzzy pairwise matrix

(1,1,1)	(0.25 ,0.21 ,0.14)	(0.25 ,0.17 ,0.11)
(4 ,4.76 ,7.14)	(1,1,1)	(1 ,0.55 ,0.33)
((5.88,4 ,9.09	(1 ,1.81 ,3.03)	(1,1,1)

In the next stage, fuzzy weight of each parameter was determined using Equations 6 and 7.

$$\tilde{Z}i = \left[\tilde{a}_{ij} \otimes \ldots \otimes \tilde{a}_{in}\right]^{1/n} \quad (6)$$

$$\begin{aligned} &\tilde{W}i = \tilde{Z}i \otimes (\tilde{Z}i \oplus \ldots \oplus \tilde{Z}n) \\ &\tilde{Z}_1 = \left[\tilde{a}_{13} \otimes \tilde{a}_{12} \otimes \ldots \tilde{a}_{13}\right]^{1/3} = [0.25, 0.33, 0.4] \\ &\tilde{Z}_2 = \left[\tilde{a}_{21} \otimes \tilde{a}_{22} \otimes \ldots \tilde{a}_{23}\right]^{1/3} = [1.1, 1.38, 1.91] \\ &\tilde{Z}_3 = \left[\tilde{a}_{31} \otimes \tilde{a}_{32} \otimes \ldots \tilde{a}_{33}\right]^{1/3} = [1.59, 2.2.22, 3] \\ &\sum \tilde{Z}_i = [2.94, 3.93, 5.31] \\ &\tilde{W}_1 = \tilde{Z}_1 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.09, 0.08, 0.07] \\ &\tilde{W}_2 = \tilde{Z}_2 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.37, 0.35, 0.36] \\ &\tilde{W}_3 = \tilde{Z}_3 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}\ )^{-1} = [0.54, 0.56, 0.56] \end{aligned} \quad (7)$$

Finally, after finding the fuzzy weights of each parameter, all the numbers are converted for non-fuzzy using Equation 8.

$$\begin{aligned} &\tilde{W}i = (\textstyle\prod_{i=1}^{3} \omega_j)^{1/3} \\ &W_1 = (\textstyle\prod_{i=1}^{3} \omega_j)^{1/3} = 0.08 \\ &W_2 = 0.36 \\ &W_3 = 0.56 \end{aligned} \quad (8)$$

4- PROMETHEE I and II method algorithm

PROMETHEE I and II are multi-criterion decision making techniques developed by J. P. Brans. These methods build a valued outranking relation and exploit this relation to gain a partial ranking (PROMETHEE I) or complete ranking (PROMETHEE II).

The basic steps of PROMETHEE methods to solve such multi-criteria problem are:

- Defining a preference function for each criterion,
- Calculating the multi-criteria preference index as a weighted average of the preference functions,
- Calculating a leaving flow, an entering flow, and a net flow for each alternative, and
- Assigning a partial or complete ranking.

A preference function (P_j (a, b) ϵ A) associated with criterion gi gives the degree of preference, expressed by decision-makers, for Alternative a over b as an input and provides a normalized output as shown by Equation 9 and 10, respectively.

$$P_j(a,b) = P_j[g_i(a)-g_i(b)] \quad (9)$$

$$0 \leq Pj(a,b) \leq 1 \quad (10)$$

If P_j(a, b) = 0, there is no preference a over b and if P_j(a,b) = 1, there is a sheer preference of a over b.

If a weight w_j is given, which shows the relative importance of each criterion, and can be used to calculate the multicriteria preference index as defined by Eq. (11):

$$\pi(a,b) = \sum_{i=1}^{k} wjpi(a,b) \quad (11)$$

The outgoing flow that shows how an alternative a_i is outranking other alternatives is defined by the equation below:

$$\varphi^{+}(a) = \frac{1}{n-1} \sum_{x \in k} \pi(a,x) \quad (12)$$

The incoming flow that shows how an alternative a_i is outranked by other alternatives is defined by the following equation:

$$\varphi^{-}(a) = \frac{1}{n-1} \sum_{x \in k} \pi(x,a) \quad (13)$$

PROMETHEE I is used to derive a partial ranking which is obtained by comparing the leaving and incoming flows, as defined by Equation 14:

$$\begin{cases} a\ P\ b \quad iff \begin{cases} \varphi+(a) > \varphi+(b)\ and\ \varphi-(a) < \varphi-(b), or \\ \varphi+(a) = \varphi+(b)\ and\ \varphi-(a) < \varphi-(b), or \\ \varphi+(a) > \varphi+(b)\ and\ \varphi-(a) = \varphi-(b); \end{cases} \\ a\ I\ b \quad iff\ \ \varphi+(a) = \varphi+(b)\ and\ \varphi-(a) = \varphi-(b) \\ a\ R\ b \quad iff \begin{cases} \varphi+(a) > \varphi+(b)\ and\ \varphi-(a) > \varphi-(b), or \\ \varphi+(a) < \varphi+(b)\ and\ \varphi-(a) < \varphi-(b); \end{cases} \end{cases} \quad (14)$$

Where P, I and R represent preference, indifference, and incomparability, respectively.

PROMETHEE II is used to derive a complete ranking which is calculated as a net flow between outgoing and incoming flows, as shown in Equation 15. If the net flow of a is greater than b, a outranks b. Otherwise, a is indifferent to b [3].

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \quad (15)$$

After the calculation PROMETHEE method and obtain a net flow to each sections, section H-3 was chosen as section with high geotechnical risk. The results are given in Table 3.

Table 3. Ranking sections

Rank	Section	Net flow
1	H-3	0.53
2	H-4	0.34
3	H-11	0.21
4	H-15	-0.06
5	H-2	-0.16
6	H-16	-0.25
7	H-1	-0.61

5- Results and Discussion

There are many geotechnical risks, including the fault zones, water inflow and squeezing in mechanized tunneling under difficult conditions that could stop the excavation operations for a long time. It is very important to evaluate the tunneling risk before excavation. In this paper, in the first step, the stability and convergence of environment and water inflow in seven section of the second part of the Emamzadeh Hashem (AS) tunnel was study by using analytical and numerical methods. Then, the most risky section was investigated and introduced using Fuzzy Delphi Analytical Hierarchy Process and PROMETHEE methods according to instability of the tunnel, water inflow and squeezing. The weighting of each criterion was determined using FDAHP method according to the severity, rate and probability of disaster. Finally, the H-3 section was introduced and selected as the most risky section based on geotechnical properties. The results of this study showed that a combination of multiple criteria decision making, analytical, numerical and fuzzy methods can be used to predict and evaluate the geotechnical risks and doing disaster risk reducing actions to reduce the risk.

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