Analysis of Protection of Body Slope in the Rockfill Reservoir Dams on the Basis of Fuzzy Logic

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Abstract: The objective of this study is to survey the most appropriate way to protect body slope of the rockfill reservoir dams on the basis of fuzzy multiple criteria decision and analyze the Fuzzy Analytical Hierarchy Process (FAHP). In the present study, the reservoir dam of Shahr-e-Bijar, situated in Guilan province of Iran, has been studied. Also, for using the fuzzy analytical hierarchy process, eight important criteria in order to select the fittest way to protect body slope of the dam as well as five methods, namely, Riprap, Concrete facing, Asphalt concrete, Soil – Cement, and Geo-synthetic protection have been studied and analyzed. The fuzzy numbers used in this study are triangle fuzzy numbers. Moreover, Visual Basic Program has been used in calculations. Due to the result of the study, concrete protection is the best method among all other methods used to protect the body slope of the dams.

1 INTRODUCTION

Iran is one of the arid and semiarid countries in the world which has about fifty five dusty dams. So, constructing control and storage dams are very important. Storage dams consist of different parts. Upstream and downstream slopes are among those parts (Rahimi, 2003).

In a rockfill reservoir dam, slope protection especially upstream slope protection is one of the most important parts which should be designed and chosen very carefully otherwise occurring lots of damages will be unavoidable.

Therefore, to prevent the erosion and destruction of upstream and downstream slopes of the rockfill reservoir dams, a suitable protective method should be considered. Making decision and choosing an appropriate method in such cases are usually complicated therefore quantitative and qualitative criteria are very important. Hence, in this article based on the Fuzzy Multi-Criteria Decision Making (FMCDM) and Fuzzy Analytical Hierarchy Process, it has been tried to consider most appropriate method to protect body slope of the reservoir dams in constructing Shahr-e-Bijar dam which is a rockfill dam. The dam designers are going to use concrete facing to cover the dam.

In this study eight effective criteria, including the economic advantage, resistance to environmental factors, cut-off, being a hard work, being time consuming, plasticity, destructive environmental impacts, and accessibility of materials for five methods of body slope protection of rockfill reservoir dams have been determined. Then, all factors have been examined. Further, by using the process of fuzzy analytical hierarchy, triangle fuzzy numbers as well as fuzzy logic, the accuracy or inaccuracy of the decision and the analysis of all items have been analyzed.

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2 THE CRITERIA OF THE STUDY

Having collected and analyzed the data required for the study, eight criteria which are effective in choosing the best method for protecting upstream slope of rockfill reservoir dams have been considered as the following:

economic advantage, resistance to

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environmental factors, cut-off, hardship of doing job, being time consuming, plasticity, environmental destructive effects as well as accessibility of materials. These criteria are classified in two categories as quantitative and qualitative criteria.

3 FIVE METHODS FOR PROTECTING THE SLOPES OF STORAGE DAMS

3.1 Riprap

One method of protecting the body of the dam's slope is using riprap protection. This layer is usually located on a filter made of sand and gravel with proper granulation. The material which is used as riprap should be made of sound stone so it can resist against factors such as frequent drying and wetting as well as weathering and erosion. Riprap protection is carried out in two ways hand placed and dumped.

3.2 Concrete Facing

Using concrete protection is another commonly used method in protecting dam's body slope.

Supplying the required materials is one of the requirements in this protection method. Generally speaking, due to the fact that applying the recently mentioned method costs more than riprap protection, concrete protection would be thiner than that of the riprap. Concrete protective layers are either located next to each other as mosaic sheets or noncoplanar and disordered layers. Concrete protection is carried out in the shape of reinforced or non reinforced concrete.

3.3 Asphalt Concrete

Another protective method is asphalt concrete protection or more accurately, concrete asphalt protection.

This protection is consisted of a mixture of sand and or fine sand with tar which can be used as protective layer in protecting of dam's body slope through a proper mix design.

3.4 Soil–cement Protection

Soil-cement protection is one of the construction materials which has been used since 1920s and enjoys competitive economic advantage and simplicity. One of the most significant applications of soil – cement protection is using this protection as a protective coverage of a dam body slope. The quality of soil – cement protection is affected by factors such as the amount of applied cement (Rahimi, 2003), the moisture content, granulation of the soil and the density percentage.

3.5 Geo-synthetic Protection

Technological development in petrochemical industries leads to the usage of geo synthetic protection. This kind of materials belongs to the family of polymers which are divided in two categories including geo-textiles and geo-membrine categories. These substances enjoy multiple properties such as reinforcing the soil for increasing the resistance of soil, filtration, cut-off, separating different materials and drainage. Ultraviolet rays and sun light lead to the decrease of the resistance of the materials.

4 FUZZY ANALYTICAL HIERARCHY PROCESS STEPS ACCORDING TO CHANG'S METHOD

The AHP method cannot straightforwardly be applied to solving uncertain decision problems and imprecisely defined ones. In this case, a natural way to cope with such uncertain judgments is to the comparison ratios as fuzzy judgments as fuzzy sets or fuzzy numbers. The fuzzy set theory was proposed by (Zadeh, 1965, pp.338-353), and Bellman and Zadeh (1970), described the decision making method in fuzzy environment. (Laarhoven and Pedrycz, 1983, pp.229-241).

Proposed the first studies that applied fuzzy logic principle to AHP (Koorepazan, 2008). Buckley (1985) initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion. Asgharpour (1997) while Laarthoven and Pedrycz were using triangular fuzzy numbers. Chang (1996) introduced a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and with use the extent analysis method for the synthetic extend values of the pair-wise comparison.

One of the most important applications of this logic is in multi-criteria decision making. Also, one of the most common methods of fussy multi- criteria decision making is the Fuzzy Analytical Hierarchy Process (FAHP) method.

Lee et al., (2008), Zare et al., (2009) and Tang (2009) are among those researchers who use fuzzy multi-criteria hierarchy process in their works for energy conservation, choosing underground mining method of Jajroom bauxite mine of Iran, and budget appropriation for Space Company respectively. Also, with this regard Yager et al., (1999), Leung et al., (2000), Karhaman et al., (2003) and Atai et al., (2007) research can be mentioned. Chang (1996) is a researcher who has done different researches and presented different methods about Fuzzy Analytical Hierarchy Process. In a fuzzy multi-criteria decision making of Chang's fuzzy analytical hierarchy process with m items and n criteria, seven steps have been defined.

4.1 Step One: Hierarchical Graph Drawing

In this step, first the hierarchical graph of the subject of the study is drawn in three levels: the first level (the objective), the second level (criteria), and the third level (the investigated items). Of course, the criterion of decision making may have some sub-criteria of decision making in the second level.

4.2 Step Two: Defining Fuzzy Numbers for Pairwise Comparisons

The fuzzy numbers which can be used are triangle and trapezoid fuzzy numbers. The fuzzy scale of numbers is obtained through considering each selected fuzzy number as well as its membership function.

4.3 Step Three: Forming Pairwise Comparison ($\tilde{A}$) Matrix with Fuzzy Numbers

Matrix of pairwise comparison ($\tilde{A}$) will be as follows:

$$\tilde{A} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \tag{1}$$

Fuzzy numbers of the matrix are as follows:

$$\tilde{a}_{ij} = \begin{cases} 1 & i=j \\ \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} \ \text{or} \ \tilde{1}^{-3},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & i \neq j \end{cases} \tag{2}$$

4.4 Step Four: Calculation of Each Rows of Pairwise Comparison Matrix

If I and j represent the numbers of rows and columns and M_{gi}^{j} show triangle fuzzy numbers of pairwise comparison matrix, the amount of $\sum_{j=1}^{m} M_{gi}^{j}$ $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}$, $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ is calculated as following:

$$\sum_{j-1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{4}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{5}$$

4.5 Step Five: Calculation of Values Magnitude

In this step the magnitude of each value is compared to other values.

Consider $S_2 = (L_2, m_2, u_2)$, $S_1 = (L_1, m_1, u_1)$ as two triangle fuzzy numbers. In order to determine their magnitude degree, the following equation is used. The degree of largeness has been shown in Figure 1.

$$V(S_2 \geq S_1) = hgt(S_1 \cap S_2) = \mu s_{2(d)} \begin{cases} 1 & \text{if} m_2 \geq m_2 \\ 0 & \text{if} l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \tag{6}$$

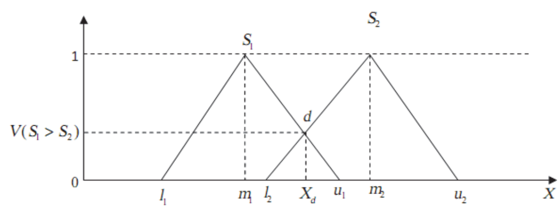

Figure 1: The largeness degree of two triangle fuzzy numbers S_1, S_2 in relation to each other.

4.6 Step Six: Calculating the Priority of Each Criterion and Item in Pairwise Matrices

In this stage use from following equation:

$$d'(A_i) = Min V(S_i \geq S_k) \qquad K=1,2,\ldots,n\ ,\ k \neq i \tag{7}$$

Through the following equation the vector of non normalized priority can be obtained.

$$w'(d'(A_i), d'(A_2), \ldots, d'(A_n))^T \tag{8}$$

4.7 Step Seven: Determining and Calculating the Overall Priority Vector

In this stage, the vector of priority which was calculated in the previous step is normalized so the overall priority vector is obtained.

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{9}$$

5 EVALUATING THE MOST APPROPRIATE COVERAGE FOR PROTECTING BODY SLOPE OF SHAHR-E-BIJAR STORAGE DAM

Shahr-e-Bijar reservoir dam is located 8 kilometers far from Shahr-e-Bijar village, 35 km from Rasht, on Zilky River in Guilan province of Iran. Zilky River enters Sepidrood River from the eastern of Sepidrood Drainage basin (watershed). The storage capacity of this dam reservoir is 105 million cubic meters which can also store water up to 165 million cubic meters،Figure 2. This reservoir dam is a rockfill one،Figure 3, therefore the correct choice of upstream slope protection type is of utmost importance. In this article, the most appropriate type of upstream slope protection for Shahr-e-Bijar reservoir dam with the use of the Fuzzy Analytical Hierarchy Process has been examined.

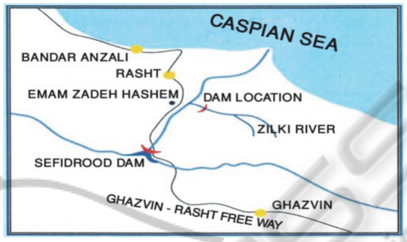

Figure 2: Location of the dam.

Figure 3: Upstream slope of dam.

5.1 Drawing of Hierarchical Graph for Evaluating the Most Appropriate Protection Coverage

The hierarchical structure of this decision for Shahr-e-Bijar reservoir dam has been shown in figure 4.

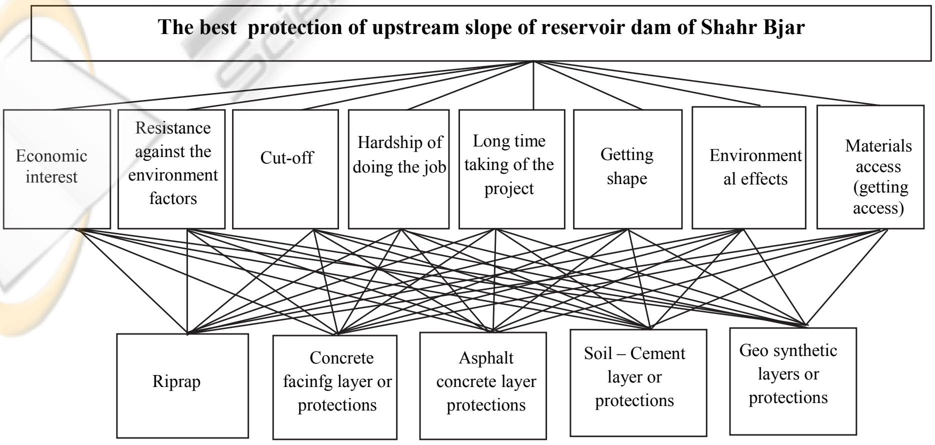

Figure 4: Analytical Hierarchy Chart.

5.2 Difining the Fuzzy Numbers

The fuzzy numbers used in this research are as follows:

$$\tilde{1} = (1.1.1)$$

$$\begin{aligned}
&\tilde{2} = (1,2,4) && \tilde{2}^{-1} = (\frac{1}{4},\frac{1}{2},1) \\
&\tilde{3} = (1,3,5) && \tilde{3}^{-1} = (\frac{1}{5},\frac{1}{3},1) \\
&\tilde{4} = (2,4,6) && \tilde{4}^{-1} = (\frac{1}{6},\frac{1}{4},\frac{1}{2}) \\
&\tilde{5} = (3,5,7) && \tilde{5}^{-1} = (\frac{1}{7},\frac{1}{5},\frac{1}{3}) \\
&\tilde{6} = (4,6,8) && \tilde{6}^{-1} = (\frac{1}{8},\frac{1}{6},\frac{1}{4})
\end{aligned} \qquad (10)$$

5.3 Making a Pairwise Comparison Matrix and Doing All 7 Steps

Regarding all eight criteria, five choices, and available statistical information or data, the pairwise comparison matrix is established. Then, for each row of pairwise comparison matrix, the required calculations should be done and the greatness degree of each compared to others is measured based on no. 5 and 6 formulas. Since calculations are to be carried out accurately and its time consuming, all calculations as well as the overall priority of each item and criterion can be calculated with the use of Visual Basic Software and then they should be normalized. The amount calculated for each item is examined based on each criterion and then the results have been shown in figures 5 to 13.

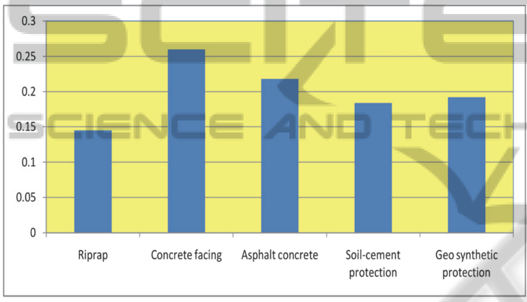

Figure 5: Normalized weight of choices in relation to the criterion of economic interest.

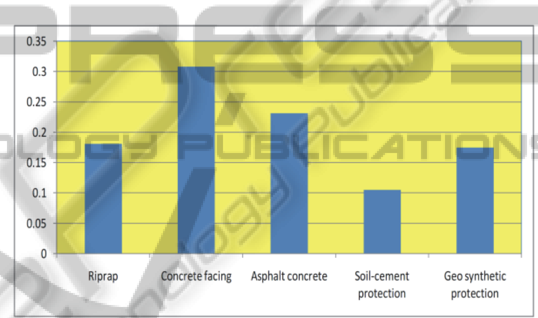

Figure 6: Normalized weight of choices in relation to the criterion of assistance environmental factors.

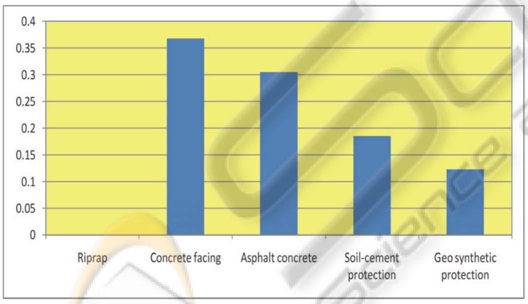

Figure 7: Normalized weight of choices in relation to the criterion of cut-off.

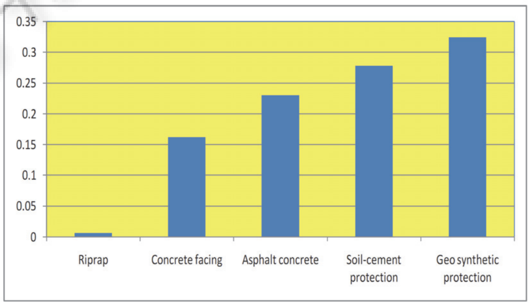

Figure 8: Normalized weight of choices in relation to the criterion of hard ship of job.

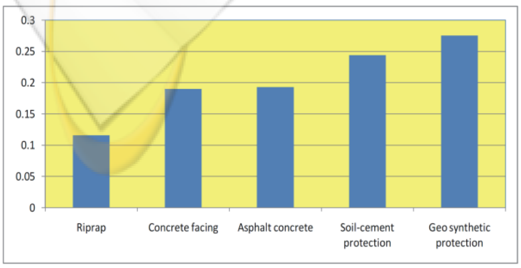

Figure 9: Normalized weight of choices in relation to the criterion of project time taking.

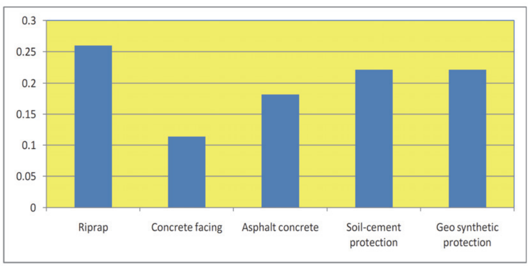

Figure 10: Normalized weight of choices in relation to the criterion of being formed.

Table 1: Results and final score of each of the options.

Final score	Material access	Environmental destructive effects	Being formed	Project time taking	Hard ship of job	Cut-off	Assistance environmental factors	Economic interest	
	0.121	0.14	0.105	0.035	0.079	0.169	0.184	0.167	
0.11	0.102	0.063	0.26	0.116	0.006	0	0.181	0.145	Rip rap
0.253	0.291	0.175	0.114	0.19	0.162	0.368	0.308	0.26	Concrete facing
0.24	0.236	0.259	0.182	0.193	0.23	0.305	0.231	0.218	Asphalt concrete
0.209	0.207	0.35	0.221	0.244	0.278	0.185	0.105	0.184	soil-cement protection
0.184	0.163	0.154	0.221	0.275	0.324	0.123	0.175	0.192	Geo synthetic protection

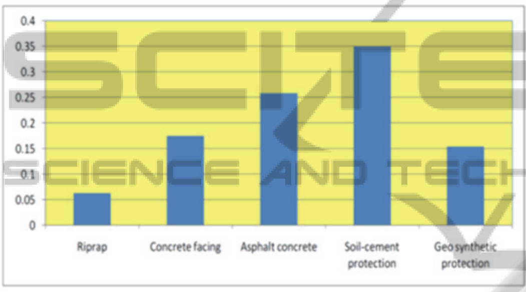

Figure 11: Normalized weight of choices in relation to the criterion of environmental destructive effects.

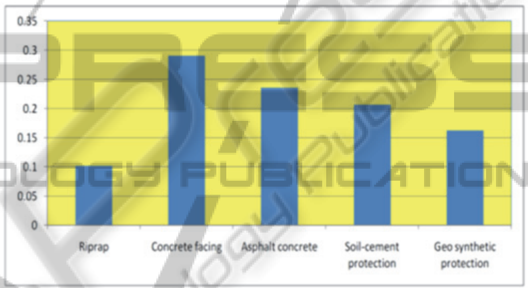

Figure 12: Normalized weight of choices in relation to the criterion of material access.

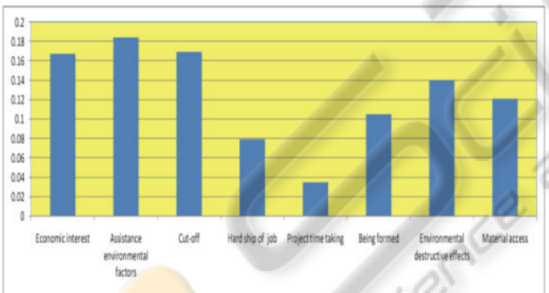

Figure 13: Normalized weight of each criteria.

Finally, results and final score of each of the options as shown in Table 1.

6 CONCLUSIONS

Five methods which have been used in the protection of the slope of the reservoir dam of Shahr-e-Bijar and have been analyzed through analytical Hierarchy are as the following:

Riprap, concrete facing protection, asphalt concrete protection, soil – cement protection and geo synthetic protection.

Shahr-e-Bijar reservoir dam is a rockfill dam type with concrete facing protection. According to the results, it can be concluded that the applying concrete facing protection is the best method of protection among all the other alternatives. Moreover, applying concrete coverage was also proved to be a proper method. However, according to the results of the present investigation it can be declared that if concrete facing protection is not used, the most proper protection is asphalt concrete protection which has the highest resemblence to the concrete facing protection through which slope of the aforementioned dam can be protected.

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