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Multiple criteria decision making method for selecting of sealing element for earth dams considering long and short terms goals

Babak Rashidi, Ehsan Shirangi* and Matin Baymaninezhad

Department of Civil Engineering, Karaj Branch, Islamic Azad University, Karaj, Iran

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Abstract. Nowadays, using math logic in great civil projects is considered by the clients to achieve the goals of project including quality optimization, costs, avoiding individual, emotional and political decision making, long-term and short-term goals and they are the main requirements of each project and should be considered by the decision makers to avoid the illogical decision making applied on the majority of civil projects and this imposes great financial and spiritual costs on our country. The present study attempts to present one of the civil projects (Ghasre Shirin storage dam) whose client was not ministry of energy for the first time and the short-term and long-term goals of the private sector were applied based on the triangle of quality, cost and time. Also, the math logic and model (multi-criteria decision making method and decision making matrix) is used in one of the most important sections of project, sealing element, policies and new materials (Geosynthetics) are considered and this leads to suitable decision making in this regard. It is worth to mention that this method is used for other sections of a dam including body, water diversion system, diaphragm and other sectors or in other civil projects of building, road construction, etc.

Keywords: Geosynthetics; earth dam; multi-criteria decision making; sealing element

1. Introduction

The engineering sciences attempt to use the correct decision making method in the design and implementation of the final product as optimized in three aspects of quality, time and cost as considered by the investor and operator. One of the most important civil projects is dam construction projects and its timely finishing and high efficiency at the shortest time are the great concerns of the investor and operator and the desirable method by the clients is the one with the high efficiency at the shortest time with the reduction of overhead costs.

In this regards, Haciefendioglu (2006) investigated the effect of transient stochastic analysis on nonlinear response of earth and rock-fill dams to spatially varying ground motion. Dynamic analyses for a suite of ground of motions were conducted by Akpinar *et al.* (2014) on concrete gravity dam sections to examine the earthquake induced stresses and effective damping. Mirzaei *et al*. (2015) introduced optimal design of homogeneous earth dams with oblique and horizontal drains based on particle swarm optimization (PSO) incorporating weighted least squares support vector machine (WLS-SVM). Rodriguez *et al*. (2015) described a new in-situ load test called the Hydraulic Cylinder Test (HCT) and its application to determine the geotechnical properties of soil-rock mixtures. Improving the performance and so increasing sediment removal efficiency of settling basins by an alternative method is studied by Zamani Nouri and Heydari (2017). Elcik and Cakmakci (2017) investigated membrane fouling caused by microalgal cells in submerged membrane systems consisting of polymeric and ceramic microfiltration membranes. Options for the remediation of embankment dams using suitable types of alternative raw materials were presented by Drochytka and Magdaléna (2017). Castelli *et al*. (2017) studied the assessment of the likely performance of an earth dam during earthquakes because its failure can result in significant human and financial losses and severe environmental impact.

Here, the sealing element of Ghasre Shirin storage dam is analyzed as pilot as one of the most important parts of this dam to achieve the required goals.

2. Ghasre Shirin storage dam

Ghasre Shirin storage dam is located in 13 km of Ghasre Shirin road to Khosravi town on the west of Kermanshah province in 200Km of Kermanshah city. The geographical location of the dam is between $34°-31' \mathit{to}\ 34°-30' \mathit{northern\ latitude\ and}\ 45°-28' \mathit{to}\ 45°-35' \mathit{eastern\ longitude}$ and a part of fields in the central division of Alvand is dedicated to Ghasreshirin town. The main river of this basin is Alvand River. The dam is outside the main river bed in a minor valley along the main river. The dam construction site is shown in Map 1 (Fig. 1).

By the complementary studies and exchange of data and views by the client consultant (Abfen company) and client consultant (Bahan Sad company) and contractor (General mechanic company) and the evaluation of the existing facilities in terms of materials, bonds and morphological conditions of the carrying distance based on the crest length,

*Corresponding author, Dr.
E-mail: shirangi@kiau.ac.ir

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Fig. 1 The location of storage dam of Ghasreshirin on the iran map

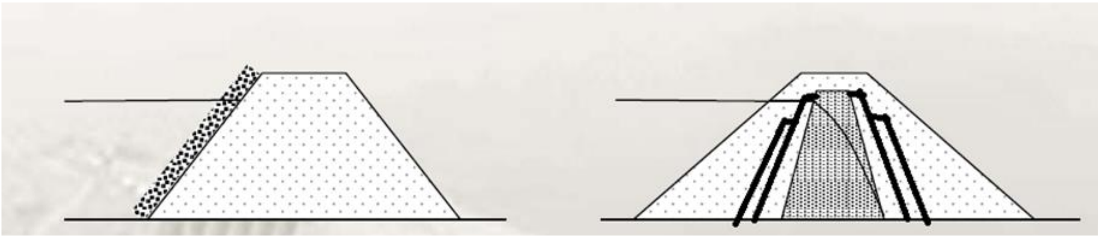

Fig. 2 The schematic view of zoned and homogenous dam

1250 m and height 35m from the foundation based on the studies of contractor consultant in selection of the best time of Ghasreshirin dam, three items are considered as:

a. The body of zoned dam with clay core and filter and vertical drainage and cut-off wall in the middle axle (Vafafyian, 2012) is shown in Fig. 2.
b. The zoned dam with asphaltic core and filter and drainage beside the core and cut-off wall in the middle axle

The body of homogenous dam with geosynthetic facing (Geomembrane and Geotextail) and cut-off wall in the heel of upstream of dam. Fig. (2) (Khodaverd 2007).

In the body of dam, as the type of sealing element has direct effect on the type of body (homogenous and zoned) and economy and design issues (Vafafyian 2012), decision making about this issue that if the choices and criteria are more, decision maker is encountered with problems as in se lection of choices ,error is occurred. Based on the collective intelligence of the design principles, it was decided to start decision making based on the topic of economy. Also, by estimation of breakdown structure and separation of activities of each item (earth dam with clay core, earth dam with asphaltic core and earth dam with geomembrane facing) via the items of dam construction price list and price list from the companies of geosynthetic materials, we can define that three choices have close price ranges and this is not a good criterion for decision making. It is proposed to use other criteria for decision making and by collecting the design principles and relevant specialists, except cost criterion, other criteria and the reasons are considered as follows:

Short-term and long-term goals: Long-term goals include the increase of height of dam and avoiding the reduction of reservoir volume of sediment during the life of dam and short-term goals are the dam filling at the same time with the construction stage for optimal use of storage potential based on reservoir created in each stage of construction and height of the dam body and cultivation in the downstream at the same time with the construction of this infrastructure and it is the early benefit of the project and this indicates the nature of private clients as determined as the main criteria.

Durability: This criterion includes the toleration and durability of executive item during the operation period under the environmental factors as cold and hot weather, sun, mechanical damage as creating basic problems for the client.

Execution speed: This criterion includes the executive operation of the body of dam and execution of sealing element simultaneously or non-simultaneously with the execution of the shell and homogeneity or zoned body of the dam can be considered.

The location of the execution of cut-off wall and sealing element: This criterion indicates that execution of cut-off wall is prior to the body execution or not (cut-off wall in the upstream is not the pre-requirement of body earth operation and is at the center of the pre-requirement of this operation).

3. Study methodology, evaluation and analysis of the topic of study

Decision making problems are performed by different methods with math logic and sometimes complex fuzzy

Table 1 Decision making matrix

	Cost (Billion Rials)	Durability	Execution speed	Short-term goal	Long-term goal	Position of element execution and cut-off wall
Clay core	793					
Asphaltic core	874					
Geomembrane	873					

Table 2 Decision making matrix with the significance of qualitative criteria

	X_1	X_2	X_3	X_4	X_5	X_6
C_1	793	Average	Low	Low	Low	Center (low)
C_2	874	High	Average	Low to average	Average to high	Center (low)
C_3	873	Low	Average	High	High	Upstream (high)

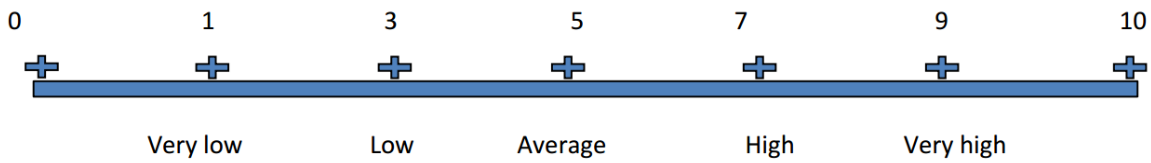

Fig. 3 Bipolar scale

logic. Here, Multiple Attribute Decision Making (MADM) as one of the branches of Multiple Criteria Decision Making (MCDM) and one of the sub-branches of Multicriteria Optimization and Compromise Solution (Vlsekriterijumska Optimizacija I Kompronssino Resenje) can be applied (Amiri 2016).

3.1 The introduction of VIKOR method

Vikor was originally developed by Opricovic to solve decision problems with conflicting and noncommensurable (different units) criteria, assuming that compromise is acceptable for conflict resolution, the decision maker achieves the final decision. Here compromise solution is a solution that is the closest to the ideal. Compromise is the agreement among the conflicting scores and they are not in the same direction. This method introduces multi-criteria ranking index as considered based on the size of close distance to the ideal solution (Amiri 2016).

3.2 Formation of decision making matrix

Decision making matrix based on the defined criteria (six) criteria and attributes (3) attributes is as follows: of six criteria, only cost criterion is quantitative and the rest is qualitative (Table 1). In the cost criterion, the low value has high suitability and other criteria are qualitative and after determining the significance and numerical index, the higher value has high suitability.

3.3 Determine the qualitative criteria values

The qualitative criteria are ranked based on significance degree. To do this, to rank the criteria from the view of elites on design and executive operation as achieving the result can be used. The interview was made with 10 elites with the required experience in earth dams and the above Table was presented to them. The result and mean of views are observed in Matrix (Table 2):

X_1=cost, X_2=durability, X_3=execution speed, X_4=short-term goal,X_5=long-term goal, X_6=position of execution of sealing element and cut-off wall, C_1=dam with clay core, C_2=dam with asphaltic core, C_3=dam with geomembrane facing.

3.4 Weighting the decision making matrix criteria by Shannon Entropy method

In the above matrix, of 6 indices, X_1 index (cost) is quantitative and the rest is qualitative and the attributes in MADM model have different scales with conflicting nature (Rajnish 2014).

To do this, to turn the qualitative criteria to quantitative criteria, interval and rank scales or bipolar scales are used (Fig. 3).

Based on the qualitative structure of decision making matrix by placing values on decision matrix with the numerical and quantitative structure, the required weight is given to the existing criteria to solve the matrix as shown in Matrix 3. The reason of using weighting method with math method to criteria is the lack of supervision of the client of the plan for good weights and only the cost criterion is considered and due to the close distance between the costs, each item is not desirable in other criteria and the suitability is given to the math logic.

To achieve the weights of each of indices, the following is performed, we achieve P_{ij} matrix [5], Formula (1), Matrix of Table 4

Table 3 Decision making matrix with quantitative values of criteria

	X_1	X_2	X_3	X_4	X_5	X_6
C_1	793	5	3	3	3	3
C_2	874	7	5	4	6	3
C_3	873	3	5	7	7	7

Table 4 Decision making matrix with quantitative values of criteria

	X_1	X_2	X_3	X_4	X_5	X_6
C_1	0.312	0.333	0.232	0.214	0.188	0.231
C_2	0.344	0.467	0.384	0.286	0.375	0.231
C_3	0.344	0.2	0.384	0.5	0.437	0.538

Table 5 Decision making matrix with quantitative values of criteria

	X_1	X_2	X_3	X_4	X_5	X_6
E_i	0.999	0.995	0.987	0.942	0.95	0.912

Table 6 Determine the weight of each criterion

	X_1	X_2	X_3	X_4	X_5	X_6
d_j	0.001	0.005	0.022	0.058	0.05	0.088
W_j	0.005	0.022	0.098	0.259	0.223	0.393

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad \forall\, i\,,\, j \tag{1}$$

As shown in the above Table, E_i for each collumn, the weight ratio is achieved based on Eq. (2) and Table 5 (Rajnish 2014)

$$\begin{cases} E_i = -k \displaystyle\sum_{i=1}^{m}[p_{ij} \times In \quad p_{ij}] \quad \forall\, i\,, \qquad j \\ \qquad k = \ {}^{1}\!/_{ln\, m} \end{cases} \tag{2}$$

$$E_i = -\frac{1}{ln\, 3}\sum_{1}^{3}[p_{ij}\, In \quad p_{ij}]$$

If the total weight is 1, d_j is achieved of Eq. (3) and the weight of each index of Eq. (4)

$$d_{j=1-E_i} \tag{3}$$

$$W_j = \frac{d_j}{\sum_{i=1}^{n} d_j} \tag{4}$$

Based on the weight calcualtion, each of the criteria is shown in Table 6.

Based on the above calculations, the weight of each of criteria is as follows:

$W_1 = 0.005$, $W_2 = 0.022$, $W_3 = 0.098$, $W_4 = 0.259$, $W_5 = 0.223$, $W_6 = 0.393$

It is observed that due to the close relationship among the cost price in three plans, the weight of this criterion, W1 is not effective on determining the type of attribute as shown by the math logic (Rajnish 2014).

3.5 Solution of decision making matrix by Vikor method

In Vikor method, to solve matrix, step-wise method is applied (Rajnish 2014).

3.5.1 First step

We form decision making matrix, the matrix of Table 3

3.5.2 Second step

We make decision matrix scale less, we normalize the matrix as shown in Eq. (5) as creating Table 7

$$f_{ij} = \frac{X_{ij}}{\sqrt{\sum_i (X_{ij})^2}} \qquad i = 1, \dots, m \qquad j = 1, \dots, n \tag{5}$$

3.5.3 Third step

The ideal positive or negative values are achieved based on Eqs. (6) and (7)

$$A^{+} = \{f_1^*, \dots, f_n^*\} = \begin{cases} C_j \rightarrow \text{ positive aspect } & A^{+} = Max_i\{f_{ij}\} \\ C_j \rightarrow \text{Negative aspect } & A^{+} = Min_i\{f_{ij}\} \end{cases} \tag{6}$$

$$A^{-} = \{f_1^*, \dots, f_n^*\} = \begin{cases} C_j \rightarrow \text{ Positive aspect } & A^{-} = Min_i\{f_{ij}\} \\ C_j \rightarrow \text{Negative aspect } & A^{-} = Max_i\{f_{ij}\} \end{cases} \tag{7}$$

It means that in the scale-less matrix (Table 6), we have

$$A^{+} = \{0.513\,, 0.768\,, 0.651\,, 0.814\,, 0.722\,, 0.855\}$$
$$A^{-} = \{0.607\,, 0.329\,, 0.390\,, 0.349\,, 0.309\,, 0.366\}$$

3.5.4 Fourth step

In this step via the Eqs. (8)-(13) the suitability or non-suitability of attributes are calculated

$$S_i = \sum_{j=1}^{n}\left(w_j \times \frac{(f_j^+ - f_{ij})}{(f_j^+ - f_j^-)}\right) \quad (8)$$

$$R_i = Max_j\left(w_j \times \frac{(f_j^+ - f_{ij})}{(f_j^+ - f_j^-)}\right) \quad (9)$$

$$S^+ = Min \quad \{S_i\} \quad (10)$$

$$R^+ = Min \quad \{R_i\} \quad (11)$$

$$S^- = Max \quad \{S_i\} \quad (12)$$

$$R^- = Max \quad \{R_i\} \quad (13)$$

3.5.4.1 The suitability or non-suitability of clay core

As shown in Eqs. (8) and (9) for clay core, we have

$$S_1 = 0.984\,, R_1 = 0.393$$

3.5.4.2 The suitability or non-suitability of asphaltic core

As shown in Eqs. (8) and (9) for Asphaltic core, we have

$$S_2 = 0.648\,, R_2 = 0.393$$

3.5.4.3 The suitability or non-suitability of dam with geomembrane facing

As shown in Eqs. (8) and (9) for dam with geomembrane facing, we have

$$S_3 = 0.027\,, R_3 = 0.022$$

Finally, the fourth step of the suitability or non-suitability is achieved based on Eqs. (10)- (13).

$$S^+ = 0.027\,,\ S^- = 0.984\,, R^+ = 0.022\,, R^- = 0.393$$

3.5.5 Fifth step

To evaluate attributes, Vikor index is used ranging 0,1 and it depends upon the opinion of decision maker. Here the index(v =0.5) is used and the calculation method is as shown in Eq. (14)

$$Q_i = \left(V \times \frac{(S_i - S^+)}{(S^- - S^+)}\right) + \left((1 - V) \times \frac{(R_i - R^+)}{(R^- - R^+)}\right) \quad (14)$$

As shown in Eq. (14), we have

$$Q_1 = 1\,, Q_2 = 0.824\,, Q_3 = 0.5$$

3.5.6 Sixth step

Ranking the attributes based on vikor index is as

$$Q_1 > Q_2 > Q_3$$

Thus, the items with low Q_i are on priority (Opricovic and Tzeng 2004) Thus

$$C_3 > C_2 > C_1$$

Here, it is observed that by Vikor method, the earth dam with geomembrane facing is on priority compared to two items of dam with asphaltic core and dam with clay core. Based on the assurance by math logic, the correct selection was reported to the client. This process is a legal method and in engineering system with math logic is a solution for decision making in important design and other items in civil projects.

4. Conclusions

Almost, all research activities are performed to achieve the definite results and explain executive and applied solutions. The multi-criteria decision making techniques by taking different quantitative and qualitative attributes and their weighting are suitable tools in decision making analysis. These techniques use various methods to evaluate and turn the qualitative attributes into quantitative attributes. The present study selects the best attribute via multi-criteria decision making. Different stages have been used to achieve this goal. In this study, by the combination of qualitative and quantitative methods, we compare and rank the choices and a final optimal solution, selection of earth dam with geomembrane facing by VIKOR method is used and this final solution is the criterion of selection of a suitable choice.

Recommendations

Based on decision making problems in different sectors of civil projects including potential search, design, execution and operation to avoid personal, emotional and political views and re –working and imposing financial and time costs, it is recommended to use math logic in the technical and executive system of the country as an enforcing regulation for all executive systems. By this method at the shortest time, based on the consistency of all principles of plan with math logic, the best decision is considered.

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