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Algorithms for use of modeling methods in selection process of hydrotechnical construction project

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Abstract. This article describes the application of modeling methods to drawing up a design drawing of hydrotechnical construction associated with a topographic surface, using modern computer graphics programs, and the creation of new computer technology algorithms. This article draws several options for the design drawing of the dam, which is one of the hydrotechnical construction. The example of a dam project drawing shows simplified versions of the existing drawing rules and ways to select the most optimal option from several options for the created project drawing. The proposed algorithms are developed following modern programming languages.

1 Introduction

In today's evolving era, the need for digitalization of every system is increasing daily. In this regard, our Republic is carrying out many works, among which there is also an increasing need to automate the design process of hydraulic structures. Thereby, our government has developed numerous resolutions and decrees. Presidential Decree No. 6200 of 6 April 2021 on "Further improvement of state management and control in the use of water resources and measures to ensure the safety of hydraulic structures" defines basic measures to develop these fields and ensure the safety of hydraulic structures.

Creating algorithms for selecting the most optimal layout from the designs created in the process of projecting a drawing of a dam on the topographic surface, which is one of the hydraulic structures, and optimizing the design process using these algorithms in automated graphics programs is one of the current problems [1-3].

Today, with the development of modern computer technology, it is possible to create digital models of various objects and incorporate them into the production process. Using computer graphics programs, digital models are widely used in design and production processes.

In addition to professional knowledge, a modern engineer should also master the methodology of system analysis and be able to evaluate and make effective decisions. The volume of tasks to be solved requires comprehensive justification of decisions, application

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of mathematical and modeling methods, and computer graphics programs. Therefore, many general and special decision-making methods are currently being developed [4, 5].

It should also be noted that the widespread use of computer technology and engineering and management activities has led to the creation of automated systems to create several project variants and choose the best option.

2 Methods

In scientific research, the design engineer develops decision-making methods for creating, analyzing, evaluating, and selecting the best design option interactively with computer graphics programs.

Algorithms for making design drawings of a dam, which is one of the hydraulic structures, and algorithms for selecting the best option from several design options:

A dam is a hydraulic structure in the form of an earthen lift constructed to block a watercourse or change the flow direction in a river bed and river bank; one can select the best option for the design drawing with the help of [6, 8].

According to the traditional algorithm, two parallel straight lines are first drawn on the topographic surface formed after the ground contours are drawn. These parallel lines indicate the width of the dam. The distance between the width of the dam will be given to us.

For example, if 2 parallel lines are given, then 2 arbitrary points are chosen from one of the horizontals to draw a straight line. As we know from analytic geometry, we can draw one line through given 2 points (x_1, y_1), (x_2, y_2).

$$\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1}$$

Using this formula, we can find the equation of a straight line:

$$y = \frac{y_2 - y_1}{x_2 - x_1} x + \frac{x_2 y_1 - x_1 y_2}{x_2 - x_1}$$

After that, draw a parallel straight line, spacing the embankment width to the given straight line. To do this:

If the general equation of the line $Ax + By + C = 0$ is given

$$d = |x_d \cos\alpha + y_d sin\alpha - p|$$

where $\cos\alpha = \pm\frac{A}{\sqrt{A^2+B^2}}$ $sin\alpha = \pm\frac{B}{\sqrt{A^2+B^2}}$ $P = \mp\frac{C}{\sqrt{A^2+B^2}}$

For example: draw a straight line parallel to the straight line given by the general equation x+y+1=0 calculating an embankment width d=10m:

$$d = |x_d \cos\alpha + y_d sin\alpha - p|$$

Via this formula $\cos\alpha = \frac{1}{\sqrt{1^2+1^2}} = \frac{1}{\sqrt{2}}$, $sin\alpha = \frac{1}{\sqrt{2}}$, $P = \frac{1}{\sqrt{2}}$

By solving the equation, we can obtain the equation of the parallel straight line of Figure 1, i.e.

$$10 = \left| x_d \frac{1}{\sqrt{2}} + y_d \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}} \right|$$

$$10 = x_d \frac{1}{\sqrt{2}} + y_d \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}$$

$$10\sqrt{2} = x_d + y_d + 1$$

$$x_d + y_d - 14{,}1 = 0$$

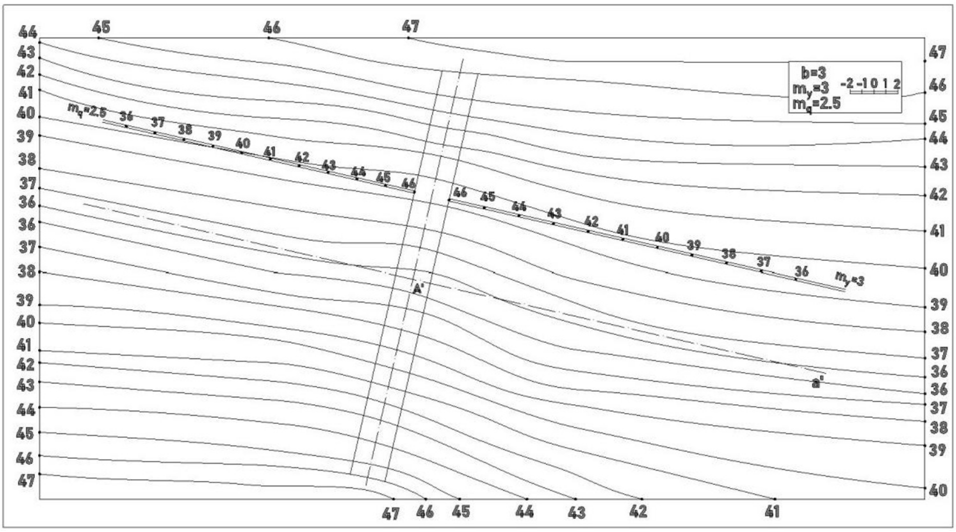

Fig. 1. Draw parallel straight line

After that, to draw perpendicular straight lines to the given parallel lines $y = k_1 x + b_1$ and $y = k_2 x + b_2$ are given by equations of straight lines; if $k_1 * k_2 = -1$ then a line is drawn perpendicular to the given line [9,10].

To find the boundary of the earth banks of the dam, we need to determine the slope; the slope can be different according to the soil structure:

Soils on dam body	Slopes along height of dam in m					
	Up to 5 m		From 5 m to 10 m		From 10 m to 15 m	
	Higher at m_1	Lower m_2	Higher at m_1	Lower m_2	Higher at m_1	Lower m_2
Mud	2,5	1,75	2,5	2	3	2,5
Sand	2,5	2,25	3	2,5	3,5	3
Fine sand	3	2,5	3,5	3	3,75	3,25
Medium sand	2,5	2	3	2,5	3,25	2,75
Coarse sand and gravel	2	1,5	2,5	2	2,75	2,25

For example, if the soil in the body of the dam is in medium sandy conditions, the dam structure should be 10 m wide, 10 m high, and 50 m long. If one considers the method of obtaining:

To do so;

- Creating several design options, e.g., 5 options, by varying the given slopes;

- aims at using Pareto-optimal methods to select the best project variant among the constructed variants;

Figure 3 in project variant 1, we take slope i=1:2.5, i=1:3 and make artificial horizontals parallel to the main body of the dam. The process of transferring the artificial horizontals is also found using the formula for transferring a parallel line by placing the distance between the given line from above, i.e., the slope scale lines to the main contour of the dam are λ=2.5 m, λ=3 m [11, 13]. We draw a parallel straight line at a distance of 3m in Fig. 2

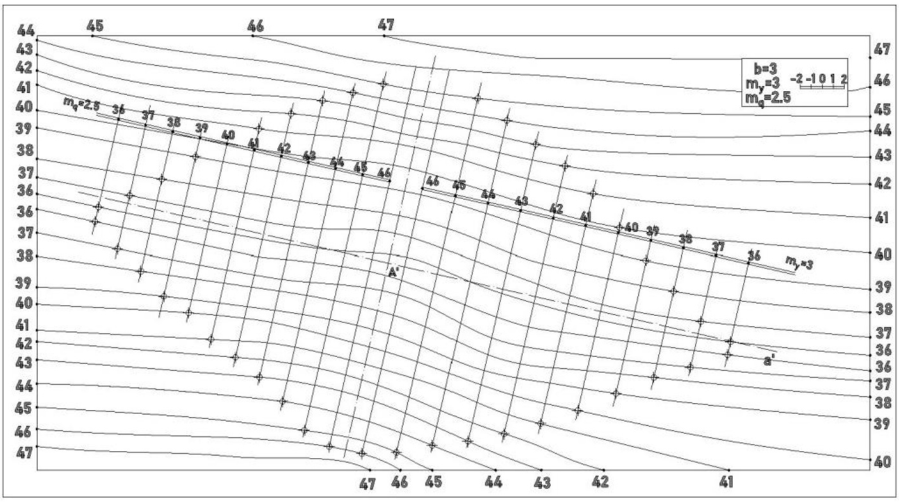

Fig. 2. Straight lines drawn parallel through inclined scale lines

The distance between the artificial contour lines depends on the slope. After drawing the artificial contour lines, the points of intersection of the natural contour lines and the artificial contour lines of the same name are marked on both sides. The points found are connected to each other using the above spline method, and the resulting curve defines the work boundaries.[14,16]. Fig. 3.

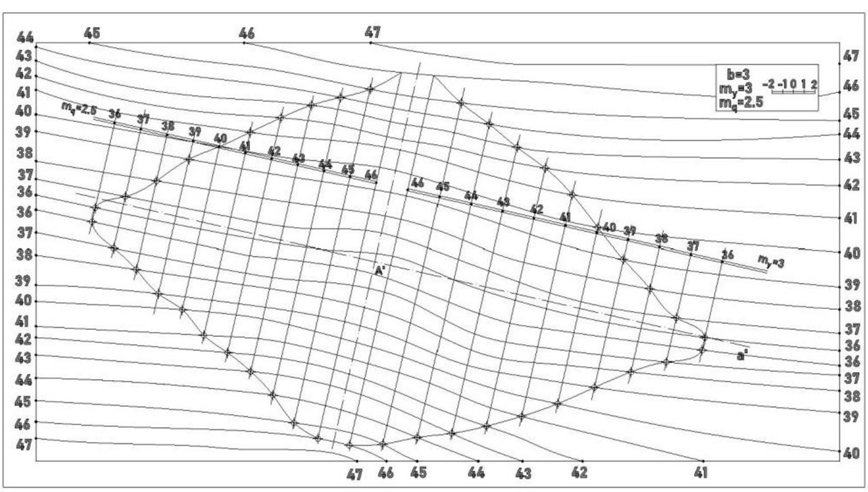

Fig. 3. Drawing of the dam structure on a given topographic surface.

Based on the above sequence 5 options are made without violating the given standards by changing the slopes of the design drawing of the given dam structure:

Variant 1: $m_q = 2.5, m_y = 3$

Option 2: $m_q = 2.6, m_y = 3.1$

Variant 3: $m_q = 2.5, m_y = 3.25$

Option 4: $m_q = 2.65, m_y = 3.15$

Variant 5: $m_q = 2.75, m_y = 3.25$

It is reasonable to use Pareto-optimal methods for choosing the most optimal variant of the project among these 5 variants; each of them is characterized by the following criteria [17, 18].

k_1 is project cost

k_2 is time spent on the project creation

k_3 is transport costs

We can describe this in the form of a table as follows:

Variants of the designed project	k_1, *project price (mln. sum)*	k_2, *take time to set up the project (hours)*	k_3, *Transportation costs (mln. sum)*
1-variant	50	15	30
2-variant	40	20	60
3-variant	90	20	25
4-variant	100	15	20
5-variant	100	40	50

One or more of the most optimal project options should be selected to do this.

In general, N objects are evaluated according to criteria $k_1, \ldots, k_j, \ldots, k_m$ of given tasks.

The most optimal project option $k_1^+, \ldots, k_m^+$ is formed from the maximum useful criteria values achieved on the set of available project options.

In addition to the most optimal project variant, an "unsuitable" project variant $\{k_1^-, \ldots, k_m^-\}$ is formed from the minimum values of the usefulness of criteria achieved in the set of available project variants. Among these project variants, the optimal project variant and the non-optimal project variant have the following characteristics [19,20]:

The best project option is $\equiv \{40\ million.;\ 15\ hours;\ \ 30\ million.\}$;

A non-eligible project is an option $\equiv \{100\ million.;\ 40\ hours;\ \ 50\ million.\}$.

To compare the different criteria for each criterion, a move to relative units is made using the following formula.

$$d_j^i = \frac{k_j^+ + k_j^i}{k_j^+ - k_j^-}.$$

The result of translating the criterion values of the project options into relative units is shown in the table below.

Structured project options	d_1	d_2	d_3
1-variant	2.16	2.3	1.8
2-variant	1.27	2.1	3.44
3-variant	2.83	2.1	1.52
4-variant	3.0	2.3	1.2
5-variant	3.0	1.6	4.50

In relative units d_j^i is interpreted as the criterion distance of project options. k_j of the best project options d_1=1.27, and the worst d_1=3.0.

In the next step, the decision-maker is asked to determine the relative importance of the criteria. From his reasoning about the relative importance of the criteria $W_1, \ldots, W_m$ are determined. In the example under consideration, since the situation with project cost, project creation time, and transport costs is almost the same, we choose $W_1 = 5, W_2 = 5, W_3 = 5$ [20, 21].

At the same time, they are compared with the best project option to identify non-compliant project options. For this purpose, the distances from the project variants to the most optimal project variant are calculated according to the following expression:

$$L_i^P = \sum_{j=1}^{m} \{ [W_j(1 - d_j^i)]^p \}^{1/p},$$

In this case, by changing the degree parameter p, the concentrations move from one metric to another. For p=1, the following formula follows:

$$L_{j=1}^1 = \sum_{j=1}^m W_j \, (1 - d_j^i),$$

Its coefficient of relative importance scales the coordinates of the project options for each criterion, and then the sum of coordinates from the "non-compliant" project options is found. The transition to the distance from the non-compliant project option is done so that both W_j and $(1-d_j^i)$ are oriented in the same way (the value of (W_j and $(1-d_j^i)$ should be considered more. When evaluating project option i criterion k_j can also be evaluated by the distance from the best project option by L_j^1 value, the more, the closer project options are to the best project option.

If p=2, the expression becomes Euclidean distance in scaled coordinates. Thus, a wide class of indicators can be used to compare project options with the most optimal project option by varying p. And the metric with $p \to \infty$ the metric takes the form:

$$L_i^\infty = \min_j (W_j(1 - d_j^i)).$$

3 Results and Discussion

Below are the results of calculating L_i^p values for different n for the example under consideration

p	L_1^p	L_2^p	L_3^p	L_4^p	L_5^p
1	10.7	2.5	9.1	9.8	10.0
2	1.9	3.6	3.4	2.5	1.7
3	4.1	3.4	1.6	0.3	2.7

The larger the value of L_i^P the closer the project options are to the optimal project option. In addition, the smaller, L_i^P the more we can exclude these criteria from the set. To ensure that the exclusion process does not depend on the indicator used, all the calculated indicators exclude the project variants furthest from the optimal project variant. For ease of analysis, each p is sorted by the distance from the most optimal project option, as is done below for the example under consideration:

$$p = 1 \quad 1 - variant > 5 - variant > 4 - variant > 3 - variant > 2 - variant$$

$$p = 2 \quad 2 - variant > 3 - variant > 4 - variant > 1 - variant > 5 - variant$$

$$p = 3 \quad 1 - variant > 2 - variant > 5 - variant > 3 - variant > 4 - variant$$

Based on these indicators, we can select the 1st project option as the best project option compared to the other options according to the 2 criteria.

Fig. 4 also shows a 3D model of this project drawing:

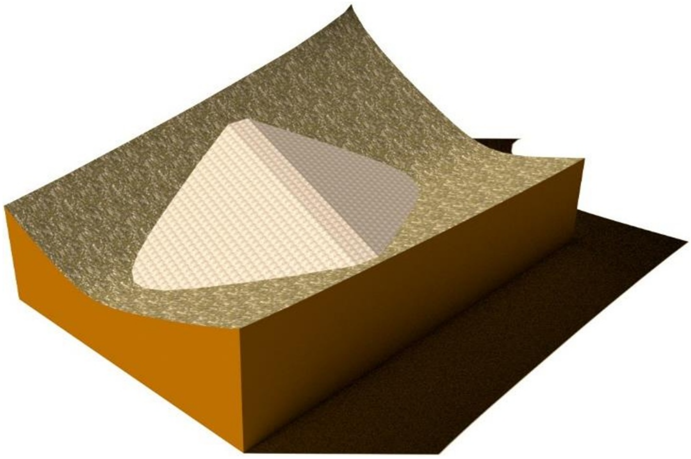

Fig. 4. Three-dimensional model of dam structure.

4 Conclusions

The hydraulic structure design algorithms recommended in this article are of a universal nature. They can be used in the design of hydraulic structures in various areas, and the method for selecting the best option recommended in the article is also of a universal nature. A decision maker has the possibility of creating several designs using these algorithms. Finding the optimal one among given variants allows applying it to discrete criterion problems. The advantage of the algorithms is that they provide easy access to programming languages.

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