POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.gov.tr/politeknik

Multi-criteria optimization of the high embankments or viaducts design

Yüksek dolgu veya viyadük tasarımlarının çok kriterli optimizasyonu

Yazarlar (Authors): *Nazim MANIĆ*[1], *Demir VATIĆ*[1], *Timur CURIĆ*[1], *Ismail NURKOVIĆ*[1], *Džemil MANIĆ*[1]

ORCID[1]: *0000-0001-8346-8255*

ORCID[1]: *0000-0001-7746-7213*

ORCID[1]: *0000-0001-5897-4279*

ORCID[1]: *0000-0003-3755-0535*

ORCID[1]: *0009-0008-9867-0905*

To cite to this article: Manić N., Vatić D., Curić T., Nurković I. ve Manić Dž., "Multi-criteria optimization of the high embankments or viaducts design", ***Journal of Polytechnic***, 28(1): 89-99, (2025).

Bu makaleye şu şekilde atıfta bulunabilirsiniz: Manić N., Vatić D., Curić T., Nurković I. ve Manić Dž., "Multi-criteria optimization of the high embankments or viaducts design", ***Politeknik Dergisi***, 28(1): 89-99, (2025).

Erişim linki (To link to this article): http://dergipark.gov.tr/politeknik/archive

DOI: 10.2339/politeknik.1376988

Multi-Criteria Optimization of the High Embankments or Viaducts Design

Highlights

- *Valuable design of high embankments or viaducts*
- *The criteria applied were: functionality, stability, aesthetics, economy, ecology and construction time*
- *The methods of weigh coefficients(Weights method) and the Promethee method were used*

Graphical Abstract

The subject of research in this paper is to find the best (optimal) solution when making a decision on what to design, a high embankment or viaduct.

The criteria for designing high embankments or viaducts were analysed and their optimization was carried out.

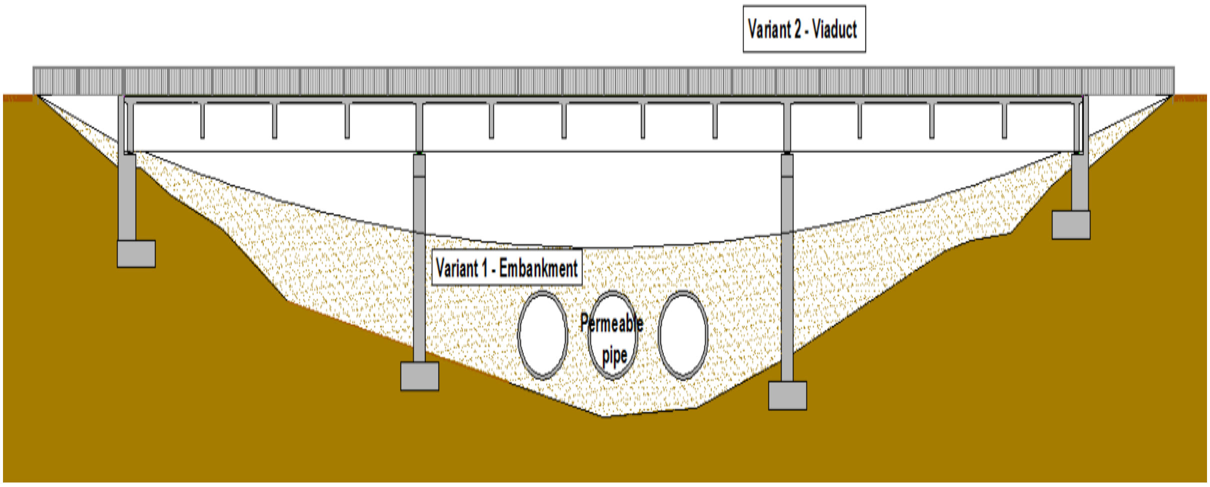

Figure. View of the bay with the possibility of designing a high embankment or viaduct

Aim

The goal is to find the optimal solution, a high embankment or viaduct.

Design & Methodology

A theoretical analysis of the case was carried out, which can be implemented on a concrete example.

Originality

This method makes it easier for designers to make a faster and better decision.

Findings

By unifying the making of an optimal decision on the scientific basis of several criteria, the system is adapted to the needs of simple and complex design complexes. In this way, the possibility of making a wrong decision in choosing between the design of high embankments or viaducts is reduced.

Conclusion

Factors for model improvement were determined.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Multi-Criteria Optimization of the High Embankments or Viaducts Design

Araştırma Makalesi / Research Article

Nazim MANIĆ[1*], Demır VATIĆ[1], Timur CURIĆ[1], Ismail NURKOVIĆ[1], Džemil MANIĆ[1]

[1]Department of Technical Sciences, Civil Engineering , State University of Novi Pazar, Serbia

(Geliş/Received : 16.10.2023 ; Kabul/Accepted : 11.03.2024 ; Erken Görünüm/Early View : 03.03.2024)

ABSTRACT

When designing roads over valleys and ravines, we are often in a dilemma about what to build, high embankments or viaducts. Ensuring economy, traffic safety, embankment and viaduct safety, comfort, environmental protection as well as shorter construction time are the basic parameters on the basis of which the decision on the construction of high embankments or viaducts is made.

The subject of research in this paper is to find the best (optimal) solution when making a decision on what to design, a high embankment or viaduct.

The criteria for designing high embankments or viaducts were analysed and their optimization was carried out. The results of design optimization are presented taking into account the criteria for determining the optimal solution (functionality, durability, economy, aesthetics, ecology and construction time). The results of the research are presented analytically and graphically.

Keywords: Roads, embankment, viaduct, criteria, optimization.

1. INTRODUCTION

Designing roads is a complex research process that considers a large number of parameters in order to find the optimal solution. It implies the analysis of a large number of parameters and the application of appropriate methods to get at an objective evaluation of design solutions.

The task of roads is to enable fast, safe, comfortable and economical transportation of people and goods from one place to another. However, in order to ensure this, it is necessary that the quality of traffic roads meet certain standards, that people and the environment are not endangered or that it is reduced to a minimum.

One of the basic problems in the road design process and at the same time, the most important area of optimization, is where to build the road and how to shape it. Embankments and viaducts play an important role in shaping the road. The basis of the road design procedure consists of reliable documentation in graphic and numerical form, the scope and content of which provide information on possibilities and limitations.

Drivers and passengers want safe, fast, comfortable and economical transport. The population wants the greatest possible economic prosperity and the cleanest possible environment. Investors want as little investment as possible, both during construction and during maintenance.

Roads that have a high standard of geometric road elements can meet these expectations. However, in terms of engineering, roads during exploitation are expected to serve with maximum quality with minimal maintenance costs, maintaining the initial level of service or close to it.

A safe, fast, comfortable and economical road, high geometric standards and quality undercarriage naturally have some negative environmental impacts. Those negative impacts are caused by motor vehicles, noise, air pollution, accidents, deterioration of the ecological balance and other risks. Embankments themselves affect the change of the microclimate, because they prevent the normal flow of air in the valleys and create an artificial obstacle to the movement of animals. Therefore, they lead to changes in both plant and animal life. On the other hand, viaducts do not change the microclimate and affect the flora and fauna to a lesser extent.

Road design, taking into account these considerations, should be in accordance with the characteristics of the region and the natural environment through which the road passes, improving economic and social well-being for road users, without disturbing aesthetic, cultural, ecological and historical values. Since many elements influence the right decision, access to the maximum amount of information and an objective analysis of all input parameters is necessary.

Embankments are the part of roads that suffers the most damage even under normal conditions, and especially in conditions of natural disasters (heavy rainfall and snow, floods and earthquakes). In order to prevent or minimize damage to embankments, and thus to avoid unwanted consequences for people, attention should also be paid to the durability of embankments during natural disasters.

2. EMBANKMENTS

An embankment is a part of a traffic road made of earth or other material. It is built by filling and compacting earth or other materials whose task is to raise the road to the required height, transfer the traffic load to the natural ground without unacceptable deformations. Embankments can be built on natural hard soil or as a substitute for the overlying soft soil. Since different types

---

**Sorumlu Yazar (Corresponding Author)*

e-posta : nmanic@np.ac.rs; nazimmanic@hotmail.com

of soil behave differently under saturation, the types of soil used for embankment construction are also requirements that should be matched to the groundwater level relative to the embankment.

Modern equipment for compaction, optimization and control of earthworks opened up the possibility of building high embankments instead of viaducts for roads.

In most cases, such alternative solutions reduce construction costs and facilitate the use of nearby material for the embankment (brought from construction excavations or cuttings and notches). Embankments occupy large areas of land, and accordingly, in suburban areas, the cost of building an embankment can be higher than the cost of constructing viaducts due to the cost of land. In addition, embankments can be covered with vegetation, thus reducing the negative impact on the environment, and their maintenance costs are significantly lower than those of bridges. The stability of high embankments improves with time, while with viaducts the situation is just the opposite (especially in the case of prestressed reinforced concrete structures). High embankments can also serve as a counterweight and thus increase the stability of unstable slopes - in contrast to viaducts, for which expensive foundations need to be built and protective measures have to be implemented to prevent the slopes from sliding. Therefore, embankments have proven to be a very successful alternative to viaducts that are constructed on the slopes.

Figure 1 shows such a section at the end of a 120m high embankment which now increases the overall stability of a 500m high unstable slope. The originally designed viaduct, had it been built, would have "floated" in the creeping ground mass (shale and schist colluvium) regardless of the fact that deep foundations were foreseen. The 600m-long embankment is horticulturally arranged so that it fits well into the surrounding landscape, thereupon the highway is almost hidden and cannot be seen at all from the settlements located in the valley, and this would not be the case if a multi-span viaduct was built instead of the embankment, [1].

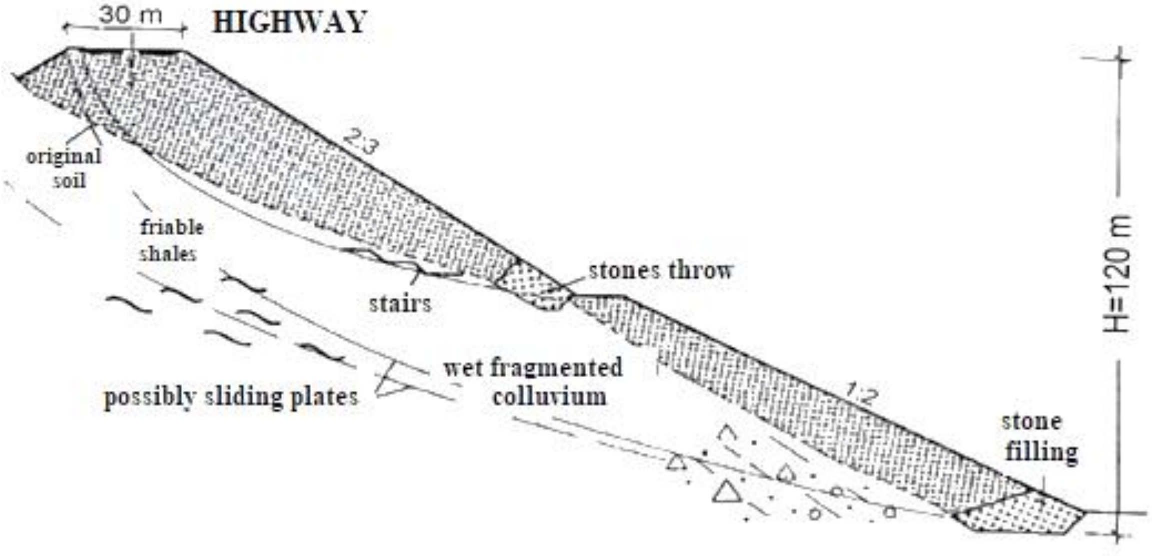

Figure 1. Embankment instead of a bridge in a narrow unstable valley [1]

Weak soil bearing capacity, large subsidence, as well as their great dependence on the magnitude of the load and its dynamic characteristics are factors that can create major problems in the construction of embankments on weak-bearing soil. Soft soil, in addition to low bearing capacity and large deformations that can be destructive, requires serious precautions for objects that require embankments on it, highways, airports, ports, etc.

Embankments are built of soil and transfer a large load to the base (soil). Due to the boundary conditions of the embankment soil and other characteristics, the embankment-base interaction is a specific problem and requires special attention. Although the embankment-soil interaction is similar to the building-soil interaction, embankments are built from a more compact and more rigidly flexible material, [3].

The following characteristics must be precisely defined for each embankment: embankment foundation, control of rolling, control of embankment compaction, moisture-density-bearing capacity ratio, stability of embankment in winter conditions, [4].

Embankments that are stable under the action of static forces may lose their stability under the action of dynamic (seismic) forces. High embankments are very sensitive, they are not reliable for seismic effects, especially in the vicinity of rasters, [9].

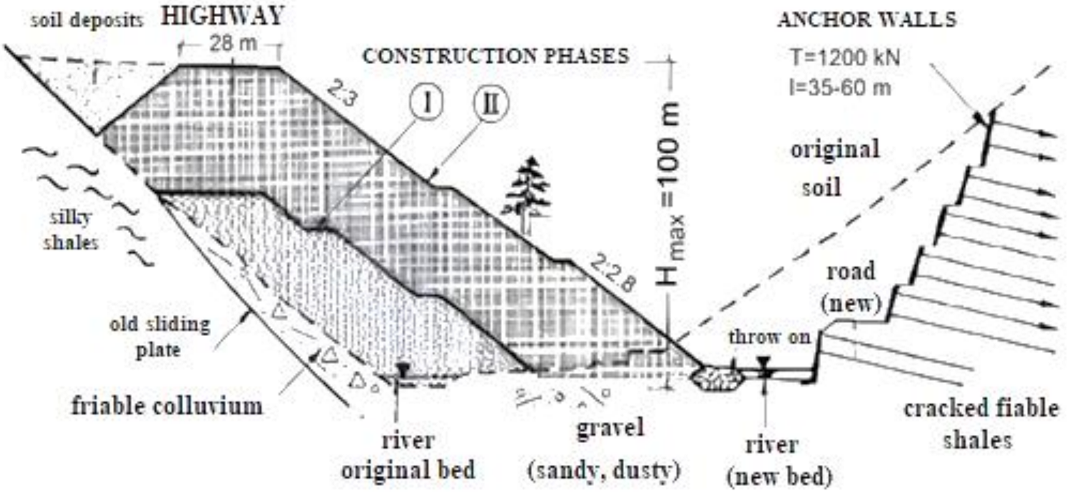

Figure 2. A hundred-meter embankment instead of a viaduct on the highway in a narrow valley [1]

Figure 2 shows an embankment that can hold an unstable slope at the same time, and if the solution with a viaduct was chosen, the foundation would be complex, and appropriate measures would have to be taken to protect the slope. On the other hand, in order for it to be possible to build a high embankment at all, the existing river bed and the federal road had to be removed, and a cut of 75 m high had to be made on the opposite side of the valley. The bottom of the valley consisted of river gravel with sand and pebbles, and the silty shale on the slope formed miolithic zones with a residual friction angle of only φ_r = 9.

Towards the foot of the slope, the underlying rock was covered with dusty-gravel and crumbling plate layers.

Due to the marked lack of space in the narrow valley, it was determined that the inclination of the slope is from 2:3 to 2:2.8. [1].

3. VIADUCTS

Viaducts are bridges over valleys, ravines or over a road. They are built in places where it is impossible to build large embankments, larger than 14 meters. Viaducts are often built as an extension of bridges over larger rivers, at the approaches of cities, where high embankments could impede traffic in the transverse direction, and those embankments, with their wide base, occupy too much land. They are also built on steep slopes, on which the earthen body of the road cannot be supported or maintained, or it would be necessary to build very high retaining walls. Viaducts are built from different materials. They can be massive, made of stone, concrete or reinforced concrete. Due to the large number of openings, they can be more advantageous than embankments, especially if they are built near populated areas. In most cases, stone arches are a favourable constructive form for viaducts, due to their sufficient height, they are environmentally acceptable. Viaduct arches can be made of concrete and stone. Viaducts made of reinforced concrete with massive pillars made of stone or concrete are more suitable than stone or concrete ones because they can take the stress and put less strain on the soil.

Viaducts built on soft ground must be founded on piles, however, piles built through soft ground may be subject to lateral loads and movements as a result of time-dependent deformation of the soil from which the approach embankments are built, [2]. In the engineering sense, every building should be safe, functional and beautiful. Although these requirements have always been valid, nowadays economy and ecology must be added to the list of requirements.

Therefore, today's standard should be that construction objects must be safe, functional, economical, beautiful and environmentally friendly! "Besides, historically, not much has changed in the way a successful viaduct bridge, or any successful structure, is defined. Beauty never ceases to be one of the basic requirements of a successful viaduct. A successful viaduct that is safe, functional, economical and beautiful will provide both comfort and practicality [5].

4. THEORETICAL BASIS OF MULTI-CRITERIA OPTIMIZATION

In solving the problem, we will use multi-criteria optimization methods with careful selection of criteria and sub-criteria for theoretical and numerical analysis.

The multi-criteria optimization problem can be presented in the following form:

$$max_{x \in X} F(x) \quad (1)$$

The multi-criteria decision-making (MCD) model has the following general mathematical formulation:

$$ax\{f_1(x), f_2(x), \ldots, f_n(x)\}, n \geq 2; x \in A = [a_1, a_2, \ldots, a_m] \quad (2)$$

Thereat, the values f_{ji} of each considered criterion f_i obtained with each of the possible alternatives a_j are known:

$$f_{ji} = f_i(a_j);\ \forall(j,i);\ \ j = 1,2,\dots,m;\ \ i = 1,2,\dots,n \quad (3)$$

Each attribute should provide a means of assessment (evaluation) of the level of one criterion (goal). A greater number of attributes should characterize each action (alternative) and they are chosen based on the selected criteria by the decision maker.

A typical way of presenting the MCD problem is the matrix form. The matrix shows the criteria values for individual alternatives:

$$\begin{array}{c} a_1 \\ a_2 \\ \cdot \\ a_m \end{array} \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{bmatrix} \quad (4)$$

A significant role in multi-criteria optimization is played by the decision maker. The main role of the decision maker is to define the criteria and structure of preferences as well as the adoption of the final solution. Other phases of multi-criteria optimization take place at the technical level in which the system analyst, in consultation with the decision maker, prepares the necessary information for the final decision adoption phase [6].

One of the following procedures may be used to make a final decision: agreement, evaluation and ranking of variant solutions, polling and voting.

The following methods will be used to determine the optimal design solution for high road embankments or viaducts:

- method of weight coefficients and
- the Promethee method.

4.1. Method of weight coefficients (Weights method)

The method of weight coefficients belongs to the group of methods in which the decision-maker has the possibility of active participation in solving the problem. The specificity of this method is that the decision maker must assign weight coefficients to each criterion. In this way, he expresses his preferences, that is, determines the importance of each individual criterion in relation to the set problem.

This method solves the problem of maximizing the vector criterion function;

$$max_{x\in X}(f_1(x), f_2(x), \dots, f_m(x)) \quad (5)$$

Consistently applying the ratings of each indicator and criterion, bearing in mind the matrix of weights, the aggregate suitability value of each variant can be expressed by the following expression:

$$max_{x\in X} \textstyle\sum_{i=1}^{n} w_i f_i(x)\,;\ w_i\ \geq 0 \quad (6)$$

The method is particularly suitable when the criteria are of the same or similar nature. The decision maker should assign each criterion the appropriate weight or weighting coefficient w_i, $i = 1,\dots, n$. The weight coefficient should be non-negative numbers, but they cannot all be equal to zero at the same time.

$$\textstyle\sum_{i=1}^{n} = 1 \quad (7)$$

Often, in practical problems, evaluations of the objective function are expressed in different units of measurement, so the weight of the criteria w_i would be unnamed magnitude, if the normalization of the objective function-f_i was not performed.

4.2. Promethee method

The Promethee method (Preference Ranking Organization Method for Enrichment Evaluation) is one of the newer methods in the field of multi-criteria analysis, which was created in 1982 and further expanded in 1984 [15].

A multi-criteria problem can be shown analytically and tabularly:

$$max\{(f_1(a_j)), (f_2(a_j)), \dots, (f_n(a_j)), |a_j \in A\} \quad (8)$$

Table 1. Tabular display of options and criteria [7]

	$f_1(.)$, $f_2(.)$ ... $f_i(.)$ ... $f_m(.)$
a_1	$F_i(a_i)$
a_2	
...	
a_i	
...	
a_n	

The Promethee method introduces a preference function P(a,b) for alternatives a and b that are evaluated by criterion functions (let us denote one of them by f). The alternative a is better than the alternative b, according to the criterion f if f(a)>f(b), the preference function is defined as follows:

$$P\ (a,b) = \begin{cases} 1 & if\ f(a) \leq f(b) \\ P\big(f(a) - f(b)\big) & if\ f(a) > f(b), \end{cases} \quad (9)$$

and the intensity of the preference for alternative a is expressed in relation to alternative b.

The preference function that is associated with a particular criterion is a function of the difference between the criterion values of the alternatives, so it can be written:

$$P(a,b) = P\big(f(a) - f(b)\big) = P(d) \quad (10)$$

The preference index is determined by the following expression:

$$\prod(a,b) = \frac{\sum_{i=1}^{n} w_i P_i(a,b)}{\sum_{i=1}^{m} w_i} \quad (11)$$

By applying the Promethee I method, according to the given conditions for each alternative, the output value of the flow (Φ+) and the input value of the flow (Φ-) are calculated, based on which a partial order of the compared alternatives is obtained.

$$\Phi^{+}(a) = \sum_{x\in K} \prod(a,x), \Phi^{-}(a) = \sum_{x\in K} \prod(a,x) \quad (12)$$

The Promethee II method determines the complete order of compared alternatives based on the pure flow relation:

$$\Phi = \Phi^{+} - \Phi^{-} \quad (13)$$

The best variant is the one whose value Φ is the highest.

5. OPTIMIZATION OF HIGH EMBANKMENTS AND VIADUCTS

In order to analyse the optimal solution for choosing a variant of designing and building high embankments or viaducts, it is necessary to study a large number of parameters. It is almost never possible to include all the parameters that influence the decision on choosing the optimal solution.

The experience with various high embankments and viaducts shows that there are no comprehensive criteria that would unambiguously evaluate the adequacy of high embankments in relation to viaducts.

Therefore, a separate decision on the construction of a high embankment or a viaduct should be made on each individual project. The main factors that influence the decision on construction of an embankment or viaduct are:

- the location, including the one of existing buildings or settlements,
- environmental and ecosystem preservation requirements (e.g., passage for animals),
- geomorphology, stability of existing slopes,
- soil properties, including the presence of water in the soil and the slope,
- allowed absolute and differential settlement of the embankment crown (in connection with the flatness of road or railway structures),
- availability of suitable bulk material,
- the amount of material (excavation and cutting in relation to the required embankment) on a certain stretch,
- the length and quality of the access roads that will be used for the delivery of bulk material,
- the number, diameter, length and location of possible leaks at the bottom and/or in the body of the embankment,
- dynamics of construction works,
- costs of construction works,
- long-term maintenance costs,
- local climatic conditions and aesthetics.

5.1. Selection of optimization criteria

Before starting the optimization and assigning weight to the criteria and sub-criteria, for the optimization of both the objects in question here, certain basic criteria need to meet in order for the objects to perform their function. Those criteria include the required capacity, throughput and the like. So as to obtain the optimal solution when designing high embankments or viaducts, the most important criteria are analysed, as well as their mutual relations for the given situation. The following criteria are analysed in this paper:

Functionality first of all means the success of a job. Within the criteria of functionality, sub-criteria are considered; traffic comfort, traffic safety, psychological effects, durability of properties, the possibility of traffic in the transverse direction, conditions of the location of the object (data on the relief, data on the quality and bearing capacity of the soil, foundation possibilities, support conditions, the situation of the object in relation to the bay, characteristics of occasional watercourses, behaviour in special-extraordinary circumstances such as planning special crossings, eventual traffic interruptions and the like).

Assess the probability of the impact of special-emergency actions, the possibility of planning special crossings, the assessment of damage to the building in extraordinary circumstances and the assessment of damage due to possible interruption of traffic.

Durability is the ability of an object to maintain its original properties over physical parameters during operation and exposure to severe climatic conditions. The closest synonyms that define the object's permanence, which are also the sub-criteria, are: safety, stability and durability. Safety is the ability of the load-bearing structure of the bridge to take all the actions it is exposed to during its lifetime. Stability is the ability of a structure to resist changing its shape. Durability is the ability of a structure to maintain the properties of safety and serviceability. Special emphasis should be placed on seismic stability.

Aesthetics is a clear demand that has its own laws, its own logic and its own means of expression. High embankments and viaducts should be beautiful and fit into the terrain and the construction tradition. Special attention should be paid to objects that are particularly visible. The aesthetic requirement of the object is not easy to comply with, taking into account the other requirements. Buildings located in urban, semi-urban and rural environments have different aesthetic requirements.

Economy implies the analysis of the cost of construction and the cost of exploitation, as dominant for the analysis. The costs of building an embankment have two main elements: costs that can be measured in money and costs that cannot be measured in money, [8].

Costs that can be measured in money can be grouped as follows:

- Embankment costs (construction costs, maintenance costs.) and
- Road user costs (vehicle operating costs, vehicle maintenance costs, traffic accident costs, costs related to journey length).

Costs that cannot be measured in money can be grouped as follows:

- Road users' recommendations (comfort and convenience) and
- Socioeconomic factors (recreation, sociocultural growth).

The total cost of the embankment can be expressed as:

$$C_U = C_I + C_O \ \ (euros) \tag{14}$$

It can be said that the unit price of the object = (total investment in construction and maintenance/number of years of the object's life).

$$C_J = \frac{C_U}{G_T} \tag{15}$$

Table 2. Comparison of the costs of construction of embankments and bridges on highways [1]

Maximum height (H) and length (L) of the road	Construction Cost (%)	
	Highway	
	Bridge	Embankment
H = 25 m, L = 130 m 2 culverts on the embankment	100	53
H = 30 m, L = 130 m 1 culvert on the embankment	100	53
H = 42 m, L = 400 m 2 culverts on the embankment	100	83
H = 40 m, L = 300 m 1 culvert on the embankment	100	66
H = 50 m, L = 330 m 2 culverts on the embankment	100	97
H = 55 m, L = 400 m 3 culverts on the embankment	100	100
H = 60 m, L = 400 m 1-2 culverts on the embankment	100	97
H = 60 m, L = 570 m 2-3 culverts on the embankment	100	100
H – the highest height of the embankment or bridge L – length of the embankment crown (slightly shorter bridge plate)		

Ecology is analysed from the aspect of the impact of construction, maintenance and exploitation of buildings on water, air and land, i.e., on the environment, the impact on the microclimate and the possibility of traffic under the building.

From everything described, as well as from the described criteria, it can be seen that each embankment or viaduct can be specific to itself and will not be measured by the same weights of criteria.

All measurable parameters should be included, compared and optimized. Dominant importance should be given to the dominant ones. We should strive for the accomplishments of the construction originality, in which there is an additional value on top of satisfying the basic primary function of a permanent transition.

5.2. Optimization criteria weights

As each route of the road is specific, so is each object on it. From the criteria described, it can be seen that there are many criteria and sub-criteria that need to be analysed. There are no unique criteria for optimizing high embankments or viaducts. Each situation is specific and the analysed criteria will be different. In addition to the diversity of the criteria the size of the criteria, depending on the situation, will be very different.

In this example of optimization, the most common criteria for the optimization of high embankments and viaducts will be shown.

Determining the relative weights was carried out by considering the proposed criteria weights by a selected survey sample of ten respondents, experts.

The most common methods used to determine the "weight" of each individual criterion are survey methods, and the most frequently used and most developed among them is the Delphi method. It is about the methodologically organized use of the experts' knowledge for the purpose of predicting future conditions, that is, phenomena. This method avoids direct discussion and confrontation of people and opinions, which make the classic method of obtaining a joint prediction of a group of experts in an open meeting non-objective.

A group of ten to fifteen experts (evaluation team) is recommended. Contacts with experts are made through a series of questionnaires [11]. This process is carried out in several steps, usually four, and the final forecast is obtained as the mean value of the forecasts from the last series of questionnaires.

In order to be able to mathematically optimize, evaluate and compare alternatives, qualitative characteristics need to be expressed with quantitative indicators. In doing so, it is necessary to perform the following:

- defining weight coefficients of criteria,
- quantification of qualitative attributes and
- attribute normalization (vector and linear scale

Table 3. Table for assessing the criteria and sub-criteria weight

CRITERIA		Criteria weight	Sub-criteria		Sub-criteria weights	Objective function	Assessment type
Ord. No.	Criteria name		No.	Sub-criteria names (f_1, f_2, ... , f_n)			
1	FUNCTIONALITY	0.30	1	Traffic comfort	0.05	max	Qualitative assessment
			2	Traffic safety	0.05	max	Qualitative assessment
			3	Psychic feelings	0.05	max	Qualitative assessment
			4	Durability of properties	0.05	max	Qualitative assessment
			5	The possibility of traffic in the transverse direction	0.05	max	Qualitative assessment
			6	Conditions of the position of the object	0.05	max	Qualitative assessment
2	CONSISTENCY	0.25	7	Facility security	0.07	max	Qualitative assessment
			8	Durability of the object	0.06	max	Qualitative assessment
			9	General stability of the object	0.06	max	Qualitative assessment
			10	Seismic stability of the object	0.06	max	Qualitative assessment
3	AESTHETICS	0.1	11	Aesthetics of the object	0.05	max	Qualitative assessment
			12	Compliance with the environment and object tradition	0.05	max	Qualitative assessment
4	ECONOMY	0.2	13	Price of object construction (land and construction)	0.1	min	Quantitative assessment
			14	The price of building maintenance	0.1	min	Quantitative assessment
5	ECOLOGY	0.15	15	Negative impact of construction on ecology	0.025	min	Qualitative assessment
			16	Negative impact of maintenance on ecology	0.025	min	Qualitative assessment
			17	Change of micro climate	0.05	min	Qualitative assessment
			18	Possibility of cross passage of animals	0.05	max	Qualitative assessment

5.3. Quantification of qualitative criteria

A scale for quantifying qualitative attributes into quantitative ones, defined on the interval [9,1/9] and based on the basic Saaty scale, [10] is used in the paper. Saaty formulated a scale of 5 (five) values and 4 (four) intermediate values, whereby the value nine (9) is the top and one (1) the bottom limit of the interval (the set of values [1, 1/9] are reciprocal values of the interval [9,1] where the value nine (9) is the bottom and the value one (1) is the top.

Table 4. Quantifying qualitative size

Qualitative assessment	Poor	Low	Average	High	Very high	Goal criteria
Quantitative assessment	1	3	5	7	9	Max
	9	7	5	3	1	Min

5.4. Vector normalization

Normalized value n_{ij} i.e. the normalized decision matrix N is obtained from the expression:

$$Norm\ a_j = \sqrt{\sum_{i=1}^{m} f_{ij}^2} \qquad (16)$$

$$n_{ij} = \frac{f_{ij}}{Norm\ a_j} = \frac{f_{ij}}{(\sum_{i=1}^{m} f_{ij}^2)^{\frac{1}{2}}}\text{; (at criteria of type } max\text{)} \qquad (17)$$

$$n_{ij} = 1 - \frac{f_{ij}}{Norm\ a_j} = 1 - \frac{f_{ij}}{(\sum_{i=1}^{m} f_{ij}^2)^{\frac{1}{2}}}\text{; (at criteria of type min)} \qquad (18)$$

5.5. Linear normalization

Linear normalization l_{ij} has the value:

$$l_{ij} = \frac{f_{ij}}{f_j^*} = \frac{f_{ij}}{max f_{ij}}, \qquad (19)$$

$$f_i^* = \{f_i | max f_{ij}\}\text{, i = 1, 2, ..., m, j = 1, 2, ..., n.} \qquad (20)$$

$$l_{ij} = \frac{f_{ij}^{min}}{f_{ij}} = \frac{min f_j}{f_{ij}}, \qquad (21)$$

$$f_j^{min} = \{f_j | min f_{ij}\}\text{, i = 1, 2, ..., m, j = 1, 2, ..., n.} \qquad (22)$$

It is possible to apply the mentioned methods of multi-criteria analysis to this modified (quantified and normalized) decision-making matrix.

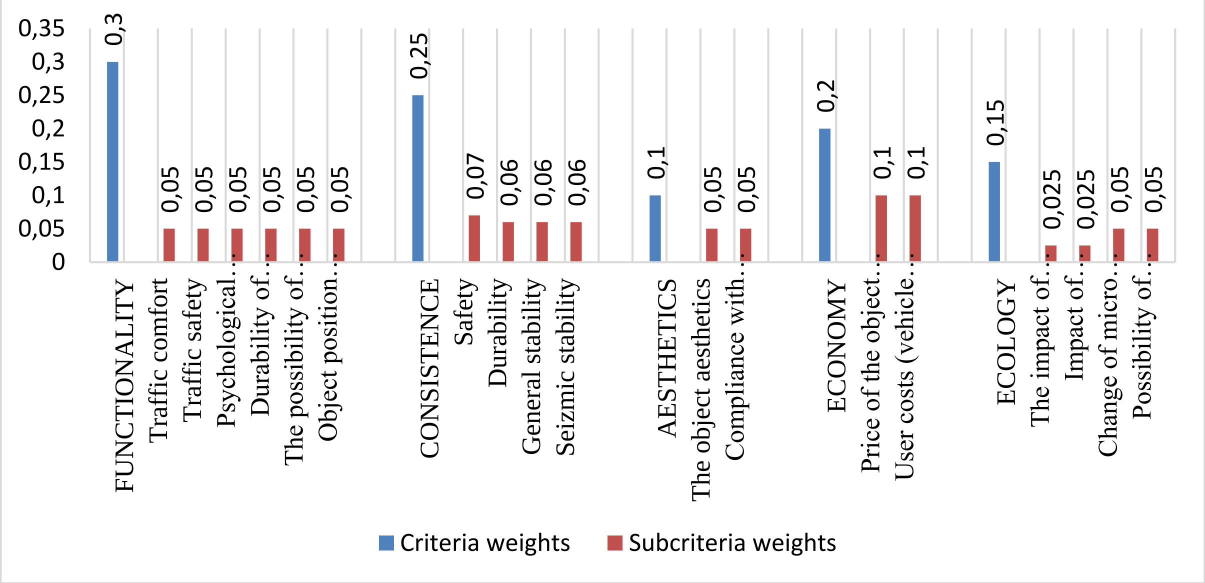

Chart 1. Diagram of the results distribution of weighting the criteria of the assessment team evaluation

6. NUMERICAL ANALYSIS

For the implementation of the paper of optimizing the design of high embankments or viaducts, an embankment with an average height of H=30m and a length of L=130m was selected, one culvert per embankment, and a special optimization software using the method of Weight coefficients and the Promethee method was developed. I Several calculation analyses were performed, and the paper shows in detail an example of the optimization of the design of a high embankment or viaduct (without a specific location, which can lead to a complete change of input and output parameters).

Table 5. Decision matrix for a high embankment or viaduct

Decision matrix																		
Variant	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14	f15	f16	f17	f18
Embankment	Very high	Very high	Very high	Very high	Average	Very high	Very high	Very high	High	Average	Very high	Very high	53	60	Average	Low	High	Poor
Viaduct	Very high	Average	Average	Average	Very high	Average	High	Low	Average	Very high	Average	Low	100	100	High	High	Poor	Very high

Table 6. Quantified decision matrix for a high embankment or viaduct

Ord. No.	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14	f15	f16	f17	f18
Embankment	9	9	9	9	5	9	9	9	7	5	9	9	53	60	5	7	3	1
Viaduct	9	5	5	5	9	5	7	3	5	9	5	3	100	100	3	3	9	9

Table 7. Normalized decision matrix for a high embankment or viaduct

Variant	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14	f15	f16	f17	f18
Embankment	0,293	0,126	0,126	0,126	0,514	0,126	0,211	0,051	0,186	0,514	0,126	0,051	0,532	0,486	0,143	0,081	0,684	0,890
Viaduct	0,293	0,514	0,514	0,514	0,126	0,514	0,386	0,684	0,419	0,126	0,514	0,684	0,116	0,143	0,486	0,606	0,051	0,006

Table 8. Linearized decision matrix for a high embankment or viaduct

Variant	f1	f2	f3	f4	f5	f6	f7	f8	f9	f10	f11	f12	f13	f14	f15	f16	f17	f18
Embankment	1,000	0,556	0,556	0,556	1,000	0,556	0,778	0,333	0,714	1,000	0,556	0,333	1,000	1,000	0,600	0,429	1,000	1,000
Viaduct	1,000	1,000	1,000	1,000	0,556	1,000	1,000	1,000	1,000	0,556	1,000	1,000	0,530	0,600	1,000	1,000	0,333	0,111

Table 9. The result of the optimization via the normalized decision matrix for a high embankment or viaduct

The result by normalized	
Variant	Variant result
Embankment	0,320
Viaduct	0,340

Table 10. Optimization result via linearized decision matrix for a high embankment or viaduct

The result by linearized	
Variant	The result of the variant
Embankment	0,759
Viaduct	0,786

Table 11. Ranking list of optimization variants of high embankments or viaducts using the method of Weight coefficients

Ranking list of embankment optimization using the method of Weight coefficients	
Ordinal number of the var.	Variant rank
1.high embankment	2
2.viaduct	1

Table 12. Ranking list of optimization variants of high embankments or viaducts using the Promethee I method

Results by Promethee I		
flow value	high embankment	viaduct
Φ+	0,410	0,540
Φ-	0,653	0,473

Table 13. Ranking list of optimization variants of high embankments or viaducts using the Promethee II method

Complete order of Promethee II		
Complete order of function dominance	High embankment	Viaduct
Φ	-0,243	0,067

Table 14. Ranking list of optimization variants of high embankments or viaducts using the Promethee method

Ranking list of embankment optimization using the Promethee method	
Ordinal number of the var.	Variant rank
1. High embankment	2
2. Viaduct	1

By choosing the "right" parameters, both proposed methods can give good and approximately the same results. In this paper, both methods gave the same results. The application of the Delphi method for determining the weight of the coefficients of the given criteria also contributes to this. The identity of the intermediate results and the results of both methods indicates the objectivity and systematicity of the presented ways of selecting solution variants.

7. CONCLUSION

In this paper, an original way to optimize the design of high embankments or viaducts is presented based on the following criteria: functionality, stability, aesthetics, economy, ecology and construction time. The results of the research refer to the improvement of the design quality of high embankments or viaducts. This systemic approach is suitable for efficient and realistic decision-making when designing high embankments or viaducts. The focus of the research is on correcting the deficiencies observed during the work when choosing what to design and build, a high embankment or a viaduct.

In the proposed optimization method, special attention is paid to the role of the user. This achieved a shift in relation to the usual approaches, the primary goal of which is to reduce construction costs.

Compared to existing approaches to this topic, the following improvements can be observed:

- Better adaptability of the system to decision makers and designers,
- Better adaptability to the user,
- Substantial improvement of design approach and
- Comprehensiveness of the embankment or viaduct optimization approach based on the most important criteria.

By unifying the making of an optimal decision on the scientific basis of several criteria, the system is adapted to the needs of simple and complex design complexes. In this way, the possibility of making a wrong decision in choosing between the design of high embankments or viaducts is reduced.

The new way of selecting and processing elements and relations corresponds to use in the field of design, which is shown in detail in the above example. The criteria that determine the elements of high embankments and viaducts were chosen based on the characteristics of perspective design. Thus, the system is conceptually adapted to the use of input data, which improves the comprehensiveness of the optimal solution.

SYMBOLS

$F(x)$ - vector criterion function

$f_i(x)$ - individual criterion functions,

x - vector variable (decision vector).

X - admissible set of solutions x.

x – vector variable,

w_i - the relative importance of the "weight" criterion,

$P_i(a,b)$ - the function of the difference of criterion values of alternatives.

C_U – total price of the object (euros),

C_I - construction cost (euros)

C_O - maintenance cost (euros).

C_J- unit price of the object (euros)

a_j - variants (alternatives for selection),

A - final set of activities,

f_{ji} - the value of the i-th criterion according to the j-th alternative.

Φ^+, Φ^- - output and input flow value

$\Pi(a,b)$ - preference index

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Nazim MANIĆ: Researched the literature, wrote the paper and analyzed the results.

Demir VATIĆ: Helped in writing, researching literature and drew figures.

Timur CURIĆ: Helped in writing, researching literature and drew figures.

Ismail NURKOVIĆ: Worked with calculations and text editing.

Džemil MANIĆ: Programmed software for the Promethee method and the method of weight coefficients, and text editing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Brandl H., "Zbijanje tla i drugih zrnastih materijala za građevine", ***Građevinar***, 54(9): 513-527, (2002).

[2] Jones C. A., et al, "Bridge distress caused by aproach embankment settlement", ***Geotechnical Engineering***, 161(2): 63-74, (2008).

[3] Çinicioğlu S. F., "Embankment-soft soil-pile interaction through Stress-strain controlled limit state analyses", ***7. symposium of geotechnics,*** Istanbul, (2017).

[4] "Guidelines for embankment construction", department of transportation, ***Geotechnical engineering bureau***, State of New York, (2015).

[5] Man-Chung Tang., "Forms and Aesthetics of Bridges" ***Engineering,*** 4(2), 267-276, (2018).

[6] Opricović S., Hajduković D., “Application of Factor Analysis in Multi-Criteria Optimization”, ***Symposium Proceedings***, 391-394, Belgrade, (1993).

[7] Džananović A., “Modern Approach to Evaluating Motorway Routes”, Master Thesisis, ***Author’s reprint, University of Tuzla***, Tuzla, BiH, (2010).

[8] Topbaş, S. A., “Karayolu proje elmanlarinin yapim maliyetine etkilerinin incelenmesi”, Ph.D. Thesis. ***Author’s reprint, Istanbul***, (2006).

[9] Manić N. et al., “Seizmička pouzdanost infrastrukturnih objekata”, ***Zbornik radova Gradjevinskog fakulteta Subotica,*** 22: 43-54, (2013).

[10] Dragašević Z., “Models of Multi-Criteria Analysis for the Ranking of Banks”, Ph.D. Thesis. ***Author’s reprint, University of Podgorica, Podgorica, Montenegro***, (2010).

[11] Džananović, A., “Savremeni pristup vrednovanja trase autoputa”, magistarski rad, ***Monografska dokumentacija, , Tuzla***, BiH, (2010).

[12] Tešović S, i Ališić S., “Hidroelektra u izvedbi projektiranja mostova, vijadukata i nadvožnjaka”, ***Građevinar***, 58(7): 569-575, (2006).

[13] Karabıçak Ç., et al., “Çok kriterli karar verme yöntemleri ve Karayolu şantiye yeri seçimine ilişkin bir uygulama”, ***Kastamonu Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi***, 13: 106-121, (2016).

[14] Ertunç, E., Çay, T., “Havaalani yer seçiminde coğrafi bilgi sistemleri (cbs) ve analitik hiyerarşi süreci (ahp) kullanimi”, ***Konya Mühendislik Bilimleri Dergisi***, 8(2): 200-210, (2020).

[15] J. P. Brans, B. Mareschal, and P. Vincke, “PROMETHEE: A new family of outranking methods in multicriteria analysis,” ***Operational Research***, 3: 477–490, (1984).