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Upgrading Criteria for Improvement Dam Monitoring Systems

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Abstract. The upstream zone of the Cerbureni tailrace channel, a phenomenon of extensive ground instability was manifested, presenting a general diffuse movement from the right slope and from the terrace towards the channel excavation. The instability of the slope significantly affected the integrity of the tailrace channel, requiring repeated interventions to restore the flowing section. Two approaches are possible. In the first option, a set of interventions is carried out on the unstable slope, eliminating as much as possible the causes of instability. In the second option, the unstable slope is left in its current conditions and the water discharge is carried out through large-diameter HDPE pipes that have longitudinal flexibility and can accommodate the slope movements. Selection of the most advantageous option was made based on multiple criteria decision analysis that is similar to a cost-benefit analysis but evaluates numerous criteria, rather than just cost. It allows to identifying and comparing different options by assessing their impacts, performances, advantages, and disadvantages, leading to a consistent decision-making.

Keywords: tailrace, rehabilitation, option selection, multiple criteria decision.

1. Condition of Cerbureni tailrace channel

The Cerbureni hydropower development is located on the Argeș River upstream of the Valea Iașului power plant, is a diversion power plant, of low head and medium power, was put into operation in 1968. It is equipped with two Kaplan turbines that utilize a flow of 90 m³/s. Installed power is 15 MW and energy production is 29 GWh/ year [1].

The tailrace channel connects the Cerbureni stilling basin to the intake channel of the Valea Iașului power plant. The channel has a trapezoidal section with 20 m at the base and has a length of 2190 m with a longitudinal slope 0.15‰. The tailrace channel has a depth of 4.25 - 4.33 m.

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Fig. 1. Cerbureni power house – downstream view.

The channel section is protected with a 15 cm thick concrete wall and sealing joints. In order to prevent the occurrence of underpressure phenomena, barbicans were made in the wall plates. A drain system was built along the slopes, consisting of longitudinal and transverse drainage pipes and trenches and collector pipes, which connect the drain system with the central drainage channel for infiltration water. In the area of the upstream zone of the channel, a phenomenon of extensive ground instability was manifested, presenting a general diffuse movement from the right slope and from the terrace towards the channel excavation, combined with a deformation – swelling – of the bedrock and possibly with effects of underpressure that can manifest more strongly when the channel is empty. The instability of the slope significantly affected the integrity of the tailrace channel, requiring repeated interventions to restore the flowing section [2],[3].



Fig. 2. Severe damages of tailrace channel.

The main causes that favored the loss of local or general stability of the right slope-of the channel are [4]:

- # reactivation of old, partially stabilized landslides, by executing excavations for the power plant, stilling basin and the tailrace channel;
- # infiltration of precipitation water into the stratified structure of the natural terrain (alternating fine sands and clayey layers);
- # development of underpressures on the protection of the channel slope, producing local failures thereof, during the execution phase and during emptying.

2. Choice of rehabilitation option

Two approaches are possible. In the first option, a set of interventions is carried out on the unstable slope, eliminating as much as possible the causes of instability and ensuring the exploitation of the spillway under normal conditions. In the second option, the unstable slope is left in its current conditions and the water discharge from the plant's stilling basin on the portion of the tailrace channel affected by instabilities is carried out through large-diameter HDPE pipes that have longitudinal flexibility and can accommodate the slope movements [4].

OPTION 1, hereinafter referred to as $j=1$ SLOPE STABILIZATION, consists of the execution of a deep drainage system, minimum 25 m, consisting of large-diameter boreholes, 1.2 m, filled with drainage material (reverse filter), connected with a collector tube inserted at the base of the boreholes using the directional drilling technique. The collected water will be evacuated first by pumping.

This option also ensures the updating and repair of existing surface water collection systems and the execution, if necessary, of new ones. In option 1, it is necessary to continue monitoring the current frequency of movements through topographic measurements, as well as monitoring the operation of surface water collection systems (clogging, deformations, flows),

OPTION 2, hereinafter referred to as $j=2$ PIPE, consists of replacing the drainage section of the runoff channel with a battery of large-diameter HDPE pipes (5 Tubimax pipes made of reinforced corrugated HDPE); their loading is carried out downstream of the stilling basin through an intake weir. This option also ensures the updating and repair of existing surface water collection systems.

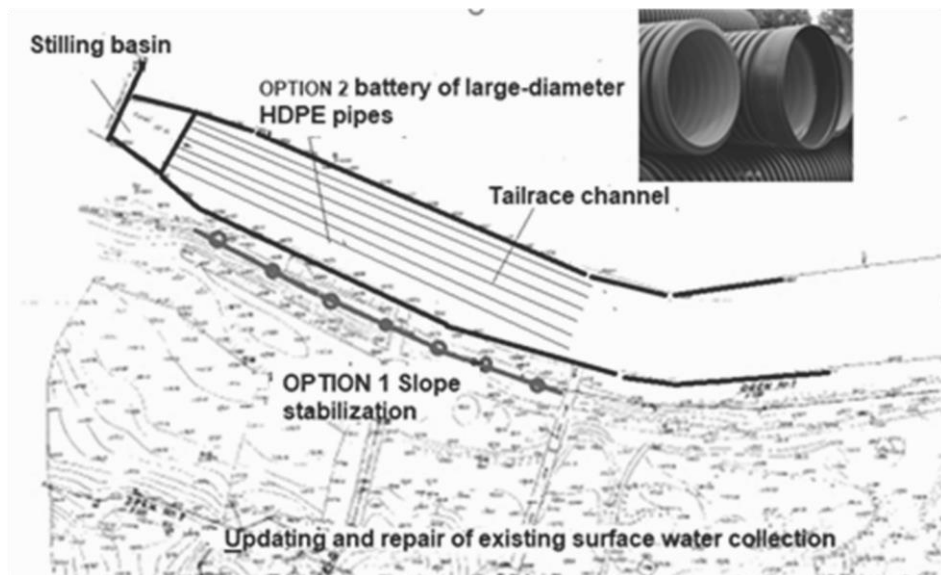


Fig. 3. Rehabilitation options.

Selection of the most advantageous option was made based on multiple criteria decision analysis (MCDA) that is presented in the followings.

3. Multiple criteria decision analysis

Multiple criteria decision analysis, or MCDA, is a structured process for evaluating options with conflicting criteria and choosing the best solution. MCDA is similar to a cost-benefit analysis but evaluates numerous criteria, rather than just cost. It allows to identifying and comparing different options by assessing their impacts, performances, advantages, and disadvantages, leading to a consistent decision-making. It consists of the addition of scores granted to the alternatives, analyzed per each criterion, and weighted by the criteria significance. The alternative with the highest score is the optimum one per all the criteria. the selection is limited to 5-8 criteria, to which the "zero" fictive criterion is added [5].[6].

The scores are granted for n alternatives, based on the $m-1$ criteria (remained after the zero criterion is eliminated) and it is carried out successively on the criteria, in two stages: *primary scores* and *normalized scores*. If the alternatives can be characterized by a quantifiable measure unit, $M_{i,j}$, in direct ratio to the advantages of the effects (for instance, the investment cost, the operation costs etc.)

$$N_{i,j}^* = \frac{M_{i,j}}{\sum_{j=1}^n M_{i,j}} \quad (1)$$

If the alternatives can not be characterized by a quantifiable measure unit, the primary scores shall be granted by estimation. By granting scores from 0 to 10, thus:

- if the effects of all the alternatives are benefic (advantageous for the environment), or if the effects of all the alternatives are malefic (disadvantaging the environment), the most advantageous alternatives shall receive the highest scores;
- if the effects of the alternatives are benefic or malefic, the most advantageous alternatives shall receive scores from 6 to 10, the disadvantageous one from 0 to 4, and the neutral ones, 5;

The scores for a criterion must be normalized so their sum, on the n alternatives, is the same, for instance equal to 1. This may be achieved by defining the $N_{i,j}$ normalized scores according to the following formula [7]:

$$N_{i,j} = \frac{N_{i,j}^*}{\sum_{j=1}^n N_{i,j}^*} \quad (2)$$

which, automatically, complies with the condition:

$$\sum_{j=1}^n N_{i,j} = 1$$

Regarding the primary scores granting 1, the condition is implicitly achieved, the primary scores being identical to the normalized scores.

After completing the scoring for all the alternatives and based on all the criteria, the next operations are:

- Calculation of the weighted scores:

$$(N_{i,j})_p = N_{i,j} \cdot p_i \quad (3)$$

Summing the weighted scores for each V_j alternative, based on all the C_i criteria, thus resulting the total score per alternative:

$$N_j = \sum_{i=1}^{m-1} N_{i,j} \cdot p_i \quad (4)$$

This score relatively characterizes the analyzed alternatives, based on all the adopted criteria. The alternative with the highest total score is preferred.

4. Alternative selection

4.1. Criteria selection

The first criterion, mandatory in any selection process, is C1 - the economic criterion. This includes the costs of the works related to the implementation of the variants, including auxiliary ones such as land development, water diversion, etc. The cost estimates are taken from expert reports or similar documentation. They are values used only to demonstrate the application of the procedure and are not binding in relation to the actual work.

Option 1 Slope stabilization

	Construction works	UM	Quantitate	Cost estimation
1	Drillings D=1,20m H=25ml (21bucati)	ml	525	328.125,00
2	Horizontal drilling D=0,6m L=200ml	ml	200	450.00,00
3	Pumping installation	ml	25	8.050,00
4	Additions 20%for above works3+4 0,20x (328.125,00+450.000,00)			155.625,00
TOTAL (RON)				999.075,00

Option 2. Pipes

	Construction works	UM	Quantitate	Solutia I
1	Gated dam to charge the pipes	mc	620	217 000,00
2	River bed regulation	ha	0.600	36 700,00
3	Pipes D= 3m HDPE	ml	500	450 000,00
4	Additions 20% to 1+3 0,20 x (217000+ 450000)			133 400,00
TOTAL (RON)				837 100,00

The second criterion, of particular importance for the chosen solution, is C2 - operational safety. In this case, operational safety depends on maintaining the functionality of the water transfer from the stilling basin to the stable section of the escape channel. The third criterion is C3 - operating costs with reference to a

standard lifespan of 30 years. Operation involves maintenance work, monitoring of behavior over time and activities related to maintaining the groundwater level, based on pumping drained waters. For a more accurate separation of variants, monetary evaluations were used.

	Activity	Option 1 Lei/ year	Option 2 Lei/year
1	Maintenance – river bed unclogging and periodic regulation	135 000	135 000
2	Monitoring the river bed evolution An emptying per year	120 000	40 000
3	Pumping the drain water	5 000	-
TOTAL (RON)		260 000	175 000

The third criterion is C3 - operating costs with reference to a standard lifespan of 30 years. Operation involves maintenance work, monitoring of behavior over time and activities related to maintaining the underground level, based on pumping drained waters. For a more accurate ranking of variants, monetary evaluations were used. A fourth criterion C4 - Technological difficulties of implementation is significant in providing the extent to which cutting-edge technologies can be correctly applied or can lead to hidden flaws that can jeopardize the success of the proposed solution. To the selected criteria, the fictitious criterion C5 - "zero" is added, less important than all the others.

4.2. Hierarchy and establishment of criteria weight

The hierarchy of criteria in order to establish the weights is allowed by the decision-makers' assessment. by mediating their options [8].

Criterion	C1	C2	C3	C4	C5
Economic - C1		1	1	0	0
Safety - C2	1				0
Operation cost C3	1	1		1	0
Technological difficulties - C4	2	1	1		0
„zero” – C5	2	2	2	2	
Total	6	5	5	4	0
Weights	0,30	0.25	0,25	0.20	0

4.3. Calculating the scores

After completing the scoring of all variants on all criteria, the following operations are:

– Calculate the weighted scores:

$$(N_{i,j})_p = N_{i,j} \cdot p_i$$

– Sum the weighted scores for each variant, on all criteria, resulting in the total score for a variant. The results are presented in the following table.

Criterion	Weight	Sub Criterion	Total weight p	V1 Slope stabilization		V2 Pipeline	
				Normalized score	Weighted score	Normalized score	Weighted score
Economic - C1	0,30	-	0.30	0.4557	0.1367	0.5442	0.1632
S Safety - C2	0,25	C21 Capability to adjust to sliding	0,091	0.4	0.0364	0.6	0.0546
		C22 - Slope stability	0.0675	0.6428	0.04338	0.3571	0.0241
		C23 - River bed stability	0,0925	0.6923	0,0640	0.3076	0.0284
Operation costs - C3	0,25	-	0,25	0.4023	0.1005	0.5976	0.1494
Technological difficulties - C4	0,20	C41 Access	0,057	0.285	0.01624	0.715	0.0407
		C42 Large diameter columns	0,057	0.66	0.03762	0.3	0.0171
		C43 Directional drilling	0,038	0.5	0.019	0.5	0.019
		C44 Site condition	0.048	0.2	0.0096	0.8	0.0384
TOTAL	1		1		0.46344		0.5349

It results that the "Pipeline" option with the transit of the engineered flow through a battery of tubes in the portion affected by the slope instability is more advantageous. In its favor are the lower construction costs and lower operating expenses. From the point of view of operational safety, the options are comparable, with an advantage also for option 2 - pipeline.

3. Concluding remarks

Multicriteria analysis or multiobjective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such

as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCDA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria.

The rehabilitation option selection case presented in the paper illustrates the applicability of the approach. Each alternative is represented by its performance in multiple criteria. The problem may be defined as finding the best alternative for a decision-maker. Explicit recognition is given to the fact that a variety of both monetary and nonmonetary objectives may influence policy decisions.

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