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EVALUATION OF THE OPTIMAL ENGINEERING SOLUTION FOR SWIMMING POOL CONSTRUCTION

RUTA MINIOTAITE

Dept of Civil Engineering Technologies, Kaunas University of Technology, Kaunas, Lithuania

The article describes the evaluation of the optimal engineering solution for monolithic reinforced concrete swimming pool (one of the most durable swimming pools). There are three alternatives for constructing an indoor swimming pool. The three swimming pool construction alternatives differ by flashing and finishing technologies. Three alternative options are analysed in order to find the optimal building technology alternative for the construction of indoor swimming pool: pairwise comparison method (only subjective significance is determined), the cross-entropy method, and expert method. The most rational (optimal) technological solution for the construction of the swimming pool was selected by means of multiple-criteria decision analysis. The closeness to the ideal point method and efficiency value method were applied. The optimal alternative was found by means of weighted sums. The swimming pool construction price in EUR/m^2 was the most important evaluation criterion in the selection of the optimal swimming pool building technology alternative. The results obtained by means of two multiple-criteria analysis methods were different; therefore the weighted sum model was applied. The best alternative for the construction of indoor swimming pool was as follows: concrete reinforced with 300 mm bars, waterproofing tape BT2025S and 1.5 mm thick reinforced waterproofing finishing film.

Keywords: Swimming pool, Technological solution, Multi-criteria evaluation, Consistency of methods.

1 INTRODUCTION

The swimming pool is a water facility of a certain capacity, which is suitable for swimming, procedures of water, hygiene, disease prevention, treatment or rehabilitation purposes. As per environmental conditions, a pool can be indoor or outdoor. The indoor pool can be used all year round and the usage does not depend on the weather conditions. The indoor swimming pools do not require so much care. An indoor pool requires extra costs for the installation of ventilation and maintaining the same level of humidity in the room. By the purpose of using, all indoor and outdoor pools are divided into private pools and public pools. The installation and equipment of the pool depends on the particular purpose.

The finishing of a swimming pool can be:

- Tiles or mosaics (ceramics of glass) – the advantage of mosaics and tiles is that the interior designer can decorate the pool in an artistic manner. However, this decoration of

pools has a disadvantage because it is difficult to ensure the pool waterproofing. Special tiles suitable for swimming pools must be used;

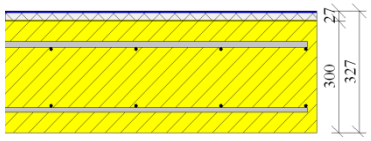
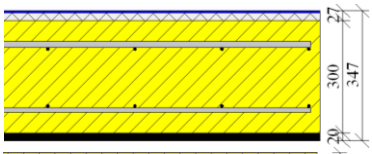
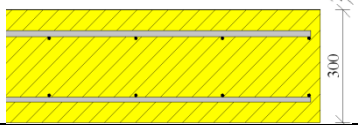
- The waterproofing membrane is 1.5 mm thick reinforced membrane especially designed for swimming pools. It absolutely ensures the waterproofing of the pool and it is a good-looking decoration as well. Pool is covered with this membrane are pleasant, soft and warm to walk. It is anti-bacterial, extremely strong and is also UV resistant. Almost 80% of all pools are covered with this membrane in Lithuania. The proposed colour range of membranes is wide enough and it provides great opportunities for the design of the pool bottom to match the interior design or landscape.

This article describes the optimal evaluation of engineering solutions of a monolithic reinforced concrete pool, which planned to be installed in a multifunctional sports and entertainment centre. This kind of pools is one of the strongest and most durable pools.

2 OPTIONS OF SWIMMING POOL INSTALLATION

There are three alternatives for constructing an indoor swimming pool. Monolithic reinforced concrete is used for building the water pool in all three alternatives. The water pool is reinforced with metal bars that are tied together. A high swelling bentonite waterproofing tape BT 2025S is used to seal reinforced concrete construction joints. The structural solutions of pool are shown in Table 1.

Table 1. Structural solutions of pool.

Alternative	Structural drawing	Structural layer, materials
A1		Reinforced concrete – 300 mm Waterproofing tape BT 2025S Waterproof Xypex Concentrate Waterproof Xypex Modified Cement / adhesive mixture – 20 mm Mosaic tiles – 7 mm
A2		Bituminous waterproofing – 2 layers Reinforced concrete – 300 mm Waterproofing tape BT 2025S Cement / adhesive mixture – 20 mm Mosaic tiles – 7 mm
A3		Reinforced concrete – 300 mm Waterproofing tape BT 2025S 1,5 mm thick reinforced waterproofing finishing film

3 EVALUATION OF ASSESSMENT CRITERIONS OF POOL CONSTRUCTION TECHNOLOGY AND SIGNIFICANCE

The criterions of assessment are divided into two groups: 1) technical-economic criteria; 2) qualitative characteristics (Sarka *et al.* 1999, Rapceviciene 2010).

Each criterion has a numeric value, the unit of measurement or its own significance. An importance of the criteria indicates how one criterion is more important compared to another criterion. An importance of the criterion can be one of three types: subjective, theoretical, complex.

The criterions of significance assessment can be determined in several ways: the method of pairwise comparison; the method of entropy; the expert method.

3.1 The Method of Pairwise Comparison

The line of priorities and significances of the optimal variation of the pool construction technology are set, when the method of pairwise comparison is chosen and the Kendall concordance coefficient is checked. The essence of this method is that all possible options are compared with each other in pairs. If it is said that the variant x_i is better than the variant x_j it means that the first one variant got "1 point" and the second one variant got "0 points".

Evaluation criterions: X_1- cost of pool installation EUR/m^2; X_2 – the duration of works (man-hours); X_3 – durability, in points; X_4 – aesthetics, in points. According to the data of experts, the total matrix is formed. The total matrix of the pairwise comparison is shown in Table 2.

Table 2. The total matrix of the pairwise comparison.

Reasons	X_1	X_2	X_3	X_4	S_i	q_i	**The priority order**
X_1	-	8	8	8	24	0,3692	4
X_2	2	-	3	8	13	0,2000	1
X_3	5	6	-	7	18	0,2769	2
X_4	1	6	3	-	10	0,1538	3
				Sum	65	1,0000	

An importance of the criterions is determined by calculating the sum of every each line of i version (Eq. (1)):

$$S_i = \sum_{k=1}^{n} x_{ik}^{*} \tag{1}$$

As the higher value of S_i is, then the variation is more effective or criterion is more significant. The priority order: $q_1 > q_3 > q_2 > q_4$; where q_i – the subjective significance of criterion.

In this case, all sizes of q_i are not less than 5%. This means that all data are overwrite in the total and transformed matrix of the pairwise comparison. There are no eliminated data. Carry out the transformation of the matrix. When the calculations are done, it is necessary to check the concordance coefficient and whether the opinions of experts match. Calculation of the necessary data: 1) calculation of the possible combinations according to the experts; 2) possible combinations according to the evaluation criterions; 3) the total amounts are calculated; 4) calculation of the concordance coefficient.

When the method of pairwise comparison (W = 0,719) is used, the concordance coefficient is higher W > 0,6. All opinions of experts match each other; as a result the data can be used for the further calculations of optimization.

3.2 The Method of Entropy

The entropy – this is a measure of random size of uncertainty. The entropy is used to determine the theoretical and complex significance of the evaluation criterion.

According to the estimates of calculated comparative variations, the initial data sheet is prepared. Table 3 provides initial data of alternative design solutions.

In order to compare all engineering solutions, this matrix needs to be normalized, because the matrix is made by the different criterions, which have different mathematical units. When a few

different criterions of evaluation are used, it is recommended to normalize the matrix with this formula (Eq. (2)):

$$\bar{P}_{ij} = 1 - \frac{\left| x^*_j - x_{ij} \right|}{x^*_j} \quad (i = \overline{1,m}; j = \overline{1,n}) \tag{2}$$

where x_{ij} is a maximum (minimum) value of the criterion. The normalized matrix is obtained where all elements are dimensionless quantities.

If all criteria are equally important or there are no determined or known subjective or experts' evaluation of the significance, the theoretical significance of the criterion is determined. If the subjective values of significance of criterion are known, then the complex significance of criterion can be determined as well. Table 4 provides the significance of criterion.

Table 3. Initial data of alternative design solutions.

Alternative decisions / Criteria	X_1 Work cost (EUR/m^2)	X_2 The duration of works (man-hours)	X_3 Durability (points)	X_4 Aesthetics (points)
A1	163,23	3,07	10	10
A2	134,42	2,46	8	10
A3	94,5	1,52	6	7
Optimum	MIN	MIN	MAX	MAX

Table 4. The significance of criterion.

Criteria	X_1 Work cost (EUR/m^2)	X_2 The duration of works (man-hours)	X_3 Durability (points)	X_4 Aesthetics (points)
The theoretical significance	0,3382	0,2124	0,1457	0,3038
The subjective significance	0,34	0,21	0,15	0,30
The complex significance	0,419	0,165	0,178	0,338

The priority order: $q_1 > q_4 > q_2 > q_3$.

A comparison the significance of the theoretical and complex criterions shows that the cost of the work is the most important criterion (X_1) and the duration of works is the least significant criterion (X_2).

4 EVALUATION OF MULTI-CRITERION OPTIMAL ENGINEERING DESIGN OF THE POOL

According to methods of multi-criterion, the optimal technological solution of the swimming pool will be selected. Two methods will be analyzed: the method of proximity to an ideal point and the method of efficiency value.

4.1 The Method of Proximity to an Ideal Point

The essence of this method is that the optimal alternative has to the minimum distance from the ideal solution and the maximum distance from the worst solution. The main principle of the method of proximity to an ideal point: forming the generalized complex criterion, based on

comparison of options deviation from the so-called ideal criterion, which consists of the best options under consideration criterion. This method takes into account the fact that each version of the decision criterion function of utility can be increased or decreased monotonically. The algorithm, when the method of proximity to an ideal point is used and the complex significance of criterion is evaluated: the matrix of alternative architectural solutions is made; the normalization of the matrix; a weighted matrix is obtained.

The optimal variation of the indoor pool construction technology, when the method of proximity to an ideal point is used and the significance of criterion are evaluated.

The matrix is made of different criterions and these criterions are made of different mathematical units. In order to compare all engineering solutions, this matrix must be normalized. The best (the most rational) architectural solution will become the one, which K_{bit} value will be max ($K_{bit,i}$=max). Using the values we form the priority sequence utility degree establishment. We compare the value of the variant examined with the value of ideal variant.

4.2 The Method of Efficiency Value

When the method of efficiency value is chosen, the following criterion is used: subjective, complex and theoretical significance. According to the individual design solutions, these criterions are not equally significant, so the evaluation takes into account the importance of the criterion to each other. The highest utility value is selected as the best option.

Method evaluation algorithm:

A set of evaluation criteria is formed; →a relative weight to each criterion is assigned; →values of criteria are found; →the efficiency value from 0 to 10 points is assigned; →the numerical value of efficiency is determined; →the total efficiency value of alternative solutions is determined.

The best alternative is *A3*, because in accordance with three criterions, the sum of utility of these options is the biggest and it is 25%.

5 RESULTS OF THE OPTIMAL DESIGN EVALUATION OF POOL

Several methods were used for the chosen optimal design evaluation of pool; a few different variations were received. Table 5 provides a summary of the results; according to the results, the points of priority are given (the most useful - 3, the least useful - 1). After the summing of scores, an optimal solution was found. The resume of results shows that the third option got the maximum number of points, and this option is selected as optimal.

Table 5. The total resume of results.

Method	Significance	Alternative		
		A1	**A2**	**A3**
The method of proximity to an ideal point	Theoretical	100,00	100,00	99,96
	Subjective	71,16	89,56	100,00
	Complex	31,23	62,75	100,00
The method of the efficiency value	Theoretical	5,46	6,98	8,10
	Subjective	5,47	6,98	8,11
	Complex	6,33	7,86	8,84
The method of proximity to an ideal point	Theoretical	3	3	2
	Subjective	1	2	3
	Complex	1	2	3
The method of the efficiency value	Theoretical	1	2	3
	Subjective	1	2	3
	Complex	1	2	3
	Sum	8	13	17

6 CONCLUSIONS

(1) The swimming pool construction price in EUR/m^2 was the most important evaluation criterion in the selection of the optimal swimming pool building technology alternative.

(2) When the optimal design evaluation of pool was proved by two multi-criterion methods of evaluation, the final results were different, so the total evaluation was carried out. In order to find out the optimal technological solution for pool construction, three different technological solutions were analysed.

(3) The best alternative is *A3*, i.e. the price of square meter is 95 EUR. The best alternative for the construction of indoor swimming pool was as follows: concrete reinforced with 300 mm bars, waterproofing tape BT2025S and 1.5 mm thick reinforced waterproofing finishing film. 7 points were given for the aesthetics of this alternative, and 6 points for durability.

References

Rapceviciene, D., Evaluation of multi residential house renovation efficiency: *Science – Future of Lithuania*, 2(2), 83-89, 2010.

Sarka, V., Ustinovicius, E.K., Zavadskas, E.K., Synthesis of the projects applying the compromised compensating models in construction, *Civil engineering*, V, 6, Technika, Vilnius, 374-385, 1999.