The choice of durable blocking waterproofing mathematical method

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Abstract. Subject: the main issue during the study is the problem of choosing the optimal waterproofing system for the underground parts of buildings and structures. Objectives: choosing the optimal waterproofing system using a mathematical method - hierarchy analysis method. Materials and methods: the procedure of pairwise comparisons that prioritize the hierarchical structure. Results: the mathematical method allowed us to determine the optimal system - a complex system with durable mineral-based waterproofing materials. Conclusions: the effectiveness of the mathematical method is reflected in the selection of the optimal solution for the protection of supporting underground structural elements. On the basis of which a new technology for the protection of foundations is proposed.

Keywords: waterproofing system, waterproofing, underground structure, reliability, mathematical method, performance.

1. Introduction
Now there is a need to determine long-term and reliable waterproofing by choosing the most optimal materials and technologies. To do this, it is necessary to analyze in detail the technical condition and reliability of building structures of buildings, the hydrogeological condition of the district, conditions of constraint, and others. The optimal solution will increase the maintainability and longevity of the operation of structures of buildings and structures, reduce the complexity of the work on the implementation of repair work with hydraulic protection of structures.

2. Objectives
The objective is to find durable and optimal materials and technologies for waterproofing. This issue is dealt with by many domestic and foreign researchers. Difficult conditions arise during overhauls of operated buildings located in confined areas with aggressive or pressure groundwater. The work of underground waterproofing is influenced not only by the influence of design factors, but also by the results of changes in hydrogeology, existing loads, the quality of construction and installation works, anthropogenic changes in the surrounding area due to new construction or laying of communications, as well as unauthorized influences. This leads to accelerated wear and failure of building structures.
Modern waterproofing materials of the same type can be considered approximately the same in their basic characteristics. Waterproofing of underground structures is a complex system, for the successful functioning of which it is necessary to focus on various materials and technical solutions, taking into account the specifics of each particular object.

The new scientific approach to achievement of a stated purpose: When deciding on the choice of structural reliability, the authors sought to objectively evaluate protective materials for underground waterproofing. At the initial stages of the study, the authors searched for effective solutions to restore underground waterproofing using the mathematical apparatus method: hierarchy analysis method (MAI), logical-probabilistic method (LVM), which would provide a systematic approach to decision making and guarantee objective reliability of the results [1-6].

3. Review of literature
When choosing an effective waterproofing of underground structures of buildings, it is necessary to identify all conditions that affect its operational performance and reliability. The authors of the article examined the studies of many authors, in whose works complete information about defects in underground waterproofing was presented, as well as their own ones were added.

As a rule, modern waterproofing materials of the same type can be considered identical in their basic characteristics, that is, the "reliability" of various materials in laboratory conditions is approximately the same and meets the requirements of the standards. Here, the concept of "reliability" actually implies only two properties - reliability and durability. Under real operating conditions, when the material becomes only one of the elements of the system, the identity of reliability indicators becomes obvious, and the restoration of waterproofing during repair and restoration works at underground structures is often technically difficult or impossible due to the close proximity of roads, communications and neighboring buildings.

As a possible solution to this problem, it was necessary to find a mathematical model or methodology that is successfully used in assessing the reliability indicators of various systems. The authors of this methodology were based on the hierarchy analysis method. The choice of a mathematical logical system and the determination of its performance using this method by the authors for the first time were fully implemented. In addition, based on the results, a new blocking technology was proposed that increases the durability and reliability of underground waterproofing.

In addition to their own research, many other authors’ developments were considered. Well-known scientists, such as the American mathematician Thomas Saati, the domestic scientist Igor Alekseevich Ryabinin, dealt with the logical circuits for finding the most optimal and durable materials and technologies for waterproofing devices. Especially complete data on are presented in [7–16].

4. Materials and methods
The method of analyzing hierarchies was the pairing comparison procedure, due to which priorities were determined that reflect the relative importance of the elements in the hierarchical structure. After determining the priorities of all elements of the hierarchy, their linear convolution was performed, as a result of which the priorities of alternative options were determined. The alternative with the highest priority value was considered the most suitable.

The stages of mathematical modeling made it possible to calculate the most stable, economical, and durable materials, i.e. to achieve the goals of the first stage, which consists in finding criteria and choosing waterproofing for the construction of the foundation according to established criteria. The number of established indicators is arbitrary, however, with the growth of their number and decision makers, the complexity of the problem increases.

The sequence of actions when choosing a waterproofing is shown in Figure 1.
To make a decision on the insulation of the building’s foundation, an algorithm has been drawn up that includes the following steps: setting a goal (choosing waterproofing), assigning technical and economic indicators (criteria) to evaluate alternatives and determine their weight, and developing possible options for waterproofing (alternatives). The logical sequence of the search for optimal waterproofing is presented in Figure 2.

Designation of indicators for calculation: X – reliability, Y – maintainability, V – cost. To determine the priorities of indicators relative to the goal, we compose a matrix of pairwise comparisons of the criteria relative to the goal in the form of table 1 and find its main eigenvector $k$ and the corresponding main eigenvalue $\lambda_{\text{max}}$, which is a vector of priorities expressing the importance of each of the established indicators. Determined on the basis of $\lambda_{\text{max}}$, the consistency index (IS) and the consistency ratio (OS) allow us to establish the degree of consistency of the result. An OS value of less than 0.01 is considered acceptable.

| K | X | Y | Z | k |
|---|---|---|---|---|
| X | 1 | 3 | 2 | 0.54 |
| Y | 0.33 | 1 | 0.5 | 0.17 |
| Z | 0.5 | 2 | 1 | 0.29 |

$\lambda_{\text{max}}$ = 3.006
IS = 0.003
OS = 0.005

After determining the priority vector of the adopted technical and economic indicators, we proceed to find the priority vectors of the alternatives with respect to each of the indicators. We denote the alternatives as follows: A - injection method, B - mounted waterproofing (screen), C - filling on the basis of bentonite clays, D - complex system. Next, we construct matrices of pairwise comparisons of alternatives with respect to the criteria and repeat all the calculations performed earlier (Table 2). As can be seen from the tables, the obtained IP indices do not exceed 0.01, which indicates good agreement between the matrices of judgments.
Table 2. Matrix of pairwise comparisons of alternatives relative to the criteria

|    | A  | B  | C  | D  | \( x_i \) | A  | B  | C  | D  | \( y_j \) | A  | B  | C  | D  | \( z_i \) |
|----|----|----|----|----|---------|----|----|----|----|---------|----|----|----|----|---------|
| A  | 1  | 2  | 3  | 0.5| 0.27    | A  | 1  | 2  | 5  | 6 0.53  | A  | 1  | 0.25| 0.5| 2 0.12  |
| B  | 0.5| 1  | 2  | 0.3| 0.15    | B  | 0.5| 1  | 2  | 5 0.28  | B  | 4  | 1  | 2  | 7 0.54  |
| C  | 0.3| 0.5| 1  | 0.2| 0.09    | C  | 0.2| 0.5| 1  | 2 0.12  | C  | 2  | 0.5| 1  | 6 0.28  |
| D  | 2  | 3  | 5  | 1  | 0.49    | D  | 0.17| 0.2| 0.5| 1 0.07  | D  | 0.5| 0.14| 0.17| 1 0.06  |

\( \lambda_{\text{max}} \) 3.963 \( \lambda_{\text{max}} \) 4.046 \( \lambda_{\text{max}} \) 4.028

\( \text{IC} \) 0.013 \( \text{IC} \) 0.015 \( \text{IC} \) 0.009

\( \text{OC} \) 0.014 \( \text{OC} \) 0.017 \( \text{OC} \) 0.010

After checking the judgments for consistency, the global (common) priorities of the adopted alternatives are determined on the basis of the calculated local priorities. To obtain a general assessment of each of the alternatives, it is necessary to multiply the priority value (weight) of the first criterion by the weight of the selected alternative, then repeat this operation with the remaining criteria and summarize the resulting products. An alternative with maximum global priority would be the best solution [17-24].

Overall rating for selected waterproofing systems:

\[
\begin{align*}
K_A &= k_1 \cdot x_A + k_2 \cdot y_A + k_3 \cdot z_A = 0.54 \cdot 0.27 + 0.17 \cdot 0.53 + 0.29 \cdot 0.12 = 0.275; \\
K_B &= k_1 \cdot x_B + k_2 \cdot y_B + k_3 \cdot z_B = 0.54 \cdot 0.15 + 0.17 \cdot 0.28 + 0.29 \cdot 0.54 = 0.285; \\
K_C &= k_1 \cdot x_C + k_2 \cdot y_C + k_3 \cdot z_C = 0.54 \cdot 0.09 + 0.17 \cdot 0.12 + 0.29 \cdot 0.28 = 0.150; \\
K_D &= k_1 \cdot x_D + k_2 \cdot y_D + k_3 \cdot z_D = 0.54 \cdot 0.49 + 0.17 \cdot 0.07 + 0.29 \cdot 0.06 = 0.294 \\
\end{align*}
\]

5. Results

The results of the calculations show that the most optimal waterproofing was option D - an integrated system with durable mineral-based waterproofing materials. The above mathematical methods allowed the authors to propose a new technology for blocking protection. Based on the mathematically obtained result, a complex two-stage blocking waterproofing technology was proposed (Figure 3), which provides protection for a period equal to the service life of the building itself.

![Figure 3. Technology of a comprehensive two-stage blocking waterproofing](image-url)
waterproofing, structural solutions of the building, its condition, the presence of groundwater, water pressure, the limitation of the construction, the presence and condition of expansion and working joints, bushings and cracks are studied; adjoining soil properties; the presence and condition of the drainage system around the building. The technology for injecting mineral waterproofing contains information about the equipment used, the location of the packers, the depth of the boreholes and their diameter, the maximum pressure during injection, a description of the measures, quality control.

6. Conclusions
The mathematical method of analyzing hierarchies made it possible to choose the optimal solution for the protection of bearing underground structural elements. Based on the results, a new foundation protection technology was proposed. The received option surpasses the others in relation to the established requirements for reliability, maintainability. The proposed technology is characterized by increased durability, creates volumetric waterproofing outside the supporting structures, thereby protecting against corrosion; does not require earthwork and can be performed in hard-to-reach places, has a service life comparable to the service life of the building itself; bentonite injection can withstand an unlimited number of freeze-thaw cycles, and also does not have a negative impact on the environment, compacts the soil, does not require expensive equipment. [8].

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