Reliability assessment of waterproofing systems of buildings underground parts

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Abstract. Subject: the main question in the course of the research is the problem of the choice of optimum waterproofing system for underground parts of buildings and constructions by means of a mathematical method. Objectives: systematic approach in the solution of a task - the choice of optimum waterproofing system by means of the mathematical method (mathematical apparatus of the Boolean algebra and probability and statistical and logical methods). Materials and methods: the system "wall-base plate" including waterproofing membrane, waterproofing the key, a repair composition, fillet, concrete preparation, reinforced concrete, drainage geocomposite. Results: the mathematical logic and probability determination of waterproofing system operability at various options allows to choose optimal system. Conclusions: the effectiveness of the mathematical method is reflected in the ability to determine the preferred option of building system on the basis of the analysis of its structure.

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

1. Introduction

Now there is a need of determination of technical condition of a waterproofing and the choice of decisions on its replacement with efficient option taking into account conditions and design features of a concrete object. For this purpose it is necessary to analyse in details technical condition and reliability of building constructions of buildings and also a hydrogeological situation of the area. Technical condition of the building and its designs consists available different extent of violations of serviceability of a building construction or its elements because of influence of external and internal negative impacts on a design, above established in the specifications and technical documentation.

2. Objectives

Systematic approach in the solution of a task - the choice of optimum waterproofing system by means of the mathematical method (mathematical apparatus of the Boolean algebra and probability and statistical and logical methods).The choice of protection of underground designs is important at a design stage and when overhauling.

The new scientific approach to achievement of a stated purpose: authors of article began work on a systemic research of change of operational properties of waterproofing systems in time on the basis of

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a logiko-probability method. Estimated result of work is scientific justification of optimization of design decisions and purpose of terms of overhauling of waterproofing systems, the providing safe conditions for the entire period of operation of the building. Some results of the performed work are given in the present article.

According to requirements of the Federal Law "Technical Regulations about Safety of Buildings and Constructions" the building and a construction has to be built so that in the course of its operation safe conditions on the following indexes were provided: humidity control on a surface and in building constructions and microclimate of rooms.

For ensuring implementation of requirements to water tightness of underground designs during the long-lived period of operation of the building the nobility only tentative properties of system of a waterproofing is not enough. It is necessary to know how these properties in time change and, the most important, what impact on change of properties of waterproofing system are exerted by the design solution of an underground part of the building. There is no reliable scientific justification of the specified changes for today. Some results of the performed work are given in the present article.

Thus authors took the first steps in the necessary direction.

The purpose of researches - creation of scientific methodology of the choice of materials and technologies for a waterproofing of designs of an underground part of buildings. The "wall-a base plate" system is given in the figure 1.

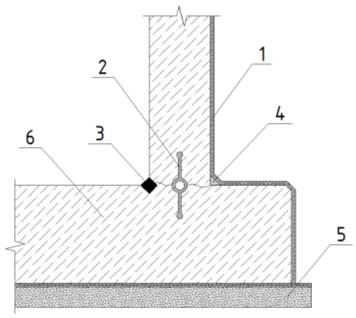

Figure 1. "Wall-a base plate" system:
1 – waterproofing membrane; 2 – waterproofing spline; 3 – indent with repair structure;
4 – fillet; 5 – concrete preparation; 6 – monolithic reinforced concrete

In a research the mathematical apparatus of the Boolean algebra and probability and statistical and logical methods is applied to assessment of operational reliability of materials and technologies. It is very important to make the right decision on a condition of a waterproofing and to pick up necessary materials and technologies.

The condition of a waterproofing of underground structures of the building is presented by us in the form of the composite multielement system in the form of multilevel models with subsystems of various levels. Therefore development of methodology of creation of the multilevel, hierarchical structure allowing to estimate not only technical condition, but also operational reliability at each level is important.

It is necessary to consider collaboration of a waterproofing and load-bearing frames and also to consider deformations, cracks, bends of designs. The waterproofing prevents from premature destruction of a design, but at their destruction it is also broken.

The waterproofing to destination happens: anti-filtrational (anticapillary), the corrosion-preventive and condensing.

All available technologies of a waterproofing can be divided on: coating, painting, spraid, plaster and with a guniting, cast, pasted, built up, getting, charging, mounted, injection, treating, grouting. By the principle of action they exist in the form of 3 types: getting, injection.

At the choice of technology for repair of a waterproofing it is necessary to consider: degree of responsibility of elements of designs; look, character, extent of defects and damages; external environment of designs; conditions of production of repair work; mode of underground waters; capacity for acting of drainage systems; compatibility of materials and anchoring strength of repair material with a design surface; processing behavior; operating time from the moment of completion of hashing of formulation constituents prior to drawing and acquisition of terminating waterproofing properties by it [1-5].

Resistance to all severe atmospheres innovative waterproofing materials on a mineral basis, thermoplastic on the basis of supersolid polyethylene and polyvinylchloride and also the getting isolation of new generation, polimertsementny mixes, repair structures on a mineral and polymeric basis have.

Waterproofing materials for repair and reconstruction of concrete and reinforced concrete designs have to provide all complex of requirements to materials on durability, deformability, the adhesion strength, resistance to influence of severe atmospheres, frost resistances, wear resistances, impact resistance, resistance to action of sign-variable temperatures.

3. Review of literature

At the solution of a question of the choice of an efficient waterproofing of underground structures of buildings it is necessary to reveal all conditions influencing its operational indicators and reliability. Except characteristic researches, developments of many authors were considered. The especially complete data on appearance of defects in an underground waterproofing are submitted in works. As a rule, at the initial stage of projection of the composite systems it is not possible to uniquely determinate optimum structure. In particular, for work of a separate element of waterproofing system not only influence of calculated factors (depth of an underlay of designs, hydrostatic pressure, etc.), but also the nature of interaction with other elements of system affects. Deviations in parameters of one of elements of waterproofing system can affect work of other elements that, in turn, can lead to change of an external environment of all system. So slushing of drainage system at a high level of ground waters and existence of slight defects in a waterproofing membrane promotes the accelerated wear of the last and as result, to water percolation in an underground construction. From this it follows that at the choice of optimum waterproofing system to have to solve not prime problem, the bound to searching and comparison of various options according to the mathematical proof of the device of this system.

As a possible solution of the specified problem it was necessary to find the mathematical model or a technique which are successfully applied at assessment of indexes of reliability of various systems. The basis for the specified technique authors were the logiko-probability method (LPM) offered the English scientists [6-9] and which was constantly improved by mathematicians. Some researchers used this method in direct or indirect statement for the proof of effectiveness and assessment of a significance of building blocks for transfer of information, for safety creation to the systems of any nature, for operating control by processes. I.A. Ryabinin (the Russian scientist) fullestly considered a logiko-probability method on examples of various systems, beginning from ship electrical power systems before operating control by space stations. In construction the method was applied to determination of reliability of network architecture and to the organization and management of civil engineering firms. The choice of waterproofing system means of a mathematical logic and determination of its working capacity by means of a probability theory was carried out by authors for the first time fullestly.

4. Materials and methods

The method of the analysis of hierarchies made the choice of reliable technologies from the alternate options (A – an injection method, B – the mounted waterproofing (screen), C – charging on the basis of bentonitic clays, D – complex system) by drawing up a matrix of paired comparisons. After check of judgments global (common) priorities of the accepted alternatives were defined on coherence on the basis of the calculated local priorities.

Common assessment for the chosen waterproofing systems:

$$K_A = k_1 \cdot x_A + k_2 \cdot y_A + k_3 \cdot z_A = 0.54 \cdot 0.27 + 0.17 \cdot 0.53 + 0.29 \cdot 0.12 = 0.275;$$
$$K_B = k_1 \cdot x_B + k_2 \cdot y_B + k_3 \cdot z_B = 0.54 \cdot 0.15 + 0.17 \cdot 0.28 + 0.29 \cdot 0.54 = 0.285;$$
$$K_C = k_1 \cdot x_C + k_2 \cdot y_C + k_3 \cdot z_C = 0.54 \cdot 0.09 + 0.17 \cdot 0.12 + 0.29 \cdot 0.28 = 0.150;$$
$$K_D = k_1 \cdot x_D + k_2 \cdot y_D + k_3 \cdot z_D = 0.54 \cdot 0.49 + 0.17 \cdot 0.07 + 0.29 \cdot 0.06 = 0.294 \quad (1)$$

The alternative with the maximal value of a global priority is an optimal solution. By results of the carried-out calculations it is visible that the option D - complex system was the most optimum waterproofing. The received option surpasses the others concerning the established requirements for reliability, maintainability and cost.

For various classes of materials depending on the properties defining them the predicted residual endurances were counted. It is necessary to select material and designs so that for all the time of service of the basis under a waterproofing resistance of a waterproofing and all layers under it to severe atmospheres was more than the loadings operating on it.

Influence of casual dispersions on safety and reliability of a design can be established only by methods of mathematical statistics and probability theory.

However in practice it is necessary to simplify all dependences strongly. In norms casual influences are considered by so-called elements of safety - normative values and degrees of safety or private reliability coefficients.

Well-timed assessment of technical condition of the bearing underground structures of buildings and waterproofing allows to make well-timed repairs and strengthening, to provide their reliability at operation, fail-safety.

For definition of the reason of distribution of defect the reasons of their emergence are in details considered. The quality of the executed waterproofing is influenced by the mistakes made at projection, installation and operation.

Destruction of a waterproofing is bound to deformations of the basis under the influence of heat drops, rainfall of the bases, inertial reaction and also is bound to a material aging.

The greatest number of refusals is bound to violation of technology of the device of a waterproofing. Because of difficulties at diagnostics of underground structures of buildings it is necessary to choose the efficient material and technology of its drawing providing the maximal endurance and operational reliability. The expert - the expert gives assessment of reliability of waterproofing systems of underground parts of buildings and constructions. Based on personal experience he assumes an optimal variant of the choice of waterproofing system. However, the probability of a mistake as it is difficult to consider all conditions, the bound to an object arrangement, influencing operational indicators and reliability of a waterproofing is high. It is also impossible to foresee in advance all violations which can appear at installation and construction works. The main advantage of statistical methods of a discernment of states is a possibility of simultaneous accounting of signs of various physical nature since they are described by the dimensionless quantity - probabilities of their manifestation in various conditions of the considered system.

Most often early "refusals" of waterproofing systems arise for three main reasons: mistakes at an early stage – mistakes of the designer because of inaccurate hydrogeological conditions and according to the insecure choice of design decisions and materials of protection of designs, non-compliance with technologies at works and also use of low-quality or cheap materials. At further operation the price of these miscalculations is extremely high as the repair cost of an underground waterproofing exceeds the cost of its tentative device. Increase of cost is bound to possible development of a soil for the device of a vertical waterproofing, realization of a necessary drainage for removal of ground waters.

Thus, the right choice of waterproofing system taking into account specifics of an object and assessment of its reliability are defining factors.

During studying of works of domestic and foreign authors [10-15] and also based on characteristic researches, the main reasons making impact on a waterproofing of underground parts of buildings and constructions were established and systematized:

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1. Cracks in the base are possible for the constructional, technological, operational reasons, and also because of the irregular drainage on building perimeter. Also the constant dampness in an object influences.

1.1 Constructional causes of cracks: calculation of a carrying capacity of the base and a soil is irregularly executed.

a) collecting loadings is irregularly executed;

b) the project of the base is developed without geological researches of soils;

c) irregularly calculated design depth of an underlay of the base;

d) irregularly calculated step of realization of straining seams;

e) irregularly calculated straining shifts;

f) the common errors of the project - reduce a carrying capacity, deformations in structures of the base, defects of a waterproofing appear.

1.2. Technological causes of cracks:

a) decrease in a carrying capacity and deformation in designs because of:

b) irregularly established and badly fixed timbering;

c) irregularly executed reinforcing of the base;

d) poor number of coefficient of reinforcing;

e) poor brand of the used concrete;

f) the poor vibrating of concrete mix at the time of laying.

g) freezing of concrete during the winter period;

h) the walls which are put up from materials with a calculated resistance on compression it is less than 5 MPa also with use of solution of less ductile consistence;

i) lack of straining seams.

1.3 Operational reasons of fracturing:

a) at superstructures – increase in number of the building without the corresponding strengthening of the base;

b) at a poor drainage or its absence;

c) at irregularly executed ring deep drainage on building perimeter:

c.1) the ring drainage is not laid along all designs coming influence of ground waters;

c.2) a ring drainage with a nonuniform bias;

c. 3) the drain tubes laid on the short basis;

c. 4) a drainage in which there is no possibility of cleaning;

c.5) the drain tube laid above the upper edge of a sole of the base;

c. 6) the standard position of a pipe in the highest point is irregular;

c.7) irregularly particular depth of laying of drain tube in the most deep point;

c.8) irregularly the given bias of a pipe;

c.9) irregularly the given thickness of the filtering covering;

c.10) the drainage system is lower than the maximum level of water in the water intake;

c.11) a butt seam of ceramic drain tubes without connecting ring;

c.12) pipes with rough or with irregular internal walls, without the express filtering fibroid;

c.13) inaccurately lay the filtering mat with a gap between a soil and the filtering envelope;

c.14) insufficiently big transverse section of drain tubes in the presence of big flow of water to a design;

c.15) presence of a reflux of water and connection to a water receiving well without device of water lifting installation;

c.16) the device of water lifting installation in drainage system without the emergency supply;

c.17) the device of water lifting installation in drainage system without hitch for access to a deposit

c.18) lack of the valves protecting from back motion of water in sections of the pipeline in which there is a danger of a veering of driving of water c.19) uncontrollable operability of the valves protecting from back motion of water in connection with restricted availability, in sections of the pipeline in which there is a danger of a veering of driving of water,

c.20) uncontrollable operability of the valves protecting from back motion of water in connection with operational service inobservant the duties, in sections of the pipeline in which there is a danger of a veering of driving of water;

c.21) the gravel sprinkling of drain tube blocking the bottom of a drainage wall on poor height, less than 50 cm from the top sawn-off shotgun of the base;

c.22) the gravel sprinkling of drain tube which is not blocking the bottom of a drainage wall

Above-mentioned defects lead to violation of a drainage system and a congestion of water. The accumulating water humidifies walls of the base or a zone of an adjunction of external walls to floors, washes away a soil, reducing its carrying capacity, increases loads of a design, destroys some structural elements. It leads to destruction and deformations of underground designs that attracts further to formation of defects of a waterproofing.

c.23) Irregularly executed bedded drainage on building perimeter leading to crack initiation and layer separation of a waterproofing.

2. Constantly formed dampness indoors at which walls become impregnated with water:

2a) incorrect work of system of heating;

2b) lack of heater of external walls of the heated underground room, walls do not correspond to a desired value of resistance of a heat transfer;

2c) poor thickness of heater of external walls or walls;

2 d) lack of ventilation;

2e) lack of vapor barrier at use of vapor-permeable heat-insulating materials;

3. Nonuniform pressure of the soil in the presence of clay inclusions in a sandy soil leads to a nonuniform seasonal flatulence and to emergence of the horizontal forces operating on underground parts of buildings and constructions, underground channels, wells, mines and so forth which promote fracturing and violation of a waterproofing, or layer separation of an adjunction of a waterproofing.

Each reason of development of defect can influence as it is self-contained, and in combination with others. Possible combinations were for this purpose made of the separate causes of defects and their sets - action of the separate reasons ("or"), action of set from several reasons ("and"). The scheme of malfunction "OR" with two entrances is submitted in the figure 2.

Table 1. Options of combinations of the reasons of defects

No.	No. of defects	"And", "OR" "
1	1.1a; 1.2a	And
2	1.2 1.3	And
3	1.22 1.3	And
4	1,12 1.3	OR
5	2.1; c23	OR

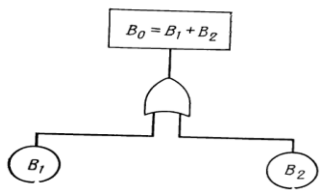

Figure 2. The scheme of malfunction "OR" with two entrances

Emergence of defect because of emergence of two reasons can be presented at once the scheme represented in the figure 3.

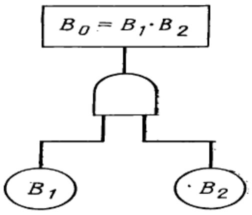

Figure 3. The scheme of malfunction "And" with two entrances

The refusal of B_0 can appear only in that case when both events of B_1 and B_2 take place.

When using a method of primary system failures calculation is conducted only to that point where primary refusals of elements are identified.

At quality standard of malfunctions the main approach is based on use of so-called minimum sections of system of malfunctions. Section is defined as a fundamental probability set, leading to an undesirable outcome. If it is impossible to exclude any from a set of the events belonging to some section and at the same time this set of events leads to an undesirable outcome, then in this case speak about presence of minimum section. Identification of minimum sections requires a computing algorithm.

It is possible to calculate a possibility of no-failure operation before emergence of this or that defect by a formula of the principle of indeterminacy of Laplace.

The probability of emergence of refusal of a waterproofing, as a result of one of the called reasons, is determined by a formula of the total probability $R_i(z)$

$$R_i(z)=1-P_{ст}(z)Q_i \quad (7)$$

where $P_{ст}$ - probability of no failure of isolation taking into account a material aging
Q_i – probability of lack of i of the latent defect which can be defined

$$\text{Qi} = \frac{2(n-i+1)}{\text{n}(n+1)} \quad (8)$$

n - amount of the considered defects
i-number of defect on ranging

And for each combination from the separate causes of defects and their sets, the probability of emergence of refusal was counted.

Table 2. Summary table of results

No.of defects / years	1	2	3	4	5	6	7
1	0.406	0.510	0.535	0.486	0.507	0.465	0.310
5	0.493	0.521	0.568	0.497	0.535	0.489	0.318
10	0.517	0.534	0.819	0.562	0.618	0.497	0.344
50	0.999	0.990	0.999	0.996	0.999	0.978	0.825

5. Results

As a result we see that the most intensive body height of probability of refusal is observed in the first year of operation. In the first year defects because of mistakes at projection are shown, because of fragility of structural elements and installation of designs. Within the next 10 years slight body height of probability of refusal is noticeable. By 50 years the probability of refusal increases practically up to 100% because of restricted endurance of materials.

For each refusal the reasons and a possibility of no-failure operation for mild prediction of refusal of this or that element are established. The organizations can define time of necessary check, a possibility of a delay of repair or need of immediate replacement.

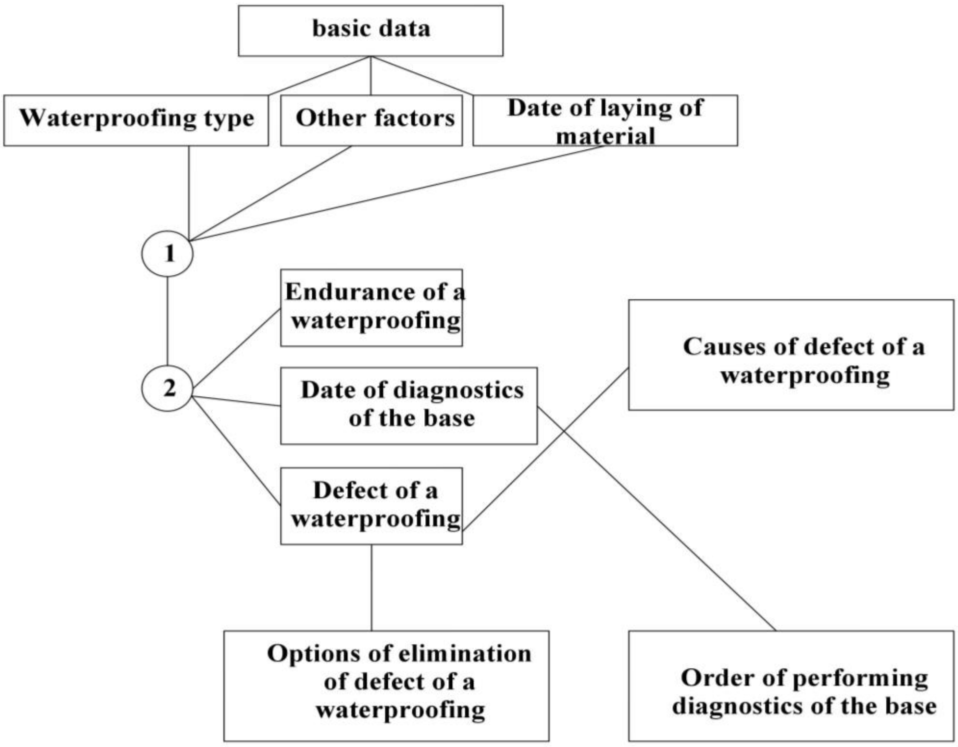

Figure 4. Algorithm of determination of reliability of material

6. Conclusions

Sets the carried-out example how efficient can be a mathematical method in the analysis of structure of waterproofing system even in case of lack of information on non-failure operation of the elements making it. Similar decisions help to define preferable option of creation of system only on the basis of the analysis of its structure. The established main reasons making impact on a waterproofing of underground parts of buildings and constructions are systematized. Thanks to the specified system it is easier to foresee probability of defect and not to make a mistake. On the basis of this information becomes possible to increase reliability level of waterproofing system thanks to creation of scientific methodology of the choice of materials and technologies for a waterproofing of designs of an underground part of buildings [16-24].

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