Innovative technological solutions to ensure the reliability of operated buildings

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Abstract. Subject: The purpose of this research work is to develop the most effective technological solution for underground waterproofing of operating structures with design features, as well as being in difficult and cramped conditions of nearby buildings. Objectives Outdoor underground waterproofing buildings, working «clamp» protects most of their supporting structures from aggressive ground waters, contributing to the acceleration of corrosion processes and leaks of water in technical room. Materials and methods: New types of waterproofing are considered and the technological scheme of performance of works is given. In addition, organizational methods of hydraulic protection of building structures have been developed. Results: This technology can be applied from the basements of the operated buildings and performed at any time of the year. Innovative technological solutions are based on mathematical calculations performed by the authors. Conclusions: Technological methods confirmed the choice of effective solutions for waterproofing, conducted by a mathematical apparatus using the methodological framework in the form of logical-probabilistic method and the method of pair comparison. The creation of "visual protection" from the mineral composition for the supporting structures of the operated buildings allows to increase the durability of their hydraulic protection, to work in cramped urban and difficult conditions, as well as to extend the life cycle of the building itself. Keywords: waterproofing system, waterproofing, drainage, underground structure, reliability, mathematical method, performance.

1 Introduction

The purpose of this research work is to develop the most effective technological solution for underground waterproofing of operating structures with design features, as well as being in difficult and cramped conditions of nearby buildings.

Technological methods confirmed the choice of effective solutions for waterproofing, conducted by a mathematical apparatus using the methodological framework in the form of logical-probabilistic method and the method of pair comparison. The creation of "visual protection" from the mineral composition for the supporting structures of the operated buildings allows to increase the durability of their hydraulic protection, to work in cramped urban and difficult conditions, as well as to extend the life cycle of the building itself.

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2 Objectives

Reliability of the building and its structural elements at its operation is defined by change of properties of materials and designs and also change of an external loading and influences. In process of increase in serviceable lifes this indicator decreases. The existing materials on protection of basic structural elements have in comparison with them small endurance. The waterproofing is necessary for ensuring normative durability and safe conditions [1-2].

All waterproofing materials of various classes stacked in an underground part of buildings demand the particular bases and also have to correspond to climatic and hydrogeological conditions. Considering complexity of restitution of an underground waterproofing of the operated buildings it is necessary to choose this protection for the most unprofitable conditions, i.e. to choose waterproofing materials with the greatest endurance and the most resistant to severe atmospheres. In actual practice carrying out rescue and recovery operations of underground constructions often is the technically composite or impossible because of the close arrangement of communications, roads or the neighboring buildings. The waterproofing of underground constructions represents the composite system for which successful functioning it is necessary to be guided by resistant compatible and long-lived materials and also technical solutions taking into account specifics of each concrete object. Having analysed all defects of different types of materials for a waterproofing of structural elements of buildings and also the reasons of their emergence, authors offered model of the choice of materials for optimization of design and operational decisions. [3]

At the Moscow State University of Civil Engineering at the Housing and Utility Complex Department works on assessment of operational reliability of a waterproofing of an underground part of buildings with use of logiko-probability methods are conducted. In accordance with GOST R 51617-2000 "Housing and communal services. The common technical specifications" operation – a stage of life cycle of an object on which its quality (operating state) is implemented, supported and restored. During operation of buildings of the first group of solidity with endurance more than 150 years the waterproofing having endurance 10-35lt, is exposed to several, rather difficult carried out, to overhauling therefore for their carrying out it is necessary to choose material with the increased operational properties.

The purpose of work is the choice of an optimal technology solution on a waterproofing of underground responsible constructions innovative materials with the maximal endurance in various external environment.

Repair of an underground waterproofing process the composite and laborious, in some cases followed by excavation and repair of the bearing concrete and reinforced concrete designs. The main percent of leaks in underground structures of buildings is the share of various seams: cold (the working seams which are formed when concreting a design), straining seams. Problem sites are the relative frame and fixed joints, pass of communications through a design, adjunctions of structural elements, through and not through cracks.

At repair of a waterproofing of constructions allocate its basic groups: cover, working by the principle of waterproofing membranes (backing, painting, coating, bulk, plaster, spraid, cast, charging); the getting action (capillary) and injection (microcements, acrylate gels, polyurethane foaming and swelling, epoxy and on the basis of bentonitic clays). For more precise and visual calculation for the choice of an underground waterproofing of walls and the bases used the program dialogue system "MPRIORITY 1.0" based on a method of paired comparisons [4, 6, 20-34]. Private criteria by which ranging was carried out for particular conditions it is accepted: tensile strength; water tightness; firmness in moderately severe atmosphere; endurance of pressure (pressure). At change of an external environment
on other objects frequent criteria were ranged also as decrease of their significance. Comparison of classes of a waterproofing on endurance and definition of priority option was carried out for: cover; getting; injection. Having analysed comparison of classes of a waterproofing by each criterion (the price, endurance, maintainability, non-failure operation) separately, results (priorities) are aggregated and calculated an optimal solution proceeding from the top priority. Having analysed design solutions of responsible constructions, it is possible to claim – injection materials and technologies since are the most efficient and hi-tech are suitable for restitution of an underground waterproofing of walls and the bases from the cellar. For work of a separate element of waterproofing system of the building not only influence of calculated factors (depth of an underlay of designs, hydrostatic pressure, etc.) affects but also the nature of interaction with other structural elements of system. [5, 8]. Deviations in parameters of one of elements of waterproofing system of the building can affect work of other elements that, in turn, can lead to change of an external environment of all system.

Reliability — complex property of a technical object consists in its ability to perform the given functions, keeping the main characteristics (under certain conditions operation) in the set limits. Enter a concept of reliability: non-failure operation, durability, maintainability and storageability. An indicator of reliability are probability of no failure, a time between failures, a technical resource, endurance, etc. [7].

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 basis for the specified technique authors were the logiko-probability method (LPM) offered the English scientists [8-9] 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) fullesty considered a logiko-probability method on examples of various systems, beginning from ship electrical power systems before operating control by space stations.

4 Materials and methods

MGSU together with OOO “Colourful world” offers the new material GSS-N2 (STO SRO - 60542948 00038-2015) and technology of its drawing for restitution and creation of a reliable waterproofing of underground load-bearing frames of the operated buildings that is very relevant task. Endurance of a new waterproofing coincides with endurance of load-bearing frames.

There are three main types of sanitation by injection materials: an external waterproofing - from the street; an internal waterproofing - from the basement (underground) room; internal consolidation of a building construction. Application of the combined consolidation method at the nonuniform nature of defects is possible [9-14].

Injection is made from the internal room, through thickness of a design, in a zone of contact of a wall with a soil. The gone injection substance is distributed on an external surface of a design, between through exits of injection channels. At respect for technology of an injection from the outer side of an underground construction the so-called vualey
waterproofing is formed. Slzdany such external waterproofing on the outer side of a design protects a load-bearing frame at the same time from corrosion and filtrational moisture. Application at fissile and aggressive impact on a design from the outside is expedient.

Material GSS N-2 is resistant to severe atmospheres, is durable, pollution-free, is not washed away by ground waters, does not lose properties at a multiple soaking-desiccation. Uniformity, number of inclusions by the size ≥ 1,5 mm - no more than 1. A permeability coefficient - no more than 5x10-6 m/days. The consumption of GSS N-2 paste has to make 20 kg - 27 kg on 1 sq.m in the absence of emptiness. GSS N-2 have to possess the following physics and technology characteristics of material:

- inertness to severe atmospheres and non-polar liquids;
- frost resistance of material at operation of a construction - not less than 200 cycles;
- reagent resistance of material to severe atmospheres (sulfate resistance acid resistance) stability in the range pH from 4 units to 12;
- resistance of material to currents of ground waters - resistance to a blurring by water flow with a speed up to 5 m/s, it is not subject to a suffosion;
- stability of physicomechanical properties of material taking into account a freezing and thawing;
- longevity when using - more than 100 years;
- the resistance to a frosty rebound has to be in an interval of indexes of sand and sandy loam.

The waterproofing dry blend of GSS N-2 with bulk weight of 1,15-1,25 g/cm³ consists of the fractional selected sands and water swelling additives. The dry blend of GSS N-2 is intended for preparation of waterproofing paste by means of which elimination of leakages in operating engineering designs and constructions, creation of anti-filtrational and waterproofing screens in the production, hydrotechnical construction by method of forcing of paste in external space of a construction by the principle a wall soil is carried out. It is applied only at repair of the buried designs. The prepared paste is stored in a pressure-tight container unlimited time. In an open container at normal humidity a shelf-life five days. Paste should be prepared and applied at a temperature from +2 to +50 degrees. At the negative temperatures it is possible to carry out forcing of material from the inside of the cellar to an external surface of a wall of a construction. At cyclic defrosting and freezing of a soil paste from material GSS N-2 the properties does not change. Paste from material GSS N-2 does not change the properties at interaction with a severe atmosphere. Material GSS N-2 in a dry and pasty look can be used in the areas. The veil from material GSS N-2 is eco-friendly as material consists of pollution-free components. The shelf-life of a dry blend is unlimited. The dry blend of GSS N-2 is frost-resistant. GSS N-2 does not form cracks at dead and inertial reaction, has the high getting and tamponing ability. At its use washing of hoses and an inventory is not required. The principle of action of GSS N-2 is based on what at interaction with water of a particle of additives is swelled, expanding more than by 20 times (a ratio of sand and additives 70:30). The adhesion to concrete is from 0.21 to 0.5 MPa. The size of the free swelling decides by duration of its interaction on water. Has steady property of swelling at multiple soaking by water and an exsiccation.

We developed the organizational fabrication documentation regulating rules of realization of technological processes, the choice of means of technological support (the industrial equipment, the tool, stock and devices), machines, mechanisms and an inventory, necessary material resources, the requirement to quality and acceptance of work and also an action for the accident prevention, labor and environmental protection.

Before an structure of a waterproofing examination of the protected design and environmental soil and also drawing up the repair list is conducted. The main criteria for evaluation of the defective sites are the look, the reason and the extent of defects and also a state, mobility and existence of access to the defective surface. The base under design walls
reinforced concrete. Soil level behind an external surface of a design not less than 1 meter in the condensed state. At inspection of the base the exemplar is cut down and the analysis of an adjacent soil and a trial injection is carried out. Results serve as justification of the following technology solution. For example, for creation of a membrane on one of the experimental buildings 64 through holes were drilled. Through express injection packers with a diameter of 20 mm about 1500 liters of injection paste were gone. The injection pump Check after completion of works was used to forcing of material showed that walls became dry, inspection of a surface of the walls adjoining to a soil established that the almost continuous protective veil is formed. For the choice of a method of an injection it was necessary to determine pressure and amount of the entered water.

Technological sequence following. Installation of structural tours for work on cellar wall height. Preparation of a concrete surface in front of the waterproofing device by means of GSS N-2 comes down, generally to elimination of the available defects: seal of cracks and hollows, etc. (if necessary) if other is not provided by the project documentation. By preparation of concrete surfaces (according to the project documentation) it is necessary to execute filling of joints and openings in constructions from prefabricated elements with the condensing materials and a waterproofing of pinholes.

In places of intensive leakages the openings (quantity of openings and a step are defined from parameters of a leakage and material of a design) going beyond obdelochnny space of a construction are bored through. In openings delivery branch pipes which external diameter has to correspond to a caliber of a hose, the applied the pump with solution becomes monolithic. Quantity of branch pipes 1-2 pieces on 1 sq.m of the waterproofed surface, depending on character of leaks. For more precise determination of pressure of forcing upon a becomes monolithic delivery branch pipe by means of a cap nut the tee with the manometer is installed.

Drilling of openings for sealing forcing is carried out to a soil, with deepening on 1-15 cm depending on quantity of leaks, the areas of flood and a type of a design.

It is carried out:

- when forcing for the protecting designs through the openings which are settling down in chessboard order, apart no more than 1 m;
- for combined reinforced concrete designs of an opening for forcing it is necessary to drill to a soil in chessboard order apart no more than 1 m in interfacing blocks;
- at elimination of local individual leaks through a monolithic and combined reinforced concrete obdelka, in the place of a leak 3-4 openings on a circle apart 0,7-1,5 meters are drilled;
- in monolithic designs of underground constructions for elimination of a soaking of surfaces of an opening 0,7-1,5 meters depending on extent of flood and specific conditions of the site of works are drilled in chessboard order apart.

Drilling of injection openings is made by means of a drill or the puncher:

- through – for creation of an external waterproofing membrane,
- not through, crossing cracks, breaks and other defects through which water enters.

In places of intensive leakages the openings going beyond an external underground part of a building construction, adjoining to a soil (fig. 1) are bored through.
The dry blend is filled up in the blender tank filled with water according to the recipe and mixes up within 10 minutes an electric drill with a nozzle.

**Table 1. Recipes of preparation of GSS N-2 paste**

| No. | Name of the recipe | Qualitative characteristic of viscosity of paste | Share of a dry blend of GSS N-2, % of masses | Share of water, % of masses |
|-----|--------------------|-----------------------------------------------|---------------------------------------------|---------------------------|
| 1   | Recipe No. 1       | small                                         | 18.2                                        | 81.8                      |
| 2   | Recipe No. 4       | average                                       | 22.2                                        | 77.8                      |
| 3   | Recipe No. 3       | high                                          | 25                                          | 75                        |

In shots delivery branch pipes which external diameter has to correspond to a caliber of a hose, the applied rastvoronas zamonolichivatsya. Quantity of branch pipes 1-2 pieces on 1 sq.m of the waterproofed surface, depending on character of leaks. Inyektor to have apart not menee1metra in chessboard order. After paste forcing to make endurance of solution within 2 days.

After control survey and lack of leaks to muffle inyektor; in case of existence of leaks to make padding pumping.

Sealing forcing of the paste prepared from GSS N-2 has to be made before the complete filling of emptiness at a working pressure not less than 0.5 MPa. Forcing of paste on the defect sites should be made from below up perimeter. The complete filling of emptiness through an injection branch pipe is considered reached at emergence of paste from the next branch pipes.

At elimination of individual leaks forcing should be begun through the central well in the place of a leak with the pastes of the increased concentration possessing a smaller razmyvyayemost and to pass sequentially to forcing through other wells with solutions of smaller concentration with more fluid consistence. Forcing has to is made through the injektor established in the drilled openings and equipped with pith cranes, or the backpressure valves providing potting of openings for forcing.

The prepared paste is pumped in zaobdelochny space of a construction before its emergence from the next branch pipes then forcing in this branch pipe stops, and it is fullered or established a flat stopper on a carving, and the hose of a rastvoronasos joins on the next branch pipe. According to this scheme hesitation pumping through all branch pipes is carried out. (Fig. 2). For increase in efficiency on forcing of the paste prepared from GSS N-2 it is recommended to attach to a rastvoronasos the distributive comb having 2 and more cranes that will allow to make at the same time forcing of paste in 2 and more branch pipes.

After pumping of paste on all surface of the protecting design of a construction has to a technological break not less than two days for a water absorption will be executed. After a surface it is checked for existence of leakages, if necessary padding forcing is made.
When forcing for reinforced concrete and stone designs of underground constructions pressure of forcing is established by the Party of Pensioners of Russia depending on engineering-geological conditions of an object and characteristics of the protecting designs and has to be not less than 0.5 MPa.

After completion of works on forcing it is necessary to make potting of openings for what to clean them from solution and to fuller the condensing material in accordance with GOST 25621.

By means of an express inventory – pumps injection material is pumped in the created openings, than the complete protection of a construction against the entering moisture is provided.

For more precise determination of pressure of forcing upon a zamonolichenny delivery branch pipe by means of a cap nut the tee with the manometer is installed. The recommended branch pipe size for all types (recipes) of mix of 25 mm.

More than 2 mm having the fissile, jet character and jointing are applied to leakages the paste prepared on Recipe No. 3. The viscosity of not hardening GSS N-2 waterproofing paste can change over a wide range. Pressure of forcing is chosen proceeding from durability of building constructions and a counterpressure of the entering water.

Minimum pressure of forcing the entrance to a delivery branch pipe has to have 4 atmospheres. The forced paste has to fill all emptiness around a building construction and protamponirovat cracks in an environmental soil on depth more than 30 cm.

At elimination of the fissile leaks pressure of forcing has to be 3 atmospheres more larger than a counterpressure of the entering water, and at first carry out forcing of a small amount of the paste prepared according to the recipe No. 1 and then final forcing of the paste prepared according to the recipe No. 3.

Padding swelling of paste behind an obdelka will create pressure no more than 0.5 atm.

The viability of the injected structures can be up to 40 minutes and is regulated by the content in catalyst mix (swelling composition). Use force auger pumps to an injetsirovaniye.

Pastes injektirutsya with use of structural auger pumps with the maximal delivery pressure of solution not less than 8 atmospheres for the waterproofing paste with small viscosity (the recipe No. 1) and the SO-150 unit for forcing of pastes with average and big viscosity (the recipe No. 2, No. 3).

Control forcing is made by material GSS N-2 according to the recipe No. 3 and No. 2 (in a case where it is impossible to protamponirovat material according to the recipe No. 3). Similarly for a combined reinforced concrete obdelka and for a monolithic obdelka.

Seal and injetsirovaniye of cracks is carried out for restitution of a wholeness of designs; obstacles to water intrusion; protection of fittings.

It is necessary to pressurize all cracks for routine designs at disclosure more 0.3mm and for strained – more 0.2mm.

The common scheme of injection at a way of creation of a veil is given in fig. 2

![Fig. 2. Injection of GSS - H2 wall soil.](image)
The waterproofing of surfaces is conducted sequentially on catches (allotments) defined in a binding of the procedure sheet to an object. When working on a waterproofing of a surface break into vertical or horizontal catches, depending on the applied means of a podmashchivaniye. At breakdown on horizontal catches arrangement of links is carried out on all scope of work within a catch, and each link occupies the next allotment. The size of allotments is established according to day development of links.

Table 2. The schedule of works on the area of 50 sq.m

| Name of works                                           | unit of measure | amount of works | Work costs of common amount of works, people/hour (mech./sm) | working day |
|--------------------------------------------------------|-----------------|----------------|------------------------------------------------------------|-------------|
| Repair work on the main load-bearing frames (elimination of cracks, seal of joints, etc.) | 1m              | 4              | 20.2                                                       | 1 2 3 4 5 6 7 8 9 10 11 |
| Marking of places of drilling and drilling of openings of D 20 mm in concrete on 1 m the puncher | 100 piece       | 2              | 92                                                         | - - - - - - - - - - |
| Immersion of injektor and hoses                        | 1m              | 150            | 1.79                                                       | - - - - - - - - - - |
| Installation and stripping of tours                    | movement        | 10             | 0.14                                                       | - - - - - - - - - - |
| Compounding                                            | m3              | 1.5            | 0.49                                                       | - - - - - - - - - - |
| Mix injection                                          | litre           | 1500           | 20                                                         | - - - - - - - - - - |
| Seal of openings                                       | piece           | 200            | 41 people/hour                                              | - - - - - - - - - - |

5 Results

As a result we see that the To the analysis and assessment of restitution of a waterproofing by an injection method with creation of a veil applied the organizational and technological model operation of a way allowing to provide the organizational actions providing optimum process of hydroprotection of the building. From the known graphic models: the linear schedules of Gant, cyclograms M.S. Budnikov, tables matrixes and network schedules the
most suitable were applied for given restitution-linear and network [15-19]. Now researches on optimization of restitution of a waterproofing with use of network models and computer programs are conducted.

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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