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MODERN ENGINEERING AND TECHNOLOGY SOLUTIONS FOR MOISTURE-PROOFING OF PLAIN- AND REINFORCED-CONCRETE UNDERGROUND AND BURIED CONSTRUCTIONS AND STRUCTURES

ABSTRACT

A principal factor effecting the durability of underground and buried structures is impact of water penetrating the building constructions and capable of causing both the destruction of concrete and corrosion of reinforcement, worsening the construction static properties and being prone to force it collapse. Besides, water penetrating the internal premises of the underground part of the structures deteriorates their service properties, disturbs the operation of the processing equipment, worsens the microclimatic conditions of the premises, etc. High-quality and durable water proofing, particularly of underground and buried plain- and reinforced concrete constructions, is expensive and labour intensive process: average cost of works is 0.1–0.5 % of the total estimate cost of the construction and assembly works; this kind of works accounts for 3 % of the total labour costs when erecting the structure [13]. As practice shows [13], in 90 % of cases the failure of underground and buried structures takes place for the very reason of failure of waterproofing; moreover the failure occurs at the early stage of operation which contributes to the accelerated wear-out of the load-carrying constructions. In most cases, the failures in operation of the water-proof systems result from erroneous choice of construction solutions, incorrect selection of insulating materials, unsatisfactory quality of the works performance and improper operation. At the same time, the repair of the waterproofing is a difficult, expensive and often also ineffective operation. To reduce the risk of occurrence of problems, it is therefore important to choose the right engineering and technology solutions for waterproofing systems designed for the whole service life of the structure with due account for all the adverse effects, which would exclude water leakages and reduce to the acceptable minimum the additional expenditures conditioned by the need of restoration of the waterproofing.

Keywords: waterproofing, plain- and reinforced-concrete constructions, waterproofing technology, waterproofing systems, preparation and repair of the construction surface, dry waterproofing mix, bituminous joint filler, injection waterproofing, silica gel.

THE WATERPROOFING OF PLAIN- AND REINFORCED-CONCRETE UNDERGROUND AND BURIED CONSTRUCTIONS AND STRUCTURES

An effective waterproofing must ensure:

- protection of underground and buried structures from water intrusion and from moistening by subsoil and ground waters;
- stability under no-load condition against static, dynamic and corrosive loads and impacts of different nature;
- protection of communications of constructions and structures, their engineering equipment, life support systems, etc.;
- the possibility of operating underground and buried structures without restrictions and minimising the costs of their maintenance.

The work on the installation of waterproofing is performed both during the construction of new and during the repair of already built structures using various technical and technological solutions. At the same time, one should consider various requirements for waterproofing located on the surface of a structure that subject to hydraulic action ("positive" water effect) as well as waterproofing located on the surface of the structure that is not subject to hydraulic influence ("negative" water effect). Here, all types of impacts are considered as a hydraulic influence on the construction structure in accordance with [6] and [11]. At the same time, the waterproofing coating, perceiving the "positive" water effect, works on "hold down" and perceiving the "negative" water effect, on the "separation". In any case, to achieve maximum effect in the construction of waterproofing structures, materials should be used in a comprehensive manner and one should take into account a variety of factors affecting the final result, including:

- hydrogeological conditions of the construction site, the chemical composition of ground water and climatic conditions in the course of work;
- volume-planning and structural solutions of constructions and structures, the presence of expansion joints;
- depth of foundations and possible deformations of structures considering their own weight and payload;
- the planned use of indoor facilities and the required relative humidity in them;
- directive terms of production of construction and installation or repair works, etc.

It is very difficult to assess and fully anticipate all possible impacts on the waterproofing system and it is almost impossible to take into account all the nuances. As practice shows, a multi-level waterproofing system should be considered affective when it is arranged using various materials combined in one technical solution and selected considering the results of studying the hydrogeological conditions of the construction site and conditions for the functioning of structures (in case of new construction) or preliminary examination of existing structures (in case of repair and restoration of waterproofing). Therefore, the following should be considered as an initial data for the selection and design of waterproofing systems for constructions and structures:

- geotechnical category of the complexity of the construction site (including the presence of weak artificial, biogenic, nonuniformly compressible soils, etc.);
- class of geotechnical risk of construction conditions according to [7];
- the results of surveys in accordance with [1]-[5], including collection, study, compilation and analysis of published and foundation results of surveys over the past years (if necessary), determination of the presence and depth of water-bearing layer bedding in the working area, chemical composition, as well as the direction and speed of groundwater movement, etc.;
- data that take into account and characterize the purpose, structural and technological features of a construction (structural diagram of the buried part of a construction and structures above it, etc.), as well as the technical condition and operational availability of individual structures and an entire construction as a whole;
- the design values of the loads and impacts that are in effect and expected after completion of the construction of the construction and the way they are transferred to the buried parts. For example, the direct impact of groundwater, seasonal and climatic fluctuations in the level of groundwater, the presence of water due to leaks from various types of water-bearing communications, etc.;
- information on vibro-dynamic fluctuations of the construction arising in the course of its erection and operation, as a result of natural and human impacts, as well as the effects of urban infrastructure, structures of underground and aboveground transport, etc.;

- information on the operating conditions of the construction, the sequence of the erection of its parts, as well as their mutual influence on each other;
- environmental requirements etc.

The modern market of construction materials and waterproofing technologies offers a wide range of various technical and technological solutions; however, reliable guaranteed results can be obtained only by proper selection of materials, considering their compatibility and strict observance of the work technology.

An important technological aspect of the high-quality waterproofing is the correct preparation of the surface of the insulated structure. In this case, special attention should be paid to ensure that there is no cement skin on the surface of the structure. When a waterproofing coating is applied to concrete with a cement skin, a three-layer system is formed: "concrete of construction - cement skin- coating", with no more than 50% of the expected strength value in the system joints is reached and the separation of a coating during operation occurs precisely at this separation line. For competent preparation of the surface of the insulated construction structure, it is recommended to use the following cleaning methods:

- mechanical cleaning method (using sandblasting machines, grinding machines, wire-brushes, etc.) is used for the processing of structures regardless of their destruction degree, except when dust or pollution of the environment is unacceptable;
- hydraulic cleaning method (using waterjets and water-sandblasting machines with operating pressure from 18 to 120 MPa). To remove weakened concrete and corrosion products, it is recommended to use a waterjet that develops pressure from 60 MPa or more. This method of treatment should not be used in cases where the change in ambient humidity is not permitted at the work area;
- thermal method of cleaning (using propane or acetylene-oxygen burners, etc.). This processing method is used to clean the surface of the structure, which has damage of insignificant depth (from 3.0 to 5.0 mm). After thermal cleaning the surface of the structure is further additionally processed by mechanical or hydraulic methods;
- chemical method of cleaning (using solutions of hydrochloric acid, phosphoric acid, etc.). This method of treatment is used in cases when it is not possible to use other methods of cleaning, considering sanitary and hygienic requirements, as well as in conditions of a constrained work site. The obligatory condition for the application of a chemical cleaning method is the subsequent profuse washing of the surface of the treated structure with water.

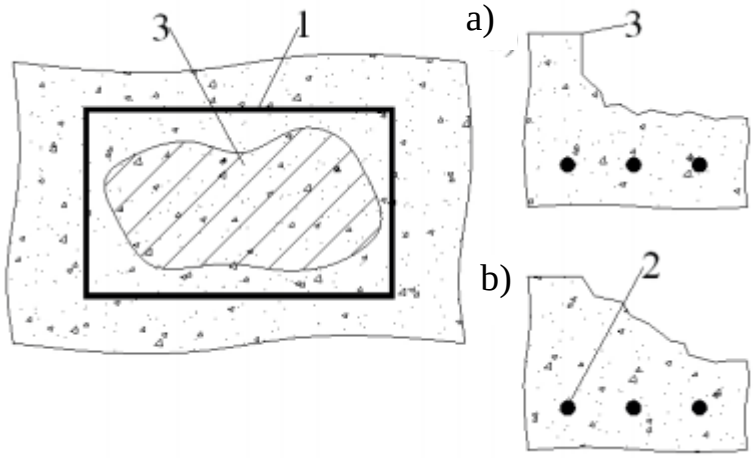
The method for preparing the surface of plain- and reinforced-concrete constructions is selected considering the minimum permissible strength of the structure concrete (Table 1).

Table 1

Cleaning method of structure surface	**Minimum permissible value of the concrete strength, MPa, no less**
Mechanical cleaning method using wire-brushes	1.5
Mechanical cleaning method using grinding machines or vibrating cutters	5.0
Hydraulic cleaning method using waterjets	0.3
Hydraulic cleaning method using water-sandblasting machines	5.0

The next step when preparing the surface of the structure for the waterproofing is the repair of the sections of the structure with the broken structure of the material, which is performed in the following sequence:

- plan the contour of the repaired area by an angle grinder on the surface of the structure, cutting a groove 10 to 20 mm deep (Figure 1) in a plane perpendicular to the surface being repaired, which will allow localizing the repair area and preventing further destruction of the surface of the structure;

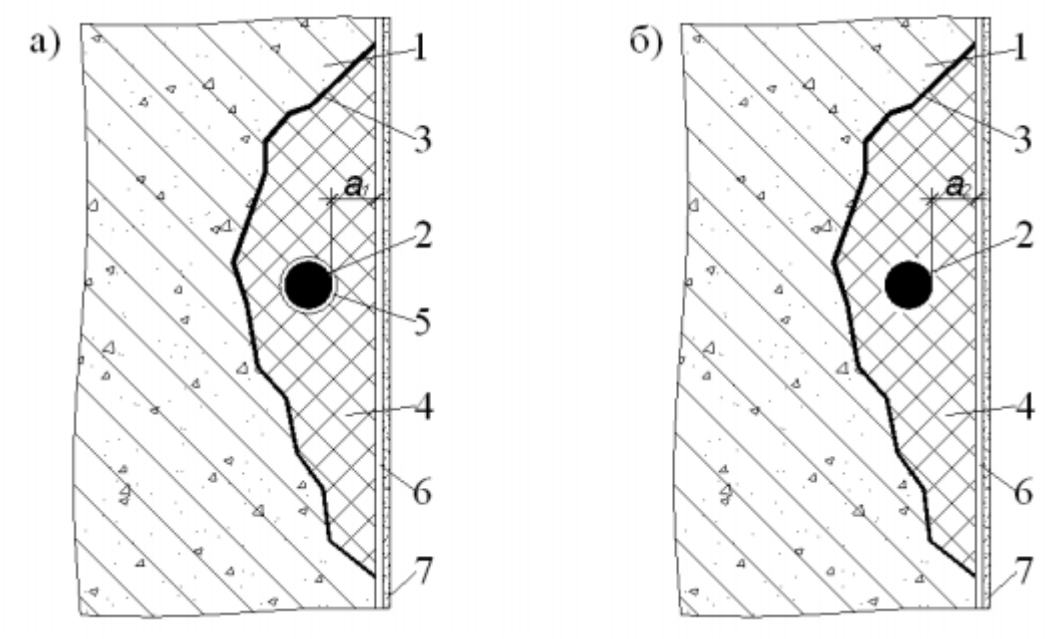


1 – contour of the repaired area; 2 – steel reinforcement; 3 – destroyed section of an insulated construction structure

Figure 1. The scheme of insulated structure repaired site preparation:
a – correct repaired site preparation;
b – incorrect repaired site preparation

- the material is removed from the surface of the structure with a broken structure (unstable, loose or exfoliated) with about 5 mm wide strip of strong material located outside the contour of the area is being repaired;
- the surface of the site to be repaired is dusted off and, if necessary, saturated with water and primer with a Kiesol waterproofing primer (for example, using polymer cement mortar repair mortars) or dried (for example, when using repair mortars with epoxy resins);
- the repair material is laid (for example, repair mortars Betofix R4, Betofix R4 SR or Betofix R2, made by Remmers company) on the prepared surface and maintain it for the time specified in the manufacturer's accompanying documentation.

At the same stage, the restoration of the protective layer of the reinforcement steel is performed. In this case, after removing from a structure surface a material with a broken structure, it is necessary to clean the reinforcement steel to the degree Sa 2 1/2 by [8]. To restore the protective layer of reinforcement steel, it is recommended to use polymer cement repair mortars (for example, Betofix R4, Betofix R4 SR or Betofix R2) (Figure 2).



a) b)

a_1 – 10 mm and less; a_2 – more than 10 mm.

1 – insulated construction structure; 2 – reinforcement steel; 3 and 4 – preparatory and base layers of repair mortar accordingly (for example, Betofix R4); 5 – mortar layer, protecting reinforcement steel (for example, Betofix R2); 6 and 7 – protective coating, including waterproofing primer and acrylic paint

Figure 2. Diagram of repair of dry sections of structures with destruction of the protective layer of reinforcement steel using the materials by the Remmers system: a – thickness of reinforcement steel protection surface with 10 mm and less; b – the same more than 10 mm.

Defects having a considerable length in concrete and reinforced concrete structures are cut using a jackhammer to form a cavity in the form of a dovetail. The size of the formed cavity should be 25 mm and more in width, and 50 mm and more in depth. Cracks with an opening width of more than 0.4 mm, as well as seams, joints, mattings and junctions are toothed along the entire length, and engineering communications inlets are toothed throughout the contour (the lateral size of the groove must be at least 25x25 mm). In this case, it is not recommended to perform grooves in joints and along cracks in the form of toothing with outward expansion. Toothing are cleaned of concrete residues, dusted and washed and also wetted to the full moisture saturation of the concrete (water absorption stop) or dried (if necessary) and then sealed in accordance with the solutions defined in the design.

At the interfaces of the structures, the fillets are arranged (the radius of the rounding is taken in accordance with the specified in the project, usually in the range of 5 to 15 cm), for example, using a Dichtspachtel (made by Remmers company) mortar or other materials with similar properties.

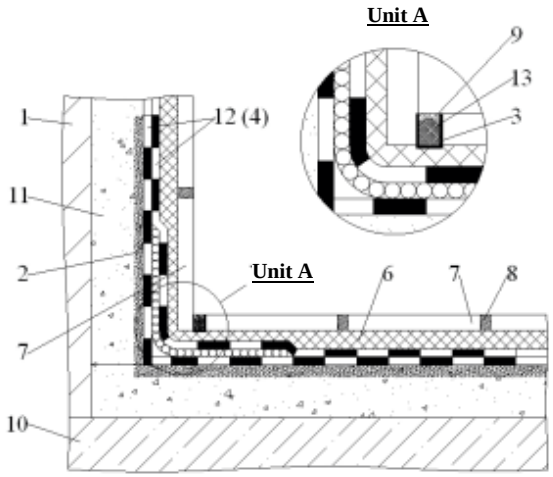
As a rule, repair mortar mixtures on the surface of the structure are applied with a thin layer and the ratio of the area of the applied mortar mixture to its volume is a significant value. This ratio is the reason for the rapid evaporation of water, which in turn leads to the development of shrinkage stresses and the formation of cracks. An interesting solution of this problem, implemented in the development of compositions of dry mortar mixtures Betofix R4 and Betofix R4 SR, is their dispersed reinforcement with synthetic fibres, which effectively influences the shrinkage deformations dimensions.

When designing the waterproofing of plain- and reinforced-concrete constructions, it should be considered that at present mainly not individual waterproofing materials are used, but their systems (programs) that represent a complex technical solution that includes a set of specific target materials that provide a certain functional of a specific solution (for example, coupling of structures, hydro-cuts, salt suppression, etc.) (Figure 3).

On the other hand, the majority of modern proposals in the field of materials intended for waterproofing refers to dry construction mixtures predominantly on a mineral basis - ready-made powders that require mixing with water or water-based polymer dispersions. Such materials have one indisputable advantage, which is ease of application to the surface of an insulated structure either by a mechanized method or manually. It is allowed using a screw mortar pump with spray nozzle for the application of mortar mixtures and plastering machine or brushes with synthetic fibre. In this case, the method of coating should provide the maximum density of the solution, the optimum water content; exclude delamination of the mortar mixture and the formation of through (directed) porosity.

Dry waterproofing mixes, as a rule, are made of cement, quartz sand and target modifying additives that determine the scope and functional characteristics of the waterproofing material, for example:

- subsoil waters impact resistance (hydraulic head, moistening, weighting water attack) (Figure 4) and other corrosive medium if mixes are used in the composition of waterproofing structures of sewage or treatment facilities, etc.;
- provision of specified waterproofing capacity (including at the influence of head ground waters), wear and freeze resistance, UV resistance, etc.



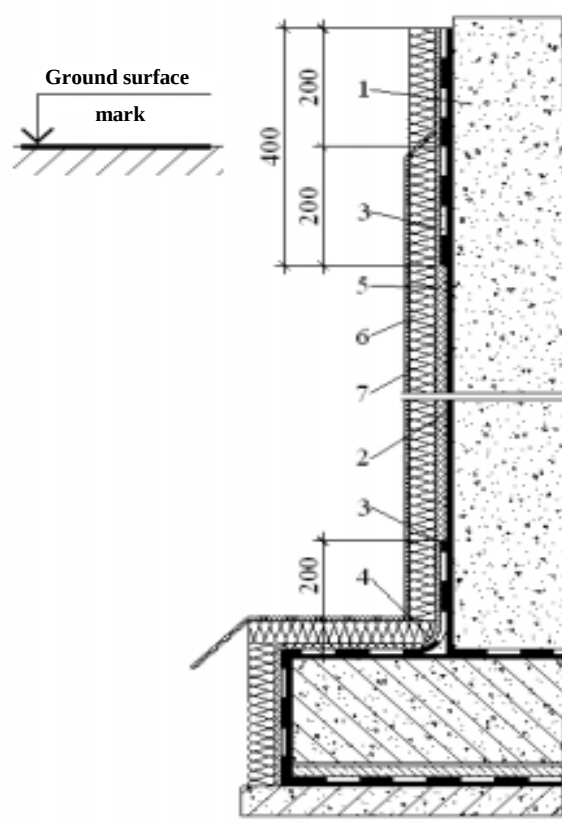
1 – the wall; 2 – primer with a Kiesol waterproofing primer; 3 – two-component primer Unterwasserprimer; 4 – mortar mixture Elastoschlamme 2K (2-3 layers); 5 – sealing seam band Fugenband VF 120; 6 – Multikleber or Extraflex facing work mortar; 7 – ceramic tiles; 8 – Colorfuge EP composition for filling the joints; 9 – Multisil nuw silicone sealant; 10 – reinforced concrete base plate; 11 – Betofix R4 mortar mix; 12 – Multibaudicht 2K mortar mix; 13 – polyethylene foam-made cord.

Figure 3. Waterproofing structure diagram of wall-water pool base reinforced concrete plate joint using materials by Remmers system.

There are no single universal protective methods and materials in any case, given the wide variety of causes that cause leaks and wetting of structures. Therefore, only an integrated approach is effective, involving the preparation of a competent technical and technological

solution for waterproofing, the selection of the required set of materials that meet the operating conditions and the results of the survey of a construction site, as well as the performance of work by specialists of the required qualifications.

As an example of the above, it should be noted that the practical experience of the installation of waterproofing of underground structures has demonstrated significant difficulties in the case of using bitumen in pure form (without additives). Here it is necessary to consider insufficient adhesion, water and crack resistance of bituminous coating, as well as the possibility of chemical interaction between the bitumen coating and the construction, which, in the final analysis, can lead to the destruction of the surface layer of concrete.



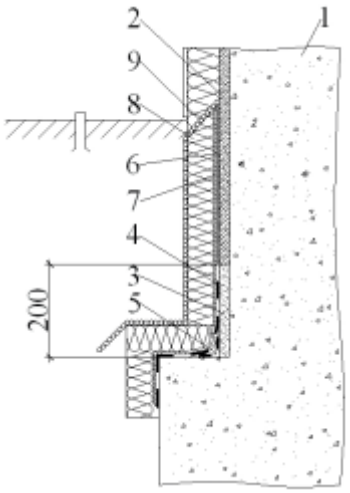
1 – the base;
2 – Kiesol waterproofing primer;
3 – Sulfatexschlamme mortar mix;
4 – Dichtspachtel mortar mix fillet (the radius of the rounding – 50 mm);
5 – Profi Baudicht 1K joint filler;
6 – thermal insulation layer made of extruded polystyrene foam;
7 – protective membrane

Figure 4. Waterproofing structure diagram of bases using materials by Remmers system

In addition, bitumen in its pure form can be a nutrient medium for microorganisms living in the ground, and their effect on waterproofing significantly reduces the waterproofing properties of bitumen [12] and [14] for several years. The problem of low durability and crack resistance could be solved by means of a waterproofing coating using joint filler based on bitumen, modified with special additives and components. It is allowed to use the reinforcement layer made of fiberglass mesh in the composition of the coating based on bitumen joint filler.

As a general matter, the repair and restoration of waterproofing coatings based on bitumen (Figure 5) using bitumen joint fillers are made in the following sequence:

- remove the old coating from the surface of the structure with a fragile (broken or exfoliated) material structure and structure material with a broken composition;



1 – insulated construction structure;
2 – existing external waterproofer coat bitumen-based coating;
3 – protective and finishing construction plaster;
4 – mortar mixture on the primer layer;
5 – fillet (the radius of the rounding – 50 mm);
6 and 7 - joint filler and sanding;
8 – thermal insulation layer made of extruded polystyrene foam;
9 – protective membrane

Figure 5. Diagram for restoring the waterproofness of an existing external waterproofing coating based on bitumen without removing the coating

- the surface of the insulated structure is finished (for example, using the protective and finishing construction plaster Grundputz (made by Remmers company)), then the surface of the insulated structure is applied with Ilack ST joint filler and sanded with quartz sand;
- bitumen joint filler is applied on the surface of the insulated structure either by mechanized method (airless spraying) or manually.

Another feature of the modern market of waterproofing materials is its orientation towards environmental multifunctional materials. For example, the basis of most Remmers waterproofing systems is Kiesol waterproofing primer, which is a non-colouring and solvent-free one-component silicone liquid for rendering water-repellent form of an aqueous dispersion, which is used for:

- priming layer, increasing adhesion, as part of waterproofing systems made of Remmers materials and having adhesion to the base;
- waterproofing impregnation of internal and external surfaces of structures;
- anticorrosive protection of structures against the influence of corrosive environmental factors.

The use of Kiesol waterproofing primer promotes:

- two-steps increase of the material waterproofness of insulated construction structure at its vapour permeability maintenance;
- an increase of a concrete resistance against the influence of corrosive environmental factors (dilute mineral acids and alkalis, organic acids, sewage and groundwater, carbonates and chlorides, etc.), as well as the increase its freeze resistance, strength and sulphate resistance;
- an increase the resistance of waterproofing coatings against chemicals influence (including corrosive waste waters, etc.);
- preventing of a capillary suction and acceleration of the cement hydration process.

The ecological compatibility of Kiesol waterproofing primer is evidenced by the fact that it can be used in the construction and repair of reservoirs intended for drinking water storage.

An interesting feature of Kiesol waterproofing primer is that it can be used for injection waterproofing and horizontal ground water cut-offs, that is, the primer can be considered as one of the varieties of waterproofing materials of penetrating action.

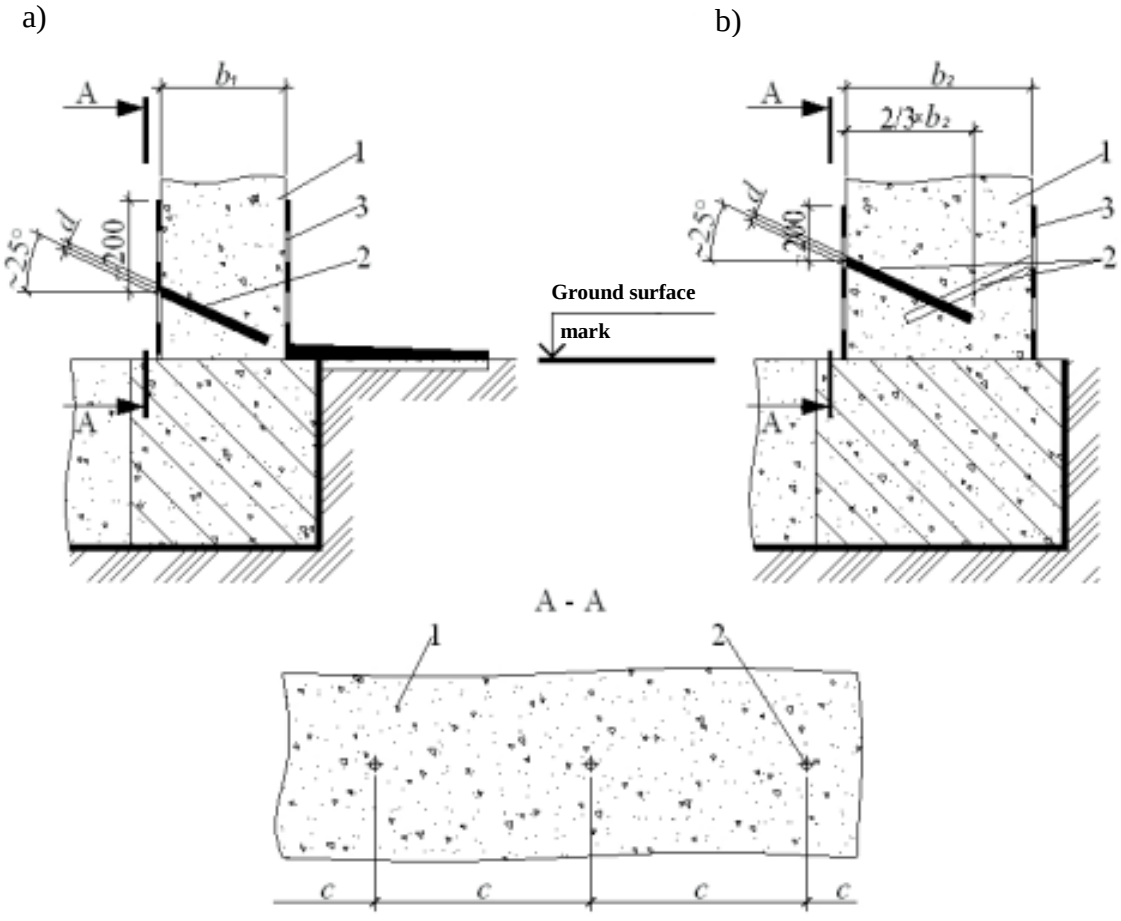
Injection waterproofing and horizontal ground water cut-offs using Kiesol waterproofing primer are performed in the following sequence:

- the surface of the insulated structures is prepared to a height of at least 800 mm above the level of the structure wetting established as a result of its examination;
- leakages are stopped, as well as seams and cracks in structures, joints and interfaces are sealed;
- holes in the insulated structure (figure 6) are drilled;
- Kiesol waterproofing primer is injected in accordance with the solutions defined in the design.

Recommended methods of injection:

- the non-pressure method of injection using special cartridges. This method is recommended to be used for injection waterproofing structures with a thickness of less than 240 mm;
- injection under pressure (from 0.4 to 0.8 MPa) with the use of special equipment (injector, hand pumps or pneumatic concrete placers, working from the compressor, etc.). This method is recommended to be used for the injection waterproofing structures with a thickness of 240 mm or more.

The change in the physical and mechanical properties of insulated construction structures (hardening, increasing the waterproofness of the material of the insulated construction structure, etc.) with the Kiesol waterproofing primer is due to the on-going and time-consuming insulating structure of the silicification process. As a result of this, a purposeful, irreversible and durable improvement of the physical and mechanical properties of the material of the insulated structure by curing inorganic polymers contained in the Kiesol waterproofing primer and the formation of a highly porous substance (silica gel) in the capillary-porous system and microcracks of the insulated structure.



b_1 – no more than 600 mm and more; b_2 – 600 mm and more; c – from 10 to 30 mm;
d – from 10 to 30 mm.
1 – insulated construction structure;
2 – holes for injection of Kiesol waterproofing primer;
3 – additional waterproofing coat of a structure.

Figure 6. Diagram of the horizontal ground water cut-off and injection waterproofing using the materials by Remmers system:
a – in a wall with thickness to 600 mm;
b - in a wall with thickness 600 mm and more

The mechanism for implementing the technology of injection waterproofing or horizontal ground water cut-offs is of special interest. After all, with apparent simplicity, this technology has certain features, due to the rather complex physicochemical mechanisms of such materials operation. The hydraulic permeability of concrete and reinforced concrete structures is largely due to the presence in the insulated material network of pores and capillaries formed, for example, by involvement in concrete of air bubbles by the filler, evaporation of excess moisture and so forth. Therefore, in order to reduce the hydraulic permeability of concrete and, in fact, to form the waterproofing properties of the structure, the formed pores and capillaries must be filled with a material compatible with concrete and solutions from the physical and chemical point of view. It should be considered that in the case of the Kiesol waterproofing primer, the waterproofing properties of the construction are formed as a result of successive reactions continuing in time and the presence of moisture and air occurring inside the structure of the treated concrete (pores and capillaries) between its constituents and components contained in waterproofing material. As a result of such reactions, poorly soluble compounds are formed, displacing water and overlapping pores and capillaries. Penetration of the chemically active part of the waterproofing material inside the structure is due to the action of capillary suction and osmotic diffusion [9]. Moreover, for the creation of an injection waterproofing or horizontal ground water cut-off, the following basic conditions must be met:

- presence in the volume of the insulated structure of the difference factor in the concentrations of the dissolved substance and the solvent (water);
- presence or occurrence in the scope of an insulated structure of semipermeable membranes.

As a result of the injection of Kiesol waterproofing primer inside the insulated structure, one of the above conditions is implemented: the difference between the concentrations of the dissolved reactive substance is artificially created in the volume of the structure. The next condition is the presence of a semipermeable membrane, which should be considered as concrete of an insulated structure, which is a capillary-porous framework capable to pass molecules of different sizes, resulting in the separation of the initial mortar into separate mortars with different concentrations of the active chemical part according to the molecular-sieve effect and deep penetration of the mortar into the construction of the insulated structure. In this case, the value of the concentration of the dissolved reactive substance at the entrance to the capillary is maximal, and it tends to zero at the end of the capillary. In the long run, as a result of deep penetration processes, the process of equalization of the concentrations at the inlet and outlet of the capillary is observed and the equilibrium of the system is established.

In view of the foregoing, it becomes evident that the possibility of implementing the technology of an injection waterproofing or a horizontal ground water cut-off is determined by the openness of the capillary-porous structure of an insulating structure material that facilitates the penetration of a chemically active part of the material to the maximum distance in depth. In addition, it is necessary to ensure proper care for the treated structure: for example, reducing the moisture level

of the insulated structure will help to suspend the formation of silica gel, which fills the capillaries and pores. On the other hand, overmoistening of the structure above the required level will facilitate the internal migration of water and the erosion of the chemically active part of the Kiesol waterproofing primer and reduce its effectiveness.

Conclusion

The conducted research allowed developing effective and economically expedient technical and technological solutions of the waterproofing for concrete and reinforced concrete buried constructions and structures [10]. The proposed set of measures provides the necessary stability of structures and preservation of their design parameters (strength, waterproofness, etc.) during the structure life. Such properties of the structure are ensured by the use of not separate types of waterproofing materials, but of various systems, including a complex of materials and technological solutions complementary to each other, creating an effective waterproofing system together. At the same time, it was considered that currently the market for waterproofing is characterized by a priority orientation towards the use of environmental mineral-based waterborne materials, having the same physical properties and high adhesion for different surface conditions of the insulated structure.

The main technical and technological prerequisites, development directions and creation of high-quality waterproofing of underground and buried constructions are established, including:

- The surface of the insulated structure must be prepared (be durable, defect-free, smooth, etc.). At that, all necessary structural components and elements must be installed before the construction of the waterproofing coating and (or) waterproofing. Expansion joints of the structure must be made using parts and elements that do not violate the integrity of the waterproofing. In the case of repair work, it is necessary to foresee a number of auxiliary operations, for example, elimination of active leaks, joints sealing, etc.;
- strict adherence to design technical solutions and technological sequence of work performance when installing a waterproofing coating and (or) waterproofing. Any changes in technical, constructive and technological solutions must be coordinated with the design organization and the waterproofing works provider, and approved in the established order;
- waterproofing coating and (or) waterproofing must ensure the protection of the entire structure without exception. At the same time, work on the installation of waterproofing must be performed by the same work provider;
- work on the installation of waterproofing is recommended to be mechanized as much as possible, but one should consider the possible decrease in adhesion of each subsequent layer towards the previous one (as part of a multi-layer waterproofing coat), in some cases, the reduction may reach 20%;
- after the work completion on the installation of waterproofing coat and (or) waterproofing, for the treated structure the relevant care must be provided. It is not allowed to produce any construction and installation work and move the building materials on the surface of the finished waterproofing coating.

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