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CHAPTER 3

MODERN TECHNOLOGIES OF REPAIR AND RESTORATION WORKS OF BUILDINGS IN USE

ABSTRACT

Rational use of resources requires a new approach to many management issues.

Renewal of residential and industrial production potential based on the reconstruction and technical conversion of buildings using new technologies is the shortest way to increase the quality level and competitiveness of domestic products, the integration of the economy of Ukraine into the European and World Community, to the successful functioning of production entities in market conditions. Carrying out repair and restoration works of buildings within the specified time depends to a large extent on providing them with a sufficient amount of technical resources in a timely manner, the need for which is determined not only by the volume of work, but also by the conditions of operation. Being a specific type of construction production, repair and restoration works are performed in more difficult conditions, which significantly affect the efficiency of construction machines and equipment and the quantitative composition of the used resources.

The production conditions of repair and restoration work do not always allow the use of typical machines, known technological schemes of work performance. For repair and restoration work in the conditions of an operating enterprise in hard-to-reach places, it is necessary to have fundamentally new schemes and appropriate equipment adapted for work in hard-to-reach places, and structures with a complex configuration at height. The use of a typical set of mechanisms reduces the efficiency of their use, reduces productivity, increasing the duration of the repair cycle and the consumption of materials.

The existing methods of determining construction needs in equipment do not allow to properly take into account the production conditions inherent in repair and restoration works, to assess their impact on the efficiency of use.

This leads to an underestimation of resource needs, which negatively affects the work of construction organizations and the quality of work.

During repair and restoration works, the issues of heterogeneity, dispersion and small volume of the performed works become more relevant. Execution of a complex of works uncharacteristic for new construction: replacement or restoration of individual structural elements, replacement of anti-corrosion coatings on individual areas, etc. All work is performed in difficult conditions, which

often significantly affects the general scheme of organization and technology of work. Increasing the efficiency of repair and restoration works depends on the level of automation.

The conditions of repair and restoration work in hard-to-reach places are reflected in the principles of the technology of automated processes, taking into account the factors of compactness, limited space, difficult access, various configurations, etc. The most time-consuming processes are: preparation of surfaces, cleaning and application of anti-corrosion coatings. Therefore, the question of choosing rational options for automating these works determines the level of exploitation. All this requires the development of more advanced mechanisms of automated systems.

The process of repair and restoration works is complicated due to the greater variety of volume-planning and constructive solutions. Therefore, a difficult and important problem is the industrialization and improvement of the quality of the coating in the conditions of the objects that are operated.

KEYWORDS

Rational use of resources, reconstruction and technical re-equipment, industrial production potential, repair and restoration works, automation, pneumatic spraying technology, equipment for coating application.

The consequence of the above-mentioned main features is that in construction organizations that perform mainly repair and restoration work, the costs associated with the organization and elimination of workplaces increase by 1.5 times, and the costs of operation increase by 1.5–3 times compared to with new construction, the specific cost increases by 1.2–1.4 times. Most of the aspects and ways of solving the issues of coating are reflected in the works of scientists of the Research, Design and Technological Institute of Concrete and Reinforced Concrete, Research Institute of Construction Economics, Central Research Institute of Industrial Buildings, Kharkiv Industrial Buildings Research Institute Project, Kharkiv Agricultural Research and Development Project, HEI of the State Research Institute of Building Constructions, State Research Institute of Building Constructions of the City of Kyiv, etc.

Analysis of the modern level of technology for performing processes on a vertical surface makes it possible to identify the main directions of their improvement and to formulate the goal and objectives of the research.

The aim of the research is to improve the technology and develop equipment for applying coatings on a vertical surface by the method of pneumatic spraying using automated systems.

To achieve the aim in the work, a number of tasks are set:

1. Systematize and classify the technological schemes of applying protective coatings of building structures, as well as to evaluate the possibility of using them for applying coatings in hard-to-reach places.

2. Establish rational technological parameters for applying coatings, taking into account operating conditions.

3. Develop a device for applying protective coatings with adjustable technological parameters and modes.

4. Investigate the work cycle of technological operations and the quality of coating applied using the developed device.

5. Prepare recommendations for the implementation of research and experimental works on applying coatings to a vertical surface; perform research and experimental work on applying a protective coating in the cramped conditions of an existing building.

6. Develop a methodology for selection and comprehensive assessment of the effectiveness of coatings when applied to a vertical surface.

The following research methods and apparatus were used to solve the problems: logical, morphological, classification, typification, mathematical statistics and probability theory, correlation-regression analysis, systematization and generalization of experience.

The scientific novelty of the obtained results is:

– in determining the dependence of effective application of anti-corrosion coatings on technological parameters;

– in determining the dependence of the physical and mechanical properties of anti-corrosion coatings on technological parameters;

– in the substantiation of the automated device for applying protective anti-corrosion coatings and removable nozzles to it for performing work in hard-to-reach places;

– in determining the impact of technological processes on the service life of the anti-corrosion coating.

The validity and reliability of the obtained scientific results, conclusions and recommendations is confirmed by: analysis and generalization of a significant number of works on the technology of construction production and the creation of mathematical models and methods of their management; adequacy of mathematical models used in scientific research due to their correct formulation; positive results of the comparison of theoretical and experimental research data; implementation of work results in production and educational developments.

The practical significance of the obtained results lies in the determination of specific technological parameters and modes of cleaning, facing and applying a film coating on a vertical surface; the means and methods of applying a film coating, technological schemes for performing works in cramped conditions have been developed; automated devices for applying film coatings with the necessary technological parameters were made; rational technological parameters of applying film coatings on various forms and configurations of structural elements are scientifically substantiated.

3.1 ANALYSIS OF THE TECHNICAL AND ECONOMIC NATURE OF THE PROBLEM

The types of surface contamination, methods of preparing the surface of the structure, applying a primer to the surface, and methods of applying film coatings (**Fig. 3.1–3.3**) [1, 2] were studied.

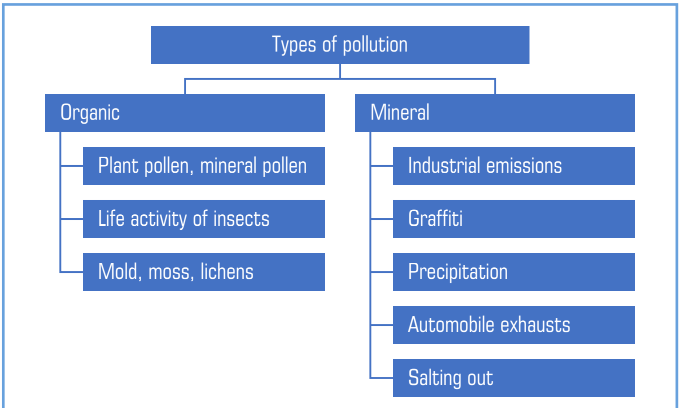


Fig. 3.1 Classification of contamination types of vertical surfaces

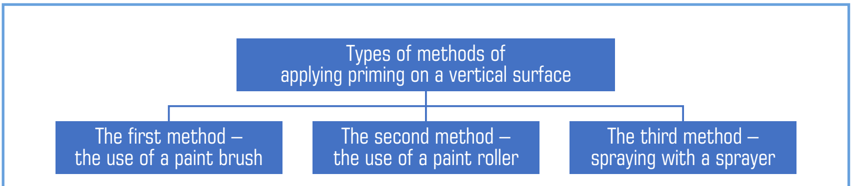


Fig. 3.2 Classification of priming application methods

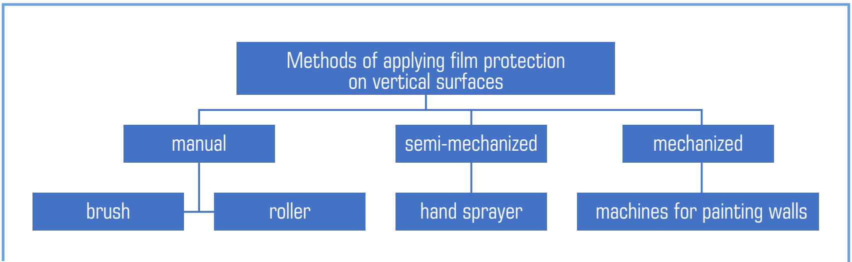


Fig. 3.3 Classification of methods of applying paint to a vertical surface

The development of issues of theory and practice of methods of applying film coatings is given in the works of a number of domestic and foreign scientists. In these works, the issue of applying coatings, their crack resistance, the technology of manufacturing paint and varnish materials, their main physico-chemical and mechanical properties, as well as the peculiarities of the properties of coatings, including reliability in aggressive environments, the use of various surface-active additives to improve the quality and durability of coatings, etc.

Paints and varnishes can be classified by appearance, composition and purpose (**Fig. 3.4**).

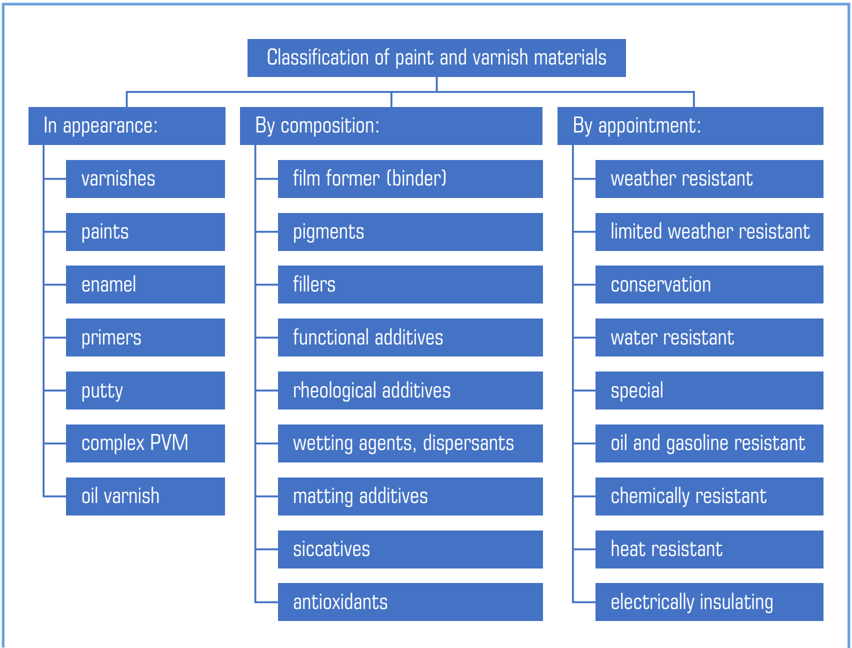


Fig. 3.4 Classification of paint and varnish materials

According to the composition, paint and varnish materials are divided into (**Fig. 3.5**):

– oil varnish – used for preparing oil-based and diluting thick-ground paints, oil-resin varnishes, primers, putties. They are also used for priming and oiling wood and other porous surfaces before painting. Drying in air, oils form soft elastic films with low protective and mechanical properties;

– primers – materials that are suspensions of pigments, as a rule, anti-corrosion pigments (or pigments with fillers) in film-forming substances and a homogeneous opaque film formed after drying, which must reliably protect the surface to be painted (metal – from corrosion, wood – from decay); reliable adhesion of this film both to the surface to be painted and to the materials that are applied on top of the soil layer (filling the pores of the wood) of the plaster, ensuring the water and air tightness of the coating. Primers are applied directly to the surface of products prepared for painting, and after hardening, putty or enamel is applied to the soil layer;

– putty – materials that are a viscous pasty mass consisting of a mixture of pigments with fillers in a film-forming substance. Intended for filling irregularities and depressions, grooves, pot-holes, seams, joints, i.e., smoothing the surface of products to be painted. Putties consist of film formers, fillers, cheap, often natural pigments, and a small amount of solvents. Putty is usually applied to a previously primed surface with a layer up to 300 microns thick. Before applying the next layers of paint, the putty layer is subjected to dry or wet sanding. Alkyd, nitrocellulose, epoxy and other putties are used in everyday life;

– paints – suspensions of pigments or their mixtures with fillers in a film-forming substance (for example, oils, oils, emulsions, casein, latex), which, after drying, form an opaque painted homogeneous film. Oil paints are produced ready-to-use and thickly rubbed, which are diluted with oil before use. In addition, oil paints include zinc, titanium and lithopone whites;

– enamels – suspensions of pigments or their mixtures with fillers in synthetic resins or other high-molecular compounds dissolved in an organic solvent, which form a solid opaque film with a different texture after drying. Depending on the type of film former, alkyd (glyphthalic and pentaphthalic) enamels, nitrocellulose, organosilicon, urea- and melamino-formaldehyde and other enamels are produced. Enamels obtained by mixing and rubbing pigments with oil, and then diluted with varnish, are called oil enamels. In terms of physico-mechanical and protective properties, enamels are superior to oil paints;

– varnish – a solution of film-forming substances in organic solvents or in water, which forms a solid, transparent homogeneous film after drying;

– complex PVM – coating consisting of several PVM layers, arranged in the following order: primer, putty, enamel, varnish – if necessary.

Paint and varnish materials are divided into two large groups: water-based compositions and compositions containing volatile organic solvents. The solid opaque film formed during the PVM hardening applied to the surface of the product performs protective and decorative functions. Simply put, it should hide the surface under it and protect it from possible mechanical influences, as well as provide the necessary level of visual comfort. These PVM characteristics are provided by its formulation, i.e., the properties of the components that make up the PVM and their ratio in the formulation:

– film-forming agent (binder) – the main component of any PVM, a substance that, after hardening in one way or another, is able to form a fairly hard film on the surface to be painted and adheres well to it. The convenience of LFM, the speed of hardening (drying), the strength and durability of the coating largely depends on the properties of the binders;

– pigments – highly dispersed inorganic or organic substances, insoluble in film-formers and capable of forming protective, decorative or decorative-protective coatings with them. Pigments give PVM color, coverage (opacity), increase hardness, weather resistance of the coating, improve protective, decorative and other properties;

– fillers – white or slightly colored highly dispersed inorganic or organic substances, which have a lower light distortion index than pigments. They do not have protective and decorative properties, but they can partially replace expensive pigments and improve the properties of PVM and coatings based on them. Fillers often perform specific functions (for example, increase the viscosity of paints, reinforce the coating, preventing the formation of flows on vertical and inclined surfaces, reduce the gloss of the coating);

– functional additives – components of the PVM formulation, which are usually introduced in small quantities (usually no more than 1–2 %) and give the PVM and the coating based on it special properties.

Oil varnish

Primer

Putty

Paint

Enamel

Varnish

Fig. 3.5 Examples of types of materials

Example:

– rheological additives – prevent the settling of the pigment part and the PVM delamination under the influence of gravity during PVM storage, and also give PVM the property of thixotropy – the ability not to form flows;

– wetting agents, dispersants – substances that provide effective dispersion of pigments and fillers in the film-forming solution;

– matting additives – substances that reduce the degree of PVM gloss;

– desiccants – substances that ensure the PVM drying, a film-former, which hardens due to the reaction of oxidation by air oxygen;

– antioxidants – substances that prevent the formation of oxide films on the PVM surface during their manufacture and storage.

For water-dispersion (WD) PVMs, it is possible to say:

– emulsifiers – substances that ensure the stability of the WD-paint emulsion;

– antifreezes – substances that prevent the freezing of water-dispersed PVMs at low temperatures and ensure the recovery of PVM properties after several freeze-thaw cycles;

– fungicidal additives – substances that are part of PVM and provide protection of painted wood from mold fungi and insects;

– antiseptics – substances that are part of water-dispersible PVMs and prevent their destruction during production and storage in containers under the influence of bacteria and microorganisms;

– solvents – liquid components of the PVM formulation that provide the necessary viscosity and fluidity.

As the theoretical and practical research shows, it covers a large number of technological parameters of the process. In a number of works, trends towards the analysis of characteristics, properties and dependencies, such as strength, viscosity of the material, distance to the applied surface, angle of inclination of the nozzle, speed of the supplied jet, etc., can be clearly traced. However, these works did not allow to combine the properties of the materials and the technology of the works.

In the works, too little attention is paid to increasing the effectiveness of anti-corrosion coatings, to the development of advanced technology for performing work in the compressed conditions of buildings in use.

An analysis of various types of anti-corrosion materials was performed, one of which is protective paint coatings. Their field of application is application to the vertical surface of structural elements of buildings during repair and restoration works and new construction. The conditions for the formation of protective coatings are considered.

Based on literature data and field data, an analysis of the influence of technological factors on the service life of film coatings was performed.

To increase the service life and reduce the loss of material, it is necessary to develop the design of the device with special nozzles for applying film coatings, the concept of the methodology of comprehensive evaluation of the effectiveness of film coatings taking into account technological factors.

Practice suggested the use of a wide range of materials in the process of performing works. In particular, to increase the strength and thickness of the film coating, it is necessary to take into account such factors as the viscosity of the material and the fineness of grinding with or without pigment. Changing these factors or replacing them caused an increase in material loss and, in some cases, a decrease in strength. The influence of these factors has not yet been fully studied for the conditions of applying film coatings during repair work on a vertical surface.

During repair and restoration works, existing stationary devices are used for applying a coating of paint and varnish materials. However, due to high productivity, their use is inefficient.

The experience of operating the existing equipment has shown that high-quality coatings are obtained only if a whole series of restrictions related to the use of special equipment, nozzles of a special design, the composition of raw materials, the mode of application, the qualifications of workers, etc., are met.

According to most authors, the strength properties of film coatings are mainly influenced by such technological factors as the distance from the nozzle to the protected surface, the angle of inclination of the material supply, the speed of the jet exiting the nozzle.

However, the numerical values of the above factors have significant limits and are set with a number of restrictions. This is explained by the fact that the research was carried out on different equipment and different materials were used.

The condition of the surface is considered one of the main factors that affect the strength of the film coating.

All methods of surface treatment are aimed at obtaining a clean surface for coating. Based on the study of the influence of technological factors, the authors came to the conclusion that in the process of operation, these factors affect the life of the protective (film) coating. The **Table 3.1** presents the types of preparation of vertical surfaces of film coatings that affect the service life.

Table 3.1 Effect of preparation of the vertical surface on the service life of the film coating

No.	Type of preparation	Service life of paint coatings		
		Environment		
		Weak	Medium	Strong
1	Without preparation (application on old paint, scale)	3	2	up to 1 year
2	Manual rust removal	4	3	2
3	Mechanical rust removal	5–6	4	3
4	Fire rust removal	4–5	3–4	2–3
5	Digestion	6–8	5–6	4
6	Sandblasting	7–8	6–7	3–4

Analysis of the table shows that any type of surface preparation extends the service life of the coating by 2 or more times in a highly aggressive environment under other different conditions (the same coating, thickness, application methods, etc.).

The influence of the thickness and methods of application on the service life, the influence of the method of preparation of the surface of structures and the degree of aggressiveness of the environment on the service life of the coating have been established.

The analysis of literature data and data from the state survey of structures operated in an aggressive enviroЬlnment showed that the conditions for the formation of film coatings are influenced by technological factors (surface cleaning, priming and application methods), the theory and practice of which need to be improved and special equipment for applying coatings in building conditions needs to be developed. which is used during repair and restoration works [1–3].

3.2 THEORETICAL ASPECTS OF THE INFLUENCE OF TECHNOLOGICAL PARAMETERS OF FILM COATING PROCESSES ON IMPROVING THEIR QUALITY

Greater losses of material occur when protective coatings are applied to the surface of structures. This is due to a number of technological factors, such as the speed of material supply, the distance from the nozzle to the surface of the supplied mixture, the diameter of the outlet hole, pressure, viscosity of the material, fineness of grinding, spray angle and other factors.

Currently, there are the following methods of performing work on the restoration of vertical surfaces. **Table 3.2** provides types of methods for applying an anti-protective coating to a vertical surface.

For each individual case, a method that has sufficient technical and economic justification is used.

Table 3.2 Types of methods when applying an anti-protective coating to a vertical surface

The name of the method of work performance	Use of an economically justified method in case of damage to the facade			
	Local damage	Vertical damage	Horizontal damage	Damage over the entire area of the facade
From the car tower	+			
From the scaffolding		+	+	+
From a cradle		+		+
Industrial climbers	+	+	+	+
Robotic devices		+		+

Below let's consider the works that are performed during the preparatory period. Currently, the following methods of cleaning the vertical surface are used.

There are four main methods of cleaning a vertical surface in the world. Each of them has a field of application, a type of equipment, and a type of surface:

1. Wall washing using high-pressure equipment. This method is the simplest and widely used in practice. At the same time, the facade can be treated both with special cleaning agents and with ordinary water. The type of cleaning liquid is selected depending on the material of the walls and the type of contamination.

2. Cleaning with a steam generator. It is used to remove old, deeply ingrained dirt. The steam generator is often used after unsuccessful cleaning of walls with a high-pressure unit.

3. Processing of the facade with a sandblasting device. With it, dirt is removed with the help of abrasive particles fed under high pressure.

With a competent selection of the size and structure of the abrasive, sandblasting solves a wide range of tasks. For example, in this way, it is possible to remove thin layers of paint and remove deep pockets of metal corrosion.

4. Mechanical cleaning. Most often, it is a preliminary stage of facade repairs. Old plaster, paint, putty, etc. are removed mechanically. A hammer with a chisel, spatulas, an angle grinder, a perforator and a steel brush help to remove them [2, 4, 6].

Next, let's consider the methods of priming the surface vertically. In modern conditions, three methods of surface priming are known. Each of them has disadvantages and advantages, scope of application.

The first method is the use of a paint brush (Fig. 3.6).

Let's pour the necessary amount of primer into a clean plastic bucket, dip a squeegee into it and evenly treat the wall.

The advantage of this method is the low price of the tool, the possibility of applying a high-quality coating, since the bristles bring the product into all recesses. The disadvantage is that during processing, the liquid flows down the handle onto the hand, which is unpleasant. In addition, due to the small contact area of the brush with the surface, applying the primer takes a long time compared to other methods.

Fig. 3.6 Photo fragment of the method of applying the primer with a brush

The second method is the use of a paint roller (Fig. 3.7).

The roller is used in approximately the same way as a paint brush, i.e. it is dipped in a special paint trough, pressed a little against the edge, and then rolled along the wall.

Fig. 3.7 Photo fragment of the method of applying the primer with a roller

The use of the roller is characterized by simplicity and high productivity. Among the disadvantages, the primer applied with a roller does not fill the relief of the surface as intensively as a paint brush. But if you put the roller on the bar, then applying the mixture becomes much faster and better than if you had to work with a paint brush.

The third method is spraying with a sprayer.

If there is to be work on a large surface, it is better to use a spray gun.

Applying a primer with a pneumatic gun has a number of advantages over manual application:

– automated priming is carried out quickly and evenly;

– the appearance of dry spots on the surface is minimized;

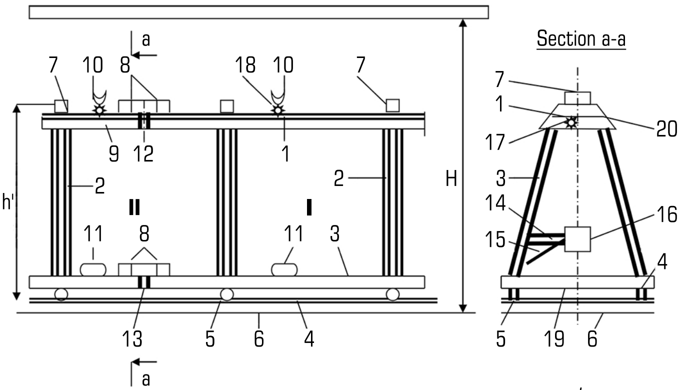
– mixture costs are reduced due to saturation of the solution with air;

– long service life.

The disadvantages include the difficulty of adjusting the distance from the surface to the nozzle. It is possible to overspend the material during windy weather.

When performing work on a vertical ceiling, it is necessary to develop a device with the help of which the work will be performed qualitatively and without human casualties.

For work at height, the authors developed the device "Portal" [7]. It includes two blocks. At the same time, the first block is the main one, which ensures autonomous operation; the second block is a semi-block that can be extended to the first block and cannot work autonomously. There can be several similar semi-blocks depending on the length of the object (**Fig. 3.8**).



a *b*

1 – portal;
2 – rack;
3 – connecting shelf;
4 – rail;
5 – wheel;
6 – sleepers;
7 – jacks;
8 – connecting bar;
9 – semi-portal;
10 – adjustable graduated element of verticality of drilling a well or sinking a pile;
11 – grips for holding an auger or a pile during their build-up;
12 – hinged connection of a portal;
13 – hinged connection of a connecting bar;
14 – console;
15 – brace;
16 – screw clamp;
17 – winch;
18 – trolleys;
19 – lower reinforcing shelf of the anchor element;
20 – upper reinforcing shelf of the anchor element

Fig. 3.8 The device for performing works on strengthening the foundations of soils and foundations and performing pile foundations for strengthening slopes

"Portal" is an autonomous frame and a half-frame, including a longitudinal span (portal) – 1; racks – 2, which are installed with an inclination relative to the vertical to ensure a more stable condition, forming an anchor element; connecting shelf – 3, which ensures a rigid connection of two oppositely located end anchor elements, and the anchor elements themselves have reinforcing shelves, respectively, the lower one – 4; upper – 5; semi-portal – 6.

For free movement around the work site, "Portal" has wheels – 7 in the form of hinged connections and rails – 8, which are laid along the road near the building or on the parapet (depending on the height). To reduce the load, rails can be laid on sleepers – 9.

In the upper part of the "Portal" at specially defined points, plates are rigidly welded, on which portable screw jacks are installed – 10. Joint operation of the main block and half-block is ensured by a hinged connection – 11, 12 with the help of connecting bars – 13.

The "Portal" is equipped with a movable guide graduated element in the form of a toothed hemisphere – 14, on trolleys – 15, on which both the first block and the second block can be equipped with devices for intensifying the injection of the liquid mixture.

In connection with the works that can be performed at different heights, the portal is made in the form of various structural elements that are built up.

Holding on the weight of the device for intensifying the injection of the liquid mixture is carried out with the help of grippers – 16 with a clamp – 17, which are attached to the console – 18 with a brace –19.

Rigging works are carried out with the help of a winch – 20, with stops, which include a ratchet wheel – 21, a shaft – 22, a dog – 23, an axis – 24, a spring – 25, different types of grips, etc. These devices do not prevent the lifting of the load, but exclude the possibility of its involuntary descent under the influence of its own weight.

For the manufacture of structures, steel alloys are used in accordance with the current standards for specific elements, depending on the operating conditions.

The "Portal" works as follows. For work in cramped, space-constrained conditions, the intensifier is used to inject a flowable mixture.

When applying the mixture to a vertical surface, the device is attached to the portal. The upper part of the portal frame is equipped with fasteners that allow the nozzle to move from top to bottom without changing its path.

This "Portal" has an advantage over the known ones in that:

– it increases labour productivity and complex mechanisation of production processes, reduces capital expenditures, which makes it possible to increase the operational suitability of buildings and structures;

– the structural elements of the main load-bearing device "Portal" are made of a mass that ensures the installation of elements manually, without mechanisms;

– during the transition to another car park, the entire complex of the mechanisation device does not require dismantling and installation during operation, due to the possibility of moving the entire assembly along rails, or by additional extension of semi-blocks;

– the hinged joint of the block and the half-block allows to perform work at the break;

– the connection of the block and the half-block ensures that work can be performed simultaneously on several clamps;

– due to the possibility of hitching equipment, simultaneous surface cleaning, priming and application of the mixture is ensured;

– the ability to apply the mixture with an inclination;

– further development of the theory and practice of modern methods of carrying out work in cramped, space-limited conditions of buildings and structures in operation and their reconstruction is achieved.

The following is a device that can be used to perform work at height (**Fig. 3.9**, **3.10**). It is used for surface cleaning, underpinning and application of the mixture.

The dry mixture of the appropriate composition is supplied by the nozzle – 1, which has a hinged-layer – 3 or rigid connection with the hollow shaft – 7 and then to the body – 2, on which the forward auger – 4 and the reverse auger – 5 are freely mounted, which begin to rotate in different directions, and special spacers – 6 ensure their design position at the same time the hollow shaft – 7 rests on the plugs – 9, which are the boundary of the body – 2.

The dry mixture gradually moves to the wetting zone, where water is supplied through the holes – 8, which are located on a certain section of the shaft – 7. Then, under the influence of acceleration, the moistened mixture moves to the reverse auger – 5 and is fed to the corresponding part of the structure. In order to regulate the amount of the mixture supplied, the nozzle – 10 has a set of valves – 11 that can be replaced and, accordingly, increase or decrease the opening and the amount of the mixture supplied.

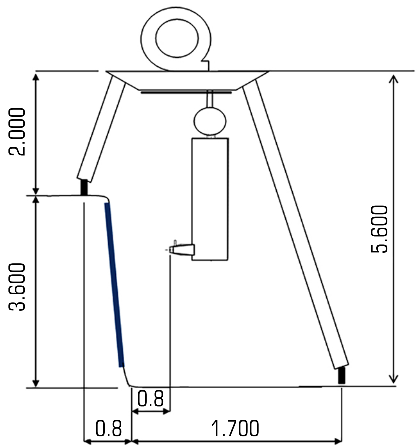
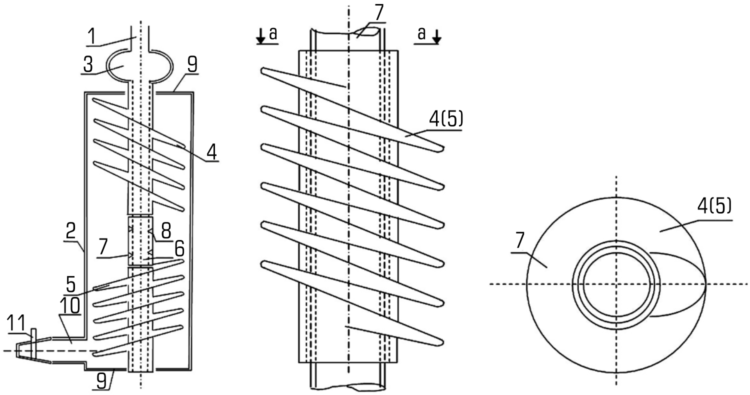


Fig. 3.9 General view of the device on a vertical surface



1 – mixture supply nozzle;
2 – body;
3 – hinge-layer connection;
4 – direct action auger;
5 – reverse action screw;
6 – spacer retainer;
7 – hollow shaft;
8 – through holes;
9 – plug;
10 – nozzle;
11 – latch

Fig. 3.10 Device for intensification of the liquid mixture injection

At the same time, to increase the feeding rate of the respective mixture, the nozzle – 10 is installed perpendicular to the axis of the hollow shaft – 7.

The specified technical characteristics ensure the use of the proposed technical solution in construction based on the following advantages:

– the quality of intensification of the spraying mixture increases;

– it becomes possible to regulate the quantity and, therefore, the speed of the supplied mixture by using one of the valves;

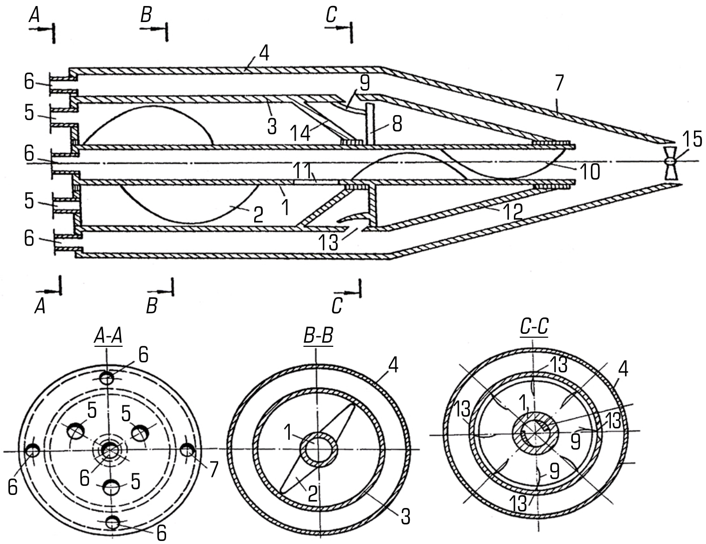
– operational suitability is increased, which ensures that such "Device..." meets the "Industrial suitability" criterion.

The set goal is achieved by the fact that the basis of the useful model "Device for the intensification of the injection of a fluid mixture" is a task in which, at the expense of the known technical solution "Device for the injection of a fluid mixture", replacing the purpose of some by means of structural changes and adding new elements and ensuring their interconnection connections during joint work, it became possible to create a corresponding "Device...", namely, a cylindrical body is limited by plugs in the centers of which a hinged or rigid hollow shaft is installed, on which the mixing elements are fixed, which rotate freely in different directions, and are equipped with spacer fasteners, so so-called direct and reverse action, creating conditionally active zones of activation and moistening, in a certain area in the moistening zone, the hollow shaft has through holes and is ball-hinged or rigidly connected to the mixture supply nozzle, and the nozzle in the form of a conical cross-section is installed perpendicular to axis of the hollow shaft and is provided by a complex of certain latches.

New in the development of the invention is the use of mixing elements that rotate freely in different directions at the same time, and the placement of the nozzle perpendicular to the axis of the hollow shaft.

Several types of nozzles (nozzles) were developed and manufactured for future research protected by patents and copyrights. The advantages of these nozzles are that the quality of the coating application increases due to the adjustment of the paint supply angle, the crushing of the mass of the mixture in the air flow, which leads to an increase in the durability of the coating, therefore, the period between repairs of buildings and structures increases.

Next view of device for spraying a liquid mixture [8]. Unlike known devices of the same purpose, in the proposed device additional mixing of the dry mixture by a turbulent mixer and additional mechanical activation of the mixture components takes place. (**Fig. 3.11**, **3.12**).



1 – hollow shaft;
2 – mixing elements;
3 – internal cylindrical body;
4 – external cylindrical body;
5 – connecting sources of the fluid mixture;
6 – connecting sources of compressed air;
7 – external nozzle;
8 – disc;
9 – curved blades;
10 – helical helix;
11 – bypass windows;
12 – internal nozzle;
13 – opening;
14 – partition as a truncated cone;
15 – latch

Fig. 3.11 Device (nozzle) for spraying the fluid mixture

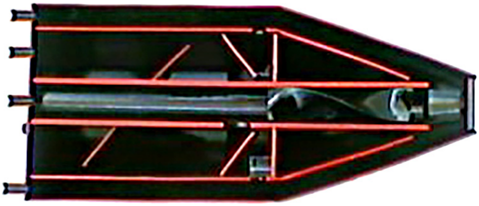


Fig. 3.12 Nozzle section

The device contains a hollow shaft with turbulent-type stirring elements on the outer surface and coaxially placed inner and outer cylindrical bodies on it. The latter are connected to the sources according to the fluid mixture and compressed air. On the outer surface of the hollow shaft is fixed a disk with curved blades in a circle. A helical spiral is made on the inner surface of the shaft.

In front of the disk in the direction of movement of the mixture on the opposite sides of the hollow shaft, bypass windows are made. The inner cylindrical body has a partition like a truncated cone. The smaller base of the latter faces the disk and is movably connected to the surface of the hollow shaft between the bypass windows and the disk. The surface of the inner cylindrical body above the curved disk blades has holes.

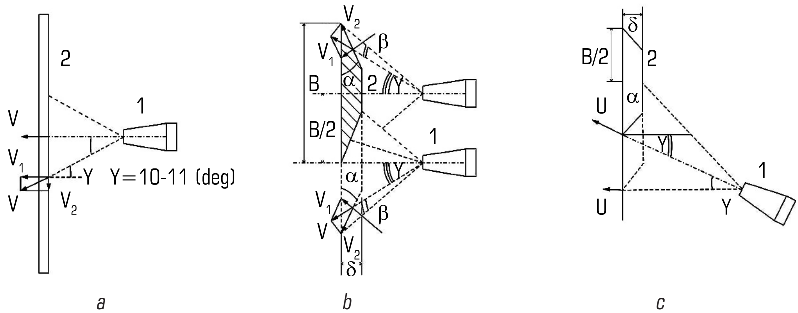
This design allows to adjust the amount of the mixture supplied, ensures high-quality mixing of the components, and additional mechanical activation of the components of the mixture reduces the energy consumption of the process and increases the quality of the coating.

The operation of the device is ensured in the following way. The components of the mixture enter the cavity of the inner cylindrical body and with the help of mixing elements made in the form of curved disks, the mixture is mixed. When compressed air is injected into the curved discs, the latter begin to rotate and involve the hollow shaft in rotation, where additional mixing of the mixture components and activation of the binder occurs with the help of a spiral. The mixture is accelerated and, moving, hits a vertical surface through the output device.

The proposed nozzle meets the technical conditions that ensure the reliability of adhesion, uniformity of thickness, the required thickness and minimal removal of the applied material beyond the surface.

A number of laboratory experiments were conducted to select the optimal parameters. Schemes of moving the nozzle along the vertical surface were chosen, the values of the factors were changed and their influence on the strength of the coating was determined.

The formation of the film coating due to the variation of the angle of inclination of the nozzle and the linearity of the movement of the jet torch was investigated. The performance of theoretical and experimental studies is valid for the formation of a film coating in height when considering several schemes of torch movement: perpendicular-straight-line, circular-perpendicular, inclined-straight-line (**Fig. 3.13**). The greater the opening angle of the jet torch, the greater the tangential velocity vector V_2, which contributes to the increase in the loss of peripheral particles in the rebound, the smaller the shock pulse and their penetration depth, the more uneven the formation of the film layer structure.



1 – nozzle; 2 – forming layer; γ – angle of incidence of the mixture parts; *V* – particle velocity vector; V_1 and V_2 – normal and tangential components of the vector; B, δ – strip width and height; α – angle of inclination of the strip slope; β – angle of the meeting of the part with the strip slope

Fig. 3.13 Schemes of the formation of a separate strip of the material layer: *a* – perpendicular-rectilinear; *b* – perpendicular-circular; *c* – inclined-rectilinear

By changing the nozzle design, it is possible to reduce the opening of the jet torch and improve the structure of the formed layer.

Research on the influence of the speed of application of the mixture depending on the distance to the vertical surface, the viscosity of the mixture, as well as the methods of preparation and application on the vertical surface are presented.

When the film mixture is applied to the surface, the speed of the jet exit changes. At the same time, the assessment of material losses in rebound was carried out. The data are presented in **Table 3.3** and **Fig. 3.14**.

Table 3.3 Dependence of the strength of the film coating and the amount of mixture loss on the speed of the jet exit

Indexes	**Jet exit speed, m/s**								
	70	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**160**
R_{bend}	38	28	18.4	11.4	7	5.7	7.8	14.3	–
R_{pr}, MPa	10.2	16	21.2	25.7	28.4	27.5	23.4	16.7	–
The amount of the film mixture losses, %	21.56	17.8	15	12.3	11.2	12.2	16.9	25.6	–

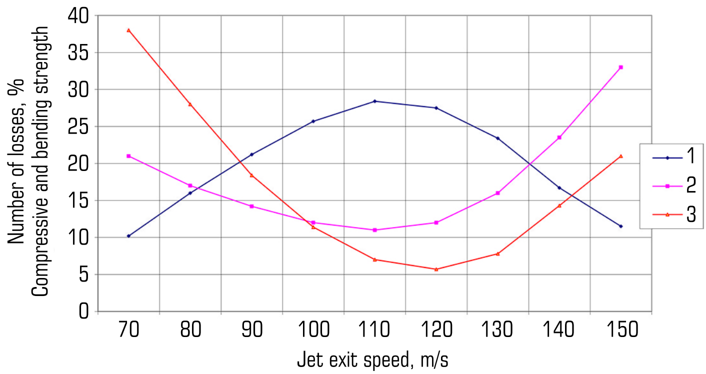


Fig. 3.14 Graphs of the coating strength dependence on the speed of feeding the film mixture and the amount of rebound

Summary graphs of the dependence of coating strength on the speed of feeding the film mixture and the amount of rebound were obtained. The graphs show the zones of change in the strength of the film coating depending on the speed of the mixture. In zone 1, with an increase in the feed rate of the mixture (from 70–100 m/s), the amount of rebound decreases, and the strength of the coating increases. At low values of the feed rate, the mixture on the surface is not compacted and almost all peripheral particles of the jet torch fall into the rebound. Zone 2 is the most favorable, because it increases the strength of the film coating to a maximum and the amount of rebound decreases to a minimum at a mixing speed of 110–140 m/s. In zone 3, at higher velocities (140–160 m/s) of the mixture supply, the force of the air jet does not compact, but rather loosens the previously compacted layer, pulling particles out of the layer, while the amount of rebound increases compared to the data obtained at lower jet velocities, therefore the strength of the coating decreases. In order to obtain optimal technological parameters when applying coatings in compressed conditions, equipment with devices for regulating the modes of supply and application of coating materials is required.

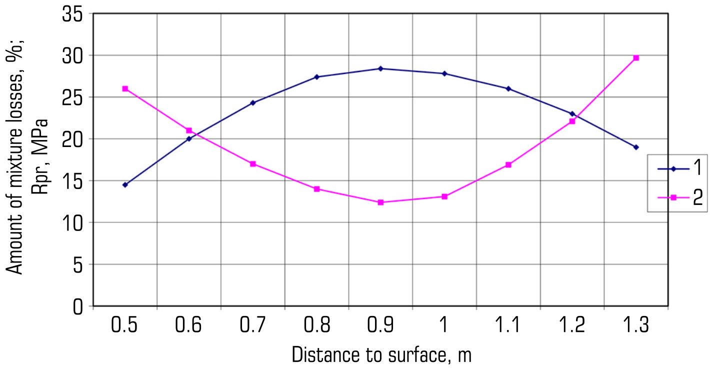
When determining the optimal values of the distance from the nozzle to the vertical surface being repaired, this parameter varied from 0.5 to 1.3 cm at fixed values of $v/c=0.4$ and the exit speed of the mixture from the nozzle of 110 m/sec. The data are presented in **Table 3.4**.

On the basis of **Table 3.4**, a graph of the dependence of the strength of the film coating and the amount of mass loss on the distance from the nozzle to the vertical surface is constructed (**Fig. 3.15**).

As can be seen from the data in **Table 3.2** and **Fig. 3.15**, the optimal distance from the nozzle to the vertical surface should be considered to be 0.8–1.1 cm. The limits of compressive strength may differ at different distances compared to the obtained strength characteristics at the optimal distance by 15–30 %. The minimum loss of the film mixture is obtained at the optimal distance from the nozzle to the vertical surface.

Table 3.4 Dependence of the film coating strength and the amount of mixture loss from the distance of the nozzle to the vertical surface

Parameters	The distance of the nozzle to the vertical surface, cm								
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**
R_{pr}, MPa	14.5	20.1	24.3	27.4	28.4	27.8	26.3	23.4	19.1
Amount of mixture losses, %	25.4	21.2	17.1	14.3	12.4	13.1	16.9	22.1	29.7



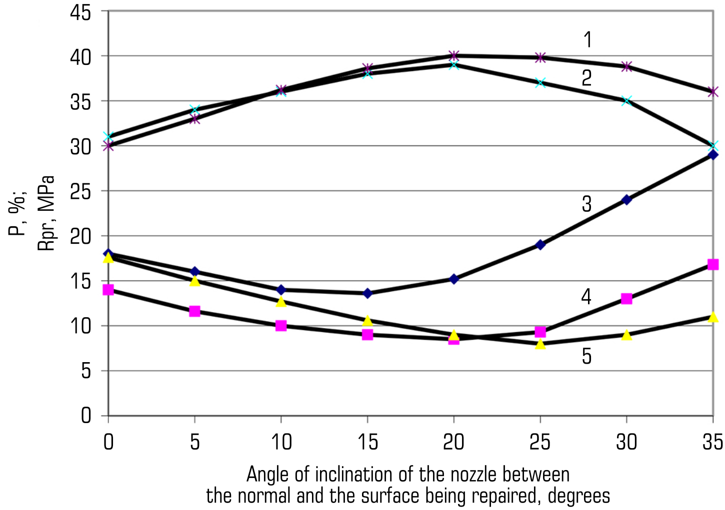
1 – compressive strength of the film coating; 2 – amount of losses of concrete mixture

Fig. 3.15 Graph of the dependence of the number of losses on the distance to the vertical surface

During laboratory tests, the following results were obtained: the distance from the nozzle to the vertical surface was from 0.8 to 1.2 cm, while the amount of rebound varies from 17.2 to 16.4 %.

According to the obtained results, a graph of the dependences of the strength of the mixture and the amount of losses on the angle of inclination of the nozzle to the surface was drawn (**Fig. 3.16**).

Analysis of **Fig. 3.16** shows that the strength of the mixture and the amount of losses depend on the angle of inclination of the nozzle and the thickness of the laid layer. With a mixture layer thickness of 50 μm and a slope angle of 150 to 250, the amount of losses reaches a minimum level of 8.5–9.5 %, and the strength limit is 37 to 39 MPa. In the engineering sense, this angle of inclination is optimal according to the criteria for assessing the strength of the mixture with the surface and the amount of mixture losses.



1, 2 – compressive strength limit, R_{pr}, MPa;
3, 4, 5 – number of losses, *P*, % (3 – thickness of the layer strip 30 μm, 1, 4 – thickness of the mixture layer strip 50 μm, 2, 5 – thickness of the layer strip 80 μm)

Fig. 3.16 Graph of the dependence of the mixture strength and the amount of losses on the angle of inclination of the nozzle to the vertical surface

Theoretical data are in good agreement with experimental data. Based on these data, mathematical models of strength dependence on the complex influence of factors were developed:

$$y=ax^3+bx^2+cx+d,$$

where x_i is the angle of inclination; $y_{i,j}$ are the functions of quantities (*i* – amount of rebound, varies from 1…*n*; *j* – film strength, varies from 1…*m*); *a*, *b*, *c* are the coefficients for the variable; *d* is free term that shows the position of the curves in the coordinate system.

The resulting mathematical models make it possible to determine and evaluate both the complex influence of all factors on the optimization parameters, as well as individual factors or their groups.

The coefficients of the obtained polynomials are partial derivative functions of the response on the corresponding variables. Their geometric meaning is the tangents of the angles of inclination to the x axis. A coefficient larger in absolute value corresponds to a larger angle of inclination, therefore, to a more significant change in the optimization parameter when this factor changes. In other words, the value of the regression coefficient is a quantitative measure of this phenomenon. The larger the coefficient, the stronger the effect of the factor. The "+" and "–" signs show the position of the curves in the ordinate system. At the same time, in each individual case, one separate factor was taken into account, and all others were taken with the most favorable (min) influence.

On the basis of the conducted research, the author proposed a number of nozzles protected by a patent and author's certificates, two samples were made of them according to two applications, and later these nozzle samples were used to solve a number of problems and researches.

3.3 DESIGNS OF THE DEVICE ON THE TECHNOLOGY OF APPLYING FILM COATINGS IN THE CONDITIONS OF BUILDINGS THAT ARE IN USE

The device is automated, which moves with the help of guides. To improve the device operation, a nozzle was designed and manufactured. Device tests were carried out with specially selected mixtures of materials that are often used to protect building structures from corrosion.

The device was carried out in several stages in order to determine the desired scheme.

The device works as follows. Before the start of work, the work sites, their volume, and the complexity of the surface relief are determined. Depending on the volume of work, in one parking lot, components of the supporting frame – 1 of the appropriate sizes are performed, corresponding vertical tray-type guides of the supporting frame – 4, horizontal tray-type guides – 5 of the supporting frame – 1. Next, rollers – 6 are installed, in vertical tray-type guides – 4 supporting frame – 1 with attachment of horizontal tray-type guides – 5, supporting frame – 1 between a pair of working frame – 2 respectively with vertical tray-type guides – 14 working frame – 2 and horizontal tray-type guides – 15 of working frame – 2, on which has a bed made in a special cut-out – 3 for installing a nozzle – 11. For the safety of work and to prevent falling out of movable elements, which are made with rollers – 6, the corresponding guides are made depending on the type of rolled metal tray (channel) or square profile – 17, 16.

In the first case, tapes – 17 are welded to the floor on both sides of the walls of the tray, and the distance between them should not be greater than the size of stable fasteners of the roller axis – 7, 8. In the other case – create a slot under the same conditions, that is, the width of the slot – 16 should not be larger than the size of the stable roller mounts – 7, 8.

At the final stage, a nozzle – 11 is installed, which is connected to the corresponding 15 containers (not shown), as well as speed controllers for the movement of the supporting frame – 1, that is, its vertical tray-type guides – 4 of the supporting frame – 1, and vertical and horizontal tray-type guides – 14, 15 of the working frame – 2.

The rollers 6 are fixed on the axis 8 using a rack 7, the axis 8 is limited on both sides by washers 9 and fixed by pins 12. Otherwise, a nut 10 is screwed onto the axis 8 on both sides.

Next, general preliminary fastening – 13 is provided.

A traverse and a cable (not shown) are hung to the supporting frame 1. On a certain section of the roof, a block with a hoist is installed, through which a cable is pulled, and a winch is placed on the ground. The assembled structure is lifted manually – 1, 2, 4, 5, 14, 15. On certain sections of the supporting frame 1 there are devices 13, which are used for final fastening with braces 21 to certain protrusions or other 25 details on the wall. The structure assembled in this way – 1, 2, 4, 5, 14, 15 is fixed on the traverse on one side, the cable is thrown through a block with a hoist, a winch (a block on the roof, a winch on the ground – we do not show it) and with braces 21 at the work site to wall 20 both from the top of the assembled structure and in the lower part – 1, 2, 4, 5, 14, 15.

Assembled together supporting frames 1 and working 2, which include vertical tray-type guides 4 of the supporting frame 1; horizontal tray-type guides 5 of the supporting frame 1; vertical tray-type guides 14 of the working frame 2, horizontal tray-type guides 15 of the working frame 2 are ready for device at the workplace.

Next, two workers – an operator and a climber, having previously installed a block with a hoist on the roof and a winch on the ground (not shown), after fixing the proposed device on the traverse with the help of a winch, lift it and with the help of braces 21 fasten it to the wall 20 by the protrusions on the wall. The device is ready for operation. Next, the climber in the cradle rises and begins to control the nozzle 11. After finishing on a certain part of the object, they move to another, removing the fasteners, lowering the device. On the new site, they ensure the device of the device in the same sequence as before. As usual, work on thermal insulation is performed from top to bottom.

If necessary, new chains 19 are added to the vertical tray-type guides 4 of the supporting frame 1 of a certain section and the work continues from top to bottom. In the process of work, special portable wedge-shaped stops 18 are additionally installed, which provide adjustment of the movement of the horizontal tray-type guides 5 of the supporting frame 1. **Fig. 3.17**, **3.18** presents the general diagram and view of the device.

CHAPTER 3

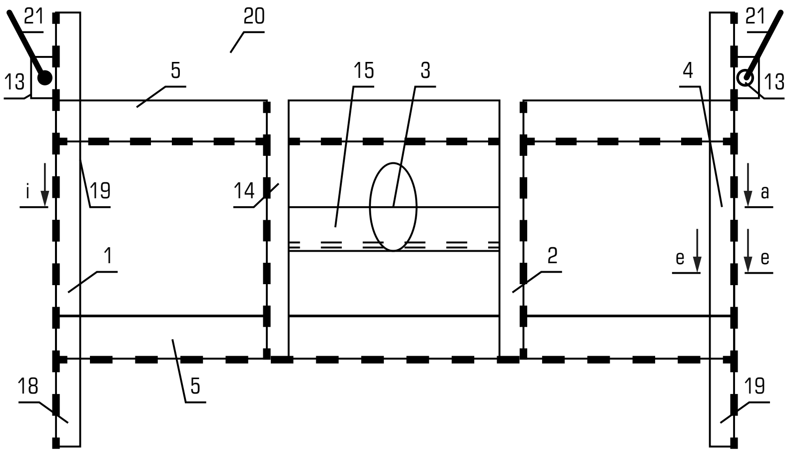
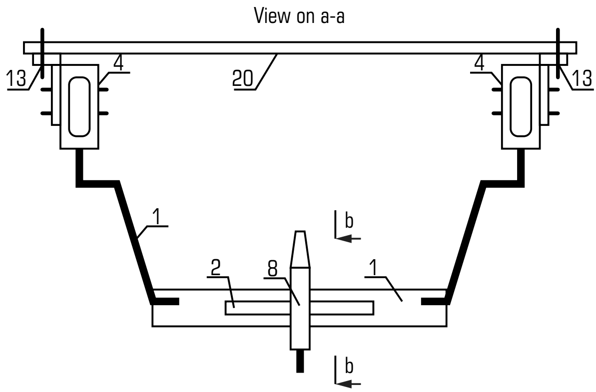


Fig. 3.17 General appearance of the device



1 – supporting frame;
2 – working frame;
3 – bed for attachment of the nozzle;
4 – vertical tray-type guides of the supporting frame;
5 – horizontal tray-type guides of the supporting frame;
6 – roller;
7 – support for fixing the roller axis;
8 – axis;
9 – washer;
10 – nut;
11 – nozzle;
12 – pin;
13 – fastening of the supporting frame to the insulated wall;
14 – vertical tray-type guides of the working frame;
15 – horizontal tray-type guides of the working frame;
16 – slot when using a square-type profile;
17 – tape when using a tray-type profile;
18 – portable wedge-shaped stop;
19 – possible places of chain extension;
20 – wall;
21 – brace

Fig. 3.18 Supporting frame, view from a-a

The device for performing film coating in front of the known has the following advantages:

– mobility, can be used in cramped conditions;

– provides mechanization of film coating application;

– transportable and easy to assemble;

– serves one climber and an assistant operator on the ground near the mortar mixers;

– it becomes possible to perform film coating more qualitatively;

– on one gripper, work can be performed from top to bottom by increasing the chains of vertical tray-type guides of the supporting frame;

– it becomes possible to perform film coating using remote control.

Setting up an experiment to study application of solutions

Experiment No. 1. The purpose of the experiments is to find the relationship between the working nozzle and the large-scale model of the nozzle for further calculation of the work performance of the large-scale model. And comparison of real results with analytical calculation (**Fig. 3.19, 3.20**).

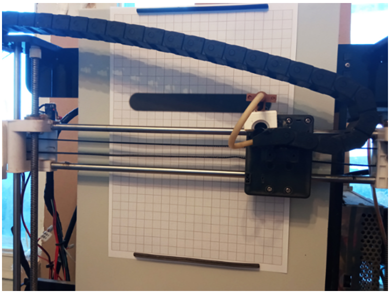


Fig. 3.19 General view of the proposed device

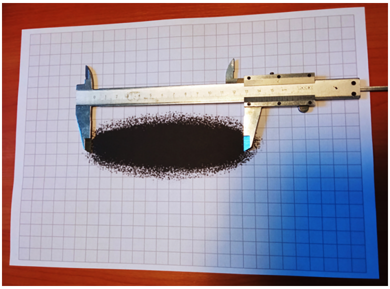


Fig. 3.20 Spot size

The purpose of the experiment: finding the dependence of paint consumption on the diameter of the torch of the working nozzle.

The technology of conducting the survey:

– device of the working nozzle on the fastening and connection of the compressor, supply of paint;
– fixing the paper on the screen;
– device at the maximum distance from the screen of a tripod with a nozzle;
– set working pressure 2 Bar;
– purging at minimum paint supply;
– regulation of paint supply;
– adjustment of the shape of the torch;

– search for optimal form and quality with replacement of paper;
– weighting of the target;
– after finding the optimal settings – setting the target on the screen;
– applying paint with a nozzle 1 s;
– weighting of the target;
– entering the results into the table;
– changing the distance between the nozzle and the screen, repeating the experiment.

The purpose of the experiment: finding the dependence of paint consumption on the diameter of the working nozzle torch.

Results of experiment No. 1. The results of experiment No. 1 are presented in **Table 3.5**.

Table 3.5 Results of experiment No. 1

No. of experiment	Torch diameter, cm	Paint consumption, g/min	Distance to the screen, cm
1	10	67	8
2	11	72	9
3	12	78	10
4	13	83	11
5	14	89	12
6	15	95	13
7	16	101	14
8	17	109	15
9	18	124	16
10	19	146	17
11	20	172	18
12	21	205	19
13	22	239	20
14	23	276	21

Let's build a graph of the dependence of paint consumption on the torch diameter (**Fig. 3.21**).

Let's build a graph of the dependence of the diameter of the torch on the distance from the nozzle to the screen (**Fig. 3.22**) and select the parameters for applying a film coating on a vertical surface (**Fig. 3.23**).

Based on the selected scheme, technical documentation and a prototype were developed, which were used for further research. Technological parameters of the device were determined, namely material consumption, spraying angle and productivity (**Table 3.6**).

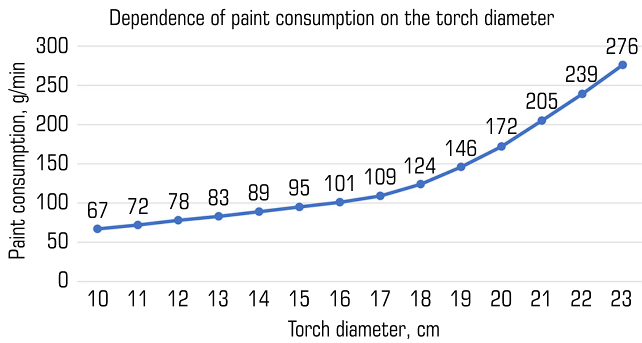


Fig. 3.21 Graph of dependence of costs of film coating on a vertical surface

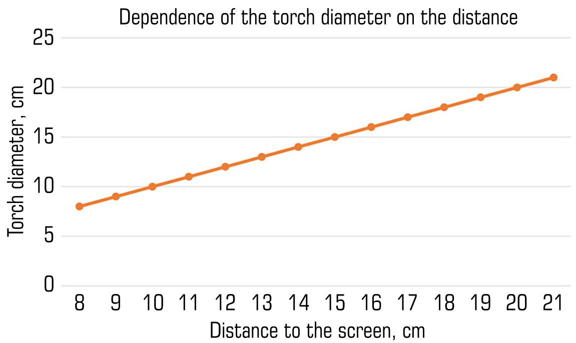


Fig. 3.22 Graph of the dependence of the torch diameter on the distance from the surface to the nozzle

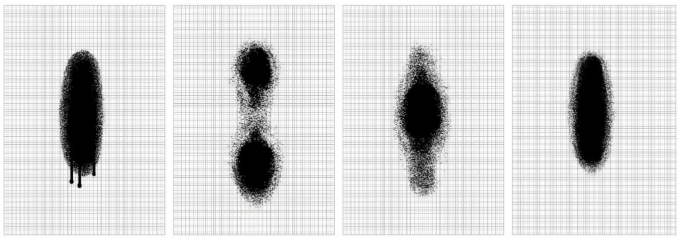


Fig. 3.23 Schemes for selecting parameters for applying a film coating on a vertical surface

Table 3.6 Technical characteristics of spray nozzles for paint and varnish materials

Spraying angle, degree, α	The length of the torch imprint, mm				Material consumption l/min depending on the outlet diameter, mm			
	For distance, cm							
	50	**75**	**100**	**125**	**0.35**	**0.4**	**0.45**	**0.5**
20	120	124	130	150	0.38	0.57	0.72	1.14
40	145	149	156	180	–	0.59	0.84	1.16
60	170	175	183	210	–	0.72	1.11	1.54
80	195	200	210	240	–	0.74	1.12	1.56

It was established that the consumption of material depends on such technical parameters as the diameter of the outlet hole, the viscosity of the given mixture, the degree of dispersion, temperature, pressure, and the spraying angle. The main technical characteristics of the material were determined by the raw material. Different variants of the film coating were considered depending on the viscosity of the raw material and the spraying angle. At the same time, the spraying angle varied from 20 to 80°.

Analysis of research results showed that:

– with the increase of the outlet opening, the consumption of the material increases by 2–3 times at the same viscosity;

– with changing the spray angle from 20 to 80°, the material consumption changes by 1.5 times at the same diameter of the outlet opening;

– with a change in viscosity (50–120 s), the consumption of the material changes by 1.2–1.5 times with adjustment of the diameter of the outlet hole.

Graphs of the dependence of material consumption on the diameter of the outlet hole (for medium-viscous materials) at different angles of inclination of the nozzle were obtained.

When applying a film coating, important technological factors are the spray angle and the length of the torch footprint.

By changing each of these values, the size of the spot was determined.

On the basis of the obtained data, graphs of the dependence of the length of the torch imprint on the height and angle of the torch spray were constructed.

Experiment No. 2. The purpose of the experiment: Finding the dependence of paint consumption on the diameter of the flame of a large-scale nozzle (**Fig. 3.24**).

The technology of conducting the survey:

– device of a large-scale nozzle on the fastening and connection of the compressor, supply of paint;

– fixing the paper on the screen;

– device at the maximum distance from the screen of a tripod with a nozzle;

– setting the working pressure 1 Bar;

– search for optimal pressure;

– search for optimal form and quality with replacement of paper;

– weighting of the target;
– after finding the optimal settings – setting the target on the screen;
– applying paint with a nozzle 1 s;
– weighting of the target;
– entering the results into the table;
– changing the distance between the nozzle and the screen, repeating the experiment.

The purpose of the experiment: finding the dependence of paint consumption on the diameter of the flame of a large-scale nozzle.

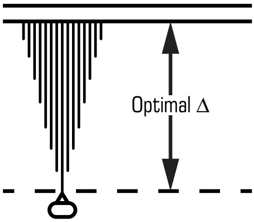


Fig. 3.24 Scheme of selecting the optimal distance from the vertical surface to the nozzle

Results of experiment No. 2. The results of experiment No. 2 are presented in **Table 3.7**.

Table 3.7 Results of the experiment No. 2

Experiment No.	Torch diameter, cm	Paint consumption, g/min	Distance to the screen, cm
1	1	6	1.2
2	1.2	7.5	1.4
3	1.4	9	1.6
4	1.6	11	1.8
5	1.8	12.5	2
6	2	14.5	2.2
7	2.2	16.5	2.4
8	2.4	19	2.6
9	2.6	21	2.8
10	2.8	23.5	3
11	3	26	3.2
12	3.2	28.5	3.4
13	3.4	32	3.6
14	3.6	36	3.8

Let's build a graph of the dependence of paint consumption on the torch diameter (**Fig. 3.25**).

Let's build a graph of the dependence of the torch diameter on the distance from the nozzle to the screen (**Fig. 3.26**). A fragment of film coating application is presented in **Fig. 3.27**.

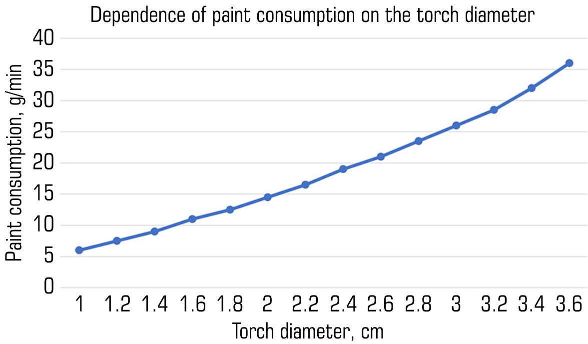


Fig. 3.25 Graph of dependence of the film coating on the torch diameter

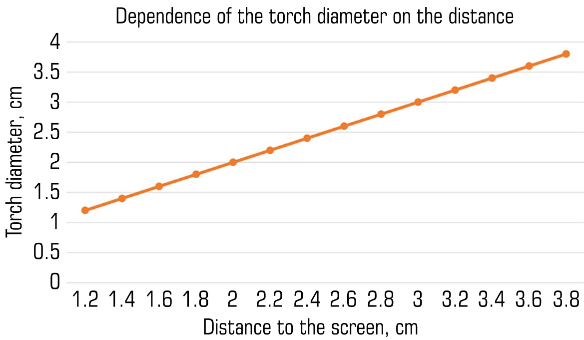


Fig. 3.26 Graph of the dependence of the torch on the distance

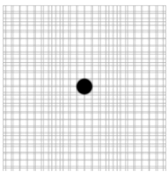


Fig. 3.27 Fragment of film coating application

3.4 METHODOLOGY OF COMPREHENSIVE ASSESSMENT OF THE ECONOMIC EFFICIENCY OF FILM COATING

On the basis of the analysis of technological factors that affect the protective coatings of construction structures in operation, a method of comprehensive evaluation of the economic efficiency of the film coating has been developed.

The methodology consists of two interrelated economic and mathematical problems:

– assessment of the comparative effectiveness of paint coatings;

– determining the optimal terms of operation of protective coatings.

The evaluation of comparative efficiency takes into account: production of paint coatings; selection of protective coatings at the design stage for use on specific objects.

The degree of economic significance of decisions made based on the results of technical and economic studies in the first and second cases is different. This also determines the difference in the requirements for the depth of the issue development, which in turn implies a different methodological approach in each case. Depending on the purpose of the technical and economic study, the following formulas are proposed by the authors for determining the total costs of production:

– when choosing directions for the development of the material and technical base for the production of paint and varnish coatings:

$$P_1 = P_k + P_m + P_{add} + P_e; \quad (3.1)$$

– when choosing a type of anti-corrosion coating for use in a specific object (on a construction site):

$$P_2 = P_k + P_m + P_{c.s.} + P_e + P_p, \quad (3.2)$$

where P_k, P_m, P_{add}, P_o, $P_{c.s.}$ – the corresponding part of the total costs of production, which depend on the costs of production of structures with paint coating at the factory (P_k); capital investments in the base (P_m); additional costs for applying a film coating after the device of structures and welding (P_{add}); operating costs (P_o); costs for equipment and coating on the construction site ($P_{c.s.}$); part of the costs that take into account the economic effect of early commissioning of the facility (P_p).

Capital and current repairs are carried out to maintain the operational qualities of industrial buildings. Expenses incurred during operation consist of expenses:

a) for replacement (restoration) of the protective coating;

b) for current and capital repairs.

The amount of costs for the restoration of coatings is determined by the formula:

$$P_e = \sum_{i=1}^{\gamma_{zk}-1} S_{es} / \left(1 + E_n\right) T_{z_i} = mC_{zk}, \quad (3.3)$$

where S_{ec} is the cost of replacing the old anti-corrosion coating, the service life of which has expired, with a new one, UAH.; T_z is the time from the start of operation to the *i*-th replacement of the old anti-corrosion coating with a new one, year; $(\gamma_{zk}-1)$ is the number of restorations of anti-corrosion coatings during the period of operation of the building; E_n is the standard for the reduction of various time costs, which is taken in the calculations as equal to 0.08, respectively.

The number of restorations of anti-corrosion coatings during the service life of the building is determined by the formula:

$$\left(\gamma_{zk}-1\right)=\left(T_c/T_{zk}-1\right), \tag{3.4}$$

where T_c is the period of building operation, the structures of which are protected against corrosion, year; T_{zk} is the period of operation of the anti-corrosion coating, year.

To determine the period of operation of the anti-corrosion coating (t_{cr}, t_{pr}) during the operation of the building, an analysis of the factors affecting it was performed.

The performed analysis of the factors allows to make a hypothetical schedule of the service life of anti-corrosion coatings depending on the degree of aggressiveness of the environment and the thickness of the coating.

As an example, graphs of capital investment, operating costs, and total production costs are given for a zinc-coated steel column operating in a mildly aggressive environment.

In order to ensure a minimized cost function for operating costs (overhaul and complete restoration), which are discrete in nature, are taken into account in the form of annual depreciation deductions.

Bringing the costs distributed according to the accepted scheme to a single point in time gives a quantitatively different result than with the real scheme.

The author proposes to base the calculations on a real scheme for the distribution of discrete and current costs.

For each type of structure (columns, trusses, beams, slabs, floors) the following graphs were compiled depending on the degree of aggressiveness of the environment (weak, medium, strong); from the type of coating (paint, metallization, combined). The dependence of the total costs of production on the terms of operation for three environments (medium, weak and strong) was obtained.

The analysis of the influence of technological factors on the service life of coatings made it possible to establish a single criterion – the economically optimal service life of anti-corrosion coatings, which is determined by minimizing the function of total production costs according to the formula:

$$y=ax^2+bx+c-\min. \tag{3.5}$$

The search for the moment of time when the total costs of production will have a minimum value – by the method of least squares, which consists in the fact that at the given points *x* and *y* obtained experimentally, let's find such values of *a*, *b* and *c* that approximate the given experimental curve.

Let's obtain a system of equations, after solving this system, let's obtain an expression:

$$x = \pm b/2a, \tag{3.6}$$

where *x* is the economically optimal service life of the anti-corrosion coating; *a*, *c* are the coefficients showing the position of the curve in the flat ordinate system; *c* is the distance from the *y* axis to the minimum *x* value.

Operating costs (P_e) associated with current (P_{pr}) and capital (P_{cr}) repairs are determined by the formulas:

$$P_e = P_{pr} + P_{cr}, \tag{3.7}$$

$$P_{pr} = \sum_{n=1}^{\gamma_{rp}-1} S_{pr} \Big/ \left(1 + E_{np}\right)^{t_{pr}}, \tag{3.8}$$

$$P_{Ar} = \sum_{\gamma=1}^{\gamma_{cp}-1} S_{cr} \Big/ \left(1 + E_{pr}\right)^{t_{cr}}, \tag{3.9}$$

where S_{pr} is the cost of one current repair, hryvnias/m^2 of the structure surface; S_{cr} is the same as capital repair, hryvnias/m^2 of the surface of the structure; t_{pr}, t_{cr} are the term of operation of the *i*-th anti-corrosion coating according to current and major repairs, year; (γ_{cr}–1) is the number of capital and current repairs for the entire period; (γ_{pr}–1) is the period of operation of the building (not including the last repair).

The number of capital and current repairs is determined by the formulas:

$$\left(\gamma_{cr} - 1\right) = \left(T_c / T_{cr} - 1\right), \tag{3.10}$$

$$\left(\gamma_{pr} - 1\right) = \left(T_c / T_{pr} - 1\right), \tag{3.11}$$

where T_{cr} is the periodicity of capital repairs for the entire period of operation of the building; T_{pr} is periodicity of current repairs during the life of the building; T_c is the term of house operation.

The developed economic-mathematical model for choosing the optimal variant of constructive solutions with protective coatings for the house as a whole, taking into account the initial cost and operating costs, is determined by the sum of the maximum total production costs.

The problem is solved with the help of electronic computing equipment.

CONCLUSIONS

The following scientific conclusions and results were obtained on the basis of the research carried out in the work:

1. It has been shown that the repair and restoration work of industrial enterprises is characterized by a high degree of difficulties, difficult conditions of performance of work, which significantly affect the composition of the equipment and the efficiency of its use. For successful work, contracting construction organizations must have in their arsenal an effective tool for assessing the technological features of work in hard-to-reach places of the existing enterprise.

2. Small-sized, transportable devices based on the technology of applying film coatings in confined conditions have been substantiated and developed.

3. The technological parameters of the device for applying the mixture to the vertical surface of the material flow, the diameter of the outlet opening, the angle of inclination, the length of the torch footprint, the productivity of the knapsack device – 0.25 m^3/h, the mobile device – 0.5 m^3/h have been determined.

4. Dependencies have been obtained that establish the relationship between the considered factors and parameters, which allows to reasonably determine the degree of efficiency in the use of resources when solving practical problems.

5. The regularities of the interaction of the considered technological factors have been established:

– with the increase of the outlet opening, the consumption of the material at the same viscosity increases by 2–3 times;

– with a change in the spraying angle from 20 to 800, the consumption of the material changes with the same hole diameter and the same viscosity;

– with a change in viscosity (50–120 s), the consumption of material changes by 1.2–1.5 times with adjustment of the diameter of the outlet hole;

– the length of the torch footprint is affected by the spray angle and the distance from the nozzle to the surface to be covered.

6. Based on the analysis of resource and time constraints, multifactorial models of technological processes of application of anti-corrosion coatings have been determined. The dependence of the film strength on the angle of inclination and the thickness of the coating layer was obtained, theoretical and experimental data were determined through direct measurement of the amount of rebound in the process of applying the coating on a vertical surface.

7. The theoretical foundations of the formation of the film coating have been developed. To increase the strength and thickness of the coating, a number of factors must be taken into account (such as the opening angle of the jet torch, the speed of the jet, etc.), changing one of them or replacing it causes increased losses, and in some cases, a decrease in strength. which affects the quality of film coatings, and ultimately, their service life.

8. Methods of comprehensive assessment of the economic efficiency of protective coatings have been proposed, taking into account technological factors and conditions of anti-corrosion works.

9. Approbation of film coating methods using the proposed device with a nozzle protected by a utility model patent in laboratory conditions has been carried out.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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