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TECHNOLOGY OF MANUFACTURING THE FORMWORK FOR ERECTING VAULTED COVERING OF ORTHODOX CHURCHE

Problem Statement. Religious buildings need to be restored as a result of years of anti-religious persecution in all post-Soviet states, including Ukraine. Repair and restoration for the main structural elements of Orthodox churches, such as foundations, walls, columns and arches, are not much different from the design and technological solutions for the other historic buildings. The vaulted coverings of Orthodox churches are of particular interest. First, it is established that the greatest percentage of destruction falls on the vaults (33 %) [1]. Secondly, the coverings of churches are shells with one or two curvatures, which have unique geometric dimensions. Thirdly, because the vaults are cover elements, the majority of the works are performed at height, which affects the main indicators for measuring performance of building construction. Therefore, there is a constant need to develop individual design solutions and construction recommendations. In addition, labor intensity and the duration of restoration work also sharply increase as a result of additional requirements for works on architectural monuments.

Analysis of publications. Despite many years of experience in carrying out repair and restoration works, it is advisable to follow domestic and foreign recommendations that are implemented at the sites of architectural heritage and have undergone scientific criticism. This is caused by redefinition of the goals and methods of restoration and improvement of building materials, mechanisms and methods of production.

A number of publications have been considered technological and organizational solutions renovation and restoration of Orthodox churches.

Such scientists as D. F. Goncharenko [2], V. N. Alekseenko [3] and others have dedicated their work to the technological and organizational aspects of the restoration of Orthodox churches.

Problems of interaction of modern and primary materials during the erection, operation and disassembling of architectural and structural elements were discussed in the works of L. Germandia [4] ets. The negative effect of the use of cement mortars for finishing works on primary constructions was established and confirmed.

The publication of G. Croci [5] was devoted to the technical state survey of the temple and the methods of performing restoration work with the use of modern composite materials.

Some scientists specialize in the development of design and technological solutions for the construction of domes with the possibility of their use in new construction, as well as in the restoration, reconstruction and restoration of buildings [6].

The propose of the article. The above materials give grounds to conclude that studies of the use of relevant building materials and technologies for the restoration of architectural monuments are relevant. Given the current level of scientific and technological progress, it is possible to improve and increase the efficiency of restoring vaulted structures. The purpose of this study is the theoretical justification of the application of technologies of additive technologies and the use of secondary polymeric materials for the manufacture of climbing form of vaulted coverings in Orthodox churches.

To achieve this goal the following tasks have been resolved:

- the analysis of existing methods of erection of vaulted coverings of temples is carried out;

- the possibilities of modern additive technologies (3D printing) for the manufacture of elements of building structures, including formwork elements, are explored;

- the choice of material for the climbing form for the restoration of vaulted structures was justified

The presentation material. The following types of vaults became widespread in Orthodox architecture: barrel, cloister, conch, pyramidal and dome vaults.

Such building materials as brick, reinforced concrete, composite mixtures, reinforcement cement elements and metal structures are used for their erection.

Technological solutions for erecting arches depend on the materials employed. There are:

1) the use of additional supporting structures - formwork (for performing mason's work, laying reinforced concrete and composite mixtures);

2) without the use of formwork (erection of vaults with a diameter of less than 5 m, using metal frames and prefabricated reinforced concrete elements).

Formwork for the construction of vaulted elements can be of the following types: climbing form, jumping ganged form, air form and permanent form. The bearing elements of the formwork are made of wood, steel, aluminum, plastic, rubberized fabric and a combination of materials.

Climbing and jumping ganged formwork belong to rigid formwork systems. The main structural elements of these formworks are the boarding joist, supporting elements and jack mechanisms. Formwork is made of boards with a thickness of 40 mm. The shape of the outline of the lower set of boards manufactured boarding joist, which consist of two layers downed jambs with a disarrangement of the seams. For stiffness, the boarding joist is radially unfastened by boards.

In the case of building a vault of reinforced concrete, the erection works can be performed by two methods. Concrete mixture for rigid formwork is supplied either with the use of a concrete bucket or a concrete pump, followed by its consolidating and leveling, or with the use of shotcreting practice.

In the case of convey concrete with a bucket or a concrete pump, it becomes necessary to use an additional external formwork to prevent the concrete mixture from sliding off. At the same time, a significant part of the labor costs was accounted by the rearrangement of the boards of the outer formwork to the next stage of concreting. In connection with the small thickness of the shell and its curvature, the process of compacting the mixture also becomes more complicated.

Using the technology of shotcrete, there is no need for external formwork and consolidating of the concrete mix. If in one step we cannot provide a completely design thickness of the shell, two or three layers of shotcrete are applied after interruption.

The erection of rigid formwork structures is characterized by an increase in duration, material and labor intensity, the attraction of highly qualified personnel.

Pneumatic formwork can be used as erection of reinforced concrete shells, and fiberglass concrete, but domestic construction organizations are used quite rarely. This is due to a number of features of this technology. First, the reusing of an expensive cloth decreases as a result of the need to maintain excessive pressure below the deck. Secondly, there is a potential probability of a malfunction in the operation of air induction equipment, which in turn may lead to the collapse or change in the structure design geometry. Thirdly, the use of pneumatic formwork is complicated in severe climatic conditions (low air temperatures and strong gusts of wind).

To restore the vaulted structures, a permanent formwork was widely used. The bearing skeleton of this construction is the radially curved steel elements, which are joined together by pre-prepared (cut-to-size and bent-shaped) segments of expanded metal sheet. An alternative to these segments can be 2 reinforcing meshes with different cell sizes. The advantages of this method include the performance of part of the work at the zero mark of the construction site. But the cost of the finished product increases due to the large consumption of steel structures. There are precedents for making church domes using metal structures. The supporting ribs of the dome are made of radial trusses, the upper chord of which are lined with sheeting and galvanized sheets, and gypsum boards are mounted on the bottom chord of the trusses.

On some objects of church construction in Kharkov city for the erection of barrel vaults reinforced concrete slabs were used. They were cut in places of voids and bent according to design requirements in building site. After completing the installation of the elements in the design position, the cutting places were grouted, and the plaster layer gave the vaults a smooth curvature.

According to the analysis, it can be concluded that the construction of dome structures is performed not without a number of drawbacks: the complexity of providing geometric forms of formwork and geometric dimensions, attracting specially trained and highly qualified personnel for shuttering, one-time use of formwork in connection with the individual architectural solutions of the vaults.

In order to increase the efficiency of the construction of vaulted structures, it is proposed to use a new formwork system.

The following requirements are imposed on formwork systems of vaulted structures:

- the high geometrical accuracy of the formwork (vertical movement of the lifting boom - (f/200), horizontal movement from the plane in the middle section - (f/200), deviation from the supports - ± 10 mm);

- the minimum number of components and sizes;

- simplicity and reliability of mating elements and formwork units;

- the minimum number and simplicity of mechanisms for assembling, operating and dismantling the formwork;

- relatively small mass of formwork elements;

- the relatively low cost of materials from which the formwork is made;

- chemical resistance to the components of the concrete mixture and low adhesion.

The main indicator of manufacturability of shuttering systems - turnover - is neglected, since the probability of a geometrically similar design of the vault is extremely small.

In order to meet the advanced requirements, it is proposed to use additive technology (3D printing) for the manufacture of the formwork of vaults. The technology of 3D printing has already found application in the restoration of historical buildings, although not without flaws. The scientists note that at the modern level of its development it is difficult to reproduce the elements with fine details and the required accuracy. In addition, there is no possibility of applying the most approximate materials to primary materials, for example, a stone.

Additive Fabrication (AF) means the production of a solid three-dimensional product of any geometric shape from a digital computer model. The quality of the original products is influenced by a number of factors: the quality of the digital model, the type of 3D printer (its calibration and installation), the type and quality of the plastic thread, the surface of the printed platform.

Despite the fact that there is a wide variety of 3D printing technology, the most common is Fusion Deposition Modeling (FDM). Its principle is as follows: by supplying a semi-molten polymer thread in accordance with the geometry of the mathematical model of the

part developed in the CAD system, geometric objects are printed layer by layer [7].

The quality of the "printed" elements directly depends on the development of the virtual model: the creation of a polygonal mesh, the presence of a substrate (sufficient area of contact between the base of the model and the surface of the printing platform) and support (a special porous structure of the plastic under the overhanging elements of the model).

Parameters of thermal printing are used to adjust the strength characteristics of the outgoing element. The height of the build-up layer is usually 80 % of the nozzle size (the dimensions of the first layer may differ). The strength characteristics of the finished product are affected by the number of perimeters or the thickness of the walls of the object and the number / thickness of the upper / lower layers. It is worth noting that it is possible to enhance / facilitate the construction due to the percentage of filling and the form of its application.

Thus, the amount of filling for most of the object is usually from 0 % (hollow elements) to 50 % (solid, very strong parts), more than 50 % are used rarely (Fig. 1) [8].

Fig. 1 – Influence of the main parameters on the final result of the finished product

Coarse-grained segments of the vaults with the required accuracy can be created on a 3D printer. The maximum size of the reproduced model is in the range of 1200x1200x1200 mm, which meets the expected size of the formwork panels. The puzzle connection of the elements between them reduces the need for additional expensive tools to zero.

Consumables for a 3D printer of this type are ABS plastic (acrylonitrile butadiene styrene). It is an opaque material of dark color with a shiny surface, resistant to moisture, lubricating oils, solutions of inorganic salts, acids and alkalis, fats and hydrocarbons, non-toxic.

The disadvantages of unmodified ABS plastic include relatively low electrical insulating properties in comparison with polystyrene, as well as low weather resistance, in particular, sensitivity to the action of ultra-violet rays in the range.

Due to the selection of initial monomers and the variation of their ratios, the physico-mechanical properties of ABS plastic may vary.

In this regard, one of the tasks of polymer modification is the adjustment of their properties depending on the requirements.

The perspective direction of development is the use of secondary polymeric materials, since it allows solving such social and economic problems as pollution of the environment, efficient use of natural resources, reduction of the shortage of material resources.

A group of scientists "Kharkiv-komunochystvod" created a polymer composition for the manufacture of building materials and structures, which has high mechanical, technological and operational properties with a relatively low price.

The composition of this composition includes a thermoplastic polymer (secondary polyethylene and secondary polystyrene) and a modifier (ethylene-vinyl acetate copolymer or thermoplastic elastomer DST-30-01 or synthetic zeolite) [9].

Secondary polyethylene, like secondary polystyrene, is produced from this type of solid household waste such as films, bags, bottles of polyethylene terephthalate. The annual growth in the production of packaging and packaging is 3 – 5 %. It shows that recycling and recycling of plastics will lead to a reduction in environmental pollution and will fill the need for raw materials.

As a result of mixing and homogenizing the constituents, the starting material takes on the shape of a strand and is ready for further use for 3D printing.

The polymer composition has the following physical-mechanical and technological characteristics:

- density - 0.91 t/m3;
- modulus of elasticity – 178 MPa;
- poisson's ratio - 0.15;
- destructive stress at bending - 24.6 - 34.6 MPa;
- coefficient of linear expansion – 2x10-4 (1/◦C);
- influence of light weather - weatherproof;
- the effect of high heating temperature - slightly flammable, slightly smoky;
- weldability - allows to form an integral joint with rational technological process;
- adhesion with concrete - is absent.

Consequently, this type of material is suitable for the manufacture of climbing formwork of vaulted structures.

Conclusion. The combination of additive technology with the use of secondary polymers allows us to solve a number of problems associated with the restoration of the vaulted structures of Orthodox churches.

As a result of using the proposed solution, the following goals are achieved:

• high geometric accuracy of formwork manufacture;

• easy assembly of the formwork (small number of element sizes, low weight of shields, convenient and reliable connection of decks among themselves);

• formwork material (polymer composite) has the necessary characteristics (possibility of use in additive processes, low density, lack of chemical interaction and adhesion with concrete mixture);

• the use of recyclables contribute to the solution of social and environmental problems of the secondary use of household and industrial plastics.

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