BUILDING CONSTRUCTIONS, BUILDINGS AND ENGINEERING STRUCTURES

СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ

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Original Empirical Research

Modern Technological Solution for Covering the Cylindrical Vault of the Nave during the Construction of the Church of St. Tikhon in St. Petersburg

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Abstract

Introduction. The article is dedicated to the history of the development and implementation of the project for the construction of the ceiling of the nave of the church of St. Tikhon, Patriarch of Moscow and All Russia, at 17 Commune Street, St. Petersburg. The church was built and is under construction on an order of a local religious organization with donations from whoever cares to do this and church visitors. The original project envisaged the construction of an arched cylindrical vault above a masonry nave, which called for complex engineering solutions and considerable labor and financial costs. By October 2024, it became clear that construction in the traditional way would not enable the church to be consecrated, having completed this project in a short time and with limited funds. The aim of the study was to develop an alternative solution to the construction of arched brickwork with puffs on the short side of the nave of the temple.

Materials and methods. Having considered the options available, we decided to make use of arched beams as stiffeners, which were supposed to take on some of the load, including from the strut. It was assumed that it was possible to replace the prestressed reinforcement of the upper row with a combined one making it possible to optimize the arch design. In order to identify the required parameters, loads were collected and the stress strain of the arch was calculated, including in the SCAD program provided it was at the operational stage. The reduction of stress zones is achieved by additional reinforcement with rods and clamps.

Results. The research enabled us to reduce costs while maintaining the structural rigidity of the arch. In accordance with the calculations, the formwork drawings have been developed. The process of transferring parameters from drawings to actual dimensions and concreting was meticulously organized by means of modern quality control tools at each stage. The installation of ready-made reinforced concrete structures turned out to be more technologically advanced and faster than a monolithic system.

Discussion and Conclusion. The brick vault project was successfully completed with minimal deviations involved. The support area of the structures and the height of the arch rise fully corresponded to the calculated values. The solution was found to have made it possible to considerably cut down the load on the base, increase the overall structural rigidity, while freeing the space under the dome from tightening, reduce construction times making it possible to meet the deadlines as well as to reduce the costs. The scientific novelty of using arches with a mixed reinforcement system is the simplicity of the design, the absence of the need to increase the cross-section of the truss elements and the possibility of using combined reinforcement.

Keywords: nave, cylindrical vault, intermediate supports, arched beam, combined reinforcement

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Оригинальное эмпирическое исследование

Современное технологическое решение перекрытия цилиндрического свода нефа при строительстве храма святителя Тихона в Санкт-Петербурге

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Аннотация
Введение. Статья посвящена истории разработки и воплощения проекта строительства перекрытия нефа храма святителя Тихона, патриарха Московского и всея России, на улице Коммуны, дом № 17а, в г. Санкт-Петербурге. Храм строился и строится по заказу местной религиозной организации на пожертвования неравнодушных и прихожан. В первоначальном проекте предполагалось возведение арочного цилиндрического свода над нефом из каменной кладки, что требует сложных инженерных решений и значительных затрат труда и средств. К октябрю 2024 года стало понятно, что строительство традиционным способом не позволит освятить храм, выполнив этот проект в сжатые сроки и при ограничении средств. Целью исследования была, разработка альтернативного решения устройству арочной кирпичной кладки с затяжками по короткой стороне нефа храма.
Материалы и методы. После рассмотрения вариантов принято решение использовать арочные балки в качестве ребер жесткости, которые должны были взять на себя часть нагрузки, в том числе и от распора. Выдвинуто предположение о возможности замены преднапряженной арматуры верхнего ряда на комбинированную, позволяющее оптимизировать конструкцию арки. Для определения требуемых параметров произведен сбор нагрузок, и расчет напряженного состояния арки в том числе и в программе SCAD с учетом ее работы на стадии эксплуатации. Снижение зон напряжений достигнуто дополнительным армированием стержнями и хомутами.
Результаты исследования. Проведённые исследования позволили уменьшить расходы сохраняя конструктивную жесткость арки. В соответствии с расчетами разработаны опалубочные чертежи. Процесс переноса параметров с чертежей в реальные размеры и бетонирование был тщательно организован, использовались современные инструменты для контроля качества на каждом этапе. Монтаж готовых железобетонных конструкций оказался более технологичным и быстрым по сравнению с монолитной системой.
Обсуждение и заключение. Проект кирпичного свода был успешно выполнен с минимальными отклонениями. Площадь опирания конструкций и высота подъема арки полностью соответствовали расчетным значениям. Было установлено, что принятое решение позволило значительно сократить нагрузку на основание, повысить общую конструктивную жесткость, при этом освободив пространство под куполом от затяжек, снизить продолжительность строительства, что позволило уложиться в заданные сроки, и уменьшить стоимость работ.
Научная новизна применения арок со смешанной системой армирования заключается в простоте конструкции, отсутствии необходимости увеличения сечения элементов ферм и возможности использования комбинированной арматуры.

Ключевые слова: неф, цилиндрический свод, промежуточные опоры, арочная балка, комбинированная арматура

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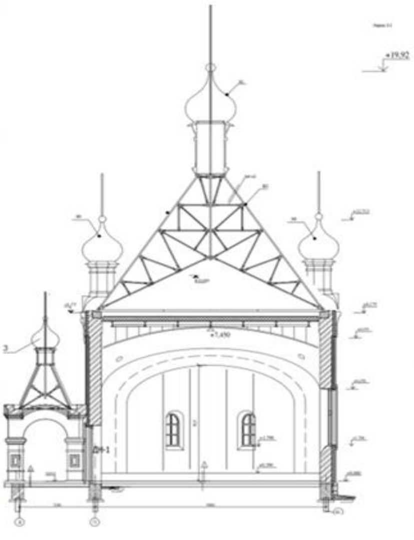
Introduction. Since time immemorial, in the most trying times, humanity have been aspiring to come together into a single cohesive unity under the protectorate of a strong state. During this period, faith serves as the greatest uplifting and unifying force. As a social institution and regulator of economic as well as other relations, the Church has the capacity to unite human society. It shapes people's worldviews, establishes moral and ethical regulations, and also lends one a sense of comfort and security that has been lost as a result of some external factors. All of this contributes to unite individuals based on a shared worldview and religion, to increase social engagement, spiritual revival, and preserve cultural heritage as well as customs, which builds an overall positive image of the country as well as its attractiveness as a tourist destination. It is also of interest to note the economic component when the revival of faith and the construction of temples contribute to creation of jobs and regional economic development. The Church of St. Tikhon, Patriarch of Moscow and

All Russia, at 17a Commune Street, is one of the first churches in the Northwestern District to have been dedicated to a real person directly related to St. Petersburg, a new martyr from the early years of Soviet power, who ran the Patriarchate in the most trying times for the church. A man who actually accomplished his own small feat and devoted his entire life to the Russian Orthodox Church and experienced the "Levashov Golgotha" [1, 2] following the Petrograd trial of 1922. 2025 marks the death of St. Tikhon, Patriarch of Moscow and All Russia.

The church was built and is being built by an order of a local religious organization and funded with the donations from parishioners of the Kursk Root Icon of the Mother of God "Of the Sign" located nearby. Construction got underway in the late 2021. In fact, the church had already been completed, and in early January 2025, Archpriest Alexander Pashkov conducted the first service. An iconostasis will be set up in the nearest future [3]. The stone church was constructed under the challenging conditions: the confined space as most of it was built outside the site designated for religious use, the rather daunting layout of the foundation as well as some funding issues with rigidly set construction deadlines to be met. The original design of the five-domed church was developed by LLC AMC-Project: made of red brick, in the neoclassical style shaped like a ship, with a tent-topped bell tower and main volume. However, it had to experience some modifications for a number of reasons. The latter were due to the need to reduce the construction time (while maintaining structural rigidity and architectural integrity) as well as the cost of the project. The objective of the study is to develop the organization and construction of arched beams on the short side of the nave as an alternative to a cylindrical brick vault with puffs given the preservation of the required height of the cylindrical brick vault and the overall structural rigidity of the church as a whole. The scientific novelty is a new reinforced concrete structure in the previously developed classical temple project with walls already built. This solution enabled the maintainenance of the structural rigidity without having to make use of the required tightening forces, thereby freeing up internal space and reducing the labour costs and indices.

Materials and Methods. Domed and cylindrical arches made of masonry have been known since the Roman Empire. These arches are among the most durable and resistant to maximum loads. The considerable disadvantages of such structures are high load on the base; the complete impossibility of mechanizing work during their construction and thereby cutting down the labour costs and construction time; the need for masons to perform work with very high qualifications; the high cost of such work. The masonry of arches and vaults must be carried out from the heel to the castle simultaneously on both sides, using two teams of masons [4]. The masonry is completed by jamming the vault with castle bricks. Masonry should be carried out in small sections to avoid collapse. All seams of the masonry must be completely filled with mortar. The central axis of each brick must be strictly perpendicular to the surface of the vault. While laying arches made of bricks or stones, it is essential to fill the seams with a liquid solution without rubbing the upper surface of the arches. The laying of arches of double curvature should begin no earlier than a week after the end of the installation of their heel. The outside temperature should be above +10 °C. If the air temperature is from +10 to +5 °C, then the period increases by one and a half times, and at temperatures from +5 to +1 ° C — by two times. The section of the vault can be demoulded no earlier than after 10-20 days at an outdoor temperature of at least +10 °C.

a)



b)

c)

Fig. 1. Church of St. Tikhon, Patriarch of Moscow: a — exterior of the temple; b — section of the church considering account the built-in arched beam structure; c - view of the church towards the altar from the inside

At lower positive temperatures, the duration of exposure of the arches on the formwork increases. While laying arches with a lifting boom, the strut must be fixed by tightening and additionally along the arc of the circle, as in our case. Precast reinforced concrete elements made of concrete of a grade not lower than M200, reinforced with structural reinforcement with a diameter of 6-8 mm, are installed in the heels where the faces are adjacent. It is also possible to use steel elements made of corners, sheet and strip steel. The ends of the puffs are passed through these elements. To increase the stability of the support units under the action of the arch strut, outrigger heels are installed in the support units, which form a cornice from the inside of the room. Outrigger heels also increase the stability of the support units. The supporting nodes of the vault must have inclined surfaces formed by stepwise laying of brickswhich must be perpendicular to the axis of the vault. The technology has barely changed since the onset of the construction of stone temples. From all of the above, the conclusion was that it was rather challenging to perform high-quality masonry, to meet a tight deadline while on a tight budget. Fig. 1 shows photographs of the Church of St. Tikhon and a drawing of the section of the temple taking into account the built-in structure. The problem of installing an entirely monolithic dome cover was not looked at. One of the flaws of solid monolithic structures for religious domes is that their construction calls for special skills and technologies, which is more costly than a system of using beam arches.

The First Assumption. In order to avoid tightening, while maintaining structural rigidity, it was critical to reinforce sections of the arch structure with a certain step, i.e., to reinforce the regular frame hidden in the filling masonry, and to make use beam arches protruding from the arch masonry, which would serve as a sort of stiffeners.

The Second Assumption. In arches made completely of clinker bricks, there is frequently extra spacer force occurring, and special devices are needed in order to perceive this spacer [5]. It was decided to reinforce the walls under the heels of these arches with pilasters which will be capable of withstanding the pressure from the weight of the vault and of accepting the strut. It is due to this solution that the arch in an overloaded area is sufficiently reinforced, although there are unnecessary protrusions in the room. The major task facing the designers working on the reinforcement of concrete arches was to design arches of a certain height with a small mass, i.e., those consuming the lowest amount of the material. They can be installed using cranes with a low lifting capacity while maintaining the required rigidity and height of the dome. The height of the arch of the arch depends on its bearing capacity: a large one increases it, because the area of the compressed zone and the moment of inertia of the section rise, i.e., the cross—section of the arch becomes bigger; an arc which is excessively large might cause a drop in the bearing capacity due to reduced rigidity and increased deflections. The optimal height should thus ensure maximum load-bearing capacity with the lowest amount of material consumed and compliance with the requirements for rigidity and crack resistance [6]. One of the key indicators of quality and mechanical safety of operation is the residual load-bearing capacity. It is identified by means of a few criteria: the strength of reinforcement and concrete, stiffness, crack formation and their opening width.

The optimal height is taken based on the bending moment and wall thickness to ensure the minimum cost of the arch in terms of how much material is consumed. The width of the nave of the temple — the length of the arch span — was taken based on the previously projected dimensions — 8.05 m, the required arch elevation — 1150 mm, considering the height of the latter to enter into the previous high-rise design of the nave vault. The height of the arch masonry is 640 mm. For the initial calculation, the height of the reinforced concrete arch, pinched at two ends, was assumed to be at least 1/15 of the span, i.e., approximately 400 mm between the outer edges of the belts. The formula for a parabolic arch was employed to calculate the radius of curvature of the arch which is part of the structure. Substituting these values, we get:

$$R = \frac{h^2 + \frac{\omega^2}{4}}{2h} \approx 6{,}85\text{m},$$

where R — desired radius of curvature; ω — the width of the span (in this case, the width of the nave) — 8,05 m; h — the height of the arch rise from the center of the span to the top of the arch 1,15 + 0,4 = 1,55 m.

0.6 m will thus fall on the support node on each side. The width for the calculation was taken based on the height-width ratio — 468 mm, which is due to the size of the upper platform of the support element. The estimated rebar pitch is 200 mm. The arches are designed using class B40 concrete.

The Third Assumption. In most projects, while using reinforced concrete arches of a similar design, prestressed reinforcement has always been used, which does not cause tensile stresses from operational loads. While designing such beam arches, there have been no studies of the effect on the distribution capacity of the reinforcement spatial system in operation. The features of reinforcement for curved span arches include the use of special indirectly spiral-reinforced reinforcement, such as individual wires, strands and rods of a periodic profile. Bundles with internal anchors and continuous reinforcement on cassettes are also used. Reinforcement tension can take place prior to concreting (on the stops) or following it (on concrete).

The downsides of this design approach are the following:

– it leads to unjustified consumption of reinforcing steel.;

– reinforcement in accordance with the material plots becomes more complicated, i.e., it becomes impossible to discontinue the reinforcement where it is not required along the entire structure.;

– it is necessary to apply great efforts to the force forms while pulling the reinforcement and crimping the concrete during transfer of forces from the stops to the concrete.

Previously used structures for relatively small spans were not cost-saving in terms of how much material was consumed. In this case, the arched beams function as a single spatial system due to the combined arrangement of the upper brick vault. It was thus decided to make use of mixed reinforcement by replacing the permissible number of high-strength beams with conventional bar reinforcement. A stressed Grade A-IV (A600) reinforcement of a periodic profile was designed in the lower belt, Grade A400 longitudinal reinforcement was used in the remaining elements, and elements of transverse and mounting A240 reinforcement were provided to maintain the transversely rigid superstructure. The bearing capacity of a beam arch depends on its geometric dimensions, materials of manufacture and operating conditions. The key factor influencing this indicator is the maximum load that the structure can withstand without deformation or destruction [7].

The loads were collected. Given the brick density $\rho \approx 1800$ kg/m^3 and the the volume of the arch masonry[1]:

$$V = L \cdot \omega \cdot H = 24\text{m} \cdot 8{,}05 \cdot 0{,}64 = 122{,}88\text{m}^3,$$

where ω — width of the arch (equalling that of the niche).

The weight of the vault is thus:

$$P = \rho \cdot V = 221{,}184\text{т}.$$

While calculating the vault, the likelihood of an increase in the constant load distributed over the horizontal projection of the vault, in the direction from the center to the supports along the curve, was considered:

$$g_x = g \cdot \left(\frac{1}{cos\varphi} - 1\right),$$

where g_x — additional constant load caused by the slope of the coating in sections located at a distance from the x support, kgf/m; g — constant load in the center of the vault a kg/m; φ — angle of inclination to the horizon of the tangent to the axis of the arch in the investigated section.

There was a task of calculating the permissibility of replacing the upper row of bundles of prestressed reinforcement with rod reinforcement[2] [8] given its further bending into the supporting compressed zone of concrete. In order to confirm the assumption, theoretical calculations of the upper belt were conducted based on the cross section of the reinforcement:

$$A_{\text{тр}} = \frac{N_2}{R_b + 0{,}01R_{sc}},$$

where R_{sc} = 355 MPa — расчетное сопротивление продольного профиля design resistance of the longitudinal profile of an operating Grade A400 reinforcement. $A_{\text{тр}}$ — required longitudinal cross-sectional area of one reinforcement rod of the upper belt; N_2 — force in the longitudinal reinforcement; R_b — calculated concrete resistance of class B40 concrete — 51,37 MPa.

With the previously assigned width of the arch elements (468 mm), the required cross-sectional height of the upper belt is $h_{\text{тр}} = A_{\text{тр}}/b$; h — 12 mm. The area of the longitudinal operating reinforcement with an average coefficient of longitudinal bending is φ = 0,9. 8 rods with a diameter of 16mm are accepted.

Research Results. In order to validate the studies and obtain a more nuanced answer, the stress state of the beam arch was calculated in the SCAD software package considering the operation of the arch at the operational stage, respectively, the loads from external forces were assigned for the stage. The accepted concrete class is B40.

[1] SP (СП) 20.13330.2011. Loads and Impacts.

[2] Krylov S.B, Chistyakov E.A, Zenin S.A., Sokolov B.S., Sharipov R.Sh., Kudinov O.V. *Monolithic Reinforced Concrete Structures with Stressed Reinforcement without Adhesion to Concrete, Design Guidelines: a Methodological Guide*. Moscow; 2017. 206 p.

The original task was to reduce the amount of prestressed reinforcement and replace the upper row of prestressed reinforcement with rod one accompanied by its bending according to the materials plot into the compressed concrete zone supposed to reduce losses in material consumption and maintain the operability of the structure. It can be seen from the isofields that the analytical calculation was performed correctly. Unlike the supporting section where the stresses in the support area are visible from the isofields on the plan, the replacement with class A400 reinforcement does not impact the bearing capacity of the arch in terms of bending moment. The obtained results of the isofields are shown in Fig. 2. It was decided to reduce such stress zones by applying additional reinforcement with conventional rod fittings and clamps, i.e., to apply mixed reinforcement.

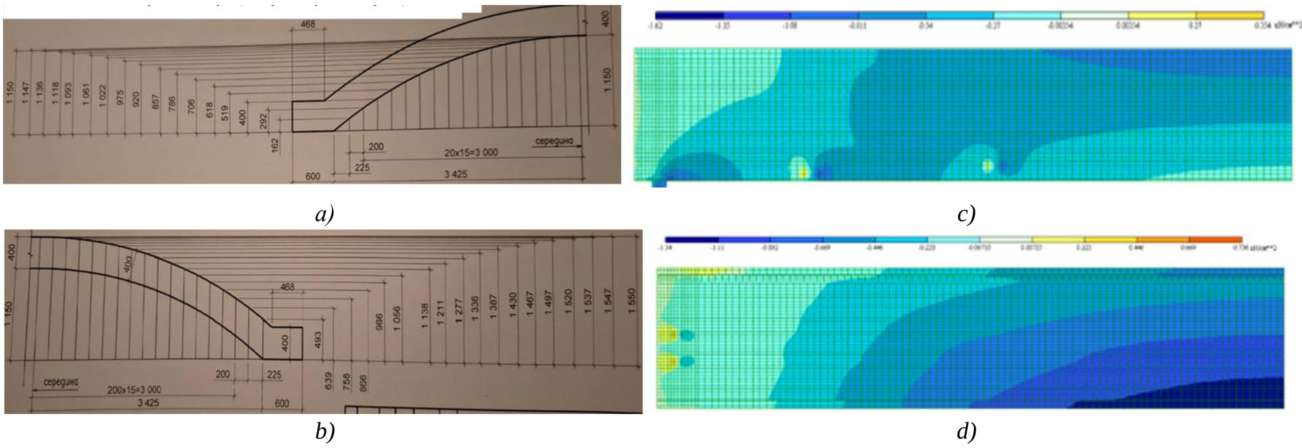


Fig. 2. Sketch for calculating the beam arch in the SCAD program: *a* — formwork diagram, center drawing (left side); *b* — shuttering drawing (right side); *c* — isofields of normal arch stresses (longitudinal section along the axis); *d* — isofields of normal arch stresses in the plan

The bordering rods are made integral with their joining in the upper zone of the support nodes and in the lower zone of the truss. The area of the longitudinal upper rods is at least 0.05% of the cross—sectional area of the support units, the diameter is 16 mm, while spatial frames and additional transverse fittings in the form of A240 steel clamps are installed at the bends of the support units to ensure reliable anchoring of the stretched reinforcement of the lower belt. In the span area, 15 rods of transverse reinforcement with a pitch of 200 mm are accepted, while additional elements are installed in 100 mm increments on the lower belt and at least 200 mm from the end of the support unit. The most challenging issue in the production of such reinforced concrete structures by means of a bench method is the accuracy of transferring parameters from drawings to actual dimensions, which is a complex and demanding task calling for a high level of professionalism. Even the slightest deviations from the set parameters might cause grave consequences with the geometry of the finished product distorted as well as the arched beam not quite matching the actual required parameters. For instance, a lack of reinforcement reduces the load-bearing capacity of the structure, while an excess of reinforcement causes an increase in the weight and cost of the product.

In order to prevent such problems from occurring, the process of transferring dimensions from the drawing to the actual structure was meticulously organized. It was also decided to form an arch on the edge as the most optimal position for concreting and transportation[3]. The alignment was performed on the geodetic substructure. In order to minimize the risks associated with possible errors in the production, the ADA 3D Liner 4V laser plane builder and the GeoMax Zoom50 1 A5 Polar total station were used. A number of actions were continuously performed[4] as part of continuous control[5] [9].

The formwork must have strength, stability, and tightness, the concrete must not leak, closely reproduce the shape of the future product, and be easy to install and remove to minimize time and labor costs. Errors during the formwork assembly might generate cracks, crevices and other defects. As the formwork was for a single order, and only eight such arches were required, the plane was made of bent plywood. In order to withstand the pressure of freshly poured concrete and prevent deformation and displacement, it was loosened with bars. The reinforcement frame was bent in place with

[3] SP (СП) 70.13330.2012. Bearing and Hedging Structures.
[4] SP (СП) 126.13330.2012 Geodetic Works in Construction.
[5] Letchford A.N., Shinkevich V.A. *Construction Control Guidelines.* SPb.; 2016. 592 p. (ISBN 978-5-904362-07-2)

little heating given the requirements for strength and rigidity of the structure. All the components are made according to the developed project considering the building codes and regulations. After the reinforcement frame had been checked for compliance with the deck shape, it was moved inside the formwork and secured based on the dimensions of the protective layer. B40 grade concrete mix was used, the work was carried out to ensure uniform pouring of concrete and prevent voids. The process is shown in Fig. 3. It was after it had been delivered to the construction site that the final product was tilted to its design position.

a) *b)* *c)*

Fig. 3. Visualization of the process of creating a reinforced concrete structure:
a — reinforcement carcass; *b* — single formwork; c — final arched beam on the edge

The work was assessed at each stage. An additional bonus is that the decision enabled the load on the base to be significantly reduced, including by reducing the height of the masonry from 1 m to 0.64 m, increase the overall structural rigidity, while freeing the space under the dome from tightening.

Discussion and Conclusion. The project was designed with minimal deviations and did not call for any adjustments during the installation, the support area of the structures and the height of the arch rise were in full agreement with the calculated values. By the onset of the arch installation, the walls had been constructed, supporting pilasters, adjustable supporting scaffolding adopted, a formwork template ("circles") and a template for angles for brickwork made. All of these were performed with an automobile crane (Fig. 4). The formwork templates under the brickwork of the vault was moved with a winch. In order to create a flow-through method of work and reduce the construction time, the dome of the nave started being laid with a one-day delay by installing the arches. All the movements were performed using scaffolding.

a) *b)*

Fig. 4. Arched beam installation: *a* — a beam mounted on a support pilaster; *b* — crane mounting with a tip

The masonry of the dome vault was performed with the installation of bricks "on the edge" simultaneously by two teams of masonry workers on both sides of the nave from the heels to the top with the seams thoroughly litigated to considerably reduce labor costs as well as to improve the stability of the vault. The work was being closely monitored during the laying. In order to prove the method had been correctly chosen, the cost of bricklaying the nave vault was calculated according to "The Uniform Standards and Prices for Construction, Installation and Repairs"[6] considering the installation of the embedded parts and the tightening of the arch as well as the installation arches as stiffeners. The calculation results are shown in Table 1 and 2.

Table 1

Calculation of labor and machine time costs for the brickwork of the vault

№	Justification (CNTD) (ЕНиР)	Technological processes	Measurement unit	Amount of work	Time standard		Labour costs	
					workers, person-h	vehicles, vehicle-h	workers, person-h	vehicles, vehicle-h
1	E3-20A	Supply and installation of scaffolding with a vehicle crane	10 m^3	4.33	1.44	0.48	0.78	0.26
2	E15-35	Installing the formwork template in the operating position	m^2	1135.68	0.37	0	52.53	0
3	E1-6	Supplying the solution to the site	m^3	174.44	0.84	0.42	18.32	9.16
4	E1-6	Supplying the bricks to the site	1000 items	37.472	0.36	0.18	1.69	0.84
5	E3-10	Laying a brick vault on cement mortar	m^3	726.84	3.8	0	345.25	0
6	E3-9	Installing supporting parapets	m^3	10.56	3.5	0	4.62	0
7	E3-18	Installing steel elements and parts into the walls	100 kg	6.8	1.1	0.33	0.94	0.28
8	E25-7	Unwinding and moving the steel rope	100 m of the rope	0.736	2.6	0	0.24	0
9	E3-18	Installing steel element puffs	100 items	0.16	24.5	1.24	0.5	0.03
10	E25-7	Winding and moving	100 m of the rope	0.736	2.9	0	0.27	0
11	E25-7	Adding an extra incision for each additional one	100 m of the rope	0.736	0.69	0	0.07	0
12	E4-1-28	Caulking and stitching	10 m	4.8	1.4	0.56	0.84	0.34
13	E3-10	Lowering the formwork on the wedges	m^2	1135.68	0.55	0	78.08	0
14	E1-6	Rearranging the scaffolding with a crane	100 t	0.33	23	11.5	0.95	0.47
15	E25-20	Moving the formwork template with a manual winch	items	20	0.76	0	1.90	0
							506.93	**11.39**

*Note: the calculated costs do not consider the production and disassembly of the formwork template for the vault.

[6] CNTD (ЕНиР). The Uniform Standards and Prices for construction, Installation, and Repairs. VolumeE 1. Internal Construction Transport Works: https://docs.cntd.ru/document/1200000897
CNTD (ЕНиР). Volume E 3. Stonework: https://docs.cntd.ru/document/1200001038
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CNTD (ЕНиР). Volume 25. Rigging: https://docs.cntd.ru/document/1200001092

Table 2

Calculating labor and machine time costs for installing brick masonry on reinforced concrete beams

№	Justification (CNTD) (ЕНиР)	Name of technological works	Measurement unit	Amount of work	Time standard		Labour costs	
					workers, person-h	vehicles, vehicle-h	workers, person-h	vehicles, vehicle-h
1	E3-20A	Supplying and installing the scaffolding with a car crane	10 m^3	4.33	1.44	0.48	0.78	0.26
2	E4-1-29	Constructing a concrete bed	m^2	4.656	0,22	0	0.13	0.00
3	E4-1-6	Installing the arches	1 item	8	1.7	0.16	1.7	0.16
4	E15-35	Installing the formwork template in the operating position	m^2	1135.68	0.37	0	52,53	0
5	E1-6	Supplying the solution to the site	m^3	174.44	0.84	0.42	18.32	9.16
6	E1-6	Supplying the bricks to the site	1000 items	37.472	0.36	0.18	1.69	0.84
7	E3-10	Laying a brick vault on cement mortar	m^3	726.84	3.8	0	345.25	0
8	E1-6	Rearranging the scaffolding with a crane	100 t	0.33	23	11,5	0.95	0.47
9	E25-20	Moving the formwork template with a manual winch	items	20	0.76	0	1.90	0
							423.23	**10.90**

*Note: the calculated costs do not consider the production and disassembly of the formwork template for the vault.

According to the calculations, technical and economic indicators have been listed (Table 3).

Table 3

Technical and economic indicators

Indicator	For the brick vault	For the vault fitted with ferroconcrete arches
Labour costs, person-cm	506.93	423.23
Costs of machine time of the vehicle crane, vehicle-cm	11.39	10.9
Number of operations	15	9
Total duration of the work given the formation of the teams, person-cm	156.6	111.9
Duration in months	7.2	5.08

Based on the obtained data and the construction outcomes, the fact that the correct decision had been made was confirmed. The beam arches were the stiffeners. They offer the following advantages:

– cost-efficiency — construction costs are reduced by using fewer materials;

– arches are characterized by a lower weight and volume compared to traditional solutions leading to a reduction in transportation costs.

It was also suggested that a combined reinforcement frame could be made use of. Beam arches are highly resistant to various types of loads. In order to minimize risks, the calculations were double-checked in the SCAD program. Such verification calculations enable the quality of work to be improved through the course of construction of critical structural elements and a three-dimensional model of the future product to be designed. A test of the structure even prior to the start of the installation cycle at the calculation stage enabled stresses in the reference zone to be identified by means of isofields, which made it possible to correct the shortcomings at the design stage. The installation of ready-made reinforced concrete structures is highly technologically advanced. On top of that, unlike a monolithic system, it barely depends on weather conditions; it does not call for a long exposure in the formwork, as factory-manufactured products are employed with a multi-series when the formwork can be used on a few serial elements cuttinf down production costs. A well-developed and standardized process simplified construction, reduced the duration of work and met deadlines cutting down the costs of work.

Modern construction is being faced with the need to keep on searching for ways to optimize processes designed to reduce the construction time of various facilities, including religious buildings. Traditional approaches based on the use of brick vaults with complex systems of tabs and strands are rather time-consuming.

The use of arched beams enabled the principle of reasonable saving of materials and labor costs to be showcased.

The efficient organization of the dimensional transfer process and control at all the construction stages enabled minimization of errors and discrepancies between the design documentation and the actual construction. Modern technologies and geodetic equipment have improved the quality, reliability and efficiency of the construction considering the use of available resources.

The use of arched beams instead of the traditional approach using embedded parts and puffs is a promising direction in modern technology for the construction of religious buildings. This method would considerably reduce the construction time: in our case, the difference in the duration of construction was about two months, which also saved funds without compromising the level of quality and safety. Given all of these advantages, a further increase in the demand for the suggested method in the construction of religious buildings is highly likely.

The scientific novelty of using arches (instead of trusses as well) with a mixed reinforcement system is the following:

– simple assembly design and manufacturing technology compared to segment trusses or a tightening device;

– there is no need to increase the cross-section of the truss elements and their reinforcement compared to diagonal trusses due to rigid assemblies;

– in the manufacture of solid molds, it is possible to make use of combined reinforcement only with a prestressed lower belt: it has been confirmed that the use of nonstressed reinforcement complete with prestressed reinforcement in these reinforced concrete structures does not disrupt its bearing capacity;

– the possibility of manufacturing beam arches in simple formwork with no use of inserts. Beam arches can also be employed in restoration of historical buildings where it is critical to preserve the original architectural style while improving the technical characteristics of the structure.

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