Assessment features of bearing capacity of large-span covering constructions in the reconstruction of religious Orthodox buildings

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Abstract. The research object is the middle part and the refectory overlap of the temple in the honor of the Holy Kosma and Domian Asiysky, located in the village of Ssezhe of Bogatovsky district of Samara region. At the time of the works, the object was undergoing a large-scale reconstruction. Based on the data of the detailed technical condition survey of the building structures of the temple overlap, the authors made calculations in a physically nonlinear setting, allowing to fully assess the stress-strain state of the monolithic reinforced concrete structure of the middle part and refectory, which is a complex unified system of thin-walled spatial structures of different contours of the middle surfaces. The recommendations on the completion of the overlap construction and its further operation were developed on the basis of the calculations results analysis.

1. Introduction

The change in political and social realities in Russia in the late 1980s gave rise to the church revival in the country. As the number of parishioners grew, it became necessary to increase the number of parishes. This period can be marked as the beginning of active restoration and construction of religious buildings of the Russian Orthodox Church. In 1988, the Russian Orthodox Church had 6.5 thousand cathedrals; in 2020 there are 40 thousand cathedrals. In the last 10 years the number of parishes of the Russian Orthodox Church has increased by 10 thousand. Most buildings for religious purposes are not new construction objects, but the objects transferred from state property back to the jurisdiction of the Russian Orthodox Church. The transferred religious buildings were erected in the pre-revolutionary period. During the Soviet period some of them were either destroyed or rebuilt for various purposes: in rural areas the buildings were often used as granaries, mechanical workshops, and clubs; in the urban areas they were mainly turned into public buildings, production workshops and even apartment buildings. Of course, when the functional purpose of religious buildings was changed, architectural, volumetric-planning and structural solutions were significantly changed too. First of all the brightest religious “signs” were dismantled: architectural decor, belfry, quadrangles, octagons, drums, domes, etc.

When re-profiling the building back to the needs of the Russian Orthodox Church, there is a need for restoration work. Over the long period of operation the buildings didn’t have often timely repairs. Some temple facilities were abandoned for decades without any reservation measures, the building structures have significant amount of damage and their technical condition deteriorated greatly. Thus, the restoration work implies a whole complex of reconstruction measures.
Now there is a practice when the restoration of half-ruined cult constructions is carried out not with working out of necessary volume of the design-budget documentation, but in an economic way. Most often this happens in rural parishes when all cares on restoration of a church are taken by the rector. At the same time, at the reconstruction, very laborious and technically complex tasks are being solved, including the restoration of the lost large-span coverings (domes, vaults, and apses), multi-tiered bell towers, and domes. It should be noted that temple overlap is often the most important element of architectural, volumetric and structural solutions of the building. Thus, it is very difficult to control the restoration work quality, including the design stage, and there is a need to determine the actual technical condition and bearing capacity of already erected or reinforced structures. Given the specifics of these circumstances, often the most common engineering methods are not suitable for the task of identifying the actual carrying capacity of structures. It is necessary to use more labour-consuming and more exact methods with modern software and computer complexes application. It allows to reveal the unaccounted reserves of bearing ability and thus to minimize financial expenses for restoration.

Members of Construction Structures department of Samara State Technical University have participated in scientific and technical support of reconstruction of buildings of religious purpose of Russian Orthodox Church. This work reflects the results of the survey of the technical condition of the middle part and church refectory, located in the village of Ssezheye Bogatovsky district of Samara region of the Russian Federation. The purpose of the set of measures for the technical inspection was to assess the stress-strain state of the overlap structure with the subsequent recommendations development for the completion of construction and installation work related to the construction of the church overlap.

The building of the temple was erected in 1827. The temple was illuminated in honor of the saints Cosma and Damian. In the 1880s, the temple was reconstructed, which was aimed at its expansion. Until the autumn of 1938, the building was used in accordance with its functional purpose, after which it was equipped with a granary. In the 1990s, the vaulted stone structures of the building envelope collapsed (figure 1). Until 2005, the building was in an abandoned condition. Since 2005, a long reconstruction process has been underway. At present the building has been restored: the lost fragments of stone walls have been reconstructed, a monolithic reinforced concrete covering has been arranged, a stone drum above the middle part has been arranged, the drum and the bell tower have been crowned with the dome.

The considered overlap is made of monolithic reinforced concrete and is a complex continuous system of thin-walled spatial structures with different outlines of the middle surfaces. The survey work was carried out in accordance with the current regulatory documents [1-5], taking into account the methods developed by the members of Construction Structures department of Samara State Technical University, partially set out in [6-8].

2. Construction planning and design scheme
A stone cross-domed one-storey one-domed church in the plan has the shape of a cross with maximum dimensions in the axes of 31.2×19.7 m. The compositional solution is axially symmetrical. The schematic plan and general view of the building are shown in figures 2 and 3, the coverage plan is shown in figure 4.

The plan structure is four-part plan; it consists of the following parts connected by a “ship”: an altar in axes 4-6, a church (middle part) in axes 3-4, a refectory in axes 2-3, and a vestibule with a built-on bell tower in axes 1-2.

The covering of the refectory is a monolithic reinforced concrete on a rectangular plan composite smooth shell formed of two shells of zero Gaussian curvature intersecting in mutually perpendicular directions: in the right and left naves, the longitudinal axes of the vaults are oriented in the North-South direction; the longitudinal axis of the middle nave is in the East-West direction.
Figure 1. View of the southern facade and covering of the temple (as of 2005)
Figure 2. Schematic plan of the temple building

Figure 3. General view of the building (http://kosma-i-damian.cerkov.ru/)
The cover of the middle part is formed as follows: the outer naves are covered with cylindrical vaults (the longitudinal axes are oriented in the North-South direction); a conical drum is arranged in the middle nave; the drum, vaults of the outer naves of the middle part and the vault of the middle nave of the refectory are united by monolithic shells in the form of concave spherical triangles (scoinson arches).

The thickness of the cylindrical vaults and scoinson arches is 100 mm, the conical drum is 500 mm thick. In axes B/3-4; Г/3-4 and B-Г/2 cylindrical vaults are thickened (with development in the lower direction) up to 300 mm, forming stiffeners 900 mm wide.

The composite shell is supported by horizontal supporting edges on the wall fence of the temple through a monolithic reinforced concrete stiffening belt to which it is monolithically connected. The dimensions of the belt cross-section are 500×200 mm. Curved lines of cylindrical vaults freely rest on the arch of the wall fence, excluding the western refectory wall.

3. Calculation model
The bearing capacity and deformability estimation of a covering design is made by a method of finite elements with use of program complex “Lira-SAPR”.

The computational model is a composite shell with different contours of the middle surfaces. Discretization of the continuum system is achieved by means of four- and triangular finite elements of the shell and two-node finite elements.

The finite element model of the shell is shown in figure 5.
Figure 5. Spatial finite element overlap model

The calculation of the system is based on the physical non-linearity of materials. When forming the finite element model we used physically nonlinear universal finite elements of the shell (№№ 241, 242, 244).

Geometric invariability of the system has been achieved by superimposing external relations: along the global Z axis in all units when resting on walls, excluding the cylindrical arch in the \( \Gamma - \frac{\beta}{2} \) axes. On one node of axes \( \Delta - \Gamma / 2 \) superimposed bonds \( X, Y, Z \); on one node in axes \( \beta - \frac{\beta}{2} \) of bonds \( Y, Z \).

Modules of elasticity of concrete in the overlap final elements are assigned in accordance with the class of concrete determined during natural examination by non-destructive methods.

The law of nonlinear deformation of concrete - № 35 is exponential (calculated strength). The law of nonlinear deformation of reinforcing material - № 11 is exponential. Geniev theory of strength is for reinforced concrete. Type of reinforcing inclusions is physical equivalent of a grid. The method of calculation of physically nonlinear problem is simple stepwise with the factor to loading on steps makes 0.05.

Calculation is made on the action of the calculated load from the own weight, including the dome and the drum which are not erected at the time of examination.

The analysis of the material state of the model shows that at the first step of loading the elements are mainly formed by lower cracks on the main sites. Concrete parts of the elements are destroyed under tension.

At the second step of loading, lower and upper cracks are formed in the elements along the main areas. In the single elements there was the destruction of the main material (concrete) in compression and crushing of compressed concrete on the upper and lower surfaces. On the fourth step of loading along with the increasing number of elements with lower and upper cracks on the main platforms and the destruction of concrete elements under tension and compression (in single elements); crushing of compressed concrete on the upper and lower surfaces (in single elements), the formation of plastic joints is observed. The tension in reinforcing material has reached the yield point (in single elements). Further the loading effect is characterized by an increase in the number of elements with stress-strain state described in the fourth loading step. In this case, the formation of plastic joints is observed only
in some elements. This is due to the fact that longitudinal forces prevail in the stressed state. The bending moments in the structural elements are negligible compared to the longitudinal forces. Destruction of the structure is fixed when the system has been transformed into geometrically variable.

Longitudinal forces, both tensile and compressive, predominate in the end elements of cylindrical arches. The highest longitudinal forces (compressive forces) in combination with bending moments occur at the rib supports in the direction of curved lines. The greatest bending moments occur in the final elements of the conical drum. Scoinson arches are mainly compressed in the vertical direction.

The analysis of the tensely deformed state of the shell shows that the end elements of cylindrical vaults are destroyed by tensile stresses (excluding the support parts of the stiffening edges, single elements at the supports and the joints of parts of the structure of the coating); the elements of the scoinson arches are destructed from compressive stress; in the elements of the conical drum destruction occurs mainly from tensile stresses, and in some areas destruction occurs from compressive stress. State of materials in the model at each step of loading is shown in figure 6 (red color and its shades - the destruction of elements under tension; blue color and its shades - the destruction of elements under compression).

**Figure 5.** The materials state in the model at each loading step
4. Conclusions

The end elements of cylindrical vaults are dominated by longitudinal forces, both tensile and compressive. The highest longitudinal forces (compressive forces) in combination with bending moments occur at the rib supports in the direction of curved lines. The greatest bending moments occur in the final elements of the conical drum. Scoinon arches are mainly compressed in the vertical direction.

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The performed calculations of a complex spatial system in a physically nonlinear setting taking into account real deformation properties of concrete and reinforcement allowed to determine the stress-strain state and bearing capacity of the overlap structure.

The recommendations on the final structure of the overlap were developed on the basis of calculations results.

References

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