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Original Scientific Paper

CONDITION ASSESSMENT AND STRUCTURAL REHABILITATION OF THE ST. NICHOLAS CHURCH IN CRNA TRAVA

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Abstract. *The paper analyzes the structural condition of the church dedicated to Saint Nicholas, which is located in the town of Crna Trava, in the south of Serbia. An architectural analysis of the observed structure is provided, as well as an overview of previous works on it, both research and rehabilitation and conservation. A detailed analysis of the structural system of the church is presented. The analysis and classification of the observed damages was performed, the works on the rehabilitation of the building were presented, and a proposal of further remedial measures was given with the aim of preventing further deterioration of the building.*

Key words: *barrel vault, damage, degradation, church, rehabilitation*

1. INTRODUCTION

The paper presents the church dedicated to St. Nicholas, which is located in the town of Crna Trava, the center of the municipality of the same name located in southern Serbia. According to most sources, the building was built during the 17th century. During its service life, and due to various cultural, political and economic changes that took place, the church building underwent certain changes. Rehabilitation works were carried out on several occasions, and during one of the stages of these works, static conditions changed over the vault of the church, which caused the appearance of a large number of cracks and fissures on it. The paper presents the recorded damages, which are classified according to the types of causes that led to their occurrence. The works on the rehabilitation of the structure performed during 2021 are presented. Also, a proposal of remedial measures was given in order to prevent further deterioration of the building.

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2. Description of the St. Nicholas Church Structure

The church complex of Saint Nicholas in Crna trava is located at the very entrance to the town, from the direction of Leskovac, on the left bank of the river Vlasina. The church yard is surrounded by a stone wall. The entrance to the port is on the north side, through a monumental stone gate. The church was built on a flat plateau above which, on the west and northwest sides, there is a somewhat steeper area which still has the role of a cemetery. The bell tower is located south of the church building, as well as the remains of the foundations of the destroyed parish home [1]. During 2020 and 2021, a new parish home was built on this place, for dual purposes. In addition to the multipurpose space intended for gathering believers, the building also contains living space intended for the priest.

The years of construction of the church are mentioned in 1565 and 1636. It was built by the local population, widely known Crna Trava builders. It is a single-nave church measuring 15x8 m. To the east is a semicircular apse on the outside and inside. The narthex on the west side was added in 1807-1808. year [1]. The nave is vaulted with a barrel vault, while above the apse there is a semi dome.

The main entrance to the church, which is not in use today, is on the west side, in the longitudinal axis of the building. There are two more doors in the north wall of the church. One is located in the north wall of the narthex, along the northwest corner of the building, while the others are placed centrally, in the middle of the nave. This door is today the main entrance to the church. During the life of the building, at one point the door was broken through on the south wall, near the altar space, which was walled up during the repair works [1, 2]. The interior of the church is covered with fresco paintings.

The church is built of stone, and the finish is mortar. After numerous renovation works, today the stone is visible on the north and west facades, with bagged joints, while the south and east facades are plastered and painted in ocher-beige shade. The roof covering was initially made of stone slabs, later of ceramide, and today it is a folded tile.

On the territory of the municipality, this is one of the most important buildings registered by the Institute for the Protection of Cultural Monuments as a building with monumental properties. The procedure of declaring this facility an immovable cultural property is in progress.

3. Historical Survey

The present day appearance of the building is the result of numerous renovations that it has undergone over time. The first renovation of this building was done at the beginning of the 19^{th} century, 1807-1808. In the part of the literature that concerns the history of Crna Trava, these years are even referred to as the years of building the church, and not renovating it [2]

For a number of years, the local population did not show interest in rebuilding the church, so it was almost completely ruined and neglected. In one period, it was even used as a dwelling for the socially challenged population, and in an even more extreme case, as cattle barn. After the Second World War, the frescoes in the church were significantly damaged, when the frescoes were first roughly chipped, plastered, and the interior of the church was painted blue. Later, in 1988, Crna trava was hit by a great flood. On that occasion, due to the river Vlasina flooding outside its riverbed, the church yard gate remained under a thick layer of silt, which covered the lower parts of the church walls.

According to the documentation of ZZSK Nis, the first serious research and conservation-restoration works were carried out right after this flood, 1989-1993. After these works, the church regained its main function after a long time, that is, it was again put to use for worship.

During 1989, in addition to probing archeological works, works on cleaning the facade, making part of the sidewalk, reconstruction of the roof cornice were carried out, and the roof covering – ceramide was partially renewed. In the stage of works in 1990-1991, inadequate and subsequently added arches and pilasters in the narthex were removed, braces were added in the upper part of the building and thus static strengthening of the upper structure was performed, facade and window openings were treated, gutters were installed, sidewalk on the west and south side, a protective retaining wall on the west and part of the south side, as well as part of the fence wall on the southeast corner of the complex were constructed. During the stage of works in 1991-1993, the complete fence wall, entrance gate was completed, part of the gate along the fence wall was leveled, the portal of the southern door of the nave was reconstructed, and the entrance door of the church was made [1, 3].

Twenty years after the last works on the church, since 2012, works on the building have been carried out again, this time without cooperation with the competent Institute for the Cultural Heritage Protection. The roof was renovated, then the floor and the iconostasis, the openings were glazed, a new chandelier was installed, as well as the necessary inventory for the service. Since 2012, the church has been in function again. In 2020 and 2021, rehabilitation works were carried out to solve the drainage of water around the church (Fig. 1).

Fig. 1 The St. Nicholas church in Crna Trava (photo: P. Petronijević)

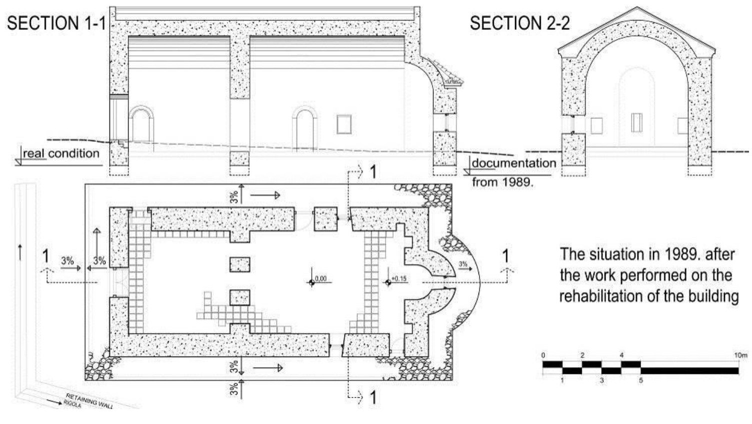

Fig. 2 Plan at the floor level, b) cross-section of a middle bay, condition from 1989, according to the documentation of ZZSK Niš

4. Description of the Structure – Structural Characteristics of the Building

The supporting structure of the church consists of bearing stone walls, about 100 cm thick. The windows are small in size and have flat end. Until the excavation of the probe pits in 2021, it was assumed that there were foundation strips under the walls, also made of stone, which were partially underpinned during the reconstruction in the period 1989-1991. The excavations determined a deviation in the depth of the foundation of the church walls in relation to the existing technical documentation of the ZZSK Nis from 1989. The depth of the foundation was on average 70 cm, and in relation to the available documentation, it is 50 cm smaller. Expansion of the walls in the form of foundation strips was not observed, as well as traces of previous underpinning of the foundations.

Above the entire building of the church, above the narthex and the nave is a barrel vault of stone. Above the vault is a wooden roof structure, with an inclination of about 30 degrees, in the form of a gabled roof, above which is a roof covering. The original stone covering was replaced with ceramide laid in crossbreed mortar, which was replaced during the last reconstruction with a folded tile placed on a wooden substructure. On that occasion, the method of supporting the roof on the vault structure was changed. The level of the roof planes was raised and tin flashing was added to the gable walls. The reactions of the vault are transmitted to the side walls, and due to the large horizontal forces that occur with such a system, metal braces were subsequently placed, in order to prevent the walls from spreading apart [4].

By a chronological analysis of the documentation of ZZSK Nis about the church, and based on the assessment of the condition of the wall masses of the church, it can be concluded that occasional and partial works on the rehabilitation did not give satisfactory results. After certain works in 1989, many years of complete neglect ensued. Thus, certain parts of the wall masses and the entire vault were brought into poor condition. So the church required significant reconstruction work.

5. Observed Damage to the Building

The assessment of the condition of the building was performed on the basis of a detailed visual inspection of the walls, vaults and roof structure. The walls were analyzed separately for direction. The outer and inner surfaces of the walls were observed, with the aim of locating places where there is a possibility of cracks propagating through the entire thickness of the wall [5]. Based on the collected data, the causes of cracks are defined and their further evolution is predicted. A comparison of crack maps in relation to the situation from 2017 was performed and critical causes of crack progression were defined. The cracks in the structure are, as a rule, a reflection of: the main stresses in it, the balance of internal forces, and the disturbances that have occurred in it over time. For this reason, significant data were obtained from monitoring damage propagation over time. This was done on the example of this facility after five years' time. During that period, the development of signs of instability was monitored, the phenomena of damage were interpreted and described, and the causes of their occurrence were identified.

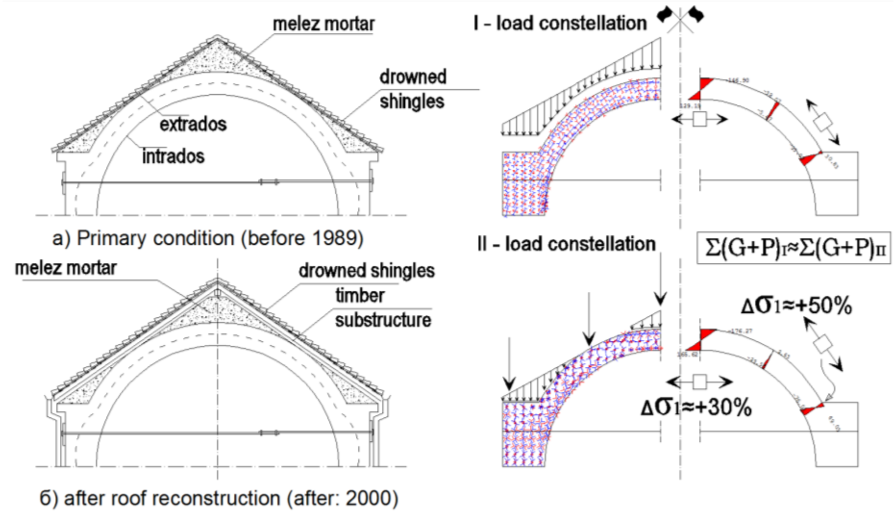

Fig. 3 Change of stress state in the vaults after the self-initiated reconstruction of the roof by the church board, (drawing: P. Petronijević).

The masonry construction of the church proved to be relatively stable, taking into account the time of its construction. Since the building is built of materials with a porous structure, the influence of moisture and frost is the dominant deterioration factor in the ground level parts of the walls. Inadequate maintenance, as well as long-term neglect and exposure to weather have caused significant structural and non-structural damage to the building. In the parts of the wall close to the ground, the moisture caused the so-called biological corrosion, which is manifested by the appearance of fungi, lichens and moss on the facade, because these organisms can live only on a wet surface. By determining the type and degree of damage to the stone blocks, the initial traces of decay, erosion and flaking were observed [6]. The church does not have stone plastic and carved structural elements, so their damage was not even considered. Only the side entrances to the church are bordered with dressed stone, and the intense effects of algae and lichens can be seen on them.

During the last reconstruction, the method of load transfer to the vaults was changed from continuous to concentrated. The load from the wooden roof structure was transferred along the top of the vault in the form of linear reactions. Arched structures are sensitive to concentrated load, so that for the same total load, up to 50% higher tensile stresses created by bending are generated on the intrados of the vault (Fig: 3) [7,8].

The characteristic of stone masonry vaults is low tensile strength due to low tensile strength of the mortar and insufficient bond between the stone and the mortar [9]. The tensile strength of the vault depends on the type and quality of the mortar with which it is built, as well as the porosity, surface roughness of the stone and the geometric relationships of the stone used for masonry. The compressive strength of masonry vaults is considerable. Although local stone crushing can theoretically occur, global failure due to pressure is unlikely, because the compressive stresses are negligible in relation to the compressive strength of the vault. The cracks in the vault were created by the action of edge tensile stresses caused by bending (Fig: 4). The cracks extend mainly through the mortar and through the joints of mortar and stone.

Fig. 4 Cracking in the barrel vault of the st. Nicholas church, (photo: P. Petronijević)

The basic step for the assessment and identification of the causes is accomplished through the examination of visible signs of damage (cracks, fissures, crushing, settlement, ...). The analysis of structural instability was undertaken, and on the basis of the collected data, the causes of damage were defined and their further propagation was predicted. Based on the five-year evaluation, a design of necessary works, interventions, construction phases, checking of temporary status during rehabilitation and necessary funds for work was made.

Analysis of cracks and the study of the causes of cracks are the basis of the diagnostic problem. In order to obtain reliable results, all relevant data related to the structure in question must be taken. Vaults made of hewn stone consist of a number of elements that function by transmitting pressure forces from one to the other and transfer the entire resulting pressure to the retaining walls. In the church of St. Nicholas the vault was made in two layers, the intrados was built with relatively regular stone, which was locally accessible, and the upper layer of the vault was made of riprap. Arched structures constructed in this way are more sensitive to changes in the regime of gravitational load transfer as well as to seismic effects. Dominant cracks in the vault can be varied.

Longitudinal cracks occur mainly as a result of differential settlement or spacing out of supports. They form on the tensioned side of the plastic joint. They become dangerous only if there are significant horizontal movements of the retaining walls. Cracks at the junction of the vault with the support indicate the process of separation of the vaulted structure and the absence of the transfer of the entire pressure force to the wall. Transverse cracks usually occur at the junction with the transverse walls or at the end of the vault. They are the consequence of inadequately constructed vault-transverse wall connections and the absence of longitudinal constraint of the vault. In modern churches with this type of structure, the crowns of the walls must be strengthened with a horizontal reinforced (RC) concrete ring (Fig. 5).

Fig. 5 Reinforcement of the masonry vault with RC shell layer (photo: P. Petronijević)

The distribution of cross-sectional forces of arched structures depends on the geometry of the support line, the conditions of support and the load constellation. Asymmetric and concentrated loads are undesirable. Vaulted structures withstand pressure stresses well, which cause oblique reactions of supports. In order to ensure the desired behavior of the vault, the compression force must be as close as possible to the center of gravity of the cross section. The bending moment caused by the eccentricity of the normal force is considered a parasitic influence in arched structures [10]. The ideal shape of the support line is given by the inverted catenary equation [7]. Tension must be prevented, the resulting force must remain in the middle third of the height. The failure of the arches is caused by the occurrence of several plastic joints, which causes the system to become a mechanism.

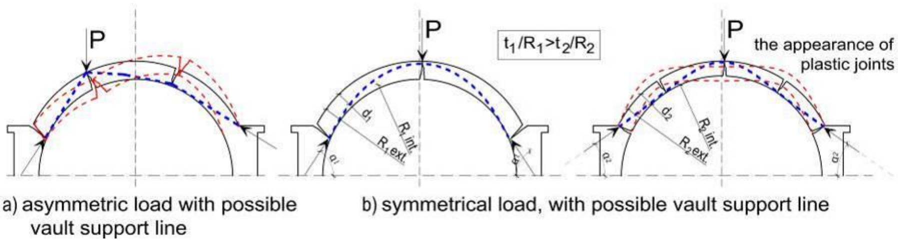

Fig. 6 Potential fracture mechanisms of barrel vault and arched structures [3]

The present damage to the vault is only partly a consequence of the concentration of load that occurred during the inadequate works in the last stage of the rehabilitation works, on the roof of the church. The bracings failure had the greatest effect on the onset and propagation of cracks in the vault. Bracings have the role of receiving the horizontal component of the oblique reactions of the arches. Thus, the longitudinal walls are entrusted exclusively with the vertical component of the reaction of the vaults, i.e. gravitational load.

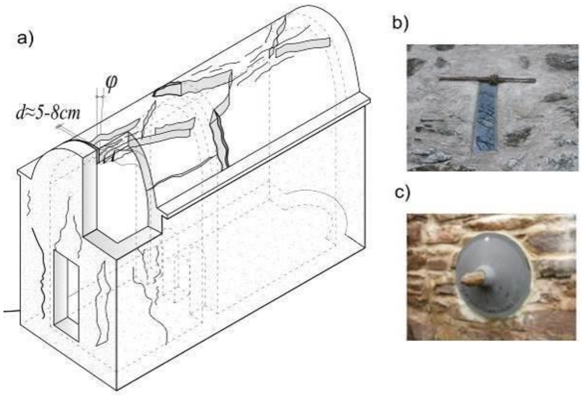

Fig. 7 a) mapping of cracks, b) influence of wall spacing and different settlement of supports on change of stress state and mechanism of barrel vault fracture [3]

The drop in the tensile force in the braces ensued due to loosening of the assembly joints, creep of the material, corrosion as well as inadequate anchoring on the outside of the longitudinal walls. Anchoring was realized with two steel members (see Fig. 7-b) in inadequate places, one brace even passing through the window. Anchoring did not include base plates so there is no possibility of subsequent force correction by increasing the tension. Arched structures are extremely sensitive to the spacing out of the supports. Braces failure and the walls spacing out at the height of the cornice by only 0.1% of the vault the span, increases the tangential tensile stress in the apex and the arch support several tens of times. This exceeds the tensile strength of the mortar multiple times, cracks and fissures occur and the supporting line of the vault is deformed depending on the number of newly formed plastic joints (see Fig. 8-a).

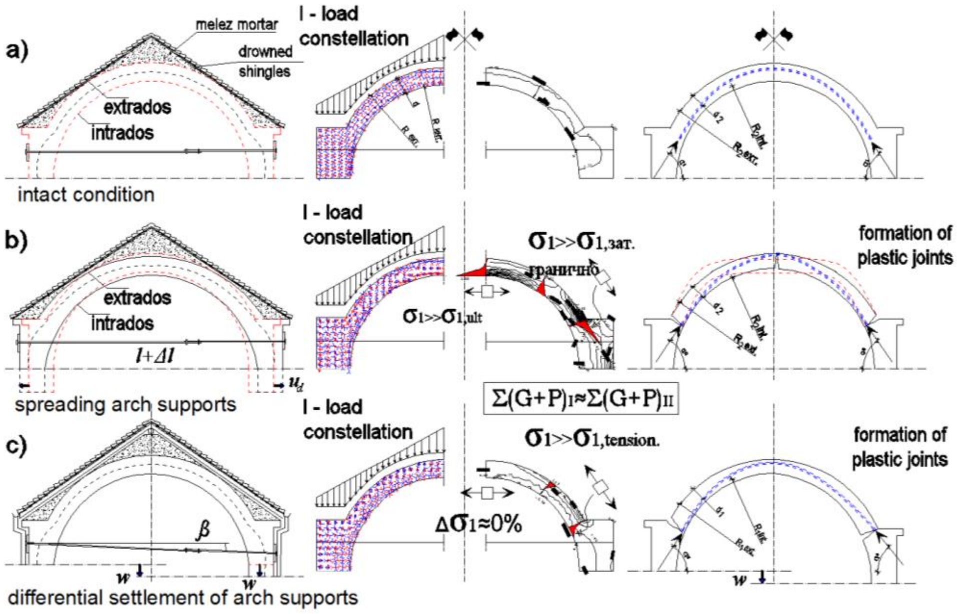

Fig. 8 The influence of wall spacing and different settlement of supports on the change of stress state and the mechanism of vault fracture [3]

The braces failure caused a widespread network of cracks in the vault, which creates a potential danger of their partial collapse. Vertical differential settlement of retaining walls has a significantly smaller impact on the change of stress state in the vault. The observed network of cracks does not indicate this phenomenon. The asymmetrical arrangement of cracks and significant areas of flaked mortar on the intrados of the nave vault occurred as a consequence of the roof leaking over a period of time.

Fig. 9 characteristic cracks between the vault and the transverse walls (photo. P.P.)

Since the walls are the supports of the vaults, their condition is vital for the stability of the structure. The depth to span ratio of the vaults is low so that the load from the roof and the own weight of the vaults are dominantly transmitted by normal forces inside the vault. Inefficient transverse bracing using metal members resulted in considerable spacing out of the support points of the vaults. This caused a flexural deformation that the structure of the vault built of stone is not able to receive. The spacing of the vaults caused the greatest consequences at the junction of the vaults with the transverse walls (Fig. 9).

Cracks in the longitudinal walls are present in places (Fig. 10), but they are significantly smaller in width than the cracks in the transverse walls. The width of the cracks registered in the longitudinal walls is up to 2 mm and is probably a consequence of the settlement of the foundations and climatic influences. In general, the causes of uneven settlement can be divided into the original ones, which stem from the inadequate dimensions of the foundations and the subsequent ones, which arose during the service of the building and are the result of water seeping into the foundations. The unevenness of the foundation soil below the building is excluded in this case. The variable depth of the foundations also had a negative effect on uneven settlements, because for the same width of the foundation strip, if the pressure is transferred to the deeper layers of the soil, the settlements are smaller. Extreme climatic conditions caused material fatigue and led to the onset of cracks of smaller or larger width. The highest concentration of cracks is at the junction of the walls in the corners of the narthex and is a consequence of the spaciong out of the arches and separation from the transverse walls (see Fig. 9).

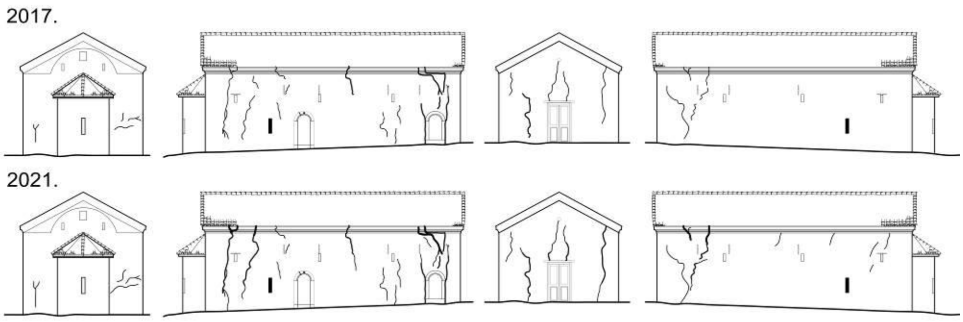

Fig. 10 Mapping cracks in the walls, condition from 2017-2021 (drawing: P. Petronijević)

Only the width of cracks larger than 5 mm indicates a significantly disrupted load-bearing structure and function of the walls and endangered stability of the vaults [6]. Although the current width of the cracks in the walls is not large, their arrangement and propagation in the last five years indicates the development of unfavorable processes. The existing map of cracks provides favorable preconditions for the occurrence of characteristic fracture mechanisms of walls during seismic actions. (Fig. 11). The possible unfavorable development of fracture mechanisms is significantly influenced by the absence of ring beams in the cornice and along the height of the wall.

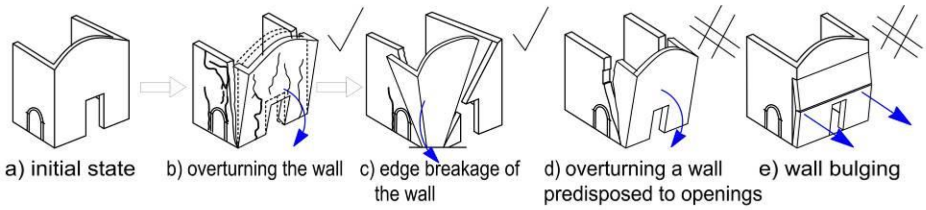

Fig. 11 Potential fracture mechanisms predisposed to the existing crack system

Horizontal movement of the cornice of the walls can be caused by: excessive horizontal component of the vault thrust force, rotational failure of the foundation structure, loss of tensile force in the braces, reduction of the vertical load. With the reduction of the horizontal load-bearing capacity of the wall and the spacing of the vault, a system of characteristic cracks appears within the deformed zone of the vault. Its manifestation is the separation of the vault from the walls, the occurrence of longitudinal cracks, and an increase in the deflection of the middle of the vault.

6. The Church Rehabilitation

Renovation of the supporting structure of the church of St. Nicholas was realized in 2021 and included the strengthening of the foundations of all external walls and the construction of a drainage system. The opening of the probing pits established a deviation in the depth of the foundation of the church walls in relation to the existing technical documentation of the ZZSK Nis from 1989 [1]. The depth of the foundation was on average 70 cm, and in relation to the available documentation, it is 50 cm smaller. The smaller depth of the foundation caused a greater degree of lateral displacement of the crown of the longitudinal walls due to the rotation of the foundation [see Fig. 12]. The longitudinal walls rotated slightly as rigid bodies. The rotation of the walls is more pronounced in the part of the narthex in relation to the nave because vertical cracks were recorded on the west façade. Further analysis of crack morphology concluded that the influence of frost and the formation of ice lenses has a significant impact on wall degradation because cracks in longitudinal walls are more numerous, sequential and extend continuously from the foundation to the crown of the wall. For that reason, and also because of the extremely difficult climatic conditions, it was necessary to increase the depth of the foundation below the freezing zone. The underpinning was realized in segments, the depth of the foundation was increased by an additional 50 cm, and an RC ring was formed on the outside of the walls. It has the role of receiving the tensile forces in the foundation zone of the walls. Reconstruction of the foundation in combination with the strengthening of the crown of the walls aims to increase the overall load-bearing capacity of the walls, which would provide secure support to the vault.

The excavated trench for the needs of strengthening the foundation was used to place a drainage ring around the entire building. Drainage was constructed using a typical system with perforated PVC pipes, covered with coarse-grained aggregate and lined with geotextile fabric. In parallel with the percolating water drainage channel, a system of surface drainage also capturing the water from the downpipes evacuating water from the church roof was also constructed.

Since moisture was the greatest danger to the quality and durability of stone and masonry structures, many causes of degradation of the church of St. Nicholas in Crna Trava were eliminated by waterproofing the foundations (see Fig. 13) and keeping the structure completely dry. Due to the effect of frost, the most common types of degradation of walls in the zone of capillary rise of water occurred: deterioration of the original mortar, deterioration of the repair mortar, disintegration of the foundation part of the wall and opening of caverns. Biodegradation was also not negligible. The plinth part of the walls turned green over time due to the moss and lichen, and over time grass also took root, further degrading the structure. The zone of plant penetration in the initial phase of works was cleaned to a height of 40 cm, with complete removal of biodegraded mortar which was replaced with repair mortar. For the restoration of the plinth wall, a mortar with a low salt content was used, which in terms of mechanical, chemical and structural properties approximately corresponds to the original material.

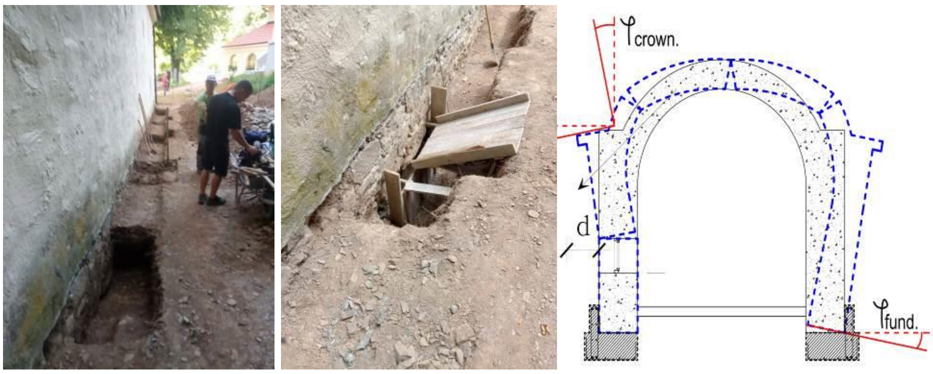

Fig. 12 Foundation underpinning

The potential of treating the walls with penetrating agents was limited due to the variety of applied stone and large deviations in porosity. Surface treatment of walls with penetrating agents without their penetration into the depth of the wall section can have negative effects. Water would continue to penetrate under the treated layers, but its evaporation would be prevented by the coating, so it can evaporate only under a certain layer, where soluble salts crystallize and cause degradation of the wall structure. Also, different humidity and thermodynamic properties would further accelerate the degradation of the wall. For that reason, low-viscosity polymer solutions applied with a pipe system, preferably under pressure, should be used for impregnation and conservation of foundation and plinth parts of walls. This type of protection is more effective with more porous stone walls. This improves many properties of the wall: it reduced capillary water absorption and improved frost resistance, while the quality parameters: water vapor diffusion coefficient, water vapor permeability, diffusion resistance coefficient did not change or changed within satisfactory limits.

The cause of the decay of the plaster is the absorption of moisture that is present on the facades during precipitation and in the vaults due to the leakage of the roof covering. The possibility of preventing the penetration of water into the walls by sealing surfaces with different types of synthetic materials should be taken with a reserve if the passage of water in the gaseous phase is prevented. Coating the wall prevents the penetration of water into the interior of the material, but prevents the water vapor diffusion flow because the material does not have sufficient vapor permeability. By choosing the right material, this phenomenon can be prevented. Silicate-based protective agents are most commonly used for this purpose. With these agents, the basic inorganic structure binds well to the inorganic substrate of the mortar and thus provides good permeability to gases. For efficient impregnation based on silicone agents, continuous application in several layers is necessary. With the correct choice of silicone agents and their adequate application, it is possible to slow down the process of deterioration of plaster and walls.

Fig. 13 a) reconstruction of the plinth wall, b) hydro-isolation, c) drainage (Photo P.P.)

The next step of the renovation includes the comprehensive repair of the vaults and the structural grouting of the stone walls. The way in which arched structures behave under static load is conditioned by several types of reinforcement. By changing the geometric shape (thickening of the arch), which affects the shape of the support line of the segments between the plastic joints. The goal is for the geometric shape to make the structure be predominantly stressed by compression, while the radial deformation and tension are limited. By increasing the thickness of the vault, the integrity is restored by removing the two plastic joints. The support line in the case of an arch with developed plastic joints touches the intrados and / or extrados, while with reinforcement it moves back within the geometry of the arch. If the vault shows visible deformations and the beginning of the development of the fracture mechanism, as in the case of the church of St. Nicholas, strengthening and rehabilitation require other types of intervention as well.

The method of strengthening the vault by increasing the thickness using the concrete saddle, despite its high efficiency, is used cautiously due to incompatibility of mechanical characteristics of concrete and that of the stone or brick vault, asymmetry of cross section and relatively destructiveness of the method [11]. The modulus of elasticity of masonry stone varies a lot and depends on the quality of the stone and the applied mortar, the type of bond and layering of the wall, the degree of stone dressing, etc. The efficiency of the solution largely depends on the degree of bond, so it is necessary to prepare the contact surface and apply anchors that resist the shear between the brick and the RC vault (see Fig. 14). Intrados shotcreting gives partial results in strengthening the vaults due to the small thickness of the additional layer. The method was popular in the 70s and 80s, but in this case it is not applicable so that the frescoes would be preserved.

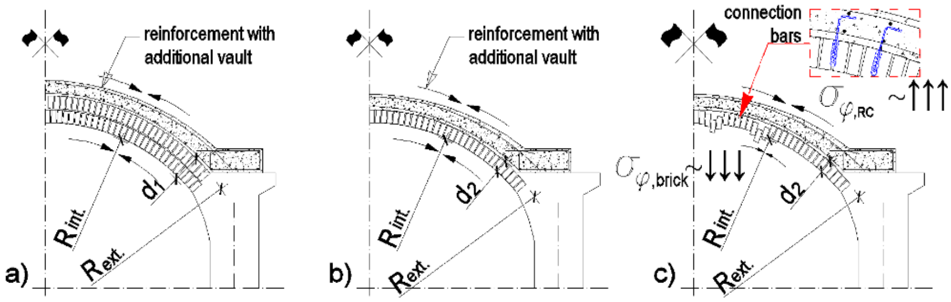

Fig. 14 Reinforcement with additional vault

Preservation of frescoes also prevents the application of composite polymers (fiber-reinforced polymer - FRP) on the intrados of vaults. In recent years, the application of FRP has been very common in the rehabilitation and strengthening of masonry and arch structures [8]. FRP reinforcement is very effective because it increases the tensile strength at the places of plastic joints. The method of reinforcement with steel arches is suitable for arches made of large stone blocks. An example of the successful strengthening of the vault with a series of steel arches is the construction of the Temple of Jupiter in Split. The absence of a massive cornice at the level of the arch support limits the application of this method in the case of St. Nicholas church. For that reason, the solution of strengthening the extrados of the vault with an additional layer of reinforced concrete with the addition of a more massive concrete ring beam is more favorable. This efficient solution has been applied many times in practice and is a common procedure for making vaults during the construction of new buildings (see Fig. 15). In this way, the structural response of the vault (load-strain) is significantly improved. Since it is not possible to influence the geometry of the vault during repairs, the stress state can be improved by changing the function of the added vault cross-section. Subsequent arch constraining is difficult to perform, so the support connection is considered hinged or elastically constrained. For most remediation procedures, a constant cross-section of the vault reinforcement is advantageous or it changes so that a larger mass is concentrated along the supports (the thicker the layer of concrete along the supporting walls) At the locations of cracks on the intrados, it is possible to use Polymer-reinforced fibers as these materials give higher tensile strength at the expense of a slight increase in weight [12]. For this purpose, Steel Reinforced Grout can also be used, which is also an effective solution for strengthening vaults in order to increase their load-bearing capacity and seismic resistance [13-15].

Fig. 15 a) Reinforcement of the vault extrados with steel arches, b) masonry vault reinforcement with additional RC vault (photo: P.P.)

7. Conclusion and Final Remarks

After the continuation of the research works on the church, which included probing the foundations and determining their depth, adequate bases were created for the preparation of design documentation for the foundation underpinning and the drainage system around the church. Structural rehabilitation of foundations and walls was realized, with the development of a drainage system for collecting and draining percolated and atmospheric water. In addition, the necessary works on the repair of the roof structure, the roof covering and the flashing were performed. In the next phase, works are planned on strengthening the vaults of the ceiling: by grouting, using repair mortars with the possible application of composite materials on the inside under the mortar, because the outer part of the church is made of stone. By grouting and joining, cracks in the vaults must be repaired and thus the harmful effects they cause on the material and structure must be eliminated. It is necessary to strengthen the entire vault by making an RC saddle on the extrados. It is necessary to repair the braces on the basic construction, do anti-corrosion protection and tighten them. It is desirable to change the anchor braces and replace the existing wedges with steel base plates. Cracks in arches and walls that extend along the entire thickness of the walls should be injected. Larger cracks in the vault are filled with repair polymer mortar. The repair of cracks in the transverse walls and vaults should be based on the installation of additional steel braces inside the nave and anchor them using the plates on the outside of the wall. The bracing of the longitudinal walls should be achieved with RC cerclage in the crown of the walls, which is also the completion of the reinforcement of the vault with RC saddle. These works should be carried out while preserving the visual integrity of the building. Conservation and restoration works are necessary on the interior fresco paintings. Subsequent layers of mortar should be removed, cracks should be grouted, semi-bonded parts of the mortar should be fixed and the painted layer should be retouched.

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PROCENA STANJA I KONSTRUKTIVNA SANACIJA CRKVE SV. NIKOLA U CRNOJ TRAVI

U radu je analizirano stanje konstrukcije crkve posvećene Svetom Nikoli, koja se nalazi u varošici Crna Trava, na jugu Srbije. Data je arhitektonska analiza posmatranog objekta, kao i pregled dosadašnjih radova na njemu, kako istraživačkih, tako i onih sanacionih i konzervatorskih. Prikazana je detaljna analiza konstruktivnog sklopa crkve. Izvršena je analiza i klasifikacija uočenih oštećenja, prikazani su radovi na rehabilitaciji objekta, a dat je i predlog daljih sanacionih mera sa ciljem sprečavanja daljeg propadanja objekta.

Ključne reči: *svod, oštećenja, degradacija, crkva, rehabilitacija*