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ISSUES AND METHODS OF RESTORATION OF KYIVAN RUS PERIOD FOUNDATION MASONRY

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Abstract

Analysis of the main problems of the emergency state of the monuments shows that the main problem of disrupting the equilibrium of the statics of the "footing-foundation-structure" system is the uneven subsidence of the foundations, weak foundation soils, moistening of the foundation soils due to the violation or absence of waterproofing. The subsidence of footings and foundations, changes in hydrogeological conditions, the absence of blind areas and disorganized drainage from the basement, ageing of masonry solutions, a decrease in the strength and bearing properties of stone, brick and plinthiform brick lead to an emergency state of stone walls, their deformation, moistening, destruction of masonry, the appearance of cracks. Unique monuments of the Kyivan Rus period have been preserved in Ukraine. Unfortunately, as a result of the Mongol-Tatar invasion and destruction of the period of atheism in the 1930s, only foundations or separate parts of many temples remained, and some temples were rebuilt during the Baroque period. From many unique monuments, only the foundations remained, in some, in addition to the foundations, walls and individual fragments remained. In this case, the main restoration task was the maximum preservation of artefacts – foundations, walls, side-chapels.

Keywords*: Kyivan Rus, authenticity, restoration, foundations, storage, museumification*

Introduction

Monuments of the period of Kyivan Rus play an important role in the cultural environment of Ukrainian cities and must be kept in an authentic form, which corresponds to international monument protective and restoration practices [1, 2]. At the same time, it does not exclude the improvement of existing restoration methods with the involvement of new modern materials that do not violate the state of the monuments, is relevant both for masonry foundations and for authentic wooden fragments of structures [1, 3-11].

These methods are constantly verified and confronted with conservation projects carried out also outside Ukraine. International contacts and research internships of researchers from other European countries allow the exchange of experience in the field of conservation of architectural monuments and urban planning. This is all the more important as the conservation community should unite and act together to protect the world heritage [12].

The results of archaeological research, surveys of existing buildings proved that from the 10th to the 14th century in objects of various functional purposes, mainly strip foundations with masonry of the "opus mixtum" type were arranged – rubble stone and plinthiform brick, rubble

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from boulders, rubble concrete (stone and plinthiform brick), from plinthiform brick, from limestone, from sandstone, from oak logs.

Typical authentic types of solid foundations were rubble (from large boulders 50–70cm), rubble concrete (broken plinthiform brick and boulders ranging in size from 50 to 70cm), from plinthiform brick on lime mortar or lime mortar with powdered overburnt brick mortar (the 12th century, the St. Michael's Golden-Domed Cathedral). It was a cross-belt strip system with brick and rubble masonry, where the intersections of the strips formed pillars – the foundations of the columns. The cross-section of the foundations of the 12th century is a layer-by-layer structure: the upper layer, 0.4 to 0.8m thick, is made of the plinthiform brick on lime mortar, the middle layer – up to 0.5 m – rubble concrete masonry on lime mortar, while as rubble stone were used boulders of 5 up to 20cm. The bottom layer, 1.2 to 1.5m thick, is made of cyclopean masonry of boulders with sizes from 20 to 70cm of irregular shape without mortar. The gaps between the stones are filled with local soil. Such foundations were built by digging upwardly widened foundation ditches and laying them on the bottom to distribute the efforts of wooden groundsills.

The problems of operating such a structural scheme were since as a result of not reaching the mortar to the lower layers of the rubble stone in the lower part of the foundations, cavities were created between the rubble stones and the adhesion between them decreased.

Another widespread type of Kyivan Rus foundations was assuredly strong foundations made of plinthiform bricks on lime and lime-clay mortars (the 12th century, St. Michael's Golden-Domed Cathedral).

The method consisted of laying brick footing on lime and lime-clay mortar on the entire height. The bases of the posts and strips did not have a bandage; it did not provide sufficient adhesion of the mortar to the brick; in some places such adhesion was completely absent. The brick in the masonry was marked by sufficient strength, but in some places, the fragile masonry of the Ancient Rus period from the plinthiform bricks had signs of destruction and the appearance of cracks.

The important information about the technique of laying Kyivan Rus foundations was obtained during the reproduction of Pyrohoshcha Dormition of the Mother of God Church on Podil in Kyiv. It was found out that the foundations of the Church of the Virgin of Pyrohoscha are of a strip type, made up of stone and plinthiform brick on pink lime mortar with powdered brick (pits 3–4). The foundation masonry from the level of 3.17 to 5.07m is made of stone and plinthiform brick using the "under trowel" technique without joint pointing, and 2–3 plinthiform bricks are made to level the masonry. The depth of the foundation in the Church of the Virgin of Pyrohoscha is much greater than the depth in other buildings of the 11th–13th centuries (it is 2.705 m from the edge of the foundation cut, and for comparison, the depth of the foundations of the Church of St. Cyril is up to 190cm). At the depths of 2.92 – 3.24m, during archaeological surveys, the masonry of the 12th century was revealed. It consists of four courses of plinthiform brick on the pink lime mortar with powdered brick. The masonry from 5.07 to 5.785m was carried out with rubble stone "under grouting". The width of the foundation significantly exceeds the width of the southern wall of the building, in turn, creates a cut off concerning the outer surface of the wall up to 45cm, which serves as the basis for the pilaster-strips and half-columns.

The walls are made of plinthiform bricks using the technique of even masonry on the pink lime mortar with powdered brick. The outer walls are laid in one course of plinthiform bricks, and the masonry in the thickness of the wall is made of plinthiform bricks, which had significant losses, or broken plinthiform bricks. Some plinthiform bricks have ornamental tracks of straight or wavy lines, some of them have marks on the grooves in the form of crosses.

Thus, a comparison between different types of masonry of Kyivan Rus temples of the different periods indicates the existence of different masonry techniques.

The authors analyzed the database of sources related to various aspects of restoration and monument protective activity. Thus, a separate group of sources related to the preservation of the cultural environment and counteraction to its degradation [1, 2], the modern restoration techniques and technologies in different countries of the world were analysed [3-13].

The national restoration techniques were analyzed according to the publications of A.Ye. Antoniuk [14, 15] and the manuals of Ukrrestavratsiia Corporation [16]. A separate group consisted of scientific sources dedicated directly to the specific architectural monuments of the Kyivan Rus era [17-21]. We also analyzed publications devoted to the reproduction of defensive structures based on chronicle evidence, in particular, the fortress in Poltava [22]. The processing of the source database made it possible to identify aspects little known to the general public, in particular:

1) the need to include the described practical experience of Ukrrestavratsiia Corporation in the global restoration base since even within Ukraine, most of the information is narrow-profile project documentation, inaccessible to the general public;

2) the need to single out one aspect – the state and elimination of the emergency state of authentic Kyivan Rus foundations – which is the main one for ensuring the statics of an architectural monument and at the same time is covered mainly in project documentation, and not in professional scientific publications.

Materials and Methods

The research methods for the restoration of architectural objects largely coincide with general scientific methods. The choice of methods is determined by a set of procedures and research objectives. Traditionally, the method of historical analysis, the method of comparative analysis, iconographic and graphic-and-analytical methods and others are used. To a large extent, all these methods are used in restoration science when conducting field surveys of a monument with the processing of primary materials (preceding the restoration and reconstruction work), complex architectural, archaeological and engineering-geological surveys of a landmark and the adjacent territory. Besides, archival iconographic and written sources are used as basic sources for substantiating the composition and content of restoration work (especially in the case of the partial or complete destruction of the object or after numerous reconstructions and loss of authenticity). The methodological principle that united the listed research methods turned out to be a systematic approach, which does not consider phenomena in general, but distributes them into groups: the principles of integrity, suggests considering physical objects or processes as a whole, is divided into components, and the principle of outstanding features, which suggests that to solve certain tasks (problems), it is precisely the defining – the main features – the criteria by which the procedures for structuring objects, in particular objects of architecture, are performed.

Results and discussion

Restoration materials and technologies are selected in such a way as not to disrupt the original structure of the monument if it has been preserved in full or in part (as was done in St. Volodymyr's Cathedral in Chersonesos), and to include new materials and structures in joint work with the old masonry, if the monument it underwent severe destruction (as was done in the Assumption Cathedral with the John the Theological side-altar) or only the foundations with several rows of masonry walls remained (as in the St. Michael's Golden-Domed Cathedral).

Considering the emergency state of most of the foundations of buildings of the Ancient Rus period and the fact that from some of them due to destruction only damaged foundations remained (Pyrohoshcha Dormition of the Mother of God Church in Podil, St. Michael's Golden-Domed Cathedral, most of the Assumption Cathedral of the Kyiv-Pechersk Lavra), which did not allow to put superstructure on them during the reproduction, in each case, recommendations were developed to strengthen the footings and foundations that preceded other restoration measures.

For each type of foundation, various reinforcement options are used [14]. So, strip rubble foundations on the lime mortar and the lime mortar with powdered overburnt bricks can be strengthened by expanding the footing, cementation, root piles with a monolithic reinforced concrete raft, jacked piles with a reinforced concrete raft, bored piles and bored piles with a

monolithic reinforced concrete raft and monolithic frames. Strip rubble concrete foundations on lime mortar can be strengthened by expanding the footing, cementation, root piles with a monolithic reinforced concrete raft, jacked piles with a monolithic reinforced concrete raft, bored piles and bored piles with a monolithic reinforced concrete raft and monolithic frames. Strip foundations from plinthiform bricks on lime and lime-clay mortars can be strengthened by expanding the footing, cementation, root piles with a monolithic reinforced concrete raft, jacked piles with a monolithic reinforced concrete raft, bored piles and bored piles with a monolithic reinforced concrete raft and monolithic frames.

It is possible to use root outrigger piles on both sides of foundations with crossbeams, jacked piles, which are arranged by pressing short sections of metal pipes using jacks and transfer forces to the base of the foundation, root piles with a diameter of 120 – 250mm.

From the point of view of the disadvantages of traditional reinforcement methods, some advantages will be gained by the method of reinforcing authentic bases and foundations with root piles [16]. For the installation of such piles, on one side of the wall at an insignificant angle of 15–19º to the vertical, holes-wells are drilled in the foundation and further in the soil to the mark of reliable rocks, reinforcement or reinforcement cage is installed in each hole and these holes are filled with a cement-sand mortar, in an obturator is inserted into the well and the cement grout is supplied under pressure of 0.5kN. This method was widely used in Italy by F. Lizzie. In the future, at the same angle on the other side of the wall, they arrange similar piles with their displaced location. Foundation masonry of insufficient strength is fixed by injection under pressure of cement grout or cement-sand mortar. So, thanks to this technology, under the building to be restored, it seems like supports, rigid roots in the soil (hence the name – root-shaped piles), which transfer most of the loads to the denser soil layers.

In the practice of the national restoration, piles with a diameter of 132–200mm were used (the largest in the St. Michael's Golden-Domed Cathedral and the Assumption Cathedral of the Kyiv-Pechersk Lavra, less in other objects), 12–26.5m long (the greatest length of piles is in the Transfiguration Cathedral in Novhorod-Siverskyi, the smallest in the St. Michael's Golden-Domed Cathedral in Kyiv); the largest number of bored piles were used in the Assumption Cathedral of the Kyiv-Pechersk Lavra [20, 21]. In general, the length of the pile was determined by the depth of the strong soils in which the piles were to pass, and the number of piles depended on the size of the object in the plan, the volume of the structure, and then the predicted loads. While observing the general technology of drilling bored root piles, each specific technology was developed for a particular task. Namely, the well was drilled to different depths.

In the Assumption Cathedral of Kyiv-Pechersk Lavra in the central part, where the 12th century's foundations and burial along with them have been preserved, on both sides, they used the method of installing jacked piles through the middle of the body of the foundation itself. First, a reinforced concrete raft was installed on the top of the foundations with holes for piling. Then, wells were drilled through the body of the foundation to its bottom and 500mm lower. Then, the foundation body itself was strengthened by injecting a cement-sand mortar under a pressure of 0.1–0.5MPa. After 24 hours, a well was drilled again through the foundation to the bottom (at the same place) and the casing was inserted, crushed with jacks, to a constant mark. It was done to ensure the passage of ground and surface waters under the cathedral towards the Dnipro River. Next, reinforcement frames were inserted into the pipes and filled with a cement-sand mortar in a ratio of 1: 1.5: 0.4 ÷ 0.5 (cement, sand, water).

Over the past decades, the destroyed St. Michael's Golden-Domed Monastery, the Assumption Cathedral of Kyiv-Pechersk Lavra, the Church of the Virgin of Pyrohoscha in Podil [20, 21] have been restored.

A peculiar feature of the masonry of the Kyivan Rus part of the St. Michael's Golden-Domed Cathedral was the use of rubble stone on opus signinum (the lime mortar with powdered overburnt brick) [21] and a system of strip foundations was used. At the same time, the cross-section view of the foundation masonry proved its layered structure, that is, the lower layer was made using the technique of cyclopean masonry with stones of different sizes of irregular shape without mortar between them (the gaps were filled with soil); the middle layer was with

masonry from broken plinthiform bricks and small stones on a lime mortar; the upper – from plinthiform bricks on the lime mortar. It confirms the fact that even within the same building and at the same time, different laying techniques were used for the given task [20, 21].

According to the historical periodization, the architecture of Kyivan Rus is divided into three main periods, and if the first period was marked by the complete borrowing of the Byzantine-Roman building techniques, then in the second period, when the earliest version of the St. Michael's Golden-Domed Cathedral was being built, local builders were actively experimenting with masonry techniques and masonry solutions, with different chemical constituents, which made it possible to consider the Kyivan Rus era as the most fruitful in the development of new masonry technologies in comparison with subsequent centuries.

The archaeological studies have established the presence of strip foundations of the 11th – 13th centuries with the use of local burnt bricks on lime and lime-clay mortar. It was found out that the foundations of the western and northern walls of the western vestibule were made of broken bricks and rubble stone on the opus signinum mortar. In the northern wall of the northern aisle, it was used rubble stone and broken plinthiform bricks from the Ancient Rus parts dismantled during the expansion of the cathedral on the lime mortar with powdered overburnt brick. According to the studies, the destruction caused by the explosion of the cathedral had different effects on different parts of the cathedral: there were areas of foundations made of bricks with mortar, which mainly retained their strength; areas with no adhesion between plinthiform brick and mortar or damaged plinthiform brick; parts of the foundation masonry with a combination of plinthiform bricks and boulders on the mortar were brittle and covered with cracks; in some places, the foundations were not preserved [20].

The depth of the soles of the foundations within the framework of the plan of the cathedral was different: the depth of the soles of the foundations of flying buttresses was 2.50–2.75m, the soles of the foundations of the apses were 1.50–1.60m, the central apse was 2.16m, in the centre of the wall was 2.32m, the northern aisle – 0.60m [20] (Fig. 1).

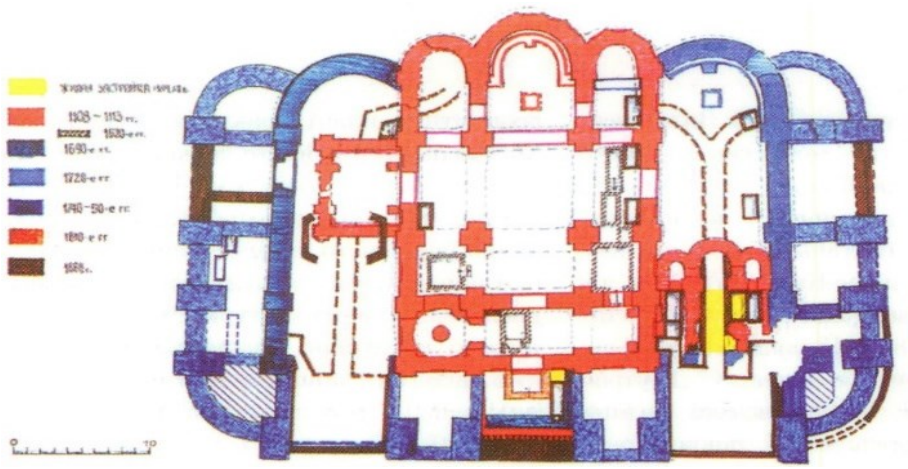

Fig. 1. Drawings of the foundations of the St. Michael's Golden-Domed Cathedral.
The photo from the archive of Ukrrestavratsiia Corporation. Red colour – foundations of Kyivan Rus period, blue colour - foundations of Baroque period.

When developing solutions for strengthening the foundations of the St. Michael's Golden-Domed Cathedral, several options for the preparation of foundations, fixing and arrangement of foundations were processed: consolidation of soils of the foundation of various types (cementation, silicatization, etc.), construction of foundations from piles of various types (roo-like, bored, jacked) with an independent reinforced concrete raft, strengthening of the existing foundations in various ways (injection of brick and polymer mortars, making the reinforced dowels, etc.).

In addition to the loads from the superstructure, the own weight of the structures of the underground part was also assigned to the foundation system. The parameters obtained from the results of the analysis of the physical, mechanical and strength characteristics of the soil layer at the construction site are included in the input data for calculating the base for the first and the second groups of limit states.

For a more detailed analysis of the stress-strain state, each of the above-described foundation systems was calculated taking into account the moisture of the soils from three local sources of moisture.

To strengthen the old foundations of the St. Michael's Golden-Domed Cathedral, special piles were used to transfer loads to the lower reliable soil layers from the new reinforced concrete raft.

In July 1996, the ruins of the St. Michael's Golden-Domed Cathedral were examined, and after obtaining the chemical and technological results, the data of architects and archaeologists, a set of priority measures began to preserve the remains of the cathedral's foundation. The first stage of this work was the conservation of the ancient masonry and their strengthening, carried out during 1996–1997.

As a result of the research carried out, the following was found.

The territory on which the buildings of the St. Michael's Monastery, subjecting to restoration, is in difficult engineering and geological conditions, due to the presence of weak heterogeneous soils directly under the foundation base. For the cathedral, under a load of existing foundations, maximum subsidence of up to 40 cm was possible, which is unacceptable for buildings. The restoration of structures in such hydrogeological conditions was impossible without additional measures to strengthen structures and foundations for the perception of significant uneven settlements.

The state of the masonry of the remains of the foundations was assessed as unsatisfactory due to the lack of adhesion between the mortar and the masonry, the inhomogeneous state of the strength of the brick – in some places the brick is fragile, the presence of cracks in the masonry of the bearing parts, the inclination and buckling of certain sections of the foundations of the posts and strips, the absence of dressings in the masonry, and between the cross ribbons, the presence of voids and the weakening of the gallery passages. The walls of the crypts and burials are located between the foundation strips of the cathedral. The quality of the masonry declined since the foundations were open, unprotected from temperature fluctuations during the 1996–1997 excavations.

The soils of the foundation under the foundations and between them were disturbed as a result of archaeological work and the opening of pits for soil research during engineering and geological surveys. Taking into account the above, the existing strip foundations of the cathedral could not be used without their strengthening as load-bearing structures for reproducing the building. Calculations have shown that when constructing shallow foundations at the level of the footing of the existing remains of the cathedral foundations, additional structural measures are needed in the superstructure of the building to perceive uneven deformations of the foundation.

In the final option, root piles, bored piles and jacked piles were used to reinforce the old foundations and to transfer loads from the reinforced concrete grillage, that provides joint flexible operation of the existing foundations and piles to the lower reliable soil layers. The root piles were installed next to the old footings; it was possible to ensure the reliability of the wall and access to old foundations through special holes in the grillage slab. The root piles with a diameter of 500 mm were used in the central part of the cathedral, that carries the most massive load; the bored piles with a diameter of 200 mm and jacked piles were used in the aisles (Figs. 2 and 3).

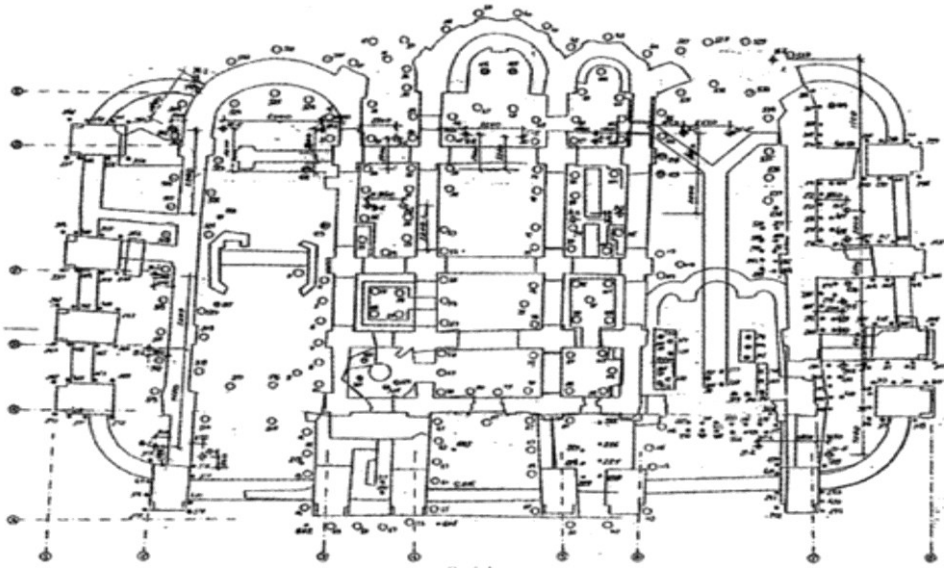

Fig. 2. The layout of the piles in the St. Michael's Golden-Domed Cathedral. Piles (circles in plan) strengthen the original foundations and located along their lines
From the archive of Ukrrestavratsiia Corporation

Fig. 3. The reproduction process of the St. Michael's Golden-Domed Cathedral.
From the archive of Ukrrestavratsiia Corporation.

An even more difficult task concerned the reproduction of the Assumption Cathedral of Kyiv-Pechersk Monastery. During the temporary occupation of Kyiv in 1941–1943, on November 3, 1941, the Assumption Cathedral was blown up [21-24]. The specificity of this site

was in the different depths of the basement heels, and the different timing of the individual parts affected the use of different types of mason work (Fig. 4).

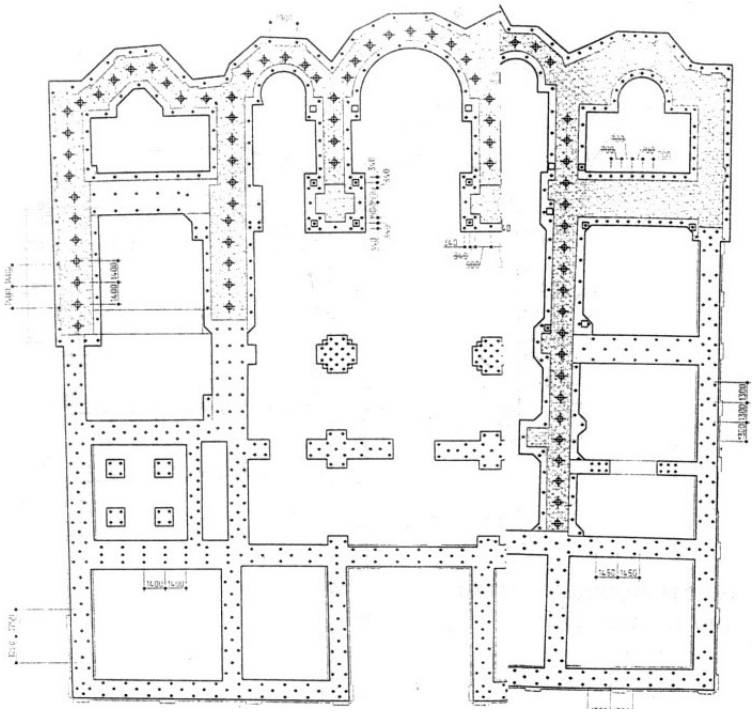

Fig. 4. The plan of the foundations of the Assumption Cathedral.
From the archive of Ukrrestavratsiia Corporation

Among the building materials of the foundations, sandstone, plinthiform brick, the lime mortar with the addition of powdered ceramics, lime-sand, lime mortar with powdered overburnt brick and lime-sand mortar with the addition of white brick of the 18th century were used (Fig. 5). According to the research carried out, such a refined periodization of the construction of the cathedral was adopted, where the first of the seven three periods concerned the times of Kyivan Rus: the first period (1073–1109), the second period (1109–the second half of the 12th century), the third period (the 13th–15th centuries). In the first period of construction, three stages are distinguished: 1073–1087, 1088–1089 and 1090-s–1109 years.

Before the baptism of Kyivan Rus, the local population built exclusively from wood. For wooden construction, they used half-round log cabins and log cabins, with the types of knitting of wooden logs “in a cage” and “upward”, with the main methods – the horizontal arrangement of logs in the form of a cage and the vertical arrangement of logs next to each other as a palisade [23].

The log structure of the wooden buildings of Kyivan Rus was characterized by static and immutability, which made it virtually unnecessary to lay foundations under them. Based on the model of residential buildings, the early wooden churches of Kyivan Rus were built exclusively by local craftsmen and were placed on logs-pillars, placed vertically, and the pillars themselves were protected by wooden covers.

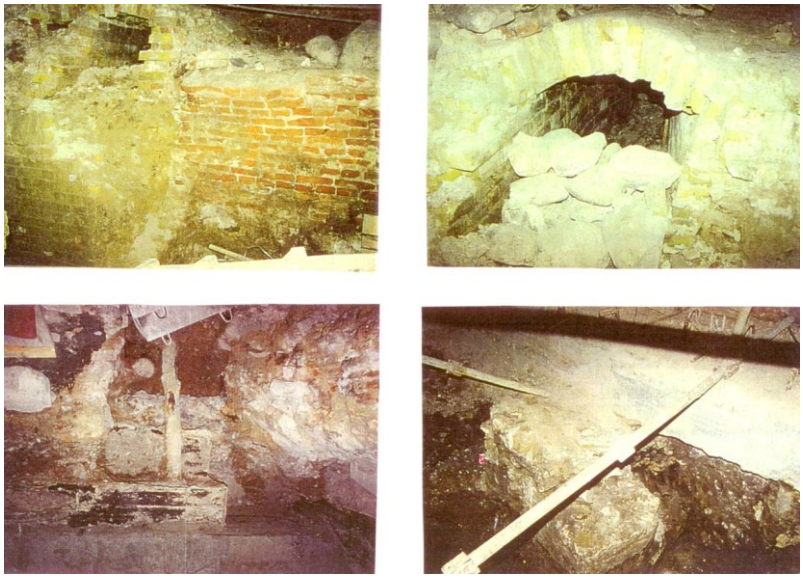

Fig. 5. Authentic foundations of the Assumption Cathedral.
The photo from the archive of Ukrrestavratsiia Corporation.

Traditionally, the first lower crown of the log walls was placed on the pillars of the foundations, which had a small depth of the lower part, but always – almost below the level of freezing of the soil. We learn about the foundation system of wooden Kyivan Rus buildings primarily from the materials of archaeological excavations, since their schematic images in the annals provide only approximate information about the appearance of iconic objects, and even then, they are inaccurate.

In contrast to the brick buildings of Kyivan Rus, authentic wooden structures of those times have not been preserved, archaeologists find only individual fragments of wooden walls and foundations, and on their basis, it is possible to make approximate reconstructions of the structural schemes of foundations and walls.

Much more information on building technologies can be obtained in the case of the remains of stone buildings. As already noted, the early stage in the history of the Assumption Cathedral is associated with the use of traditional Roman-Byzantine building techniques with the use of plinthiform brick and boulders, in the “opus mixtum” technique with a recessed course of bricks, and with the use of ”opus signinum” mortar according to Greco-Byzantine technologies, when a lime binder was supplied with powdered overburnt bricks, as well as ceramics, the so-called ”opus signinum” [17-21].

A similar construction technology using the lime mortar with powdered brick existed in Kyivan Rus from the 10th to the 13th century. The territory on which the Assumption Cathedral is located was conventionally divided into three zones: a zone of complete destruction within the epicentre of the explosion, a zone of significant destruction with the remains of ancient walls and a zone of partial destruction with the St. John the Theological side-chapel, which survived after the explosion [17-21].

The complexity of the tasks was that a significant part of the ruins turned out to be split into separate elements and deformed, and according to the restoration requirements, all the remains of ancient structures had to be preserved and provided with the possibility of their further study. Besides, the St. John the Theological side-chapel/aisle was in serious emergency condition.

The research of the state of foundations by the electric wave method, carried out earlier by the Scientific Research Institute of Building Structures, made it possible to identify defects in the body of some foundations. The foundations under the northern wall of the 11th century

had significant damage. Cracks, displacements and potholes were recorded in the strip foundations between the north wall and the northwest dome column. Cracks and potholes in the masonry were also recorded in the foundations of the southern wall. The foundations in the northwestern corner of the sacristy were in relatively good condition.

The difficulty was also in the fact that the depth of the foundations in different parts of the cathedral was different [17-21].

It was noted that plinthiform bricks and mortars of the 11th century are among the most durable among the monuments of Kyivan Rus of the pre-Mongol period, therefore, the re-preservation of the remains of the cathedral`s masonry from the upper layer should be done urgently to use the summer period to dry the entire spot of the cathedral. The masonry block for the pylon of the 11th century was proposed to take out of the cathedral spot, conserve it and preserve it as a kind of memory of the destroyed unique structure.

The most critical issues arose in connection with the methods of strengthening the foundations of the cathedral. The arrangement of strip foundations would destroy the archaeological layer at the site of the cathedral's existence and would not guarantee the reliability of structures (even reliefs), given the very difficult geological conditions and the need to preserve the remains of the cathedral. Due to the difference in views, the further design was stopped.

The work program provided for scientific research to study the engineering-geological and hydrogeological situation not only "under the spot" of the Assumption Cathedral, but also the adjacent territory of the Upper Lavra with the buildings located on it and to determine the impact of the restoration of the cathedral on the adjacent buildings and the overall stability of the Upper Lavra platform [21].

The restoration work was preceded by measures to strengthen the foundation of the building, strengthening the foundations and authentic parts of the cathedral with their inclusion in a single structural system. The solution to the project provided for the possibility of exhibiting the existing remains of walls and foundations and were aimed at maximizing the preservation of the cultural layer.

The complexity of the task of restoring the Assumption Cathedral was that a significant part of the ruins was split into separate elements and deformed. Following the restoration requirements, all ancient structures had to be preserved and provided with the possibility of their further research [19, 21].

Taking into account the difficult geological conditions (the presence of loess soils under the foundations of the Assumption Cathedral), it was decided to pass the piles through the existing rubble foundations without touching the burial. Due to the significant complexity of the work on their implementation, only specialists from Ukrrestavratsiia Corporation undertook. They drilled the authentic foundations of the central part of the Assumption Cathedral by crushing the piles in metal casing pipes, without disturbing the "cultural layer" with a large number of burials (Figs. 6 and 7).

The piling technology was carried out in a similar sequence, in particular, along with the entire height of the foundation and 500mm below the level of the base, the foundation was cemented, and then after 2 days, the well was re-drilled to the design depth. A reinforcement cage, an injector pipe was installed in the well, along which filling with a cement-sand mortar "from the bottom up" took place, the well obturator was installed, and then the well was pressurized under pressure and the solution was topped up to the design level.

To strengthen the ancient foundations of the Assumption Cathedral, bored injection piles were used: inclined at an angle of 10–15º and a diameter of 200mm and vertical jacked piles with a diameter of 200mm. The reinforced concrete raft was built on a floor of piles and the remains of foundations. Before installing the piles, the foundations were cemented by injecting the special solution. The piles passed through the remains of the foundations and were pushed into the depth to a length of up to 20m. The need to create a deformation-free foundation due to the piles was due to the need to transfer loads from the existing walls and pylons to the lower reliable soil layers.

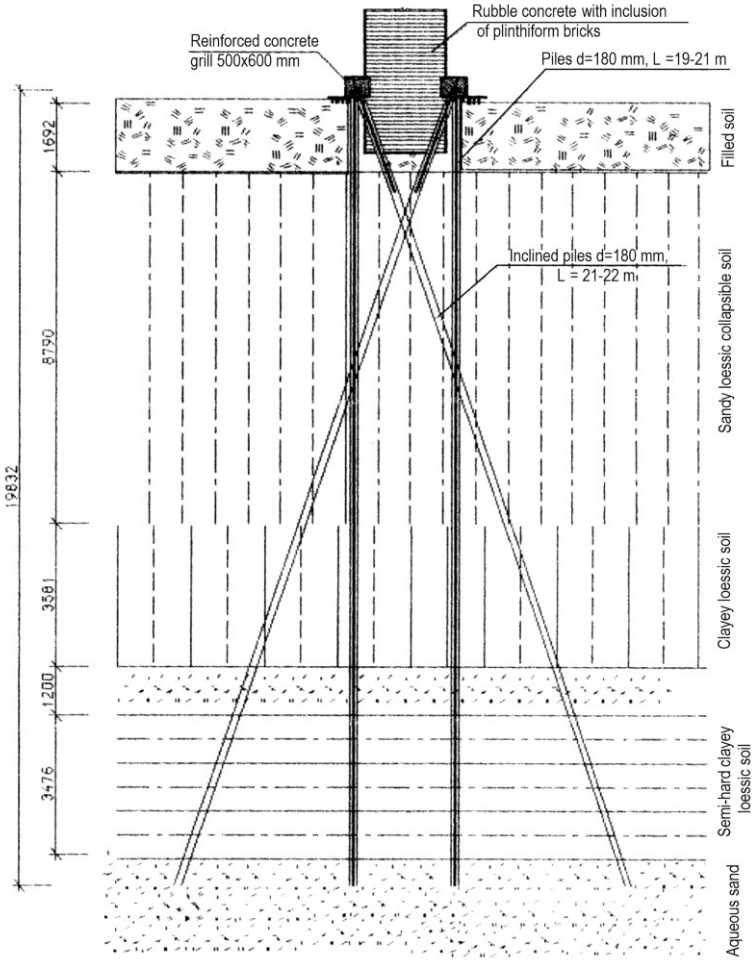

Fig. 6. The scheme of reinforcing pile arrangement in the Assumption Cathedral.
[the archive of Ukrrestavratsiia Corporation]

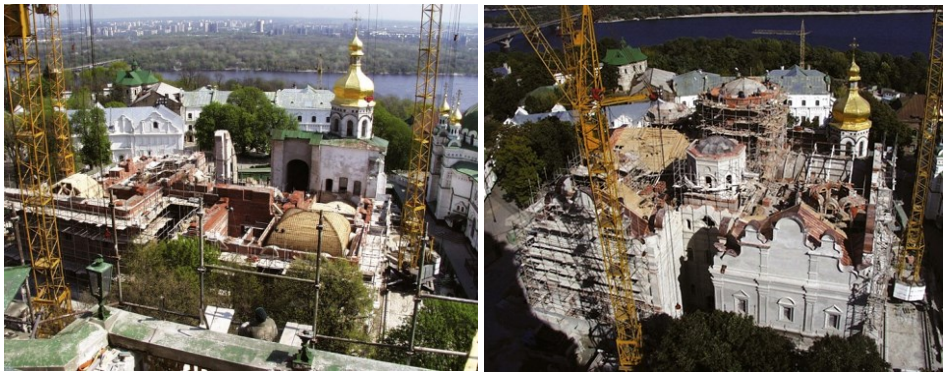

Fig. 7. The process of reproduction of the Assumption Cathedral.
[the archive of Ukrrestavratsiia Corporation]

In figures 8 and 9 are presented two examples of monolithic reinforced concrete raft, respectively Assumption Cathedral of Kyiv-Pechersk Lavra afer the works.

Fig. 8. The fragment of the monolithic reinforced concrete raft.
[the archive of Ukrrestavratsiia Corporation]

Fig. 9. Assumption Cathedral of Kyiv-Pechersk Lavra nowaydays.

Conclusions

The authors drew attention to only one aspect related to the strengthening of authentic foundations of the Kyivan Rus period, since the main problem of violation of the static structure of a building is the uneven subsidence of the foundations, weak foundation soils, wetting of the foundation soils due to the violation or absence of waterproofing, violation of the static of the "footing – foundation – structure" system. In the national restoration, the following methods are used to strengthen the foundations: the expansion of the base; additional laying of the foundation; laying the foundation with pillars in wells; reinforcement with bored, jacked and root-like injection piles. Reproduction of outstanding monuments proved the effectiveness of the use of bored piles and piles of various types combined with a monolithic reinforced concrete raft on top of them.

In the St. Michael's Golden-Domed Cathedral, bored piles (in the central part of the cathedral), bored injections and piles and jacked piles (in the side aisles) were arranged next to the authentic foundations, and on top of them, there was a monolithic reinforced concrete slab with

holes for further museumification of the foundations (Fig. 8).

The need to create a deformation-free base due to bored root piles was caused by the need to transfer loads from authentic walls and pylons to the lower reliable soil layers. To strengthen the authentic foundations of the Assumption Cathedral, bored root and jacked piles were used. The reinforced concrete raft was built over the piles and the remains of foundations.

On the example of two objects that are unique in their importance and complexity of the work – the St. Michael's Golden-Domed Cathedral and the Assumption Cathedral of Kyiv-Pechersk Lavra (Fig. 9), we demonstrated two options for using a combination of different types of piles to strengthen old foundations: vertical and inclined bored and jacked in the Assumption Cathedral; bored, root and jacked in the St. Michael's Golden-Domed Cathedral.

In conclusion, it should also be noted that the research presented above was partially carried out during the research internship. This internship also consisted in the exchange of experiences in the field of the conservation process carried out on historic buildings outside Ukraine, especially in Poland, where similar problems are observed with the conservation of historic buildings and their access and adaptation for visitors.

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