Volume 3, Issue 3, March - 2025 **ISSN(E):** 2938-3773

RESEARCH ON MATERIALS USED IN THE CONSTRUCTION OF ARCHITECTURAL MONUMENTS

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Abstract
Further comprehensive study of the structures of civil buildings erected in the late XIX and early XX centuries, included in the list of protection of architectural monuments of Bukhara and materials used in their construction, has great scientific and practical significance. This article presents the results of studying the architectural designs of some interesting monuments of Bukhara architecture, for the tourists mentioned above. The compressive strengths of bricks and masonry mortars used in the construction of foundations and walls of buildings were investigated.

Keywords: Design, Construction Materials, architectural monuments, seismic resistance, solution, masonry, clay gypsum, evil knitting «kyry», clay potatoes, known.

Introduction

The position of a state in the global community is determined not only by the volume of its gross domestic product but also by the scale of its cultural heritage and the level of folk architecture. A prime example of this is the cultural monuments in the countries along the Great Silk Road, including the monuments in Bukhara, Republic of Uzbekistan.

Undoubtedly, Bukhara is renowned worldwide for its architectural monuments and unique examples of folk architecture. The architectural monuments of Bukhara are known across the globe, and as a result, UNESCO has recognized this city as a World Heritage Site.

Architectural monuments around the world have been studied using various methods from ancient times to the present day. In most cases, restoration efforts have been carried out by specialists in archaeology, architecture, geodesy, hydrogeology, seismology, seismic resistance of structures, and other related fields.

Unfortunately, few researchers have addressed engineering issues in the restoration of architectural monuments. There are few scientific studies dedicated to examining the structure, technology, and properties of the construction and finishing materials used. The research conducted in this field has not been systematized and remains sporadic.

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Systematic archaeological and architectural-artistic studies of ancient Central Asian culture began primarily in the mid-1930s. The results of many years of systematic architectural, artistic, and historical-archaeological research formed the basis for the creation of the multi-volume "Universal History of Architecture." This book contains materials on the historical development of Central Asian architecture. However, even in this significant scientific work and other studies, issues related to solving architectural and engineering challenges in the restoration and reconstruction of monumental structures are insufficiently covered.

In this regard, further comprehensive research on the structures of buildings included in the list of protected architectural monuments of Uzbekistan in general, and Bukhara in particular, as well as on the materials used in their construction, holds great scientific and practical significance.

In ancient times, civil (residential and public) buildings and structures worldwide, including in Central Asia, were built from clay. Clay modified with plant waste, most commonly cereal stalks, annual plants, and reeds, was widely used. Materials made of clay were also successfully used in the construction of fortress walls in Khiva, Bukhara, Termez, and other cities. For instance, the four-story country house "Chodra Khovli" in Khiva, built from clay (pakhsa), is evidence of the craftsmanship of Uzbek builders.

UNESCO's monitoring of architectural monuments indicates that more than 50% of historical buildings and structures were constructed using ceramic materials, products, and elements. The process of firing ceramic bricks, blocks, tiles, and other products has remained virtually unchanged for 5,000–6,000 years. Decorative ceramics and majolica were developed as early as 1000 BCE, with glazing and engobe techniques gradually being refined using special clay compositions.

More than 80% of the architectural monuments in Samarkand, Bukhara, Khiva, Shakhrisabz, Termez, Kunya-Urgench, Khujand, and other cities of Central Asia were built using structural and decorative ceramic materials, products, and elements. Clay mass was used to manufacture wall, floor, and roofing materials, as well as glazed and engobed colored and matte tiles, terracotta, pipes, and containers.

Fired brick was used in the monumental adobe structure of the 9th–10th century "Kyrk-Kyz" in ancient Termez. The dimensions of both fired and adobe bricks ranged from 29–34 x 29–34 x 4.5–6 cm. The colors of the bricks varied from pink, scarlet, brown, and dark brown to beige, yellow, and greenish shades. The exterior and interior finishes of the Samanid Mausoleum (864–868 AD) and the Kalon Minaret (1127 AD) in Bukhara were entirely executed using ceramic bricks arranged in ornamental patterns (Fig.1).

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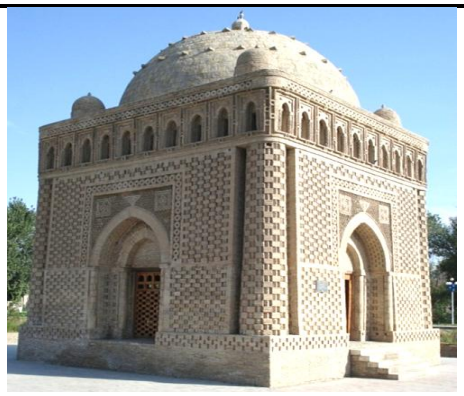

Fig.1. General view of the Samanid Mausoleum, built in 864-868.

Fig. 2. A fragment of the interior walls and staircase of the Kalyan Minaret, made of baked brick.

Studies on the physico-mechanical and deformation properties of ceramic bricks used in the construction of monumental structures in Uzbekistan show that the materials and products were made from carefully purified clay raw materials while strictly following the manufacturing technology of the raw mass and the final product quality control [4,5].

Analysis indicates that comprehensive research on the technology and properties of ceramic construction materials and traditional masonry mortar using modern methods and instruments to determine their composition, properties, and manufacturing technology is highly relevant. This research is particularly important for reviving heritage and subsequently applying it to the restoration of architectural monuments in Bukhara.

The results of studies on the properties of traditional bricks from the architectural monuments of Shakhrisabz [1] show that the compressive strength of bricks ranges from 5.9 to 22.8 MPa. These values practically meet the current seismic construction standards.

According to literary sources, it is generally known that in the brick masonry of Central Asian architectural monuments, various binding materials were used, including clay, clay-gypsum, gypsum, lime, and lime-pozzolanic mortars. It is noted that the binders in brick masonry or cladding served as adhesives without any added finely ground mineral substances [1].

Scientific studies on the structure of construction mortars indicate that inert fillers, such as natural sand, were rarely used in the preparation of mortars. In the architectural monuments of Central Asian countries, construction mortars were based on pure gypsum, gypsum with clay additives, gypsum with cementitious materials, gypsum with fine-grained sand, gypsum with ash additives, and lime-based mortars containing lime-ash binders known as "Kyry."

In most cases, an active filler in the form of ancient coal ash or plant ash was used. As a rule, wall masonry was made with clay paste without additional fillers. The outer layers of the masonry were constructed using pure gypsum mortar or natural clay-gypsum, which is a natural mixture of low-fired gypsum, loess, and semi-hydrated gypsum.

A review of literary sources on this subject shows that studies on the construction and materials of the architectural monuments included in the list of protected sites—masterpieces of Bukhara built in different periods, including the late 19th and early 20th centuries—remain insufficiently explored.

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By the Decree of the President of Uzbekistan dated December 2, 2016, "On Measures to Ensure the Accelerated Development of the Tourism Industry of the Republic of Uzbekistan," targeted objectives and priorities of state policy in the field of tourism for the medium-term perspective were defined. To further develop and enhance the efficiency of the tourism potential of Bukhara and the Bukhara region, Presidential Decree No. PP-2980 of May 19, 2017, "On Measures for the Accelerated Development of the Tourism Potential of Bukhara and the Bukhara Region for 2017-2019," tasked the Ministry of Culture with proposing a targeted list for the restoration and reconstruction of historical and cultural heritage sites in Bukhara for the period 2018-2027.

In this regard, the intensive development of tourism and related tasks of restoration and preservation of historical sites have become even more significant.

Bukhara is one of the oldest cities in Central Asia and one of the largest and most well-known trading centers on the Great Silk Road. Over thousands of years, the city has gained worldwide fame for its rich and unique historical development, closely linked to the most important milestones of global civilization and its enormous contribution to cultural, educational, and spiritual-religious values.

A direct acknowledgment of Bukhara's historical and cultural significance for the enlightened world was the inclusion of its historical center in the UNESCO World Heritage List in 1993.

The present study examines the structures and building materials used in the construction of unique civil buildings in Bukhara during the late 19th and early 20th centuries, which are included in the list of protected architectural heritage sites. The first results of research on the strength properties of masonry materials used in the foundations, walls, and other structural elements are presented.

In the late 19th and early 20th centuries, Bukhara saw the construction of architectural masterpieces known for their unique architectural solutions, including: The Faizullah Khodjaev House Museum with its inner and outer courtyards; The Sitorai-Mokhi-Khosa Museum building; The Emir Alim Khan Mosque, part of the Poi-Kalon ensemble; The two-story S. Ayni Theater, located in the southern part of the "Bolo Hauz" architectural complex; The two-story building of present-day General Education School No. 6, situated in the southern part of the grand Ark fortress; The two-story building of the present-day State Museum of Art and Architecture, located in the western part of "Toki Sarrafon,"; The two-story administrative building of the Bukhara Regional Multidisciplinary Medical Center; The two-story medical buildings of this medical institution; The two-story "House of Scientists"; Single-story buildings along B. Naqshbandi Street; A public building (church) near the railway station in Kagan; The administrative building of the Vabkent District Medical Association; The arched stone bridge built over the Zeravshan River in the center of the Romitan district; And several other unique architectural heritage sites.

1. The Faizullah Khodjaev House Museum, built in 1891, stands out for its scale, national architectural expressiveness, interesting volumetric-planning and structural solutions, durability, and longevity. While the above-ground part of the building was used as a residential house, the basement was intended for production purposes, which remains an intriguing concept even today, especially in the context of the development of family entrepreneurship (Fig. 3).

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The basement walls are made of stone masonry using ceramic bricks and, presumably, gypsum-based construction mortar. Currently, some physical damage to parts of the basement wall masonry, which is 100 cm thick, can be observed.

Fig. 3. General view of the flight rooms of the house-museum from the inner courtyard

2. The architectural building of the present House of Scientists was built in 1876. Over the years, the building has been used for various purposes; in particular, during the years of the Bukhara Emirate, it was used as a military barracks. The overall dimensions of the building, based on modular layout axes, are 25 × 22.3 m. Service rooms and offices are arranged around the vestibule, which is located in the central part of the building. The structural system of the building is frameless, with a structural scheme featuring both longitudinal and transverse load-bearing walls in different areas. The construction system consists of traditional brick masonry. The actual floor-to-ceiling height of the building is as follows: 4.75 m for the first floor and 4.6 m for the second floor (Fig. 4).

Fig. 4. General view of the "House of Scientists" building (from the northwest)

Fig. 5. A fragment of a building wall made of ornamental masonry with significant cracks requiring restoration using historical materials.

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The foundations of the building are partially made of rubble stones and partially of brick masonry. The walls of the building are made of brick masonry, with a wall thickness of 51 cm. The results of studies conducted using the modern electronic device "Onyx-2.51," which belongs to the category of non-destructive testing methods, showed that the strength of the bricks ranges from 12 MPa to 15 MPa, while the strength of the masonry mortar is at least 5 MPa.

Analyzing the obtained data on the strength of the brick masonry walls, they meet the requirements of current building standards /6/. Therefore, the studied building withstood strong earthquakes, the epicenter of which was in Gazli, without significant damage or destruction. However, during the more than 140 years of operation of this architectural monument, significant cracks have appeared in the exterior walls of the southern, western, and eastern orientations (Fig. 5). Sealing the formed cracks with modern cement mortar significantly reduces the architectural value of the heritage. Therefore, studying the composition and structure of the construction materials used in this building, as well as in other architectural monuments, particularly the masonry mortar and bricks, is a relevant task.

3. The architectural building of the current S. Aini Theater The architectural building of the current S. Aini Theater was built in the southern part of the Bolo Hauz Mosque in 1922–1924. The volumetric and planning solution of this unique building is very convenient for both those working in the theater and its visitors. The arrangement of corridors and rooms follows a distinctive layout that corresponds to its purpose. The clear width of the auditorium is 17.7 meters. The total length of the hall on the first floor is 21.4 meters, while on the second floor, including the balcony structures, it is 25.5 meters.

The structural system of the building is frameless, with a constructive scheme featuring longitudinal load-bearing walls. The construction system is made of traditional brick masonry. Both square bricks measuring 25×25×5 cm and ordinary ceramic bricks measuring 25×12×6 cm were used. The depth of the stepped brick foundation is about 230 cm, and its footing width is 210 cm. The foundation footing is made of rubble stone masonry. Its upper part is constructed using square bricks measuring 25×12×5 cm and some type of construction mortar.

Fig. 6. General view of the S. Ayni Theater building.

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The exterior load-bearing walls of the building are made of brick masonry with a thickness of 110 cm (one-story). The thickness of the load-bearing walls of the arches in the auditorium is 152 cm. The total height of the auditorium from the floor to the ceiling of the stage is 9.1 m, while at the back of the hall, it is 8.3 m. The actual width of the side corridors of the building is 4.95 m, and the floor-to-ceiling height is 3.9 m (two-story).

The total height of the arch from the foundation to the inner part of the crown is 7.5 m, and up to the bottom of the roof structures, it is 7.9 m. The height of the upper part of the arch is 0.4 m, the span is 3.8 m, and the rise of the arch is 2 m. The width of the arch columns varies from 90 cm (on the inner side) to 10 cm (on the outer side). The thickness of the arch columns is 110 cm.

The average strength of the bricks in the masonry walls is 18.2 MPa. Actual strength values in different sections were recorded as 13, 18.2, 19, 22.7, and 33.2 MPa. The average strength of the masonry mortar is 4.3 MPa, with actual values of 3.6, 4.2, 4.3, 4.4, and 5.1 MPa. Tests have shown that the strength of individual bricks reaches up to 33.2 MPa. When struck with a hammer, a ringing sound is produced. However, various cracks are observed in some parts of the building's walls.

The roof structures of the auditorium and stage are made of wooden trusses. The inter-floor and attic floors in the rest of the building are made of wooden beams (logs) in a traditional national style. The load-bearing structures of the roof are wooden, and the roofing is made of metal sheet.

4. The two-story building of the present-day Bukhara State Architectural and Art Museum-Reserve was built in 1912 on the Shokhrud canal, which required great knowledge and experience from the designers and builders. This was a rather complex construction decision. The volumetric and spatial planning of the building features a unique layout with interesting corridors and rooms. Previously, this building housed the central bank of Bukhara.

The structural system of the building is wall-based, with a structural scheme that includes both longitudinal and transverse load-bearing walls. The construction system is made of brick masonry. The inter-floor and attic floors are made of wooden structures in a traditional national style. The floors are wooden planks, and the ceilings are mainly made of plywood. The roofing is made of zinc-coated sheet metal.

The building's foundations are partially made of natural stone and partially of brick masonry. The exterior walls of the building are made of brick masonry with a thickness of 64 cm (in some places up to 77 cm). The average strength of the building's bricks is 9.5 MPa, with a brick grade of M100 and a construction mortar grade of M50. Despite the high strength indicators of the materials, significant cracks are also observed in some parts of the building, requiring restoration using historical materials of the desired composition.

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Fig. 7. General view of the building of the Bukhara State Architectural and Art Museum-Reserve from the northeast.

Fig. 8. Sealing a crack with cement mortar reduces the architectural value of the building.

The two-story building of the current secondary school No. 6, which is included in the list of protected architectural monuments of Bukhara, was built in 1924. At one time, this building housed the Bukhara State Pedagogical Institute. The overall dimensions of the building, according to the layout axes, are 53.6 × 40.5 m. The actual floor height of the premises is 4.1 m for the first floor and 4.2 m for the second floor. The building's layout follows a corridor system.

The structural system of the building is frameless, with a structural scheme featuring longitudinal load-bearing walls. The construction system consists of brick masonry; the thickness of the exterior walls and internal longitudinal load-bearing walls is 0.51 m, while the internal transverse walls are 0.38 m. The inter-floor and attic ceilings are made of wooden structures (wooden beams, plank floors, plywood ceilings). The load-bearing roof structures (rafters) are wooden, and the roof covering is made of sheet metal.

Fig. 9. General view of Secondary School No. 6 building (north orientation)

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Fig. 10. A fragment of the western end wall of the building; dangerous settlement cracks are present, and restoration using historical masonry materials is recommended.

The building's foundations are multi-tiered and made of masonry. The brick grade is M100, and the mortar grade is M50.

The exterior walls of the building are made of brick masonry with a thickness of 2 bricks (51 cm), while the interior walls are 1.5 bricks thick (38 cm). Additionally, each wall section is reinforced with pilasters that are 70 cm wide and 20 cm thick.

The two-story building, which currently houses the administration of the regional multidisciplinary medical center, was built in 1900 and has a unique and distinctive architectural appearance. Previously, this building housed the Bukhara post office. The overall dimensions of the building, according to layout axes, are 37.15 × 18.6 meters. The building's layout follows a corridor system.

The structural system of the building is frameless, with a design scheme based on longitudinal load-bearing walls. The construction system consists of brick masonry. The inter-floor and attic ceilings are made of wooden structures in a traditional national style. The roof's load-bearing structures are wooden, and the roofing material consists of sheet metal and slate.

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Fig. 11. General view of the building of the current administration of the regional multidisciplinary medical center.

The actual floor-to-ceiling height of the premises is 4 meters (2 floors). The foundations are partially made of rubble stone and partially of brick masonry. The walls of the building are made of brick masonry with a thickness of 51 cm.

The foundations of the building are partially made of natural stone and partially of brick. The average strength of the bricks in the building's masonry is 13.4 MPa, and the strength of the masonry mortar is 5.7 MPa.

At present, we continue conducting research for a comprehensive study of the composition, structure, physical and mechanical properties of materials, and masonry technology (bricks and construction mortars) used in the unique architectural monuments of Bukhara from the late 19th and early 20th centuries. The goal is to restore, revive, and apply them in restoration work.

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