

KEY ASPECTS ON DESALINATION IN HISTORIC BRICK MASONRY

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Abstract

The article analyzes the problems of brickwork in historical fortifications. It is proven that in most cases, the causes and consequences of damage to brickwork are common to objects in different regions and in different countries. The experience of brickwork desalination, tested at objects in Ukraine by specialists of the Ukrrestavratsiia corporation, is described. Salt presence in brick masonry represents one of the key factors in the degradation of historic monuments. The presence of soluble salts leads to the destruction of the porous structure of brick and mortar, initiates the formation of efflorescence, and contributes to the gradual loss of historic substance. This process is particularly intensive in ground-level zones, where prolonged interaction with moisture drawn capillarily from the ground occurs. Removing salts only from the surface layer of the masonry and strengthening only the outer layer with hydrophobic substances does not solve the problem, since water-soluble salts remain in the masonry thickness. Specialists have developed a technology for desalination of the lower part of a brick wall to a height of 2–3 m from the ground surface in the absence of waterproofing and perimeter paving. The salinity level, salt composition, and causes of salinity (from groundwater, atmospheric pollution, etc.) are previously established.

Keywords: Desalination feature; Historical brickwork

Introduction

The preservation of architectural heritage, particularly monuments of exceptional cultural value inscribed on the UNESCO World Heritage List, represents a significant challenge in contemporary conservation practice. The Venice Charter and UNESCO guidelines provide the overarching principles that must be followed in order to preserve the authenticity and integrity of historic fabric. The approach to be taken is based on rigorous scientific research, minimal intervention, and the long-term durability of applied technical solutions.

Historic masonry structures are of significant cultural and historical value, serving as tangible evidence of past construction technologies, local craftsmanship, and region-specific building traditions. Consequently, any measures implemented for their conservation must address two fundamental considerations. Firstly, the preservation of original material must be ensured,

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and secondly, the provision of safe conditions for its continued existence under changing environmental and operational circumstances must be guaranteed.

Brick fortifications, castles, and defensive walls – frequently constituting pivotal components of World Heritage properties – represent a subset of historic architecture that is particularly susceptible to damage. These structures are particularly vulnerable to degradation caused by long-term exposure to moisture, groundwater influence, atmospheric factors, and climate variability. These processes characteristically evolve over time and often go unnoticed until substantial damage to the historic fabric has already transpired, thereby significantly complicating the implementation of effective conservation interventions.

In this context, the control of moisture- and salt-related deterioration is of crucial importance in the protection of historic brick masonry, including UNESCO World Heritage Sites. The migration of soluble salts within the porous structure of masonry materials and their crystallization under fluctuating environmental conditions represent one of the most destructive mechanisms affecting historic walls, especially in ground-level zones. It is imperative to comprehend these phenomena and formulate efficacious, preferably non-invasive mitigation methodologies, to safeguard the Outstanding Universal Value of architectural heritage for posterity.

Salt presence in brick masonry represents one of the key factors in the degradation of historic monuments. The presence of soluble salts leads to the destruction of the porous structure of brick and mortar, initiates the formation of efflorescence, and contributes to the gradual loss of historic substance. This process is particularly intensive in ground-level zones, where prolonged interaction with moisture drawn capillary from the ground occurs.

Effective conservation of historic walls requires the removal of salts from the entire volume of the wall, not just from its surface layer. Treatments limited to the near-surface zone can only lead to temporary improvement in the state of preservation and do not eliminate the destructive mechanisms occurring deep within the material. For this reason, methods should be used that enable volumetric migration and removal of salt ions while maintaining the safety of historic materials.

Some problems associated with emergency conditions are common to historical fortifications. These include proximity to water bodies, high groundwater levels, subsidence of the base soil, green plantings near the walls with absent or damaged blind areas, natural and climatic conditions with sharp temperature drops, and high humidity. Negative factors also include atmospheric pollution due to human activity (industry and transport). Each of the negative factors has its own consequences, in particular:

- proximity to water, increased groundwater level, increased humidity, lack of blind areas and drainage, greenery – lead to waterlogging of structures and leaching, biofouling, and, as a result, an emergency state of structures;
- subsidence of soils, vibrations from transport, uneven subsidence, cracks;
- temperature differences – cracking of bricks, peeling of the outer layer of bricks.

It is worth noting that these negative factors are typical for objects of different periods and different constructive schemes. Although in this article we limit the list of objects to a few outstanding brick castles, we are rather talking about the commonality of problems.

Let's take one aspect – the approach of lawns and herb gardens to the walls and basement with damaged or missing blind areas and waterproofing. Although this problem is typical for ancient castles, in the Mariinskyi Palace in Kyiv, it became one of the causes of wall clogging.

The purpose of the study was to use the examples of the castles in Oświęcim and Malbork to show the commonality of problems and their consequences and to present existing ways of solving these problems.

To address the goals and objectives of the study, the appropriate source base was developed in the following areas:

- preservation of the historical environment of the place [1–3];

- correspondence of the style of the object and the environment, the nature of their interaction and mutual influence [4–5];
- restoration methods and experience of reprofiling [6–18];
- experience of restoration of historical fortifications [19–24];
- technologies of desalination of architectural monuments' brickwork [12];
- diagnostics, monitoring, research methodology, and rehabilitation techniques [25-34].

Materials and Methods

Research Methodology

The study included field surveys conducted by the authors, photofixation, and processing of scientific and archival sources, as well as analysis of modern experience in brickwork restoration technologies. In particular, such general scientific research methods as the method of historical analysis, comparative analysis, and system-structural analysis were used. Based on the system-structural analysis method, a structural-logical model was developed with connections between the problem, the cause, and the methods of elimination.

The method of historical analysis allowed us to systematize the periodization of the construction of the studied castles, and the method of comparative analysis allowed us to compare the periods with each other and to compare the construction of castles of different periods to determine the common and different points between the two castles, including existing preservation problems and their causes.

Pre-Design Diagnostics

In order to properly design the desalination process, comprehensive pre-design diagnostics should be carried out, including field and laboratory studies of the brick wall. These diagnostics should enable the assessment of the degree of moisture content, content of soluble salts, and physical and chemical properties of bricks and mortars.

Point test drillings can be performed in the lower parts of walls, with material sampling every 5 cm to a depth of about 30 cm from the face of the wall. These tests should be conducted primarily up to a height of about 2 m, where salinity is usually greatest as a result of capillary moisture uptake from the ground.

The content of soluble salts can be determined by the conductometric method, while the chemical composition of salts should be identified using ion chromatography, which allows for the distinction of chloride, sulfate, and nitrate ions. Recognition of the type of salt is important for the selection of desalination technology because their mobility and destructive impact on historic materials vary.

Complementing the diagnostics are studies of the pore structure of bricks and mortars, including the assessment of open porosity, pore size distribution, and mechanical strength. It is possible to demonstrate that the dominance of capillary pores with diameters from 0.1 to 10 μm favors intensive salt accumulation and the generation of significant crystallization stresses, leading to material degradation.

Results and discussion

Case Studies: Comparative analysis of castles: history, periodization, common and distinctive features

The study analyzed only one aspect, namely the state of brickwork. Today, many famous medieval castles are located in the structure of modern cities. The study was conducted on the example of two historical castles – the castle in Oświęcim and the castle in Malbork. What they have in common is the following:

- both constitute the core of the medieval city and are located within the Old Town;

- both stand on the banks of the rivers, Sola and Nogat;
- both were originally built in approximately the same period and subsequently underwent changes and reconstructions due to changes in owners and functions;
- both are built of brick, within the castle – brickwork of different times with different characteristics;
- both are located in greenery.

However, there are differences:

- protected status (UNESCO Heritage listed object and monument of local significance);
- Malbork Castle was converted into a museum in 1961 and Oświęcim Castle in 2010;
- size and height (Malbork Castle is the largest brick Gothic castle in the world; the built-up area is about 21 hectares, the length with Przedzamcze (Low Castle) is about 700 m);
- scale of reconstructions and additions;
- the Soła River is narrower, and the Nogat is wider;
- difference in distance from the river – Oświęcim Castle is on a hill with artificial tunnels of the 19th-20th centuries (about 500 m from the river); the north-eastern part of Malbork Castle is separated from the river by meadows and a path; the lower castle is not on an elevation (several metres);
- there are no meadows around Oświęcim Castle; the green spaces are separated by paving.

Parts of the castle in Oświęcim have the following dating: tower – mid-13th-14th century; tunnels – 18th-20th century; representative part – 19th century (Fig. 1).



Fig. 1. Castle tower. Current state, 2024

The history of the castle in Oświęcim covers the following periods:

1st period – 11-12th centuries, wooden fortifications.

2nd period – 11th-15th centuries – the eastern rampart was built in the middle of the 13th century – the 2nd half of the 13th century – in the half of the 14th century – in the southeastern part a stone tower and a brick Piast castle; the tower could have been lower.

3rd period – late 15th century-16th century – modernization as a residence of the Jagiellonians; after the fire of 1503, reconstruction of 1503–1508 by the Roe, and until 1534, a bastion was built in the northeast; the oldest southern part of the castle was strengthened.

4th period – 17-19th centuries – foreign occupation by the Swedes and Austrians for military functions.

5th period – from 1904 – renovation of the castle as a hotel and winery; between 1908 and 1910 – renovation of the tower; it was covered with a sloping roof.

6th period – after 1914 – administrative functions, construction of a two-story building with a risalit.

7th period – occupation during World War II – accommodation of the German military administration.

8th period – after 1945 to 2006 – accommodation of the Polish administration.

9th period – 2006–2010 – restoration of the castle as a museum and opening of the museum in 2010.

The stages of Malbork's history are as follows:

1st period – 1280–1457 – the castle under the rule of the crusaders.

2nd period – 1457–1772 – the residence of the Polish king.

3rd period – 1466–1568 – the Kingdom of Prussia.

4th period – 1568–1772 – the Maritime Commission.

5th period – 1772–1804 – the administration of the Kingdom of Prussia.

6th period – 1817–1842 and 1844–1944 – reconstruction and restoration of the castle.

7th period – 1945 – destroyed; 1947–2016 – phased restoration.

In 1949, the castle in Malbork received the status of a monument; in 1994, the status of a historical monument; and in 1997, a World Heritage Site.

Unlike the castle in Oświęcim, which consists of a single building with parts from different periods, the castle in Malbork actually consists of three castles combined into one complex: the High Castle, the Middle Castle, and the Low Castle (Przedzamcze) (Fig. 2).



Fig. 2. General view of the castle in Malbork, 2025

The High Castle included the main church of the Blessed Virgin Mary (late 13th century – 1309–1344 (Fig. 3), with the so-called Golden Gate entrance, decorated with symbolic polychrome sculptural subjects; the Chapel of St. Anne, the burial chapel of the Grand Masters; the Chapter Hall; the Convent kitchen; the Refektarz (refectory) of the Convent; the Gdańsk Tower with the public toilets of the brethren; the Klesza Tower (1325–1350); the main tower at the High Castle church (late 14th-15th centuries); the Dietrich Tower; the Szewska Gate; the cemetery of the brethren; the inner garden of the Grand Master; and a well.

The Middle Castle (the residence of the Grand Master) with a large courtyard included the Palace of the Grand Masters (1380–1396); the summer Refektarz (refectory); the winter Refektarz (refectory); the chambers of the Grand Masters – the home chapel of St. Catherine (before 1380, 1380–1383); a bedroom; a living room; a small office; a dressing room; and the Great Refektarz (refectory) (1320–1337) – the largest public room of the complex with a palm vault on three granite pillars; the Infirmaria – a room for the elderly and infirm with a separate chapel and refectory; a tower; the guest chapel of St. Bartholomew; and the chambers of the Great Komtur.



Fig.3. The altar part of the main church with the figure of the Madonna, 2025

The Low Castle included the Przedzamcze and fortifications. In particular, these are the Chapel and the gate of St. Lawrence, Bell foundry, Buttermilk Tower (Modra) (around 1335–1340), the Northern Gate, Billet Tower (Korotka), Clock Tower (Wołowa) (early 15th century), Eckturm Tower, The Three-Wall Tower, Powder Tower, Armory and Carriage House, the main gate, The Tower of the Vice Prefect and his house, the tower Above the Bakery, the nameless tower, the tower To the City, Furt Gate, Sperlinek (Sparrow) Tower, Bridge Gate, St. Nicholas Gate, rampart (1417–1419, 1441–1449, 1st half of the 17th century); and the main entrance to the castle – the New Gate (1418–1420).

Problems of damage to the brickwork of castles

Based on field surveys of many castles, e.g., Wawel Castle in Kraków, castles in Oświęcim, Malbork, Khotyn, and Kamianets-Podilskyi, we will analyze the general problems of brickwork inherent in most historical castles.

The facades closest to the river suffer the most from leaching, where leaching spots, destruction of the outer layer of bricks, and chipping of mortar in the joints are observed. The objects usually contain areas of brickwork from different times and are visually noticeable, for example, 19th-century masonry and medieval, more damaged. Even in parts of 19th-century masonry, where the brick is in normal condition, due to problems with waterproofing and blind areas, plants and green moss biofouling may appear on the bottom of the wall. Such problems have been recorded in many historical objects, not only in castles.

On the front surface and in the mortar of the joints, spots of biofouling can be observed, and plants can be seen in the gaps between the rows of bricks. Efflorescences in the lower part can occur not only in external but also internal walls.

Brickwork inside castles has a varying degree of preservation; places of masonry in the 19th-century and after World War II are usually distinguished by lighter, even bricks with the preservation of mortar in the joints. In medieval parts of the masonry, the bricks may have

potholes, and the mortar is laid in uneven rows, sometimes in spots. Where historically there were internal gardens and trees at the castles, they are still preserved today. For example, in the High Castle in Malbork, the walls of the buildings are entwined with ivy, there are trees planted in the brotherhood cemetery, and a rose garden has been arranged to the south, which is called the Grand Master's Garden. In Wawel Castle, the castle territory is landscaped with flower beds and trees; around the castle in Oświęcim, there are hillsides landscaped with trees, and close to the castle walls, there are green lawns. Although landscaping around castles and on their territory adds picturesqueness and authenticity, it also creates additional problems related to moisture in the foundations and foundations.

Given the specifics of subsidence soils, there are cracks in the buildings of many castles on the riverside, the causes of which are being investigated. Separately, it should be said about the masonry of the walls of spiral staircases, pointed arches, and star-shaped Gothic vaults with ribs. Often, brickwork is supplemented with details made of natural and artificial stone. Cracks can be located curvilinearly, along the contours of the arch of the vault from top to bottom. Uneven subsidence of the walls with the appearance of cracks can cut through the mural (like the 19th-century mural in the main reception hall in the Middle Castle – the Great Refektarz) (Fig. 4).



Fig. 4. Elimination of cracks on the premises of the Great Refektarz, 2025

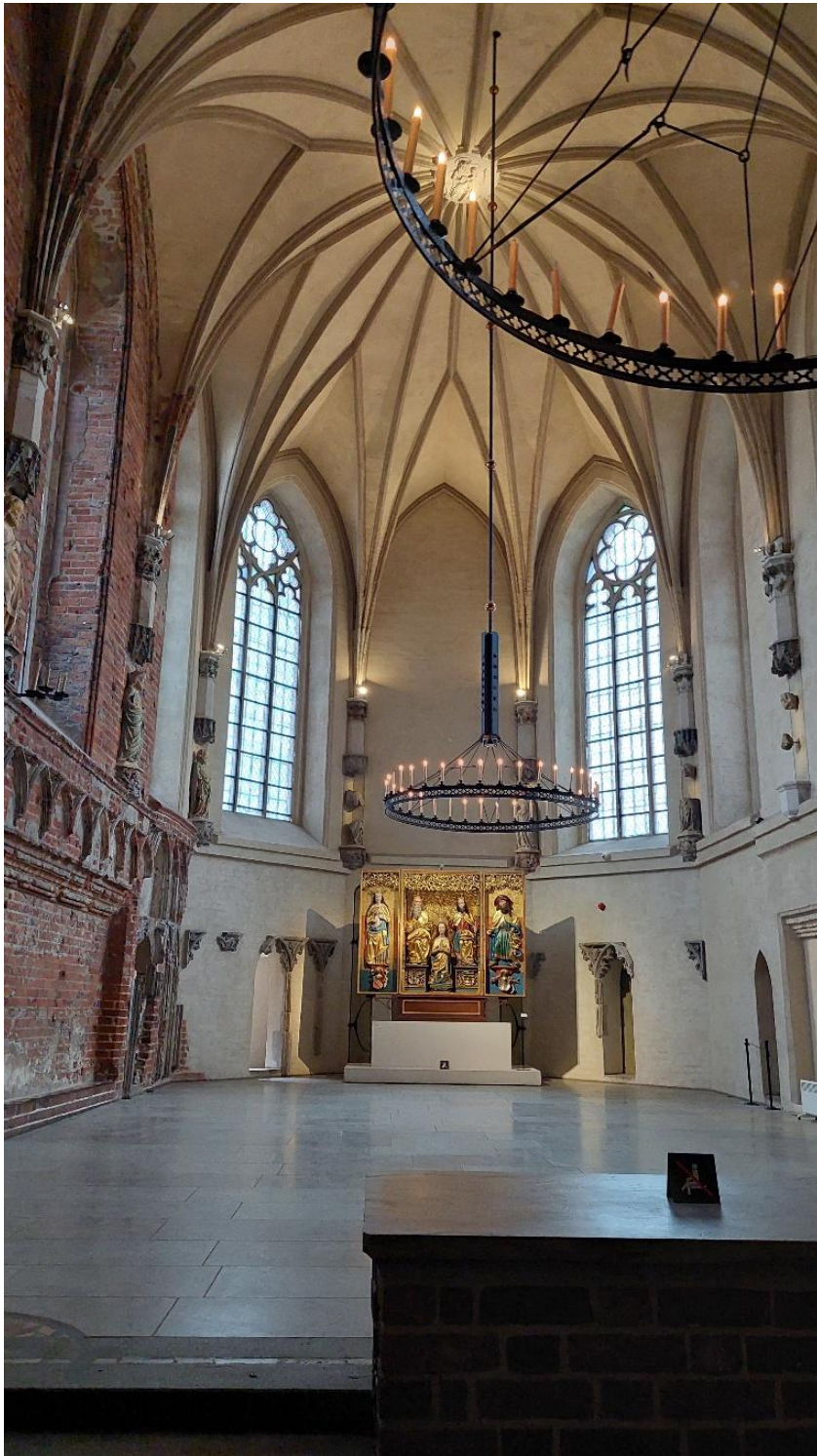


Fig. 5. Interior of the main temple with separation of the authentic and completed parts, 2025



Fig. 6. Fragment of the tower's masonry, 2024

When restoring historical castles, they try to preserve and recreate the original structures as much as possible. Since it was not possible to make a vault in the Grand Master's Chapel in the 19th-century due to a series of reconstructions, a flat roof was made in the 19th-century, but the original structures were left in place. On the second tier of the Upper Castle gallery, there is a 19th-century addition with frescoes and ceramic tiles.

In the main church of the castle, in the name of the Blessed Virgin Mary in the castle in Malbork, part of the walls and vaults are authentic, except for the altar, which, together with the figure of the Madonna, was destroyed by a tower that fell on it. Reconstruction work continued from the 1960s until 2016, when the Madonna was recreated with the inclusion of some authentic fragments of clothing. The authentic parts of the church were left unplastered; the supplemented parts were plastered to show their different time periods (Fig. 5).

The most optimal location for a castle is on a hill. Incidentally, this is how the famous Wawel Castle in Krakow is located. This, to some extent, protects the castle buildings from flooding, waterlogging, leaching, and biofouling. The castle in Oświęcim also stands above the river level and is protected from flooding, situated on a hill with artificial tunnels and moisture control. As in the castle in Malbork, its lower part – the foundations and basement – is built of rubble stone, and brickwork is arranged on it (Figs. 6 and 7). The oldest part of the castle is the tower, where you can see the remains of the old masonry and the sections that were replaced in the 19th century. At the same time, the entrance was broken through in the lower part.

Causes of damage to brickwork and methods of its restoration

The natural and climatic conditions in Malbork are characterized by partial cloudiness in summer; the annual temperature ranges from -5°C to 24°C , snow and wind in winter, and moderate rains all year round. The climate of Oświęcim is between the colder northern and southern climates; the annual temperature ranges from -4°C to 24°C , frosty and windy in the winter. Combined with the proximity of the river, this is a powerful factor influencing the condition of brickwork. The main factor negatively affecting the condition of brickwork is frost, especially at high humidity. Excessive moisture accumulates in the pores of the masonry and expands when it freezes due to a decrease in external temperature. As a result, the internal structure of the brick and mortar “breaks” from the inside, manifesting itself externally as microcracks, peeling of the facing layer of the brick, and falling out of the brick and mortar. If such freeze-thaw cycles become more frequent, the process of brick destruction accelerates, and the masonry loses its strength. These processes are most noticeable on the basement masonry and external walls.

Not only frost, but also heat poses a certain danger. In hot weather, bricks heat up and expand, and if the walls heat up unevenly, this causes internal stresses and also cracks and deformations of the masonry. Over time, these cracks become a place for moisture to penetrate and additional soaking of the bricks. High air temperatures also cause the mortar to dry out, the joints to lose strength, and cracks to appear in them.

Rain also harms the condition of brickwork. If the level of precipitation is excessive and the drainage system cannot cope with it, rainwater falls directly on the walls – on the bricks and joints, accumulates there, and leads to the appearance of efflorescence and biofouling, weakening the connection between the masonry and the mortar of the joints. Efflorescence on the surface in combination with low temperatures also leads to the destruction of bricks.

Salt-Related Degradation Mechanisms

Numerous specialists and authors have conducted research that has shown that the most saline areas of walls are in basements up to two meters high. Excessive salinity increases the wall's sorption capacity. As well as efflorescence forming on the surface and destroying the surface layer of the brick, negative processes occur within the wall's thickness.

In addition to the aforementioned negative factors, it is worth mentioning the constant excessive moisture caused by condensation on the surface and deep inside the wall at lower relative humidity. With daily temperature fluctuations outside, salts change their crystalline form as their volume increases. This leads to the destruction of the brick due to tensile stresses appearing in the walls of pores and capillaries.

The predominance of capillary pores with diameters ranging from 0.1 to $10\ \mu\text{m}$ has been shown to promote intensive salt accumulation and the formation of significant crystallization stresses, resulting in material degradation. In addition to the influence of the previously mentioned negative factors, it is important to consider the constant excessive moisture resulting

from the condensation of moisture on the surface and within the thickness of the masonry at lower relative humidity. Daily fluctuations in the external temperature result in a change in the crystal hydrate form of salts, leading to an increase in volume. This, in turn, gives rise to the destruction of the brick due to the appearance of tensile stresses in the walls of pores and capillaries.

It is possible to demonstrate that the dominance of capillary pores with diameters ranging from 0.1 to 10 μm favors intensive salt accumulation and the generation of significant crystallization stresses, leading to material degradation.

As the experience of the Ukrrestavratsiia corporation shows, first of all, the condition of the foundations under the building, foundations, waterproofing of foundations, and the presence of a blind area should be examined.

One of the methods involves the removal of water-soluble salts from the basement of the external walls of architectural monuments (Fig. 7).



Fig. 7. Brickwork with salinization and biofouling, 2025

Removing salts only from the surface layer of masonry and strengthening only the outer layer with hydrophobic substances does not solve the problem, since water-soluble salts remain inside the masonry. Specialists have developed a technology for desalination of the lower part of a brick wall 2-3 m above the ground surface in the absence of waterproofing and perimeter paving. The salinity level, salt composition, and causes of salinity (from groundwater, atmospheric pollution, etc.) are previously established.

Electroosmotic desalination is based on the forced migration of salt ions in an electric field, which enables their movement throughout the entire thickness of the wall and controlled discharge outside the material structure. This method is particularly applicable to massive walls without effective waterproofing, where other techniques have limited effectiveness.

Under the action of a direct current with a density of 0.1–1.0 A/m^2 , which is supplied to the electrodes in the capillary-porous system of masonry filled with a steam solution, the salt solution is electroosmotically squeezed out of small pores, where it is held by capillary forces, into large draining pores. In the draining pores, the solution moves downward under the influence of gravitational forces. At a current density of 1 $\text{A}/\text{kV}\cdot\text{m}$, the electrolysis process intensifies, which is an undesirable phenomenon. At a current density of 0.1 A/m^2 , the process of electroosmosis and salt extraction proceeds more slowly. For historic brick, it is recommended to

use a current density in the range of 0.3-0.5 A/m², which allows limiting the risk of overheating of the material and degradation of lime mortars.

The schematic diagram of the device for removing water-soluble salts from wall masonry is shown in the scheme (Fig. 8). Along the upper edge of the wall section that is being de-energized at a height of 2–2.5 m from the ground level, a plate anode 0.2–0.5 m wide is installed, which can be made of sheet lead, aluminum, or other metal that has high resistance to electrochemical corrosion. The cathode must perform the function of grounding; it is in the soil adjacent to the foundation at a distance from the building. A compress made of cotton fabric with high porosity is placed between the anode and the brick wall. The upper end of the application is immersed in a tank with water, and the lower end is immersed in a tank for collecting the filtrate. The first tank is placed above, and the second is below the anode. The anode is connected to the positive pole of the DC source, and the cathode is connected to the negative pole.

The process of desalination of the masonry proceeds throughout its thickness in the zone located below the top of the anode. As the salts move down from the anode, the salt content in the lower rows of the masonry increases. Over time, the desalination front moves to the lower rows, and then the salts pass into the soil.

The greatest effect of desalination at the level of the anode is achieved from the side of its location and in the lower rows of masonry – from the opposite side.

A sufficient condition for the end of the desalination process is to achieve a salt content that has an acceptable value in the lower zone of the wall at a depth of 5–10 cm from the side of the anode installation, which takes about 2–3 months.

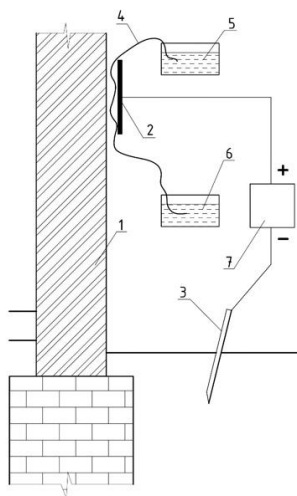


Fig. 8. Schematic diagram of a device for extracting water-soluble salts (from the M. Orlenko collections):
1 – wall subject to desalination; 2 – lead plate – anode; 3 – cathode; 4 – fabric application; 5 – power tank; 6 – filtrate collection tank; 7 – DC source

Washing the anode zone with an application is necessary to remove the by-products of the electrolysis process. The washing water is an additional source of moisture for the wall, necessary to dissolve the entire amount of salts contained in the masonry.

The amount of current supplied to the electrical circuit depends on the specific current density, which is recommended and calculated per unit area of the anode, and the area of the anode depends on the size of the area being treated.

It is recommended to use sheet lead for the anode, which is the most resistant to electrochemical corrosion. In addition, due to its plasticity, 1 mm thick lead easily takes the shape

of the surface being treated, which is necessary for tight contact of the electrode with the wall. The sheet lead has a width of 0.5 m.

For the application, you should use various unpainted cotton fabrics, which are laid in two layers in pieces of at least 1.3 m in length vertically.

Desalination works are usually carried out during the period of greatest wetting of the walls with a moisture content of approximately 10–13% by weight, since then the vast majority of salts are in a dissolved state and the masonry has good electrical conductivity. In Ukraine, these works are carried out in April–June, since the following summer–autumn months contribute to further natural drying of the masonry.

The sequence of work is as follows:

- the boundaries of the desalination site are determined;
- solid scaffolding 1 m wide is mounted at a distance of 1.5 m below the upper limit of salinity, fences, devices for climbing onto the scaffolding, and shelves for installing inventory containers at the levels specified in the scheme (Fig. 9);
- wooden plugs are installed for temporary fixation of the anode (at the level of the top of the anode with a step of 70 cm);
- lead strips are hung on the plugs with a preliminary gasket between the wall and the lead of the compress in two layers and then fastened to the wall with wooden plugs in 2 rows after 0.5 m;
- inventory containers are installed on the shelves at a distance of 5–10 cm from the wall with the subsequent introduction of the ends of the compress into them;
- mount the cathode using the grounding method (three pipes driven into the ground, connected by a circuit of metal plates).

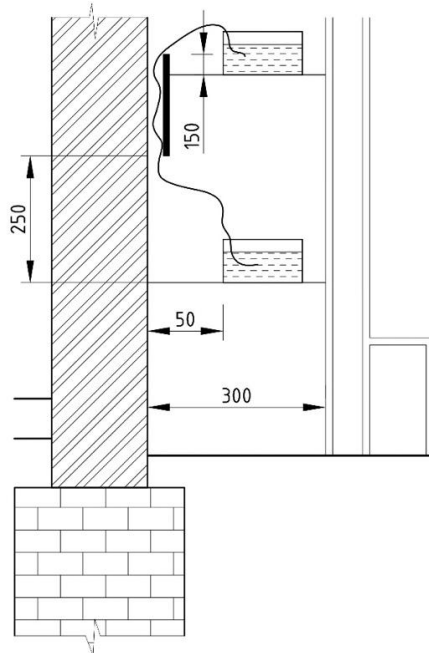


Fig. 9. Tank mounting scheme (from the M. Orlenko collections)

During the treatment process, a constant water level is maintained in the upper tank by adding water once a day, and as the filter accumulates, water is poured out of the lower tank. During the desalination process, records of work are kept under the guidance of a specialist, in which the instrument readings, time, and location of samples taken for control are recorded daily. The work is stopped at the instruction of the person responsible for the work based on the results

of laboratory analysis of control samples. After the treatment of the salted area is completed, the electrical circuit is dismantled, the holes formed after removing the corks are covered, and the scaffolding is dismantled. After the desalination work is completed, work is carried out to waterproof the walls and install a blind area in order to avoid repeated salinization due to capillary water seepage.

If the wall is salted to a height of more than 3 m, several strips of anodes are used to accelerate the desalination process, located parallel to each other at a distance of 2–3 m (Fig. 10).



Fig. 10. Salinity at a considerable height of brickwork, 2025

The effectiveness of the treatment is assessed based on the results of chemical analyses of samples taken at a distance of 5 cm from the ground level to a depth of 5–10 cm. It is recommended to take control samples once every 10 days. During the initial period of current treatment, the salt content in the lower part of the wall increases, which indicates the beginning of the formation process. The basis for stopping work is the salt content in the control sample equal to or less than 1%.

Conclusions

The structure of castles usually has layers from different periods; medieval brick is darker and uneven and is more poorly preserved. The change of owners also influenced the change in the appearance of castles. For example, in Malbork, the owners at different times were the Crusaders, the Polish king, the Prussian Kingdom, and Poland. The Prussian authorities rebuilt the castle for military purposes, and at the beginning of the 19th century, a romantic restoration in the neo-Gothic style took place, when new ones were often made on top of the medieval murals in the style of 19th-century romanticism. The walls show the different periods of the brick: early black and smooth 19th-century. and during the restorations of the 20th century.

Based on the field surveys conducted, the main problems of brickwork, typical for historical castles, were identified. In particular, these are the proximity of water and high groundwater levels (salting, subsidence, and biofouling); climate (cold in winter and humid); lawns near the walls without blind areas and waterproofing; and subsidence soils.

Studies conducted by specialists of the Ukrrestavratsiya Corporation and authors have clearly demonstrated that the zones of highest salt concentration in historic brick masonry are

located in the basement areas, typically up to approximately 2 m above ground level. Excessive salinity leads to an increased sorption capacity of masonry, which intensifies degradation processes both on the surface and within the internal structure of the material. In addition to the formation of salt efflorescences resulting in the destruction of the brick face layer, adverse processes also occur within the thickness of the masonry and often remain undetectable at the early stages of deterioration.

A significant factor accelerating these processes is the persistent excessive moisture content of the masonry, resulting not only from capillary rise of groundwater but also from moisture condensation on the surface and within the pore structure, even under conditions of reduced relative air humidity. Moreover, daily fluctuations in external temperature promote cyclic transformations of salt hydration states, accompanied by volumetric expansion. These processes generate tensile stresses within the walls of pores and capillaries, ultimately leading to progressive degradation of bricks and mortar.

The conducted analyses confirm that removing salts solely from the surface layer of masonry and strengthening only the outer zone using hydrophobic treatments does not provide a lasting solution. Water-soluble salts remain active within the masonry core, retaining their capacity for migration and recrystallization. In response to these limitations, a technology for volumetric desalination of the lower parts of brick walls, extending 2–3 m above ground level, has been developed and successfully applied in structures lacking effective waterproofing and perimeter paving. A prerequisite for this approach is the prior determination of the degree of salinity, the chemical composition of salts, and the identification of their sources, including groundwater influence and atmospheric pollution.

Desalination of historic brick masonry is a complex process that requires an individual design approach. The effectiveness of conservation measures depends on properly conducted diagnostics, appropriate selection of technology, systematic control of process parameters, and elimination of the causes of secondary salinity. Research has also demonstrated that the causes and mechanisms of brick masonry deterioration are largely universal and occur in historic structures across different regions and countries. This universality enables the application of proven methods in diverse conservation contexts, provided that they are individually adapted to local material and environmental conditions.

Following the completion of the desalination process, secondary protective measures are essential, including moisture insulation, perimeter drainage systems, and protective ground surfaces, in order to prevent re-salinization caused by capillary water ingress. The selection of renovation materials must account for their physical, chemical, and aesthetic compatibility with historic materials. Systematic monitoring and regular testing of control samples are of crucial importance for assessing the durability of the achieved results.

Only a comprehensive approach—integrating diagnostics, appropriate selection and implementation of desalination methods, and effective secondary protection—can ensure long-term preservation of historic masonry and safeguard its cultural value for future generations.

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