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Selected problems of protection of historic buildings against the rainwater and the groundwater

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Abstract. The paper presents selected problems in the selection of the state of the art modern civil engineering solutions for drying moisture or wet, in particular parts of the underground structures of the brick historic buildings. The repair works of the immobile cultural heritage civil engineering objects require the appropriate choice of the design solution. These should be achieved by obtaining the assumed effects in the form of the effectiveness of repairs regarding all possible measures of protection of the cultural heritage buildings. Another key issue of the analysis of the causes of moisture formation in underground masonry structures is the necessity of consideration of the historic character of these buildings. Based on authors' extensive experience and expert knowledge, a range of diagnostics process as well as the assessment of the causes of the moisture problems of historic buildings for several selected cases was proposed. Moisture is transferred from the outside of the building to the basement interior by four mechanisms liquid water flow, capillary suction, vapor diffusion and air movement. The variety of the different mechanisms of moisture transfer, especially regarding buildings of cultural heritage implies that the selection of the most suitable system solution for solving moisture problem is the most crucial and a key issue in a specific case.

1 Introduction

Dealing with the symptoms of moisture, like damp, humid air, odor, mold, mildew, as well as efflorescence, spalling of masonry, etc. is one of the main challenge of operation and maintenance of historic building structures. These symptoms and effects are often the result of bad and poor technical condition of waterproofing and insulations [1,2]. The main purpose of this paper is to describe and present selected problems of protection of historic buildings against the rainwater and the groundwater. However it should be mentioned that except for liquid water from rain or ground-water, there are other sources of moisture, like interior moisture sources such as bathrooms, cooking, humidifiers, unvented clothes dryers, as well as exterior humid air that enters the basement and condenses on cooler surfaces. This means that the problem of moisture is very often complex and requires a lot of

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experience and expert knowledge due to various sources and mechanisms of moisture, type of building structure, building materials, as well as local conditions.

The moisture problems described in this article caused by rainwater and groundwater impact relate in particular to masonry foundation walls of decades-old buildings, usually enlisted in regional cultural heritage list. Counteracting rainwater and groundwater is very burdensome and requires contractors to be highly accurate in conducting construction works, especially at discontinuous points. Moreover when moisture is observed building experts and specialists making a direct assessment of the technical condition of the building, need to make decision to the further selection of the state of the art modern civil engineering solutions for drying moisture or wet. The purpose of this selection is to perform the effective vertical and horizontal waterproofing of the basement walls together with the use of renovation plasters, as well as ensuring the evaporation of the existing moisture in these walls and floors. Additionally, due to the insufficient degree of natural ventilation of basement rooms, it is usually necessary to use the effective mechanical ventilation.

However in some cases the location of historic buildings, which requires the protection against the rainwater and the groundwater, particularly in densely urbanized area and in the vicinity of adjacent buildings or underground installations, excludes the application of the solution of making vertical insulation by digging out the entire basement walls. In such situations, the system solution needs to be selected that ensured tight hydro-insulation layer made.

Based on authors' extensive experience case studies related with moisture observed in The Main Library of Mazovian Voivodeship and in Warsaw Citadel, along with several detailed approaches to solving these problems are presented in this paper. These examples are related to the defects of waterproofing and insulation. Further operation of buildings with defective and leaky waterproofing insulation, without proper maintenance management, may lead to damage to the brick elements of masonry structures in a relatively short time [3, 4].

2 Description of the structural health of the building structure

2.1 The main Library of the Mazovian Voivodeship

The outbuilding was built in 1938. During the World War II it was significantly damaged and it was partly rebuilt in 1949 [3]. Now, it is a semi-basement building (east and middle outbuilding) and has two over-ground storeys (eastern outbuilding has three storeys) and a unusable attic. The cubic capacity of the entire facility with outbuildings, warehouses and reading rooms is 50 470 m^3, usable area is 9 052 m^2, and the building area is 2 499 m^2. In order to assess the technical state of the building a detailed technical inspection of the building as well as macroscopic "in situ" tests were conducted. Moisture has been found in basement walls, often at their entire height. It appeared as a result of the lack (or damage) of horizontal and vertical cavity wall insulation. As a result of moisture, these walls had a reduced thermal insulation and were subjected to faster technical wear, which reduced their load-bearing capacity.

The explanation for this occurrence is connected with both phenomenon - firstly, the presence of damp causes some materials to deteriorate. Secondly, the presence of salts influences destructively on the masonry materials themselves. The salts crystallise as the moisture evaporates. Then the pressure created by individual salt crystals growing within the pores, physically break down the matrix of masonry surrounding each salt crystal. The process repeats itself and finally the masonry breaks down in layers and spalls off. Some of the salts cause a chemical reaction that also destroys the internal structure of the masonry.

In the cellar rooms, the plaster and wall covering were blistering by migration of water, as well as the salt damp was observed - Fig. 1. In addition, these salts also increased the hygroscopic properties of basement walls. The bubbled and blistered internal plasters reduced also the aesthetics of the basement rooms.

Fig. 1. "Salt damp" damage observed (fretting mortar, bubbling paint and plaster, as well as serious decomposition of the wall materials) on the rear wall of the eastern outbuilding in the basement. Visible places of holes in the wall made during the drying works using the crystalline injection method.

Long-term damage to the waterproof insulation caused the basement walls to get wet above the ground level, in basement rooms up to the level of the ceiling - Fig. 2. It should be stressed that unsuccessful attempt to protect against moisture by using a crystalline injection was made. Therefore, to fully protect the damp external walls against further moisture penetration, it was recommended to perform a new vertical waterproofing and insulation of the walls from the outside using the traditional method. The design provided for the walls to be excavated in sections. Due to the fact that during the building inspection leaky splash apron around the building were found, its restoration while maintaining its leak tightness and proper cross slope from the outside of building was designed.

Fig. 2. Ceiling above the basement of the eastern outbuilding.

2.2 The Warsaw Citadel facilities

The described facilities were built as an integral part of the historic defence complex, the so-called The Warsaw Citadel. The fortress is a pentagon-shaped brick structure with high outer walls, enclosing an area of 36 hectares. The Citadel was built by personal order of Tsar Nicholas I after the 1830 November Uprising. Its chief architect, Major General Johan Jakob von Daehn (Ivan Dehn), used the plan of the citadel in Antwerp as the basis for his own plan. Work on it commenced May 31, 1832, on the site of a demolished monastery and of the estate of Fawory. Its construction required the demolition of 76 residential buildings and the forcible resettlement of 15,000 inhabitants [5].

The building numbered as No 36 is located near to the entrance gate from Dymińska street. Moisture in the walls and ceiling vaults of this facility occurred first of all in rooms that are intended for the security guards - Fig. 3. Traces of moisture were observed almost on the whole surface inside the building. Their presence was the result of the lack (or damaged) of horizontal and vertical existing waterproofing insulation. As a result of moisture, a reduced thermal insulation of walls were diagnosed.

Fig. 3. Moisture accumulated on the ceiling vault in the building No. 36.

During the in-situ building inspection combined with macroscopic organoleptic tests the bubbled and blistered plasters were observed on the walls of described above rooms. It could be explained as the result of the migration of the mixture of water and salt crystals - Fig. 3. The interaction of the salt solution with the brick structure resulted also in increased hygroscopic properties of the walls.

After removing the made ground, the test bore-hole of the wall was performed with a ϕ 90 mm diameter of the drill. The aim of this inspection was the verification of the layer arrangement under the embankment and the assessment of the condition of waterproofing insulation over the damp rooms. The following arrangement of layers was found (Fig. 4): mixture of sand, rubble and clay ~ 110 cm, concrete screed (strongly damped) ~ 5.0 cm, lean concrete ~ 5.0 cm, insulation in the form of 2 x tar paper (crumbled and strongly damped) concrete screed ~ 3.0 cm, fine sand ~ 1.0 cm and finally brick vault. In the exploratory bore-hole, the presence of zinc sheet being the original insulation of the building from the period of its construction was also found.

a) b)

Fig. 4. A vault over the damp rooms of the building No. 36; a) the visible the test bore-hole of the wall after drilling b) insulation layers discovered (tar paper and zinc sheet).

Another analysed building being under assessment was facility No. 60, which is part of the bastion fortifications. Also in the case of this fortification object, moisture occurs both on the entire surface of the walls as well as in the ceiling vaults - Fig.5.

Fig. 5. Blistering of wall covering and spalling of masonry construction in rooms of facility No. 60.

Similarly to the first case considered, in order to determine the arrangement of the layers under the topsoil and the assessment of the technical state of waterproofing insulation over the damp rooms the test bore-hole was made using drill with 90 mm diameter (the topsoil was removed firstly). The following arrangement of layers was found (Fig. 6): mixture of sand, rubble and clay ~ 165 cm, concrete screed (strongly damped) ~ 5.0 cm and brick vault. No insulation layer was found, which could have caused a high degree of moisture in the structure.

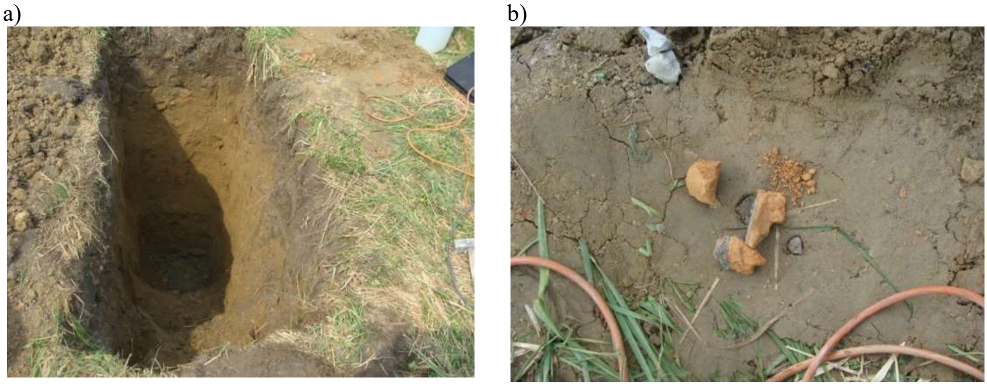

Fig. 6. A vault over the damp rooms of the building No. 60; a) the visible the test bore-hole of the wall after drilling b) material collected for testing (concrete and brick) moisture content.

In order to determine the degree of moisture content in the built-in materials in the structure, samples were taken to determine their moisture using oven-drying method. The following results were obtained:

- Brick:

  tare weight: $m_T = 28{,}75$ g
  tare weight with damped brick : $m_{mT} = 103{,}08$ g
  tare weight with dry brick : $m_{sT} = 88{,}22$ g

Soil moisture content in brick could be calculated using above samples' weights from the following formula:

$$w = \frac{m_{mt} - m_{st}}{m_{st} - m_t} \cdot 100\% = 24{,}99\%$$

- Concrete:

  tare weight: $m_T = 28{,}75$ g
  tare weight with damped concrete : $m_{mT} = 103{,}08$ g
  tare weight with dry concrete : $m_{sT} = 88{,}22$ g

Soil moisture content in concrete could be calculated using above samples' weights from the following formula:

$$w = \frac{m_{mt} - m_{st}}{m_{st} - m_t} \cdot 100\% = 11{,}08\%$$

On the basis of the obtained results, it was clearly stated that the layers of the vault structure over the rooms of the building No. 60 were very moist. This situation was additionally worsened by the insufficient natural ventilation of the rooms and the fact that some of them were not operated and heated.

3 Proposal packet of repair systems and solutions

3.1 The main Library of the Mazovian Voivodeship

It was recommended that the repair works related to the removal of moisture in the basement walls include the carrying out of a new horizontal waterproofing insulation based on the injection with a gel resin having with low viscosity close to that of water, as well as the construction of new vertical walls. The design involved the removal of bubbled, blistered and corroded (damp and saline) plasters at their entire height in all cellar rooms. The repair technology process consisted of the following stages:

- Cleaning the external wall surface - i.e. walls should not be wet, dirty, greasy or dusty;

- In the case of elements of bricks poorly connected with the wall, spalling of masonry or the presence of heavily corroded bricks - they were removed, and then the resulting cavities were refilled;

- Gel injection was performed through special packers, which were spaced at least every 20 cm;

- Plasters enabling evaporation of water from a damp wall, as well as providing high water vapor permeability, small capillary and good resistance to salt were used. The plaster was laid in accordance with the plaster manufacturer's recommendations.

It should be noted that in order to improve the adhesion of new renovation plasters to the renewed façade, a rendering coat is made in the first step. If the renewed surface of the façade has a reduced strength or a different structure, the utilization of a surface reinforcing mesh (Rabitz wire mesh or fiberglass) is crucial to avoid cracks. Such a reinforcing mesh is assumed before the rendering coat is made.

3.2 The Warsaw Citadel facilities

Due to the lack (building No. 60) or damage (building No. 36) of waterproofing layer above the vaults, the new hydro-insulation, as well as a new flashing is proposed. The following order of repair works is indicated in the design:
- Removal of topsoil along with humus layer over the vaults of buildings;
- Cleaning and alignment of the upper vault surfaces associated with appropriate setting of cross fall gradient;
- Making new flashings;
- Laying new insulation in the form of the following layers (from above):
  - geotextile with a weight of 250 g/m^2,
  - *0.15 cm* of insulation - a PVC welded membrane, eg of the ALKORPLAN type,
  - geotextile with a weight of 140 g/m^2,
  - *1 cm* HDPE drainage film,
  - geotextile with a weight of 140 g/m^2,
  - a minimum of 5 cm of concrete screed,
- Re-covering of building structures with previously excavated material and restoration of vegetation and grass.

The waterproofing in the form of a weldable membrane has to be tightly connected with the new insulation of the existing ventilation chimneys (Fig. 7), using liquid foil, and turned over to the new flashing. In addition, it is designed to combine it with a new vertical waterproofing of the walls.

In order to make a new vertical waterproofing of walls of buildings' rooms, the soil should be removed from the walls, as well as from the upper surfaces of the vaults. The vertical insulation should be performed to a depth of 30-50 cm below the level of the floor. The Structural Health Assessment of the building walls should be conducted during engineering works. In the case of diagnosing the poor technical condition of the external walls, the wall face should first be repaired by refilling gaps with cement mortar with additions of plasticizers. This will both reinforced the wall and create a suitable surface for new waterproofing.

Fig. 7. Roofing of the building facility No. 60.

The insulation should be made as seamless with flexible bitumen and rubber materials in the form of pastes applied with a plastering trowel (e.g. Nafuflex 2K or Superflex-10). The entire surface of the insulation should be reinforced with a plastic mesh (eg polypropylene fabric). The insulation surface must be secured first with Styrofoam boards or with thick geotextile, before being buried. Existing damped and damaged plasters on internal walls should be removed. In place of the removed plasters, new renovation plasters should be made, e.g. Schömburg's Thermopal system. New plasters must be put with silicate paints (e.g. Tagosil from Schömburg), with very high water vapor diffusion property. It is unacceptable to use traditional plasters and paints with low water vapor diffusion properties, e.g. emulsion paints based on polyvinyl acetate bases or acrylics.

4 Discussion

The geotechnical investigations carried out under the foundations of the Main Library of the Mazovian Voivodeship have shown that underneath the foundations are soils with low load-bearing capacity in the plastic state. Soils with a higher value of load-bearing capacity are located at a depth below 3 m from the ground level (behind the eastern outbuilding). Moreover, in the lower part of the walls in the basement the moisture caused by capillary suction is observed. The wall drying carried out several years ago using the crystalline injection method did not achieve the intended effect. The test bore-hole of the floor and its layers performed in the room under the “terrace” outbuilding revealed the lack of any waterproofing insulation. In addition, there no drainage layer was noted, which significantly worsens the conditions of supporting the floor slab. No reinforcement was found in the slab, therefore, in order to transfer the load of 900 daN/m^2, a new reinforced floor slab together with a drainage layer and new insulation should be made.

The second of the analysed cases concerned The Warsaw Citadel facilities. The renovation of buildings No. 36 and No. 60 located in the historic military complex in Warsaw, the so called Warsaw Citadel, requires, apart from obtaining a building permit, issuing a prior opinion and decision of the conservator-inspector, due to the fact that these objects are enlisted in the Regional Heritage List. Wide scope of renovation works specified in the proposed design and consisting of a significant amount of earthworks, causes its costs to exceed the financial capacity of the Administrator. Nowadays, small partial repairs are being carried out, which improve the technical condition of the assessed buildings. However it would be expedient to perform a comprehensive renovation in the manner and scope described in this paper. It is obvious that alternative and less expensive solutions may be used, however it is crucial to ensure the effective solving the moisture problem in the analysed building facility [6, 7]. An alternative design of waterproofing buildings can be insulation in the form of a heat-weldable tar paper layers (e.g. two layers of tar papers Icopal P Base Speed Profile SBS) on the previously prepared and primed surface (e.g. with IZOLBET-A material).

Designing and performance of a waterproofing insulation of historic buildings is associated with high responsibility. The designer and engineer are also required to have extensive experience and wide range of knowledge in this area. Their improper design and performance may even lead to serious accidents, an example of which may be the breaking off of a fragment of the cornice of the tower of St. Anna's church in Warsaw. An additional difficulty and obstacle in this type of construction works are guidelines, recommendations and instructions given by the conservator-inspector, which often require the use of built-in materials compatible with the historic character of the buildings.

5 Conclusions

From our studies and obtained results the following conclusions could be formulated:

- When carrying out repair works related to the implementation of an effective anti-moisture system, in particular in the parts of the underground structures of the brick historic buildings, the special attention should be paid to the need to remove corroded and damaged internal plasters. These plasters are often strongly saline as a result of migration of groundwater and rainwater and have the ability to accumulate moisture. In both analysed cases, the salt efflorescence were observed on the internal plasters, which had to be removed along with the plasters.
- The repair systems used for the protection of the underground parts of the historic buildings against rainwater and groundwater should always be selected individually depending on the local conditions and the assessment of the properties of built-in building materials. The proper diagnosis of the causes of the moisture problem in the underground parts of this type of buildings as well as the practical evaluation of possible repair systems allows to choose the suitable solution that will ensure the long-term effectiveness of repairs for a several decades.
- The modern market solutions based on absorption of moisture from walls in a chemical way or based on the microwaves application are short-term solutions. The key task of the repair system should be the removal of the causes and not the effects of the moisture caused by both - the rainwater and the groundwater.

References

1. C. Sullivan ,B. Horwitz-Bennett, *Historic Masonry: Restoration and Renovation*, Building Design & Construction, Vol .**50**, Iss. 8, (2009), p. 21-28.
2. N. Sathiparan, U. Rumeshkumar, Journal of Building Engineering, Vol. **17** (2018), p. 23-31, https://doi.org/10.1016/j.jobe.2018.01.015
3. R. Chmielewski, L. Kruszka, *Expertises and technical opinions in the area of building construction* (WAT, 2005-2017), *in Polish*.

4. R. Chmielewski, L. Kruszka, J. Lalka, Biuletyn WAT, **684**, 4, (2016), p.123-141 *in Polish.*
5. http://wislawarszawska.pl/warsaw-citadel/?lang=en (*The Warsaw Citadel*)
6. B.M. Smith, *Moisture Problems in Historic Masonry Walls; Diagnosis and Treatment.* (Government Printing Office, Washington DC, 1984).
7. E. Franzoni, Construction and Building materials, **54**, (2014), p. 123-136 https://doi.org/10.1016/j.conbuildmat.2013.12.054