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MOISTURE INSULATION WITH CLAY OF UNDERGROUND BUILDINGS ON THE EXAMPLE OF MODERN ERA FORTIFICATIONS AND WARSAW ELIZEUM

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ABSTRACT: Based on the analogy of the structures of underground buildings - the Warsaw Elizeum and many fortress buildings from the eighteenth to the nineteenth century, the article is an attempt to present an overview of historical methods of protecting their interiors against moisture penetrating from embankments, condensation, pulled up by capillaries or diffusing from the ground. The methods of moisture protection in the modern fortifications were developed over 4 centuries of its development (16th – 19th c.), as a result of gradual accumulation of experience and engineering knowledge. Important elements of these protections were clay/loam cladding and corridors running around underground spaces, which had not only transport function, but also served as an insulation and ventilation buffer. Underground buildings, properly designed for extremely unfavorable conditions of use, can last thanks to the delicate balance, which is very easy to disturb. The first condition of this balance is to maintain a proper ventilation and heating regime for condensation-prone interiors. At the end, care and maintenance activities aimed at stopping the progressing degradation of the building are proposed, and indications for the research program and pre-design assumptions for future necessary renovation and conservation works are outlined.

KEY WORDS: Historical monuments, underground buildings, moisture, protection, clay

1. Introduction

Reading a collection of essays entitled Elizeum. Prince's underground salon...[1] brings to mind defensive architecture, including Srebrna Góra Fortress[2], which seems astonishing, given the drastic difference in function and scale of these two objects [Fig. 1]. Both buildings are almost of equal age (the Elizeum was built in 1776-1778, the central part of the Fortress 1765-1768), both were constructed in order to achieve the strategic goals of the investors (strengthening the position of Prince Kazimierz Poniatowski among the capital's elites, and strengthening the rule of the King of Prussia in Lower Silesia). Elizeum, just like fortifications, is distant from the commonplace buildings, which allows to consider them as examples of 'extreme architecture'. Their designers had to know or find a solution to similar problems - protection against moisture and water which would be effective enough to achieve a microclimate of the interiors ensuring: in the Elizeum - comfort to the prince's friends and delicate ladies during occasional meetings, and in the Fortress - maintaining combat capability during the blockade and siege.

In the architectural-engineering sense, the similarity of the applied solutions lies in the surrounding of the interiors protected against humidity by the perimeter insulation and ventilation corridor. Such a corridor, established on the side of the embankment, in Elizeum runs around the central salon whereas in Srebrna Góra it surrounds the casemates around the Donjon's moat.

Due to the scarcity of sources and research, the detailed solutions used by the builders of the fortifications will be discussed in the further part of the article on the examples of other, younger defensive works - mainly from Toruń.

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1 Gutmejer K. (ed.), *Elizeum. Podziemny salon księcia. Dla Przyjaciół i Pięknych Pań* (collective work), ed.: The Capital City of Warsaw 2016. The material for this article was commissioned by the Warsaw Monuments Conservator's Office in 2017 for the planned second publication on the Elizeum, and was also referred to the seminar "Historical materials and technologies. Clay insulation in historical underground buildings", in September 2017, followed by the conservation conference "Clay in historical buildings. Protection and conservation" in Malbork, in March 2018.

2 Podruczny G., Przerwa T., *Twierdza Srebrna Góra*, Bellona Publishing 2010.

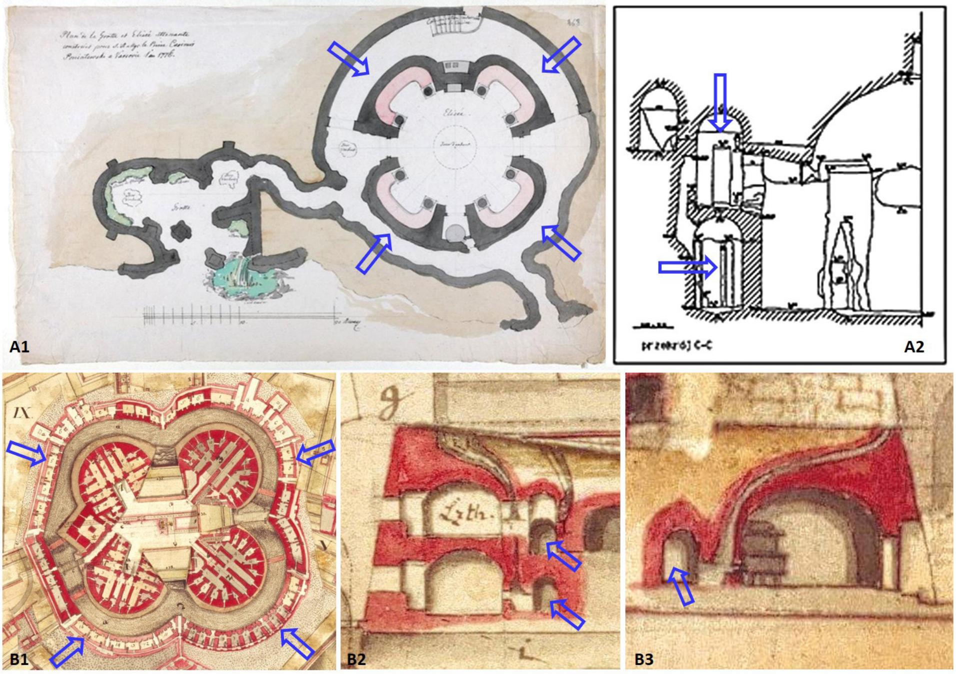

Fig. 1 A1 – Elizeum. The third design (…), underground level, 1776-1777 (BUW G.R. 137); A2 – cross-section (inventory); B1 – Srebrna Góra Fortress, central part – the Keep (Donjon), fragment of the plan from 1776 (GStA PK G 70032); B2 and B3 – cross-sections, fragments of the plan as above, Perimeter corridors marked with arrows

2. Moisture protection in the modern fortification

Erection of underground cubatures (here: buildings covered with earth embankment), which were almost common feature of the fortifications in the 17th-19th century, required solving the problems of drainage and moisture protection in order to eliminate or reduce the negative impact of moisture from rainwater, groundwater and condensation, both on the durability of building structures and its functionality, i.e., mainly on the health of the personnel and the durability of warfare material resources (gunpowder, armaments, food). A characteristic feature of fortress rooms is low and stable temperature of the interiors, thanks to their thick walls and earth mantle. Such building partitions are characterized by high thermal inertia, which makes it difficult to heat the rooms (but makes it easier to maintain the temperature) . However, it also makes them susceptible to condensation of water vapor.

The modern fortifications during 4 centuries of development (16th-19th c.), as a result of gradual accumulation of experience and engineering knowledge about specific physical features of these buildings, developed relatively simple yet effective methods of multi-stage protection of underground buildings against water and moisture. They were supposed to ensure faster drainage of water than the rate of water penetration through building partitions. Clay was used for this purpose, but it was one of many complementary techniques used. Depending on local needs, environmental conditions and technical possibilities, the following solutions were used selectively or interchangeably:

a) for protection against water penetrating from above:

- forming embankments without horizontal surfaces and depressions, covered with turf (on slopes, under rain or snow, turf forms a "thatched" pattern, thus allowing water to flow down the grass stalks);
- earth embankments with a laminar structure, with alternating layers that are pervious and non-pervious (if there were soils with the desired properties on the site);
- wall sidefills: desiccating - of sand, laid on horizontal (oblique) surfaces; draining - crushed stone, coarse gravel or rubble, laid at the perimeter walls; - insulation cladding - from clay/ loam;
- waterproof finishing of covered wall surfaces - smoothly applied masonry plasters based on hydraulic lime, trass, later Portland cement;
- drainage surfaces on the vaults, in the form of broken, sloping patches with run-offs directed to the façade cornice and/or the embankment (the so-called donkey backs);

b) for protection against capillary action or diffusion of moisture from the ground:

- stone continuous footing and stone foundation walls;
- horizontal insulation made of lead sheet, slate, cement mortar;
- sand cushions under floors (if necessary);
- brick asphalted 'canal' floors (in gunpowder storage rooms);
- wooden floors on brickwork and ventilated air void (in barracks);

c) for protection against condensation moisture:

- installation of ventilation and insulation corridors on the side of covered walls (in gunpowder storage rooms and underground magazine blocks);
- bricklaying of gravel earth covered perimeter walls with circulating ventilation ducts within these walls (in work and storage rooms);
- bricklaying of the lower layer of vaults with hollow brick (in Prussia after 1881[3]), maintaining continuity of openings connected with ventilation;
- adjustable gravitational ventilation (closing / opening) depending on temperature and humidity gradient;
- heating of barracks rooms (stoves, fireplaces).

These techniques were not only characteristic of fortress architecture, they were in a way a "common heritage". The need to use these techniques in residential-palatial construction was rare, because it would add unnecessary costs from troublesome location of construction sites in the field and then from their exploitation. However, there were exceptions and the underground Elizeum is one of them.

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[3] Wichrowski M., *Załoga fortu i jej skoszarowanie*, Atlas Twierdzy Toruń (hereinafter: ATT), Zeszyt 11: Fort V – Chodkiewicz (Fort III – Scharnhorst), Toruń 2018, p. 12.

The engineering knowledge necessary for the construction of underground buildings[4] was still passed directly from the master to the apprentice in the seventeenth and eighteenth centuries, and the education of building fortifications in Europe was just taking its first steps[5]. In the Napoleonic era, it became a subject of military education. The oldest (known to the author) textbook was created in Prussia by order of the Head of the Engineering Corps and the General Inspector of Fortresses and was accepted in 1836 as confidential training and instructional material for the Engineers' Corps[6]. It includes a systematic course of the New Prussian fortification. On several drawings we can find examples of the use of clay as waterproofing insulation on the vaults, ceilings and earth covered walls [Fig. 2].

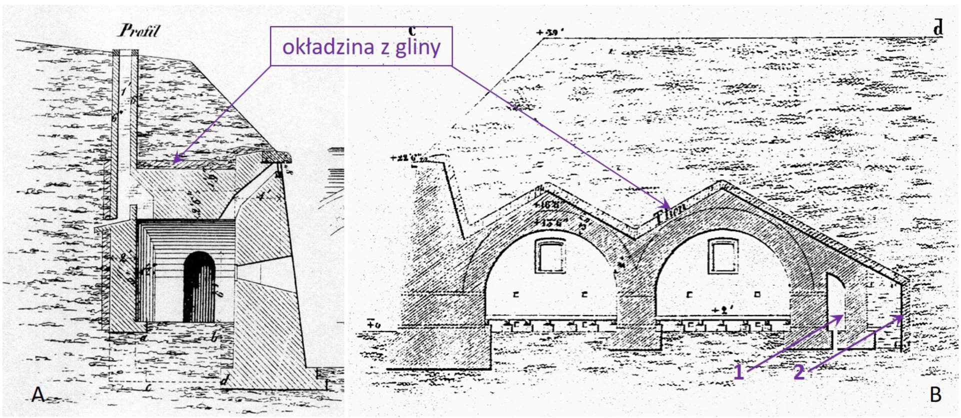

Fig. 2 Examples of use of clay cladding on earth covered walls and vaults in fortress buildings, according to Moritz von Prittwitz, Beitrage..., Taf. 30, 53 (fragments): A - shooting gallery, cross section; B - war powder magazine, cross section. Especially noteworthy are: the peripheral corridor (1) and the moving the clay cover away from the earth-covered outer wall of the perimeter corridor running around the gunpowder room (2)

On the basis of the preserved (and known to the author) archival documentation of the fortifications of the Prussian fortresses in Toruń, as well as Srebrna Góra, Kłodzko, Giżycko and others[7], it can be concluded that the design drawings only exceptionally present the use of clay as an insulation or, more generally, as a barrier protecting buildings from water contained in the ground or flowing water [Fig. 3 and 4].

4 In this article, the term "underground structure" refers to objects covered with earth, but does not include those built underground by mining methods.

5 Dybaś B., *Fortece Rzeczpospolitej. Studium z dziejów budowy fortyfikacji stałych w państwie polsko-litewskim w XVII wieku,* 2nd edition, UMK Toruń 2018, pp. 348-380, ibidem literature. Military engineering was only one of the fields of study at the Stanislas Knights' School , operating between 1765-1794. (See: *Dzieje Szkoły Rycerskiej – Korpusu Kadetów w latach 1765–1794.* Warsaw, 2015).

6 von Prittwitz M. und Gaffron, *Beitrage zur angewandten Befestigungskunst, erläutert durch Beispiele aus der neuern Preußischen Befestigungsanlagen auf 100 Tafeln*, Posen 1836.

7 The fortification archival drawings cited here are in the collections of *Geheimes Staatsarchiv Preußischer Kulturbesitz in Berlin, ensemble XI Heeres Archiv, Kriegsministerium, Festungspläne* (hereinafter referred to as GStA PK) and have been reproduced in ATT, Volumes 6 and 9.

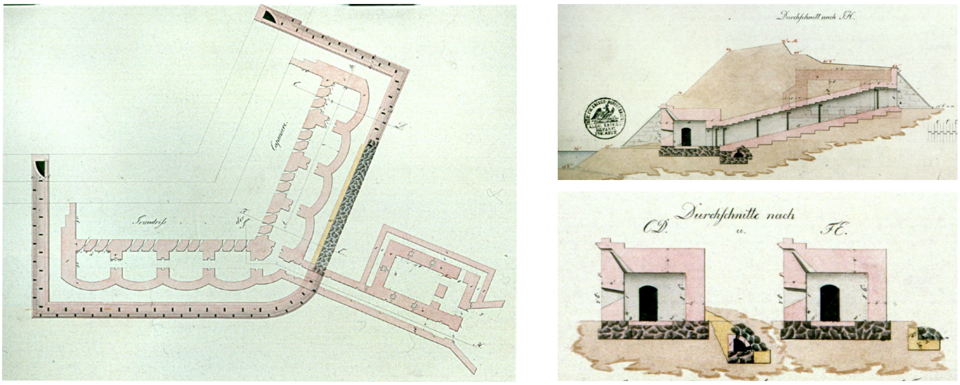

Fig. 3 Fragments of the detailed executive drawing of Caponier 2 in Toruń, 1823 (GStA PK F 70851, after: ATT, Z. 9, Fig. 10B), projection and cross sections. Visible drainage canal installed on the side of the embankment with outlets into the moat, whose operation is supported by a clay barrier

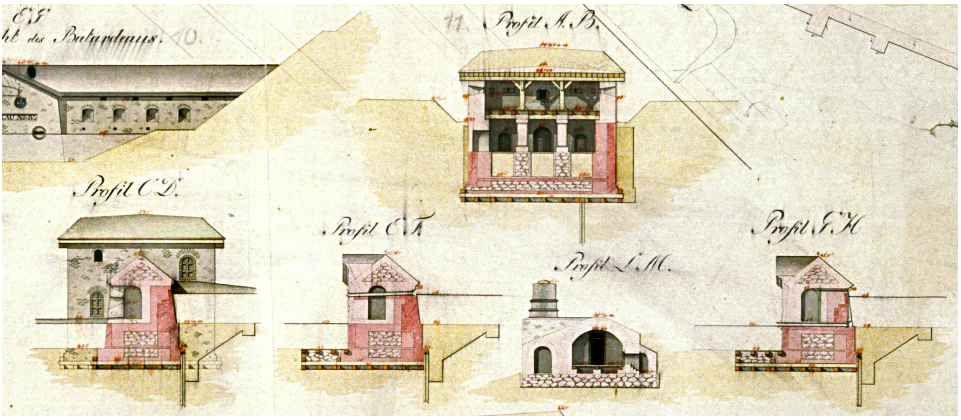

Fig. 4 A fragment of the drawing of Cofferdam IV in Toruń, 1824 (GStA PK E 70716, after: ATT, Z. 6, Fig. 39), cross sections. Visible use of clay as a barrier protecting the wall of the blockhouse against infiltration of water from the ground (profile AB) and a barrier protecting the Cofferdam against washing out by high water in the moat (profiles CD, EF, GK). The sections are marked as "peaceful" and "wartime". (high) water level in the moat

Practical solutions can be observed on the existing and studied objects. In the excavation made for the construction of the Contemporary Art Center in Torun, in October-November 2006, the remains of an element of demolished fortifications of the fortress core - Caponier 1[8] [Fig. 5, cf. Fig. 3] were found. An insulating lining made of greasy clay, about 30 cm thick (1 Prussian foot), was found not only on the walls of the building [Fig. 5, lower picture], but also on the brick canal, which led under the embankment and discharged excess water from the moat of modern ramparts into the medieval moat [Fig. 5, top picture]. As can be seen in the reproduced archival drawing, the insulations are not included in it.

[8] Documented by archaeological surveillance. See: Grzeszkiewicz-Kotlewska L., Szczepanik M., *Opracowanie wyników badania archeologicznych przy ul. Wały gen. Sikorskiego 13 w Toruniu (2005-2007)*. Archaeological and Conservation Services, Toruń 2007. (Archive of WUOZ in Toruń, ref. W/3482). The location of the caponier in relation to the CAC building and its layout is shown by a commemorative plaque in situ.

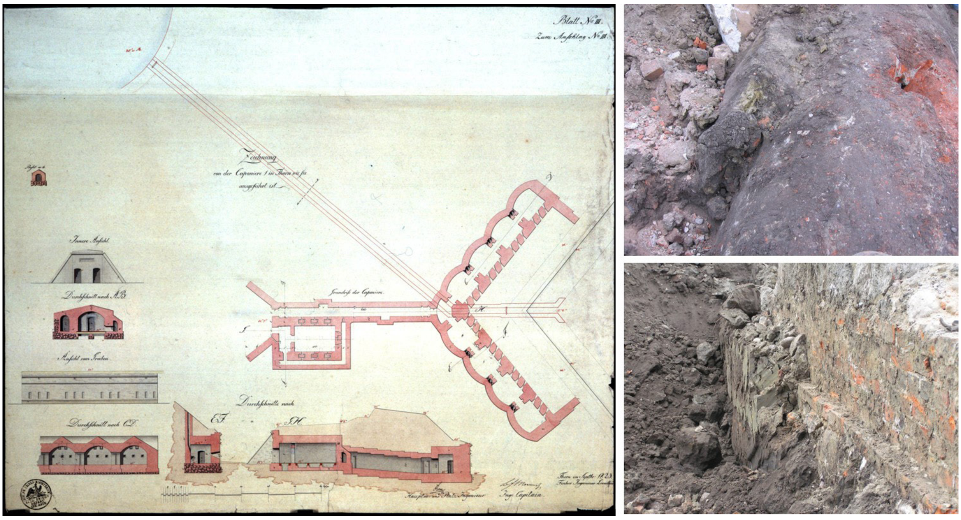

Fig. 5 Executive drawing of Caponier 1 in Toruń, 1823 (GStA PK F 70852, after: ATT, Z. 9, Fig. 10A). On the relics of Caponier 1, uncovered in the building excavation site, clay linings are visible, which are not included in the drawing. Photo by L. Narębski, 2006

The use of clay in the embankments of younger Toruń fortifications (objects of the outer fortress ring, 1880s and 1890s) was discovered in soil research. Clay insulation layers of 6 to 37 cm thickness were found in the embankments above the buildings, laid not directly on the building structure (here - concrete detonation slab of 1.0 to 1.2 m thickness, made of gravel concrete, unreinforced and without expansion spacers), but on a sandy drainage layer of 30-50 cm thickness. The total thickness of the surcharge including the humus layer above the insulation, ranged from 16 to 37 cm[9], and it can be assumed that the clay served not only as a waterproof barrier above the building, but also to retain moisture in the turf layer.

During the works carried out in 2016 aimed at preventing the dampness of the Fort IV shoulder caponiers (built in the years 1879-1880, reinforced by concreting the vaults only in 1900, clay insulation was found in the embankment on the concrete detonation slab. A relatively thin drainage layer was covered with a layer of loam, turning by the edges of the embankment into a layer of cohesive (though crumbled) clay on the disappearing drainage layer[10].

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[9] Ratke M., *Charakterystyka gleb antropogenicznych na wybranych fortyfikacjach w Toruniu*. Toruń 2004. (Master's thesis written in the Department of Soil Science at the Faculty of Biology and Earth Sciences of Nicolaus Copernicus University in Toruń, under the supervision of Prof. Renata Bednarek), m-pis, pp. 26-34, 37, 45.

[10] Implementation of the task entitled Toruń, Fort IV Żółkiewski (XIX century): Desiccation of the left and right caponier casemates and interventional repairs of the right caponier wall - stage V, with the subsidy of the Minister of the Culture and National Heritage, under the 'Monuments Protection' program.

3. The issues of moisture protection in the Elizeum

Comparison of the moisture protection techniques used in the modern era fortifications - using clay as a waterproof cover for the walls of the subterranean building, in conjunction with the perimeter corridor as an insulating and ventilating buffer to protect the interior against condensation - with the solutions used in the Elizeum[11], allows to better understand this unique architectural work and appreciate Zug's comprehensive professional preparation as an engineer-architect[12].

The Elizeum's perimeter corridor is not only a fragment of the "artificial grotto" leading the prince's guests on a mysterious, winding and dark road to the even more surprisingly beautiful, luxurious lounge, it was not only a way for the servants serving "friends and beautiful ladies". (lower level) and a place for a band of musicians (upper level), but also cutting off the comfortable (and thus heated) interior of the lounge from the cold and moisture of the ground covering the building. Above the corridor, a continuation of this separation is the double-mantel dome, i.e., containing the built-in thermal air insulation [Fig. 6, 7].

Fig. 6 Elizeum, perimeter corridor, ventilation. A - ventilation hole in the vault of the corridor, B - ventilation hole in the wall below the vault, C - ventilation duct with a blocked outlet, D - vault of the perimeter corridor 'shining' with moisture above the visitors' heads. Photo: L. Narębski, 2017

11 Gutmejer K., Elizeum. *Podziemny salon...*, op. cit., ibid.: Bojanowska A, Wolanski A., chapter Izolacje, p. 86.

12 A complete overview of Zug's work: Kwiatkowski M., *Szymon Bogumił Zug architekt polskiego Oświecenia*, PWN Warszawa 1971.

Fig. 7 Elizeum, A - perimeter corridor: lower, to the right of the contemporary entrance (A1), lower, western section, visible inlet of the ventilation shaft and entrance to the upper storey (A2), upper, view of the left wall closing the corridor (A3); B - dome: general view, visible traces of the original decor and outline of the original oculus (B1), uncovered wall fragment in the inner mantle of the dome (B2). Photo: L. Narębski, 2017

Here is the question - if these solutions were so good, why has the Elizeum deteriorated so much? The answer is twofold: the building is in poor condition after 240 years, but it does exists. The structural remains stable, but its decoration has not been preserved. It is hard to expect that the waterproofing and damp-proofing protections built into the structure of the Elizeum would still work. Ventilation and dehydration do not work, because the oculus in the dome was first deprived of its rain cover - a gazebo and (probably) airflow control devices (glazing of the gazebo walls, blinds?), and then drastically reduced and finally covered. The ventilation ducts leading out of the perimeter corridor are also blocked [Fig. 7 A2, 6 A-C]. The insulating layer of clay has mechanical damage (cavities) and is most probably perforated by the roots of several generations of trees, which have at least partially decayed. Although the perimeter walls have been covered with drainage layer and a drainage system was built at their base, the efficiency of these installations may be very problematic or none at all, due to the overgrowth of tree roots following water and silting by dusty soil fractions migrating with water.

Fig. 8 Silver Mountain Fortress, insulation and ventilation corridors. A - a corridor with a 'drip' vault. (Photo: G. Basiński); B - corridor with a gargoyle of vault drainage of adjacent casemates (Photo: W. Szymański)

Based on the visual inspection of the Elizeum and many years of observation of the phenomena taking place in post-fortress facilities, including my own experience of protection and renovation works in the fortification facilities, I believe that the following actions should be proposed ahead of the planned conservation and renovation works in this facility:

A) protection works:

• improvement of surface drainage by appropriate, for the an underground structure, maintenance of the lawn above the structure - mowing the grass high.

• installation of an entrance lock (e.g. installation of a second door in the entrance hallway), in order to limit condensation dampness - by closing the entrance to the lock at high temperature and humidity of the air outdoors.

B) pre-design works:

• All-season climate studies[13] (spring/summer/autumn/winter), consisting of recording temperature and humidity of indoor and outdoor air in correlation with the temperature and humidity of perimeter walls and vaults: A/ in the existing (present) condition, and B/ after opening the dome and ventilation shafts in the perimeter corridor. Control of time of condensation appearance on the dome, vaults and walls after opening the entrance, in correlation with external conditions; in winter conditions, observation of possible icing (ice infiltrates, icicles - Fig. 9).

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[13] Methodology of climate research see: Rouba B. J., , *Badania klimatyczne a problematyka konserwatorska, Od badań do konserwacji* - Conference materials - Toruń 23-24 10 1998, UMK Toruń 2002, p. 193-198; the same thing: *Zagadnienia klimatu a bezpieczeństwo zbiorów* (article access: https://wuozprzemysl.pl/sites/ default/ files/do-collections/2019-12/145%20ROUBA%20Klimat%20Wyd.%20MNRiPR-S.%20Szreniawa%202015%20 r.%2C%20s.%20191-208%20.pdf - DOA 2020-05-12).

Fig. 9 Fortress buildings in winter. "Fixed" water leaks: A - from the earth-covered vaults of the Lower Bastile of the Silver Mountain Fortress Donjon (photo: G. Basiński); B - from the gargoyles on the elevation of the barracks of Fort I of the Toruń Fortress (photo: L. Narębski)

The aim of the research will be - on the basis of the obtained results - to determine the needs for ventilation and (possible) heating, as well as to develop an element of the instruction manual: under what thermal and humidity conditions it is allowed to make the facility available, under what conditions the access should be limited, how to control the ventilation depending on the season and weather conditions.

• calculation (checking): A/ thermo-insulation of the upper zone of the dome with oculus and the surcharge above it, correlated with the reconstruction of the lantern gazebo above the oculus, examination of the upper ring of the oculus for traces of the attachment points of the oculus cover; B/ gravitational ventilation of the object with the reconstructed oculus in the dome and ventilation shafts in the perimeter corridor.

The aim will be to design: A/ thermal insulation (if calculations confirm the need) - to eliminate the risk of condensation dampness due to excessive cooling of the dome, especially the oculus ring; B/ ventilation control - alternatively by: closing the oculus (with a flap, louvre flap), closing the walls of the lantern gazebo (glazing?), reconstructing the ventilation shafts' outlets from the perimeter corridor with covers to regulate the air flow; C/ possible introduction of auxiliary mechanical ventilation (e.g. for events with high attendance, in adverse weather conditions).

• adopting the assumption of preserving, without interference, of the original clay cover as an integral element of the monument, designing a replacement, contemporary surface cover to drain deeper layers of soil above the protected building (e.g. drainage geotextile) placed on the level of ground freezing, and at the top of the dome to the level of the clay lining , on the area exceeding the building outline, surrounded with a French drain to the west and on the sides, descending (cascading?) to the foot of the escarpment.

The aim will be to protect against water penetrating from the ground, without disturbing the original structure of the building and endangering its statics even by temporary eccentric load reduction in the case of removing the embankment.

Note: application of the drainage shield and drainage should retain the diffusion properties of the structure: building partition / ground surcharge, but without drying out the turf layer!

4. Conclusions

Underground constructions, designed for extremely unfavorable conditions of use[14], can last thanks to a delicate balance of durability factors and the destructive forces, an equilibrium that is very easy to break. The first condition for balance is to maintain a proper heating and ventilation regime for condensation-prone interiors[15].

Keeping the embankment above the structure in balance is about proper care of the turf cover - mowing the grass high (so that the stalks drain rainwater); preventing the growth of high self-seeding greenery - because the crowns of trees and shrubs suppress the turf, the root systems penetrate the insulating linings and drainage layers and can damage the masonry structures. Maintenance of the embankment also means ongoing repairs of possible landslides of the earth escarpment. Drainage efficiency has an impact on the durability of earth slopes - water concentration in the ground threatens mainly the structures, but can manifest itself as surface outflows or even landslides.

One must not forget that even if we use the underground structure only as a seasonal attraction - it must survive the whole year, even in winter conditions. Winter reveals all the weaknesses of the waterproofing and thermal insulation by "stopping" the penetrating water in the solid state [Fig. 9].

From this paper we should therefore derive generalized proposals of practical actions for managers, indications for designers of adaptation of underground buildings (mainly modern fortifications), as well as issues worthy of scientific research:

Protection and maintenance measures: removal of invasive greenery, maintenance of the turf cover of the embankments, maintaining the efficacy of drainage and ventilation, implementation of a regime of use to limit the condensation of moisture in the interiors (e.g., it is a common mistake to ventilate underground rooms that have cool walls in warm weather);

Pre-design activities: comprehensive historical research; architectural reconnaissance: foundations, soil and water conditions, structure, tectonics and physical properties of building partitions covered with an earth mantle, built-in ventilation and drainage systems, all-season climate research;

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[14] In the case of Srebrna Góra, effective and efficient drainage of the fortress casemate was particularly important due to local climatic conditions in the Góry Sowie mountains. On the edge of the mountains over the Ząbkowicka Valley, on Góra Warowna mountain, the average annual rainfall is almost twice as high as in the town of Srebrna Góra. Therefore, the peripheral insulation and ventilation corridors in the fortress also play a drainage role; they are covered with vaults made of flat stones laid without mortar (dripping vaults), and/or water flowing down the vaults is directed to them [see Fig. 8].

[15] The NCOs of the former fortress garrisons responsible for the maintenance of the underground storage (cold rooms) and barracks (heated rooms) followed specific instructions. These recommended ventilating the rooms when the difference in air temperature between the inlet and outlet of the ventilation did not exceed 2-30 C and reheating the residential interiors in spring to reduce the temperature gradient of the earth-covered walls and the air indoors. In the Polish military literature, engineer Lt. Colonel Hornowski described these principles in a very communicative way. *Wilgotność kazemat (podwalni) i sposoby jej usunięcia. (uwadze korzystających z kazemat-podwalni)*, Saper i Inżynier Wojskowy, 1925, pp. 1159-1165. Reprint with introduction by Krzysztof Biskup, INFORT no. 12 (1996), pp. 12-14.

Design: drastic changes in building physics should be avoided - applied damp-proofing and insulation should take into account the diffusivity of the structure of historical building partitions and the earth mantle.

The question of what engineering knowledge was available and how was it applied by designers and builders of fortifications and other "difficult" objects in the 18th and 19th century and how were they educated - including Szymon Bogumił Zug - is undoubtedly an interesting and poorly studied research problem. A promising tool for the research of this problem are, of course, the existing monuments, but above all the professional literature of the period, including mainly military instructions and technical regulations[16].

Despite the loss of their original functions, the interiors of historic underground buildings provide a unique, multisensory experience to contemporary audiences, being an important component of the tourist attractiveness of the former fortifications. For the Elizeum such reception was programmed by the investor and the designer. Nowadays, despite general degradation, lack of context and complete stripping of the interior from its decor and furnishings - it still makes strong impressions with its mysteriousness, arouses interest in history (places, people, epochs), provides visual experience (darkness), aural (silence), stimulates imagination (what the place must have looked like in its time).

That is why it is worth recognizing, understanding, checking the effectiveness (through appropriate calculations and/or research) of the original moisture protection and ventilation, before we build new, expensive (and usually monstrous) ventilation, air conditioning, dehumidification installations, etc. into these interiors. Maybe for contemporary needs it is enough just to support what the old engineers left behind?

[16] In Prussia, the military authorities issued successively updated technical regulations for military construction (Technische Vorschriften), which were normative acts. See: Wagner R. v..: *Sammlung technischer Bestimmungen für Fortifikations-, Artillerie- und Garnison-Bauten*, Berlin 1881.

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