THE ACTION OF THE UNDERGROUND WATER ON HISTORICAL CONSTRUCTIONS

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Abstract

Among the actions of the environment factors on the buildings in general and of the historical structures in particular, the water in the water table is not only the most present factor but also the most aggressive one.

Be it water that is naturally present in the water table, or water that got into the water table through a construction error, it generates the most substantial damages and degradations of the structures of the historical buildings. These damages and degradations are more dangerous as the action of the water is slow, even invisible most of the times and almost without exception a long term one.

The causes that lead to the aggressive action of the water on the historical structures are either natural, due to a soil that is not suitable for construction, or human, due to inadequate construction solutions or to subsequent human actions that generate damaging actions on the buildings.

The presence of the water in the immediate vicinity or contact with the historical structures is impossible to avoid. Because of this, any of the solutions regarding the waterproofing of the buildings have both advantages and disadvantages. The action and/or the contact of the water with the construction is impossible to avoid. The invasive or non-invasive, reversible or irreversible, visible or invisible measures cannot completely avoid the contact of the water with the building. For this reason, the option for a solution or another must have as a purpose the maximum protection effect of the building against the damaging actions of the water.

The identification of the causes, the understanding of the way the water acts on the historical buildings and the correct identification of the solutions regarding the protection of the buildings against the actions of the groundwater are the key points of this study.

Key words: groundwater, degradation, historical buildings, waterproofing, protection

INTRODUCTION

Since ancient times, whether we are talking about the area of Europe or Asia, the way to build was based on structures made of brick load-bearing walls or stone blocks, wooden slabs and timber frames supported by brick vaults or wooden beam grids. For finishing works, the lime was used in its double form, aerial or hydraulic.

In the 1950s - 1960s a new type of construction system began to spread, based on a structural framework made of cement and iron (reinforcement). This major difference can be expressed as the difference between two absolutely different methodologies of construction. It is therefore obvious that the whole historical real estate heritage has nothing in common with the new construction methodology. The first and biggest difference is the lack of cement from the first construction typology.

Based on these major historical differences, one might think that, in the general collective mind, but especially of those in the field of constructions (designing engineers and builders alike), everything that represents a historical real estate heritage has a special place, and consequently, any intervention on it must be made in full respect of the monument and with maximum professionalism. Of course, this phrase implies finding the correct architectural, structural and infrastructure solutions, but also applying techniques and materials compatible or even identical with the historical ones. The complexity of such an endeavor is all the more so since, along with the craftsmen, it is known that many of these techniques and materials have disappeared, and the efforts to maintain and/or revive them involve considerable material and human efforts. And yet, the daily practice proves that far from being aware of such a responsible and respectful professional conduct towards the built heritage, humanity is, in many cases, far from the truisms stated.

In principle, humidity is defined as the amount of water vapor or the degree of saturation with water vapor of the air at a given time. Regardless of temperature, the unit of measure defined as a cubic meter of air, may contain a certain maximum amount of relative humidity. Therefore, the actual percentage of humidity in the unit of measurement of air, is called Relative Humidity, and is defined as a percentage. If the R.U. is maximum, the cubic meter of air is defined as saturated, and the Relative Humidity is 100%.

The amount of relative humidity decreases with the temperature, causing the water vapor to be eliminated as the air temperature drops. When this phenomenon happens outside, it takes the form of clouds or dew. If, on the other hand, the phenomenon occurs inside, it is called condensation or the well-known and unpleasant humidity.

Based on the World Health Organization, the ideal relative humidity, either in indoor or outdoor spaces, is in the value range between 40% and 50%, regardless of temperature. Starting with the value of 60% of relative humidity, the states of discomfort begin to appear, while from 70% of relative humidity, phenomena such as dew, condensation and even mold appear. As an expression of how relative humidity can be influenced, it is well known that an average family produces on average 10 liters of water vapor through washing, cooking, etc.

Condensation occurs when the air in a room cools in contact with a cold surface existing in that space. The most illustrative example is the bathroom mirror, having a surface cooler than the indoor air temperature. Another ”classic” example is the wall of a room facing North or East. Less known to the general public, but just as obvious, is that a wall is cooler if through it the phenomenon of capillary ascension of water occurs. For a good example it is useful to know that a gram of water that evaporates, extracts 540 calories from the surface on which it evaporates, resulting in its cooling.

Anyway, the most effective way to combat the emersion of condensation and mold is the intervention of interrupting the capillary ascension of the water in the masonry.

MATERIAL AND METHOD

Bringing the discussion at present, we find that after more than 2000 years of use of old types of mortars based on hydraulic or aerial lime, they have disappeared from the market from the 1950s – 1960s, and along with them also disappeared the laying related technology. Obviously, the legitimate question arises: why did this phenomenon happen? The answer is very simple: being able to combine with the old types of mortar, the cement has simply become a stronger mortar, with a faster setting, with a stronger adhesion, and last but not least, cheaper. Looking at the phenomenon from this perspective, naturally, the following question arises: if so, why use the old mortars again? As a first impulse, the answer seems very simple. Even guided by the best intentions, the use of cement has become so widespread that it seems useless to try to find and justify any answer.

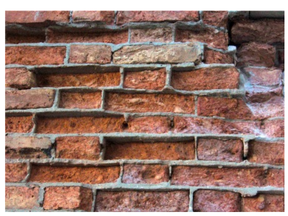


Fig. 1. The action of the ascending water in a historic masonry with cement mortar
Fig. 2. The action of the ascending water in a historical masonry with lime mortar

On closer analysis, however, we can differentiate the following nuances of the problem. First of all, cement is not a better mortar. It is a better bonding material than the old mortars. It is a material that, chemically, is radically different from the old mortars. For this reason, applied to the so-called historical masonry, it behaves according to its own physical and chemical rules, most often incompatible with the morphological structure of the historical masonry. In conclusion, here it is that, in practice, the awareness that cement-based mortar is not compatible with the historical masonry structures does not occur. In other words, without special attention paid to historical heritage, hence to old buildings, attention that inevitably must also be found in national laws, the traditional techniques and materials are destined to disappearance and oblivion. Suggestive for this process subject to change constantly is how cement and its use in the field of construction has been viewed over time. If at the beginning of its widespread use it was perceived as a ”novelty” and an exponent of ”progress”, nowadays, almost exclusively, in the field of restoration, it is excluded a priori from the intervention solutions.

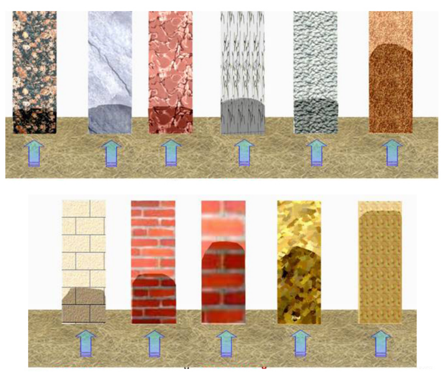
Beyond the cultural and/or moral arguments stated, however, is the use of cement in the field of the conservation and rehabilitation of the historical heritage so serious? The answer is unequivocal yes, precisely due to the superior characteristics of the cement-based mortars.

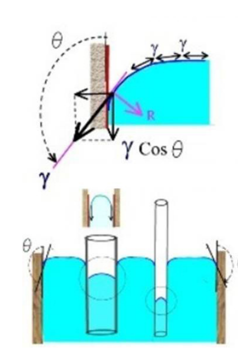
1) NOT REQUIRED. A conventional cement-based mortar is about four or five times stronger than a traditional lime-based mortar (the compression strength is at least 150 kg/cm2, compared to 35 kg/cm2). Such strength not only is not required in a masonry that works at a maximum of 7.5 kg/cm2, but when used to fill in the missing areas, it generates different behaviors of the historic masonry.
2) IRREVERSIBLE LOSSES. Any type/element of historical material, once built or fixed with the aid of cement-based mortar, is irreversibly degraded and thus lost. Why is this happening? Because the cement-based mortar fixing is, in the overwhelming majority of the cases, stronger than its own strength of the historical material itself.
3) IT IS NOT PERMISSIVE. Cement-based mortars are much less permissive when the water passes through the masonry structure. This means that, under normal conditions of capillary ascension, the humidity will evaporate from the historical material, instead of this process occurring from the layers of mortar joining the building blocks.
4) COMPLEX SALT OF ETTRINGITE. A chemical compound specific to cement, but lacking in traditional mortars, namely tricalcium aluminate, reacts in a humid environment with the sulphates present, thus forming a complex salt of ettringite, in which the crystals formed have a double volume compared to the initial state. This expansion obviously breaks and dislocates the historical material in the immediate vicinity of the cement-based mortar.
5) WATERPROOF PLASTERS. It is already proven that a cement-based plaster is much less permissive when evaporating water from the wall structure than a historical lime-based plaster. By default, this implies reduced indoor comfort, generated by increased indoor humidity, humidity deriving through capillary ascension. Finally, in

addition to the harmful effect on the indoor environment, the physical degradation caused to the historical masonry will be massive and most often irreversible.

RESULTS AND DISCUSSION

The phenomenon of capillary ascension in historical built structures exists because the constructive system has always been based on the same principles: solid brick or stone masonry, elements joined together by mortars based on aerial or hydraulic lime and sand, placed directly in the natural ground, without any kind of waterproofing. Therefore, in the load-bearing structures the ascension happens automatically, precisely due to the construction system, and this phenomenon occurs both in the vertical direction, through the walls, as well as in the horizontal direction, especially through the floors of the ground floor, or, as the case may be, of the basement.





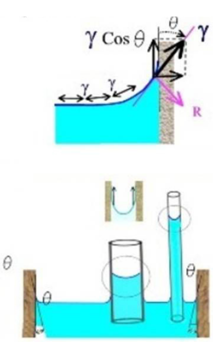


Fig. 3.Capillary ascension in different types of walls: granite, marble, chalk, cement plaster, lime plaster, medium limestone, new brick, sandstone, travertine
Fig. 4. Waterproof contact
Fig. 5. Hydrophobic contact

Following numerous observations and studies, the existence of two types of contacts between water and the wall support with which it comes into contact was established. First of all, it is about the waterproof contact, in which the contact between the water and the wall is convex, the angle between the horizontal of the liquid and the vertical of the wall being greater than 90°. In the second case it is the hydrophobic contact, in which the contact between the wall and the water is concave, the angle between the horizontal of the water and the vertical of the wall being less than 90°. The type of contact depends on the type of materials that compose and generate the process. The classic examples are those between water and glass, which generates a hydrophobic contact, while mercury and glass generate a waterproof contact.

According to Jurin's law, in the absence of evaporation, the ascending force of each capillary is given by the type of material, the radius of the capillary, the density of the liquid and not least by the contact angle. Based on the aforementioned law, a capillary with a diameter of 1 micron, can raise the water up to 15 meters high. However, the phenomenon of evaporation existing and also acting concomitantly with that of capillary ascension, the ascending effects of water/humidity are blurred and balanced by all the factors involved and all their actions.

In conclusion, therefore, the amount of water that will be absorbed and rised in a certain time interval (minute, hour, etc.), by a certain type of material, depends on its structure, on the number and type of capillaries, on the connections between them, etc., essentially on its porosity and its absorption coefficient.

In practice, the total amount of water absorbed will continue the ascension process until it finds the first surface capable of allowing the evaporation process. At the limit, in the ideal case, the balance between capillary ascension and evaporation occurs when the amount of water absorbed is equal to the amount of water eliminated by evaporation. Moreover, once the maximum height of ascension is established, the hydrodynamic balance is established between the ascension and the evaporation processes. Otherwise, if the evaporation process intensifies (higher heat or stronger wind), the visible humidity level inside the wall will decrease. On the contrary, if the evaporation process decreases, the visible humidity level in the wall will rise.

Moreover, since we are talking about a continuous process, its effects are continually amplified or diminished, permanently modifying the material and its physico-chemical properties. Why and especially how is this phenomenon happening? Because, in principle, up to this point of the analysis, isolated concepts were discussed. In reality, however, there is no distilled water in the natural environment. Fact for which, without exception, all the amount of water that by ascension and absorption enters the structure of the walls, contains dissolved mineral salts: chlorides, sulphates and nitrates. Further, it is known and proven that the water will evaporate from the surface of the wall, while salts will not, instead they will form salt crystals on the outer surface of the wall. These crystals will clog, block up and seal the surface of the wall, thus diminishing the breathability capacity of the wall in the respective area.

Their origin lies in the water that evaporates from the surface of a wall, originating from the capillary ascent of the water from the groundwater, either from the capillary ascension or the propagation caused by the defects of the sewers existing inside the building. These waters always contain mineral salts. Through this process, the water evaporates but the salts do not. As a result of this phenomenon, these salts remain on the outer surface of the walls forming increasingly larger and more crystals.

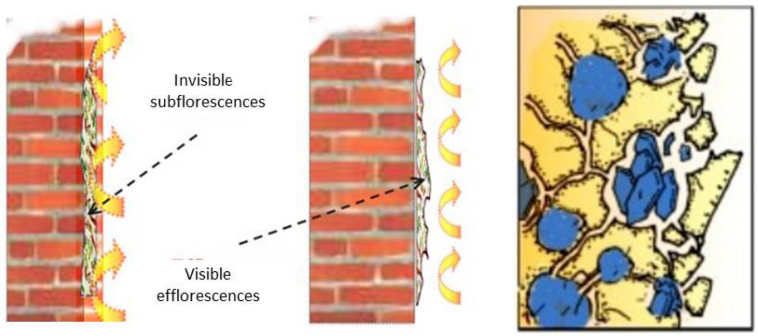


Fig. 6. Invisible subflorescences below the plaster of the wall
Fig. 7. Visible efflorescences on top of the plaster
Fig. 8. Salt crystals that destroy the plaster/wall

However, it is not these salts, respectively efflorescences, that produce the degradation of the parietal surfaces, but the so-called subflorescences. They are located in the first 10 – 12 mm of the thickness of the plaster or wall. Subflorescences, invisible, through their continuous expansion, produce the breaking, dislocation and rupture of the upper layers of the wall or plaster.

The position in which salts form efflorescence or subflorescence crystals depends on two factors:

1. The type of masonry and/or material from which the wall is formed, respectively its plaster. And because these salts occur at the molecular level, also in the case of masonry/plaster we discuss about their capillary structure.

2. Secondly, it is the climatic conditions that the respective wall has to face. These climatic conditions refer to humidity, temperature, exposure or not to solar radiation, exposure or not to the actions of the wind, etc.

As a result of those described above, the following conclusions are obvious: the behavior of the masonry subject to the actions of the inner waters varies during the same day. Under such conditions, two extreme behavioral scenarios can be developed. The first of these refers to the phenomenon of maximum evaporation. It involves high temperatures, strong wind and low-intensity relative humidity. In this way, the air penetrates the masonry in depth, thus favoring the evaporation of the subflorescences. At the opposite pole, the low temperatures, the total or almost total lack of the wind, respectively the existence of a high relative humidity, will favor the evaporation on the outer surface of the masonry, respectively of the efflorescences.

CONCLUSIONS

The application of cement-based plastering, does nothing but reduce the degree of permeability to evaporation and favors capillary ascension. Similarly, the application of cement-based mortars, either in the structure of the walls or as asphalt layers on horizontal surfaces (markets, sidewalks, roads, etc.), will have the same result on the historical building material. And finally, in order to maximize the destructive effect, the aggressive and invasive methods of ”cleaning” and ”preparing” the masonry for the application of new mortars based on cement are also worth highlighting.

Finally, it should be mentioned that also in the case of structural consolidation, the use of materials compatible with the historical structure of the building, can generate results at least similar to those that would be obtained if the interventions were carried out with mortars and/or materials based on cement. From the category of the first, the most common are reinforced or cross-linked fiber plaster, based on aerial or hydraulic lime. Less accepted, knowing that these are also irreversible, but certainly not as harmful as those based on cement, epoxy resins in small quantities are another option for structural consolidation interventions.

Therefore, the comprehensive understanding of the whole phenomenon, with all the causes that generate it, respectively with all the implications they generate on the historical structures, represents a good starting point in establishing correct solutions.

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