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Water and salt transport and storage properties of Mšené sandstone

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Abstract

Basic water and salt transport and storage properties of Mšené sandstone, a material frequently used in historical buildings on the Czech territory for many centuries, are studied in the paper. Moisture diffusivity and water vapor diffusion resistance factor represent the water transport parameters, sorption isotherm and water retention curve water storage parameters, ion binding isotherm the salt storage parameter and salt dispersion coefficient the salt transport parameter. Experimental results show that the analyzed material has mostly favorable water and salt transport and storage properties which can be attributed mainly to its open pore structure and to its negligible amount of small pores. As a consequence, a risk of damage due to salt crystallization and due to ice formation seems to be low for this material. This makes it appropriate for application in severe conditions, such as the permanent exposure to water or salt solutions.

Keywords: Water transport; Water storage; Salt transport; Salt storage; Mšené sandstone

1. Introduction

Historical masonry often contains significant amount of various salts. They can originate from several sources. One of them is underground soil with water-soluble salts. As in most historical buildings horizontal water-proof insulation is missing, salt solutions can be transported into materials of load bearing structures by capillary forces. Another source of salts in masonry is sodium and calcium chlorides used for winter maintenance of pavements and footways. They can diffuse either into underground soil or directly into the masonry. Salts can also be formed by reactions of acid-forming gases in the air with basic components of building materials. Some salts can be formed by actions of living organisms and microorganisms. Water-soluble salts in the form of hydrated ions capable of transport in the porous system can also be presented in masonry materials themselves.

If salts are presented in porous system of masonry materials in the form of solution, they are mostly not dangerous. The harmful effects of such salts consist in the fact that after possible water evaporation or temperature changes salt crystals and crystal-hydrates are formed that often have crystallization pressures higher than the strength of the particular material. The pressure exerted on pore walls can then lead to material destruction.

The damage assessment of historical masonry due to the effect of salts can be performed in simplest way by taking specimens from damaged walls and analyzing them in laboratory. This provides information on water content and on the type and amount of ions in material which is very useful for appreciation of the current state. The possible reasons for the presence of the particular ions can also be estimated on the basis of these analyses. However, it is very difficult to make reliable predictions of further damage on

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the basis of these data. This requires years or even decades of on site measurements, aside from the fact that the extent of such analyses is logically restricted by the amount of material which can be taken from a historical building.

Prediction of water and salt movement and salt crystallization in the walls of historical buildings can be done effectively by means of mathematical and computational modeling. In this way, the time development of water and salt concentration fields can be obtained which is crucial for a proper assessment of possible future damage. However, the accuracy of simulated water and salt concentration fields critically depends on the availability of all input parameters.

There are two types of these parameters which have to be known in advance. The first are initial and boundary conditions. Initial conditions can be determined using on site analysis of water and salt concentration fields in the walls. Boundary conditions are of two types. The first of them are meteorological data for temperatures, relative humidities, rainfall and solar radiation, possibly also concentration of acid-forming gases in the atmosphere. This type of data can be obtained from meteorologists in the form of so-called TRY (Test Reference Year) data which present certain average values over a sufficiently long time period. The second type of boundary conditions involves water content and salt concentration in the underground soil close to the studied building. These data can be obtained again by on site analysis.

The second type of input parameters are water and salt transport and storage parameters of the materials of the wall which appear in water and salt mass balance equations. These depend on the type of model used for description of water and salt transport.

In this paper, the Bear and Bachmat diffusion-advection model [1] is used which takes into account (in addition to salt dispersion in the liquid phase) the influence of moisture flow on salt transport and also the effect of bound salt on pore walls. In this model, the salt mass balance can be expressed in a 1D approximation as

$$\frac{\partial (wC_f)}{\partial t} = \frac{\partial}{\partial x}\left(wD\frac{\partial C_f}{\partial x}\right) + \frac{\partial}{\partial x}\left(C_f\kappa\frac{\partial w}{\partial x}\right) - \frac{\partial C_b}{\partial t}, \tag{1}$$

where C_f is the concentration of free salts in water (in kg m^{-3}), C_b the concentration of bound salts in the whole porous body (in kg m^{-3}), w the volumetric moisture content (in m^3 m^{-3}), κ the moisture diffusivity (in m^2 s^{-1}) and D is the salt dispersion coefficient (in m^2 s^{-1}).

The water mass balance (with the addition of water vapor transport which is not included in the original model [1]) is expressed as

$$\frac{\partial w}{\partial t} = \frac{\partial}{\partial x}\left(\kappa\frac{\partial w}{\partial x}\right) + \frac{\partial}{\partial x}\left(\frac{D_v M}{RT\rho_w}\frac{\partial p_v}{\partial x}\right), \tag{2}$$

where D_v is the water vapor diffusion coefficient (in m^2 s^{-1}), p_v the partial water vapor pressure (in Pa), R the universal gas constant (in J mol^{-1} K^{-1}), M the molar mass of water (in kg mol^{-1}), T the absolute temperature (in K) and ρ_w is the density of water (in kg m^{-3}).

So, for the chosen model of coupled water and salt transport, the water and salt transport and storage parameters include moisture diffusivity and water vapor diffusion coefficient as water transport parameters, sorption isotherm and water retention curve as water storage parameters, which make it possible to eliminate either w or p_v from Eq. (2), salt dispersion coefficient as salt transport parameter and ion binding isotherm as salt storage parameter making possible to eliminate C_b from Eq. (1). These parameters can be determined by common laboratory methods. Samples for the determination of water and salt transport and storage parameters can be obtained most easily from the walls of the analyzed historical building. If this is not possible, stone samples can be taken from the original quarries which are usually known for a particular building.

In this paper, water and salt transport and storage parameters of sandstone from the Mšené-lázně quarry in Czech Republic are determined. The main aim of this

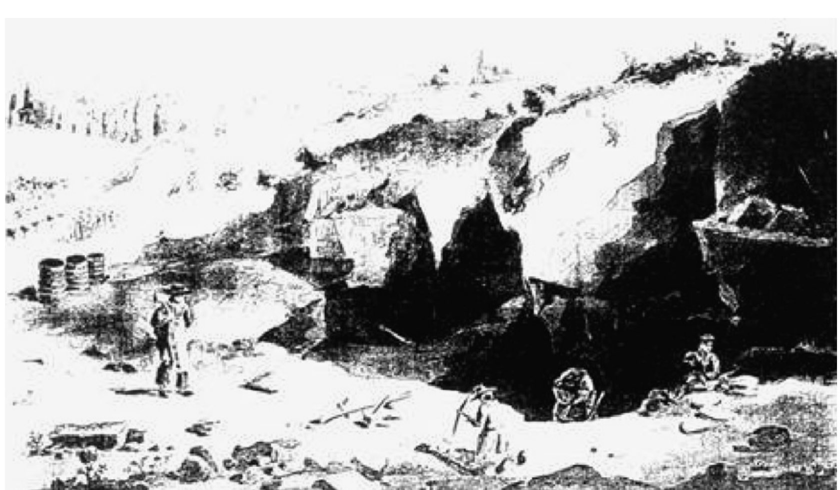

Fig. 1. The sandstone quarry close to Mšené-lázně on J. Štembera's drawing from 1826.