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Zbigniew SUCHORAB[1], Marcin WIDOMSKI[1], Grzegorz ŁAGÓD[1]
and Henryk SOBCZUK[1]

CAPILLARY RISE PHENOMENON IN AERATED CONCRETE. MONITORING AND SIMULATIONS

ZJAWISKO PODCIĄGANIA KAPILARNEGO W BETONIE KOMÓRKOWYM. MONITORING I SYMULACJE

Abstract: Capillary rise is a dangerous phenomenon touching many objects built of aerated concrete which is a porous material and highly prone to water influence in case of any horizontal water insulation failures. Aerated concrete is the artificial building material offering both suitable strength parameters and heat insulation properties. Water migrating from the ground to the walls of the building negatively influences not only its construction but also increases heat loses and decreases indoor air comfort (low temperatures, fungi and bacteria development) which is in the World's literature called SBS (*Sick Building Syndrome*). All above presented facts connected with water migration through the aerated concrete walls underline the need to monitor and simulate capillary rise phenomenon in building envelopes made of aerated concrete. The paper presents the simulation of capillary rise in a model aerated concrete sample. The model applied for simulations will be based on the Richards equation for water flow in unsaturated conditions. The model is commonly used in agrophysics and this work is an attempt to use it for building materials. The simulations results will be verified with laboratory experiment of capillary rise in the real samples of aerated concrete equipped with Time Domain Reflactometry (TDR) probes which will enable to monitor the phenomenon propagation.

Keywords: capillary rise, monitoring, simulations, TDR

Water, which is a necessary substance for all living organisms causes many problems during buildings exploitation. Unfortunately in moderate climate countries it is a common problem and should be considered from both engineering and the ecological point of view. Water contents exceeding acceptable states are the most common in historical buildings made of stone or red brick without suitable water proof insulations but also they occur in many new buildings, sometimes built of modern materials like aerated concrete. Aerated concrete is one of the most popular building materials in Polish market [1]. It is not natural material and its cellular structure was intentionally designed to obtain suitable heat insulation parameters. Method of aerated concrete production was invented at the end of XIX-th century.

Basic assortment of aerated concrete consists of the following apparent densities: 400, 500, 600 and 700 kg/m^3. Two first variants have weaker strength parameters, but better insulation parameters. The other are better from the constructional point of view with still satisfactory heat insulation parameters.

From that point of view it should be underlined that aerated concrete is a particularly interesting solution from the point of view of ecology and environment engineering, especially that there are production technologies providing ashes utilization from powerhouses [2].

The major reason for buildings destruction by water influence is caused by capillary structure of the material (Fig. 1). This causes the building barriers to absorb water from the

[1] Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, tel. 81 538 43 22, email: Z.Suchorab@wis.pol.lublin.pl

ground, water falls or sanitary installations fails in the common phenomenon called capillary rise.

a) b)

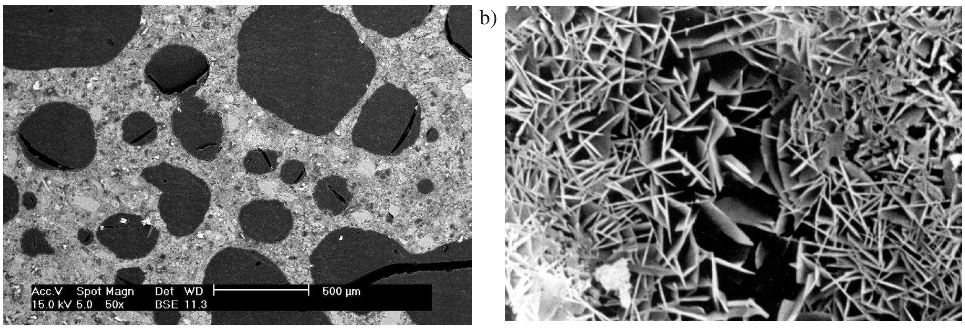

Fig. 1. Scanning Electron Microscope photography of aerated concrete: a) porous structure (spherical macro-pores in black color), b) micro-capillars with flat, needle-shaped crystals, and macro-capillar [3]

Sometimes the damages are caused by phase changes during winter season (congealing and thawing) or transportation of salts which during evaporation crystallize and destroy the porous structure of the material, but especially external plasters.

All above-mentioned exploitation problems indicate the necessity to predict and monitor the behavior of building barriers from that point of view.

Materials and methods

The studies presented in this work are separated into two parts. The first part is modeling of capillary rise phenomenon in aerated concrete sample, second part is the laboratory experiment of capillary rise with constant moisture monitoring, which from that point of view, should be treated as the applied model verification.

Numerical simulations were conducted using the FEFLOW 5.2 program (*Finite Element subsurface FLOW systems*). The software by Wasy Ltd, Germany [4], based on the finite element method was used in the studies. FEFLOW is a popularly used and repeatedly, successfully verified model [5-9] applied in numerical calculations of groundwater movement, pollutants and heat transport in saturated or unsaturated porous media.

Mathematical description of water movement in the porous medium applied in the FEFLOW model is based on Darcy's law [1]:

$$\vec{q} = -k\nabla\Psi$$

and Richards equation [4]:

$$C(\Psi)\frac{\partial\Psi}{\partial t} = \nabla \cdot k(\Psi)\nabla\Psi - S(\Psi)$$

where: q - water flux, Ψ - hydraulic potential, k - Darcy's constant (water permeability coefficient), C - differential water capacity of the material, t - time.

Above-mentioned equations are solved basing on sample parameterization (initial and boundary conditions).

The sample model was of the following dimensions: 22×16×6 cm. Initial condition was moisture value equal 0.1 cm^3/cm^3 (10% vol.) and the boundary conditions were the following:

- vertical left and right, horizontal top - constant flux value equal zero (water insulation),
- horizontal bottom - water.

The reference points were set of the following positions above water level: 5, 10, 15 and 20 cm. Duration of the simulated process was set for 20 days.

To measure the capillary rise phenomenon a technique of constant, quantitative monitoring TDR (*Time Domain Reflectometry*) was applied [11-15].

For that aim a sample of aerated concrete with the following dimensions 24×16×6 cm was prepared. The sample moisture was set to 10% vol.Then the sample were isolated with bitumen mass to minimize any ambient air influence of moisture properties of the sample (sorption from the air). Bottom sample surface was left without water isolation. The experiment was conducted in isothermal conditions - 23°C (±0.5°C).

In such a prepared sample four Time Domain Reflectometry LP/mts (Easy Test) probes were inserted in regular distribution of 5 cm (mostly determined by the area of TDR probe influence range) on the following attitudes - 7, 12, 17 and 22 cm.

In a water container, on a special holder a measured sample was set to provide the maximal contact of the sample with water environment. The container was filled with water 2 cm above the bottom edge of the sample and the TDR probes were consequently placed 5, 10, 15 and 20 cm above the water level (Fig. 2). Constant water level was kept by especially prepared device.

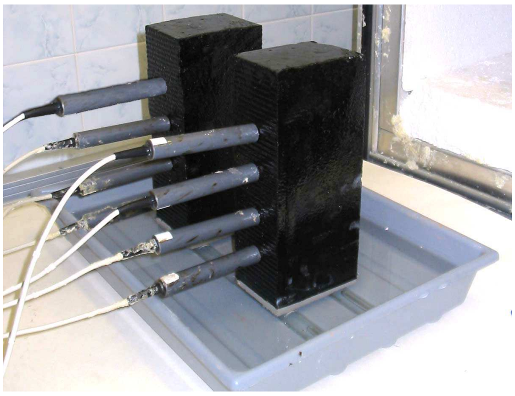

Fig. 2. Experimental setup for capillary rise determination

The measurement was conducted during the period of 20 days until the saturation state (34% vol.) was obtained.

Results

The simulations results (Fig. 3) are presented in the form of changing moisture on the different levels of the sample. Initial moisture of the material was 0.1 cm^3/cm^3 (10% vol.). The first increase of moisture occurred on the height of 5 cm above water level after 6 hours of simulation. Since then the moisture increase slope was steep, and after 2 days it reached 30% vol., which was close to state of saturation (occurred after 5 days of the process) and in case of this concrete was 34% vol. At the level of 10 cm the water increase was noticed after 2.5 days of simulated process, at 15 cm after about 5 days of simulated time. The increase of moisture at the height of 20 cm occurred later (after 10 days of simulated time).

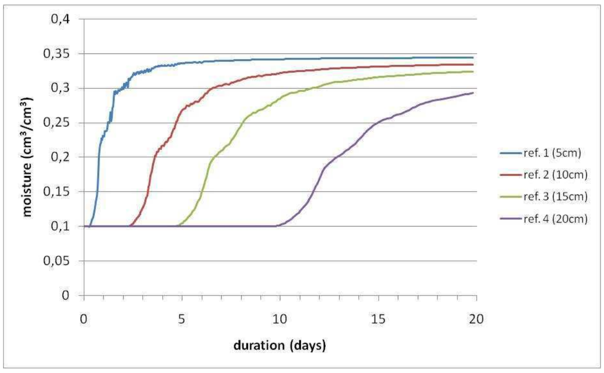

Fig. 3. Moisture changes in the reference points of the modeled sample

The result of the laboratory experiment represents the comparable moisture changes which are presented in Figure 4. TDR sensors installed on the level of 5 cm initially showed moisture about 0.1 cm^3/cm^3 and the first increase was observed about six hours later. After 2 days moisture value was about 30% vol. and was increasing gently during the whole experiment to reach the value of 34% vol. which was nearly saturation. At the height of 10 cm moisture increase appeared after 2.5 day of the experiment which is similar to the simulated trend. At the level of 15 cm moisture increase readouts were observed about fifth day of the experiment and the probe 20 cm above water level during seventh day of the experiment.

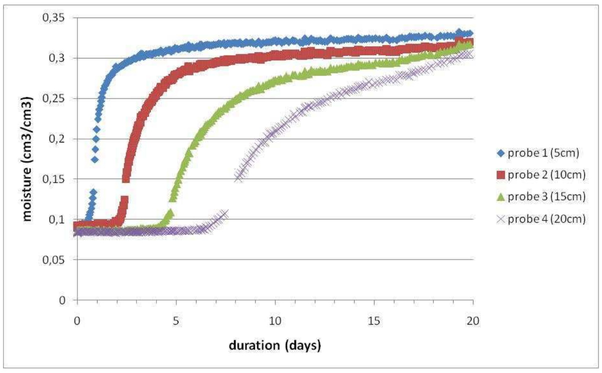

Fig. 4. Moisture changes in sample determined experimentally

Laboratory experiment confirmed the efficacy of the applied model to simulate the capillary rise phenomenon. Moisture changes have similar progresses. Correlation coefficients between particular probes readouts and reference points on the model sample are the following: 0.992 for the probe at a level of 5 cm; 0.956 for 10 cm probe; 0.978 third probe (15 cm) and finally 0.877 for the probe set 20 cm above water level. Weaker correlation between simulation results and the laboratory experiment (probe 4) may be explained by the insulation from the above which also prevented air permeation and thus slowed water rise. In case of laboratory experiment the insulation allowed the air to escape and the capillary rise was more regular.

Conclusions

Both computer modeling but also laboratory experiment confirm strong capillary properties of aerated concrete which is not a good property of the material, especially when suffers rainfalls, floods or moisture insulation fails.

Modeling software (FEFLOW) applied for simulation of groundwater movement can be successfully used for modeling of capillary rise phenomenon in building materials when suitable parameterization and discretization is done.

Time Domain Reflectometry (TDR) is a good method for quantitative monitoring of water movement in building materials and can be successfully applied for laboratory or *in situ* verifications of water movement models.

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References

[1] Siejko J. and Babiński Z.: *Co to jest beton komórkowy? Budowanie z betonu komórkowego*. Poradnik-Katalog. Wyd. Stowarzyszenie Producentów Betonów SBPB, Zeszyt 1, 2005, 11-59 (in Polish).

[2] Narayanan N. and Ramamurthy K.: *Structure and properties of aerated concrete: a review*. Cement & Concrete Composities, 2000, **22**, 321-329.

[3] Roels S., Sermijn J. and Carmeliet J.: *Modelling unsaturated moisture transport in autoclaved aerated concrete: microstructural approach*. Building Physics 2002 - 6th Nordic Symp. (Norway 2002), 167-174.

[4] Diersch H.J.G.: FEFLOW 5.2 Finite Element Subsurface Flow and Transport Simulation System. Reference Manual. WASY Ltd., Berlin 2005.

[5] Diersch H.J.G. and Kolditz O.: *Variable-density flow and transport in porous media: approaches and challenges*. Adv. Water Res., 2002, **25**, 899-944.

[6] Zhao Ch., Wang Y., Chen X. and Li. B.: *Simulation of the effects of groundwater level on vegetation change by combining FEFLOW software*. Ecol. Modell., 2005, **187**, 341-351.

[7] Mazzia A. and Putti M.: *Three-dimensional mixed finite element-finite volume approach for the solution of density-dependent flow in porous media*. J. Comput. Appl. Math., 2006, **185**, 347-359.

[8] Trefry M.G. and Muffels Ch.: *FEFLOW: a finite-element ground water flow and transport modeling tool*. Ground Water, 2007, **45**, 525-528.

[9] Widomski M.: *Assessment of the influence of water erosion control system on water conditions in the soil profile*. Monographs of Environmental Engineering Committee. Vol. 43. Polish Academy of Science, Lublin 2007 (in Polish).

[10] Zaradny H.: Matematyczne metody opisu i rozwiązań zagadnień przepływu wody w nienasyconych i nasyconych gruntach i glebach. Prace IBW PAN, Nr 23, Gdańsk 1990 (in Polish).

[11] Topp G.C., Davis J.L. and Annan A.P.: *Electromagnetic determination of soil water content: Measurements in coaxial transmission lines*. Water Res., 1980, **16**, 574-582.

[12] Sobczuk H. and Plagge R.: Time Domain Reflectometry Method in Environmental Measurements. Monografie Komitetu Inżynierii Środowiska Polskiej Akademii Nauk, 39, Lublin 2007.

[13] Suchorab Z., Sobczuk H., Łagód G., Pavlik Z. and Cerny R.: *Zastosowanie metody TDR do pomiaru wilgotności materiałów budowlanych*. Materiały, Tom 2. Monografie Komitetu Inżynierii Środowiska PAN, 2005, 33, 1063-1070 (In Polish).
[14] Pavlík Z., Pavlíková M., Fiala L., Černý R., Sobczuk H. and Suchorab Z.: *Application of time-domain reflectometry method for measuring moisture content in porous building materials*. Trends Appl. Sci. Res., 2007, **2**(3), 188-200.
[15] Suchorab Z., Jedut A. and Sobczuk H.: *Water content measurement in building barriers and materials using surface TDR probe*. Proc. ECOpole, 2008, **2**(1), 123-127.

ZJAWISKO PODCIĄGANIA KAPILARNEGO W BETONIE KOMÓRKOWYM. MONITORING I SYMULACJE

Politechnika Lubelska

Abstrakt: Podciąganie kapilarne to niebezpieczne zjawisko dotyczące wielu obiektów wymurowanych z betonu komórkowego, będącego materiałem porowatym, podatnym na wpływ wody w przypadku zniszczeń poziomych izolacji przeciwwilgociowych. Beton komórkowy to materiał pochodzenia sztucznego, zapewniający zarówno wysokie właściwości wytrzymałościowe, jak i cieplne. Woda migrująca z gruntu do przegród budynku wpływa negatywnie nie tylko na jego konstrukcję, lecz również zwiększa straty ciepła, obniża parametry komfortu cieplnego (niskie temperatury, rozwój grzybów i bakterii), prowadząc do tak zwanego w literaturze Syndromu Chorego Budynku SBS (*Sick Building Syndrome*). Wszystkie powyżej opisane fakty dotyczące migracji wody w ścianach z betonu komórkowego podkreślają potrzebę monitoringu i symulacji zjawiska podciągania kapilarnego w przegrodach budowlanych z betonu komórkowego. Artykuł przedstawia symulację zjawiska podciągania kapilarnego w modelowej próbce betonu komórkowego. Model zastosowany do symulacji oparto na równaniu Richardsa dla przepływu wody w warunkach nienasyconych. Model jest w powszechnym zastosowaniu w dziedzinie gruntoznawstwa, a niniejsza praca jest próbą zastosowania go dla materiałów budowlanych. Wyniki symulacji zostaną zweryfikowane za pomocą badań laboratoryjnych zjawiska podciągania kapilarnego w próbkach rzeczywistych z betonu komórkowego z zainstalowanymi sondami TDR (*Time Domain Reflectometry*), które umożliwią pełny monitoring zjawiska.

Słowa kluczowe: podciąganie kapilarne, monitoring, symulacje, TDR