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Erratum

Errata to "Poroelastic model for concrete exposed to freezing temperatures" [Cement and Concrete Research 38 (2008) 40–48]

Olivier Coussy, Paulo J.M. Monteiro

The following errors were found in our paper:

1. In the first full paragraph below Eq. (27), the truncated sentence "The term $<\rho_L^0$) between liquid water and ice crystals." must be replaced by:

   "The term ε_{th} accounts for the overall thermal deformation resulting from the mismatch of the thermal deformations of the various components. The term $\varepsilon_{\Delta\rho}$ is the volumetric dilation that results from the difference of density ($\rho_c^0<\rho_L^0$) between liquid water and ice crystals."

2. In the first term on the right side of Eqs. (29) and (30), there is a factor ΔT missing.
3. Eq. (1) must be replaced by

$$\left(1-\rho_C^0/\rho_L^0\right)(p_L-p_{atm})+p_C-p_L=\Sigma_m(T_m-T). \tag{1}$$

Because of the small value of $1-\rho_c^0/\rho_L^0$, the first term in Eq. (1) was neglected in the original paper. This approximation is no longer valid when the value of the liquid pressure p_L is much greater than the atmospheric pressure p_{atm}. This is actually the case for the values reported in Fig. 4 of the original paper.[1] As a result the liquid saturation S_L as a function of cooling ΔT reported in Fig. 2 will only be valid for a drained test, where p_L remains equal to the atmospheric pressure p_{atm}. In an undrained experiment, where the sample is sealed, the correct approach consists of first determining p_L as a function of S_L. This can still be done along the guidelines given in the original paper, by expressing the conservation of the overall water mass (both liquid and solid) with the help of the constitutive equations of unsaturated poroelasticity and equilibrium Eq. (1). The derivation leads to

$$p_L-p_{atm}=(p_L-p_{atm})^{Cryo}+(p_L-p_{atm})^{Hydrau}+(p_L-p_{atm})^{Therm}, \tag{2}$$

where

$$\begin{aligned}(p_L-p_{atm})^{Cryo}&=-\frac{AKM}{K_u}\Sigma_m(T_m-T)\left(\frac{1}{M_C}+\frac{bb_C}{M_C}\right),\\(p_L-p_{atm})^{Hydrau}&=\frac{AKM}{K_u}\left(1-\rho_C^0/\rho_L^0\right)\phi_0S_C,\\(p_L-p_{atm})^{Therm}&=\frac{3AKM}{K_u}\phi_0(\alpha_S-S_C\alpha_C-S_L\alpha_L)(T_m-T),\end{aligned} \tag{3}$$

where A is given by

$$\frac{1}{A}=1-\left(1-\rho_C^0/\rho_L^0\right)\frac{KM}{K_u}\left(\frac{1}{M_C}+\frac{bb_C}{K}\right). \tag{4}$$

The various contributions to the liquid overpressure are

- $(p_L-p_{atm})^{Cryo}$, due to cryo-suction;
- $(p_L-p_{atm})^{Hydrau}$, due to hydraulic pressure;
- $(p_L-p_{atm})^{Therm}$, due to thermal deformation.

Because $A\approx1$ the expression of p_L provided by relations (2)–(4) is formally the same as the expression of p_L evoked in the paragraph just before Eq. (24) of the original paper. However, the pressurization term in Eq. (1), where p_L-p_{atm} appears as a factor, cannot be neglected to determine the liquid saturation S_L as a function of the temperature. This determination can be done by using the cumulative pore volume fraction $1-S(r)$ as a function of the pore entry radius r reported in Fig. 1, and noting that the relation

$$S_L=S\left(r=\frac{2\gamma_{CL}}{p_C-p_L}\right) \tag{5}$$

holds irrespective of any specific value of p_L. Substituting (V) into (II), where the current poroelastic properties depend on the current value of S_L according to the relations provided in the original paper, we obtain p_L as a function of the unknown current radius r. The current value of the radius r can be numerically determined as a function of the current cooling T_m-T by solving Eq. (1), after substitution of the expression (II) of p_L and the expression (IV) of p_c-p_L as functions of r. As a result, the procedure finally provides the current value of S_L and p_L as a functions of the current cooling T_m-T.

Fig. 1 of these errata shows the comparison between the crystal saturation $S_c=1-S_L$ as a function of T_m-T which can be derived from the liquid saturation S_L shown in Fig. 2 of the original paper, and the crystal saturation obtained when using the approach depicted above. As expected, taking into account the pressurization term in (I) limits significantly the extent of the frozen zone as the temperature decreases. In turn, because of the limitation of the extent of the frozen zone the liquid overpressure drops down significantly as shown by the comparison in Fig. 2 of these errata between the curve labelled 'accurate' and the liquid overpressure curve given in the original paper. The S_L–T curve and the liquid pressure values reported in Figs. 1 and 2 of these errata can be then used to update the results of the original paper.

Finally, because of the low values of both terms $\Sigma_m(T_m-T)(1/M_c+bb_c/K)$ and $\phi_0(\alpha_s-S_c\alpha_c-S_L\alpha_L)(T_m-T)$ when compared to $(1-p_c^0/p_L^0)\phi_0S_c$ it can be shown that the term $(p_L-p_{atm})^{hydrau}$ constitutes the main

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E-mail address: monteiro@ce.berkeley.edu (P.J.M. Monteiro).
[1] The authors warmly acknowledge Prof. George Scherer for drawing their attention to this inconsistency and to its significance.

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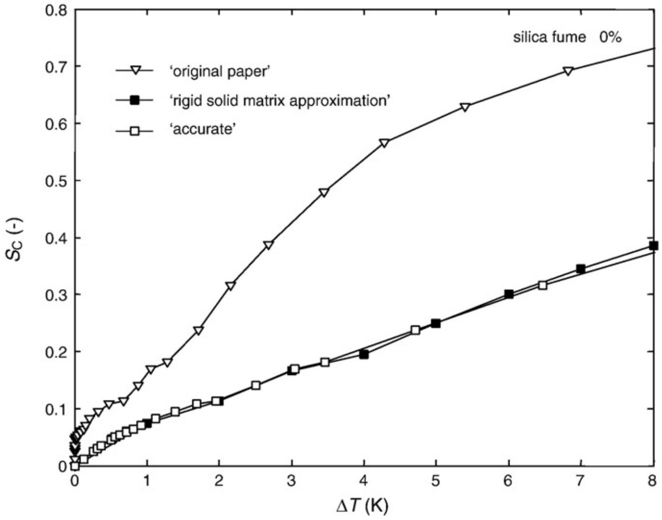

Fig. 1. In a sealed experiment, taking into account the liquid pressurization term corresponding to the first term in the liquid–solid equilibrium Eq. (1) limits significantly the extent of the frozen zone as the cooling increases.

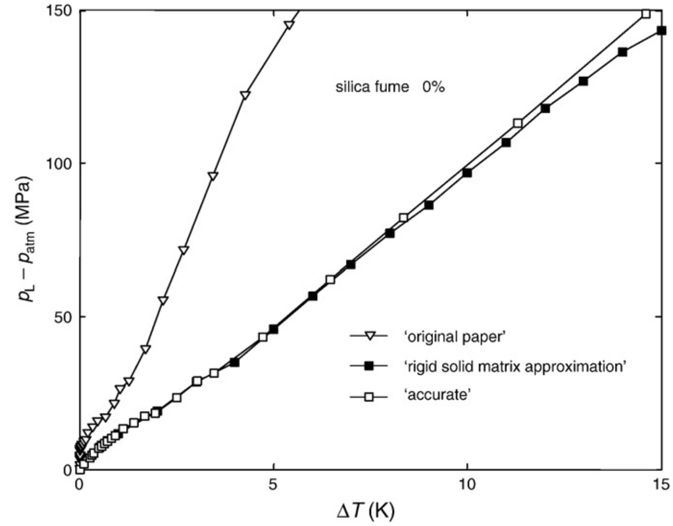

Fig. 2. In a sealed experiment, the liquid pressurization limits the extension of the frozen zone and finally the liquid overpressure as the cooling increases. This is illustrated by comparing the curve given in the original paper with the curve labelled 'accurate' that accounts for this pressurization effect as explained in these errata. See the main text for the explanation of the curve labelled 'rigid solid matrix approximation'.

contribution to the liquid overpressure. Because of the poor compressibility of the solid constituent with regard to water compressibility, we finally get

$$p_L - p_{atm} \approx S_C \left(1 - \rho_C^0 / \rho_L^0\right) \frac{K_L K_C}{S_L K_C + S_C K_L}. \tag{6}$$

The liquid overpressure predicted by approximation (VI) and labelled 'rigid solid matrix approximation' compares well with the curve labelled 'accurate'. This shows that, in saturated conditions and for sealed experiments, the hydraulic pressure effect is the leading effect.

It should be noted that the calculations of the spacing factor presented in the original paper remain correct because, in the air void, the liquid overpressure is close to zero and therefore is also close to zero everywhere at equilibrium. The liquid saturation curve as a function of the temperature given in the paper applies to this equilibrium condition. In summary, only the value of the liquid saturation as a function of the temperature is changed, not the expressions where this liquid saturation is involved.