Research Brief
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Modeling freeze-thaw in concrete

PROBLEM

Premature damage to concrete slabs during freezing and thawing cycles represents a major challenge to pavement durability and resilience. The common practice of entraining air to accommodate freezing is well established, but not always successful. The transport of water and associated electrolytes in concrete remains poorly understood, including permeability, kinetics of water and air movement within cement and concrete, and resistance to freezing and deicing fluids. Thus it is important to develop meso-scale models and connect them to macroscopic properties such as resilience and permeability.

APPROACH

We have developed an accurate and efficient meso-scale model of water sorption and transport in 2D microstructures that approximate the gel pore network in concrete. The air-water interface propagates by capillary condensation according to Kelvin's equation, naturally accounting for sorption hysteresis. Water and ion transport are described by diffusion through percolating pathways in the water phase. Freeze-thaw transitions can also be predicted within the microstructure using the Gibbs-Thompson equation as a first approximation.

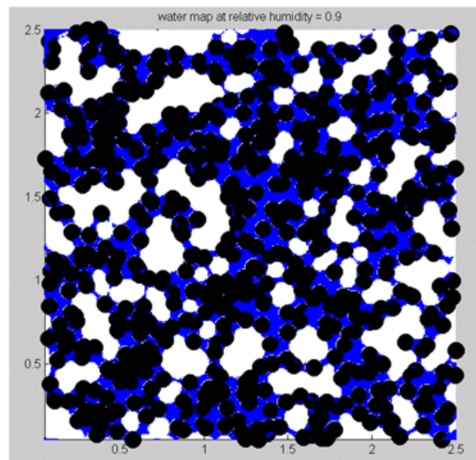

Fig. 1: Simulation of the capillary condensation and transport in a random 2D microstructure of overlapping cylinders (black). As the relative humidity increases, liquid water (blue) condenses to fill blocks of pore space (white), which provides percolating pathways for transport of water and dissolved ions.

FINDINGS

Consistent with experimental water sorption data from the Hub, our model of phase transitions in nano-porous media supports the idea that damage is not primarily caused by the expansion of freezing water in the cement paste. The freezing temperature change predicted by the Gibbs-Thomson equation indicates residual super-cooled water inside the smallest pores. For example, water in 2 nm gel pores in concrete is predicted to remain liquid down to -40^{o}C, or even lower temperatures from the freezing-point depression caused by dissolved ions. In some cases, ions from de-icing agents or other sources are easily transported into the smallest gel pores, where they can directly cause large disjoining pressures, or lead to destructive chemical reactions with the C-S-H matrix, and trigger the observed pavement damage at larger scales. This alternative hypothesis for freeze-thaw damage in the presence of deicing salts will be assessed in extensions of the condensation and transport model accounting for ionic transport and surface forces under strong confinement in nanoporous solids.

IMPACT

A improved understanding of freeze-thaw and damage mechanisms in concrete will enable the development of quantitative durability models that can be used to predict their long-term impacts on pavements. In particular, the research suggests that freezing is suppressed in nanopores of concrete, which may be damaged instead by disjoining pressure, related to the use of de-icers. The implication is that pavement microstructures must be designed to reduce ion transport and minimize electrochemical damage.

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Authors: T. Zhou, in collaboration with Prof. M. Z. Bazant and Dr. R. J.-M. Pellenq.