Natural air convection in road construction materials

Karlis Rieksts
Norwegian University of Science and technology

Natural air convection can considerably increase heat extraction rate from underlying soils during winter periods. The air convection can be initiated for coarse unbound mineral materials with open graded particle gradation. The main objective of this study is to investigate the limit conditions and the extent of possible air convection. The study is separated into three part: i) large scale laboratory experiments, ii) field test site observations and simple analysis, iii) numerical model of field test site.

Large scale laboratory experiments allows for establishing intrinsic permeability for various road construction materials (crushed rock and lightweight aggregates). The experimental setup consist of a heat transfer box with an inner volume of $1m^3$. The samples are tested for downward and upward heat transfer conditions. This allows observing and measuring the extent for natural air convection when it sets in for the upward heat transfer case. The experimental measurements allows defining intrinsic permeability that highly defines the critical temperature gradient at which convection will be initiated. The experimental results show that for some materials convection can be initiated at temperature gradients as low as 5 °C/m.

Test site was constructed to investigate heat transfer properties and material performance under field conditions. Two road sections are investigated that are constructed using open graded crushed material and foamglass material. Both of these materials under laboratory conditions showed that they are prone to natural convection under relatively small temperature gradients. The field tests site allows to measure temperature distribution throughout the structural layers. Temperature measurements were used to calculate temperature gradients imposed on different layers. Temperature gradients in combination with experimentally defined permeability allows calculating apparent Rayleigh (Ra) number that represent the magnitude of natural convection. Based on the measurements it was clearly showed that natural air convection can contribute to the heat extraction rate during winter periods. These periods refer to the time span when apparent Ra number exceed its critical value and air convection is induced.

A numerical model using COMSOL Multiphysics was developed to further validate the convective heat transfer under field conditions. The model uses input parameters from laboratory measurements and sets the boundary conditions based on field temperature observations. The model shows the presence of natural convection and have a good agreement with field observation.