EVALUATION OF HYDRAULIC PROPERTIES OF UNSATURATED STRUCTURAL SOILS WITH INNER POROSITY

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論　文　要　旨

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論文題名
EVALUATION OF HYDRAULIC PROPERTIES OF UNSATURATED STRUCTURAL SOILS WITH INNER POROSITY
(粒子内部に空隙を有する不飽和土の水理特性とその評価)

論　文　内　容　の　要　旨

Drylands cover about 41% of Earth's land surface and are home to more than 38% of the total global population of 6.5 billion. Some form of severe land degradation is present on 10 to 20% of these lands, the consequences of which are estimated to affect directly some 250 million people in the developing world, an estimate likely to expand substantially in the face of climate change and population growth. The United Nations has periodically focused on desertification and drylands, notably adopting the Convention to Combat Desertification in 1992 and designating 2006 as the International Year of the Desert and Desertification.

Because of the serious situation of desertification, prevention of the degradation of land becomes key issue. Among existed countermeasures, greening is considered to be one of the most effective methodologies which can protect the biodiversity threaten by desertification. The conventional revegetation practice has had little or no success primarily due to the limited soil moisture. Low and sporadic precipitation that occurs in the arid regions is either not sufficient to support seed germination and plant development or it comes too late for plants or seeds to survive. In the arid regions where the groundwater table is relatively shallow, the groundwater can be used as a main water resource for the plants surviving. However, the water holding capacity and capillary rise of original soils (single-porosity soils) are limited, which leads to water stresses in the root zone. It's one of problems for vegetation restoration to overcome or mitigate desertification. Diatomite and zeolite can be used as soil amendment to retain water and plant nutrients in root zone. The high porosity associated with the inner structure of these materials allows them to retain much water, which can be released slowly during dry periods. A promising method to reestablish plants could be effective to use these materials, which have inner porosity, as a material to wick shallow groundwater to the root zone of the plants. This method could allow for the reestablishment and sustainability of vegetation in arid areas where the groundwater table is shallow but not easily accessible by young plants. In order to evaluate amended effect, the knowledge of hydraulic behavior of original soils and inner porosity soils is the foundation of seepage analysis in the vadose zone. Although hydraulic properties may be obtained by direct measurements, it is time-consuming, labour intensive and expensive. In this study, alternative theoretical approaches are used to estimate hydraulic properties through the use of more easily measured data. The dissertation made some original contributions as mainly described in Chapeter 3, Chapeter 5 and Chapeter 6.

In Chapter 1, the research background, sets the research objectives and defines the research scope are introduced. The layout of the thesis is also comprehensively presented.

In Chapter 2, the existing studies are reviewed, including the experimental techniques on hydraulic properties and the pore geometry, and the analytical models for hydraulic properties.

In Chapter 3, the physically based scaling technique was extended to the Arya and Paris model (AP model) to predict soil water characteristic curves for single-porosity soils. AP model used to estimate the soil water characteristic curve from particle-size distribution curve. The basis for this approach is mainly on the shape similarity of the two curves. An empirical parameter α was introduced in AP model which used to scale pore attributes from hypothetical formations to natural structures. The parameter α sensitively affect the predicted results. However, original method to calculate α was quite complicated. The scaling technique is used to characterize hydraulic properties of field scale, using measurement scales that are typically much smaller. Kosugi and Hopmans presented an elegant physically based scaling technique which provides convenient way to coalesce multiple soil water characteristic curves into a single reference soil water characteristic curve. In this chapter, the physically based scaling technique was extended to the AP model to calculate parameter α. Comparing with original method, this approach simplifies the calculation process. Experimental soil data which selected from the Unsaturated Soil hydraulic Database are used to verify proposed approach. Results showed that the physically based scaling technique improved the AP model accuracy.

In Chapter 4, the basic properties of the dual-porosity soils used in the laboratory experiments are presented. Four commercial materials are used in this study, two diatomaceous earth pellets and two zeolites. Particle-size distribution, chemical compositions, inner structure and soil water characteristic of materials were investigated and the results were compared with a single-porosity sandy soil. Results show that the shapes of soil water characteristic curves for dual-porosity soils are bimodal. And the water holding capacity of raw diatomaceous earth and zeolites are higher than sandy soil, even though the particle size of these materials is coarser. The results suggest that raw diatomaceous earth and zeolite could be as sand amendments for revegetation in drylands.

In Chapter 5, a bimodal soil water characteristic curve model is proposed for dual-porosity structural soils. In the last decades, several models have been proposed to describe bimodal soil water characteristic curve. Although these approaches were successfully applied to dual-porosity structural soils, they are lack of a physical basis for their parameters due to the fact that the unimodal SWCC functions which they extended were known as empirical equations. To encounter this problem, a bimodal lognormal soil water characteristic curve model has been proposed in this chapter. It was derived by assuming a lognormal pore size distribution for each pore domains and using weighting factors combined individual functions. The proposed model is defined by parameters that have physical significances which can be related to the distribution of pore morphology of the soil. Experimental data fitting and parametric analyses were used to illustrate the fitting capability of the proposed modle. The proposed approach resulted in good agreement between measurement and simulation.

In Chapter 6, a new function is proposed for predicting unsaturated hydraulic conductivity of dual-porosity structural soils. Simulation of flow and contaminant transport through the vadose zone requires knowledge of the soil hydraulic conductivity. Although hydraulic conductivity may be obtained by direct measurements, it is time-consuming, labour intensive and expensive. In this chapter, a new function was proposed for predicting unsaturated hydraulic conductivity of dual-porosity structural soils based on the bimodal soil water characteristic curve model proposed in Chapter 5. Experimental data verification and parametric analysis are undertaken to demonstrate the fitting and predicting capability of the proposed equations. Results demonstrate that the proposed model improved capability of representations of the hydraulic curves to simulate water flow in structural soils. These functions can potentially be used as an effective tool for identifying hydraulic properties in structural soils.

Finally, a summary of conclusions and recommendations for further research are given in Chapter 7.