A Geotechnical Countermeasure for Combating Desertification

Une mesure géotechnique pour lutter contre la désertification

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ABSTRACT: A self-watering system and the design method are proposed. The self-watering system, which can collect and store all kinds of water, comprised of the simple ground is much efficient to support surface vegetation. The system is designed by installing soil structures into original sandy ground. Finer soils or artificial materials can be used as the materials of the soil structures. The system can continually raise the ground water to a certain depth in the sandy ground using the capillary force. Moreover, it can minimize the evaporation from the system, which provides the potential to prevent salinization. To design the system practically, information like soil water retention curve, hydraulic conductivity and other information such as planting density and weather condition are needed. The self-watering system works under the condition of no extra energy input.

RÉSUMÉ : Un système d'auto-arrosage et le procédé de conception sont proposés. Le système est conçu en installant des couches de sol fin dans un sol sableux d'origine. Les sols fins ou es matériaux artificiels peuvent être utilisés comme les matériaux de la structure du sol. Le système peut élever continuellement l'eau du sol à une certaine profondeur dans le sable à l'aide de la force capillaire. En outre, il peut minimiser l'évaporation du système, ce qui offre la possibilité de prévenir la salinisation. Pour concevoir ce système en pratique, des informations comme la courbe de rétention d'eau du sol, la conductivité hydraulique et d'autres informations telles que la densité de plantation et les conditions météorologiques sont nécessaires. Le système d'arrosage fonctionne dans la condition de non apport d'énergie supplémentaire.

KEYWORDS: unsaturated soil, desertification.

1 INTRODUCTION

Desertification is the degradation of land in arid, semi-arid, and dry sub-humid areas due to various factors: including climatic variations and human activities (UNCCD 1994). The rapid expansion of desertification has resulted in serious environmental deterioration, economic loss, locally unsteadiness political situation and social upheaval. 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 methodology which can protect the biodiversity threaten by desertification, minimizing cost and providing positive multifunction. In the application of the methodology, the vegetation is the core. However, in order to fulfill the requirement of the growth of the plants, available water resource is the one of the important limitation. In arid land, groundwater is usually used as one of important water resources. Therefore, the technical methodology is suggested, which use groundwater to fulfill the requirement of the growth of the plants. However, there are numerous barriers to its implementation. One of these is that the costs of adopting sustainable agricultural practices sometimes exceed the benefits for individual farmers, even while they are socially and environmentally beneficial. Another issue is the simplicity of the technique to be acceptable by local people. From the geotechnical and geoenvironmental point of view, any technique should solve the issues such as, mechanism of raise of the groundwater up to the root zone of the plants, prevention of the salinization of the ground and design of the system that can sustainably provide the water to the plants.

In arid or semiarid area, which characterized by lack of available water, water is one of the main limitations to the growth of plant. Frequently, capillary fringe is too deep to be used by plant in these areas. The self-watering system has been proposed. The self-watering system, which is designed to collect and store all kinds of water, comprised of the simple ground is much efficient to support surface vegetation. A self-watering system and the design method are proposed. The system is designed by installing soil structures into original sandy ground. Finer soils or artificial materials can be used as the materials of the soil structures. The system can continually raise the ground water to a certain depth in the sandy ground using the capillary force. Moreover, it can minimize the evaporation from the system, which provides the potential to prevent salinization. To design the system practically, information like soil water retention curve, hydraulic conductivity and other information such as planting density and weather condition are needed. The self-watering system works under the condition of no extra energy input.

2 SELF-WATERING SYSTEM

The soil layer often provides a medium to plant for its requirement of rooting, water and nutrient. The water flow has effect on physical property, such as consistence, strength of aggregates, aeration and temperature of soil, which is relevant to the growth condition of plant. The most direct effect of the water condition of soil is that it influences the growth of plant. The root of plant can absorb the amount of water to fulfill its need for transpiration and the amount of solute for its mineral nutrient. The transpiration water disappears in atmosphere as vapor condition. Finally, a water flow moves through soil towards to root.

In arid or semiarid area, which is characterized by lack of available water, water is the main limitation to the growth of plant. Frequently, capillary fringe is too deep to be used by plant in these areas. The self-watering system, which is designed to collect and store all kinds of water, comprised of the simple ground is much efficient to support surface vegetation. The design target of this system is to setup an equivalent condition between the storage capacity of water and rate of usage.

The maximum water content can be held in soil before it drains downwards is field capacity, θ_{fc}, which is water content when drainage ceases. Field capacity is closely correlated to the volumetric water content retained in soil at -33 kPa of suction (Richards and Weaver, 1944). The capillarity storage capacity (CSC) in unit area of a soil layer can be determined by integrating its volumetric water content over its thickness, m, it can be described by

$$CSC = \int_0^m f(\theta)\,dz \tag{1}$$

where, $f(\theta)$ is mathematic function for wetting branch of soil water retention curve, z is elevation above a vertical datum.

However, not all of this stored water can be absorbed by plants. The minimum water content the plant requires not to wilt is permanent wilting point, θ_{pwp}, which is defined as the water content at -1500 kPa of suction. Evaporation can also reduce water content of soil to residual condition, e.g. this value can be generally considered as zero for sandy soil. However, the evaporation processes mainly influence the area near ground surface. Considering the capillary enhancement system is buried at certain depth in the ground, the stored water within the system is only removed by plants. The available capillary storage capacity (ACSC) can be written as follows

$$ACSC = CSC - \theta_{PWP}m \tag{2}$$

For every growing season, the amount of transpiration shows a parabola relationship with time. When the transpiration rate becomes low, the plant will become dormant. Thus if the stored water exceeds the amount of transpiration during the whole growing season, the plant can live with the support of the system. The designation of the system needs the information of available capillary storage capacity, which is relevant to the thickness, depth of soil layer. However, it is not good to design a soil layer with great thickness, since the zone, which is deeper than the root does not provide direct effort to the growth of plant. Integrating the volumetric water content over the depth of the overlying horizontal layer yields total water in plate.

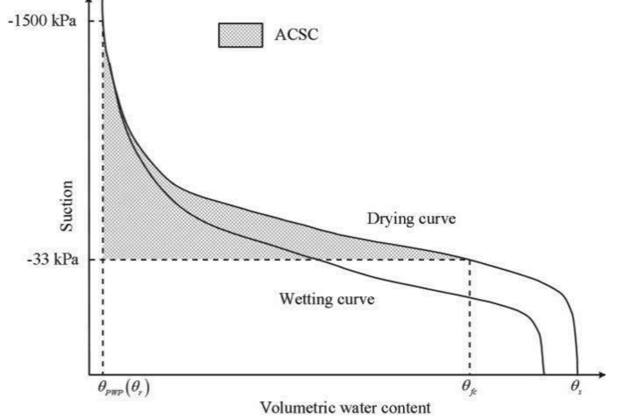

Figure 1 Concept of the capillary storage capacity and available capillary storage capacity

There are several designed functions of the self-watering system. First of all, the system can continuously supply water to fulfill the requirement of growth of the plants. Secondly, the system can absorb and storage the water that comes from various resource, such as, atmosphere (precipitation, dew), surrounding ground or ground water. Thirdly, it can minimize the quantity of evaporation of the water in the system. Fourthly, the system works without extra energy input. Based on the designed functions, the self-watering system is proposed.

Figure 2 shows a conceptual diagram for the self-watering system located in sandy ground. As shown in the figure, two types of the self-watering system are proposed. The left side of the figure is the system in 'T' type. The right side of the figure is the system in suspended type. Both the two types of the self-watering system are made from installing fine soil layer in sandy ground.The 'T' type fine soil layer consists of plate part and pillar part. The plate part is horizontally buried in sandy ground. The main function of plate part is to store capillary water. Therefore, the design of this part should be large enough to reach the required storage quantity. The pillar part is vertically inserted down to the ground water level in sandy ground. The main function of pillar part is to absorb water by capillary force. Therefore, the design of this part should be large enough to assure the rate of supply to the plate part. For a self-watering system in suspended type, it contains only a plate part. The function of the plate concludes both functions of plate part and pillar part of the 'T' type system.

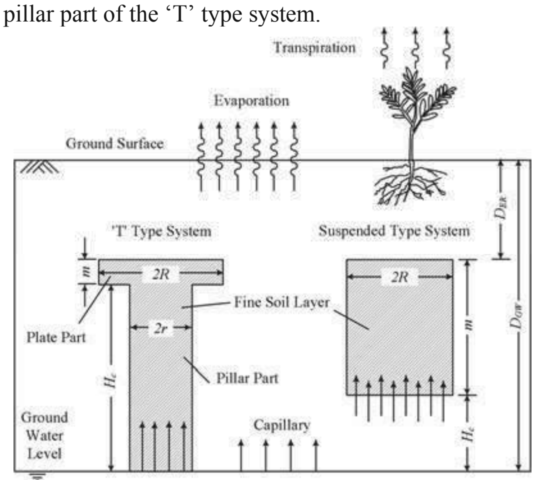

Figure 2 Image of the self-watering system

The self-watering system is formed at the interface of hydraulically dissimilar unsaturated soil layer where a fine soil layer overlies an original relatively coarse soil ground at the certain height. Under natural unsaturated conditions, the retention characteristic at the interface between the two kinds of soil layers allows the capillary water flow from coarse layer into fine layer. Ground water or irrigation water continually entries into the fine layer until the hydraulic equivalent is achieved. The water will be suspended and stored within the fine soil layer. The evaporation and transpiration will break the hydraulic equilibrium of the system. Then a new dynamic hydraulic equivalence will be setup subsequently.

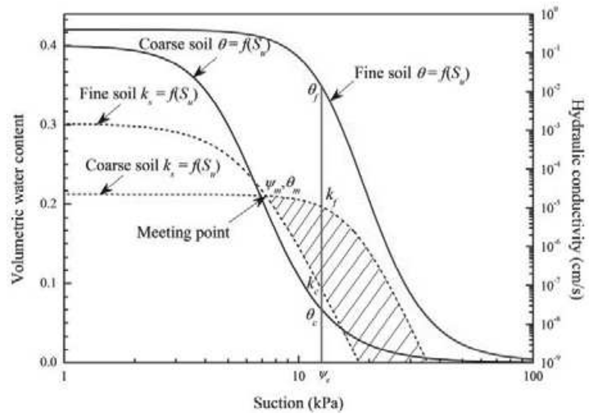

Figure 3 Soil water retention curve and unsaturated hydraulic conductivity for finer soil and coarser soil

Theoretically, continuity of the pore water pressure requires that the matric suction in the two layers must be equal at their interface. As a result, the matric suction in the finer layer should be equal to ψ_e (Figure 3). The volumetric water content in the finer layer and coarser layer at ψ_e is noted as θ_f and θ_c respectively. Obviously, θ_f is larger than θ_c, which indicates the finer layer has a higher capillary storage capacity (Equation 1). However, the speed of the water flows from coarser layer into finer layer is also influenced by hydraulic conductivity of both layers. As shown in Figure 3, the two dash lines are unsaturated hydraulic conductivity for finer and coarser soils respectively. Two areas are formed by these two dash lines. One of these areas is when the hydraulic conductivity of coarser soil is larger than that of finer layer. On the opposite, the other area is when the hydraulic conductivity of coarser soil is smaller than that of finer layer. Therefore, k_f and k_c is corresponded to the hydraulic conductivity of finer soil and coarser soil respectively, and k_f is larger than k_c.

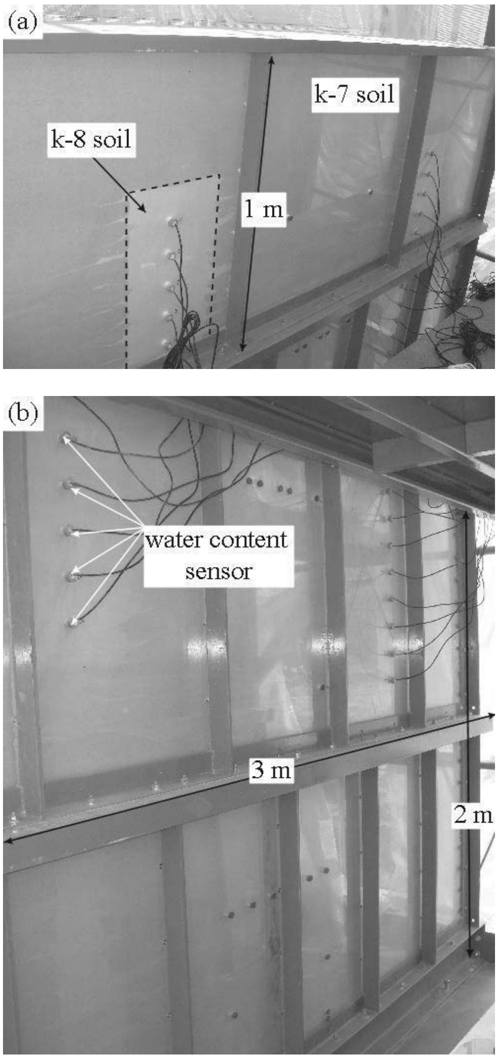

Figure 4 Picture of the model test. (a) 2-3 m. (b) 0-2 m.

3 VERIFICATION OF SYSTEM

Based on the design method mentioned above, this section will give out a design case by using the k-7 soil and the k-8 soil. In here, the k-7 soil and k-8 soil are used to simulate the coarser soil and the finer soil respectively. Both model test and numerical simulation are performed to verify the design.

3.1 *Model Test*

As shown in Figure 4, the model test is conducted within a steel chamber (300 cm × 300 cm × 25.5 cm). Figure 5 shows the schematic view of the setup of the model test. The left side of the figure shows the setup of the 'T' type system. The right side of the figure shows the setup of the suspended type system. According to the soil water retention curve of the k-7 soil (Figure 3), the water entry value is around 12 kPa. Therefore, at critical condition, the plate part of the 'T' type system is laid at 120 cm above the water level. Based on the observation of evaporation test, the maximum effective depth of evaporation is assumed as 40 cm, and then the thickness of the plate part is determined as 130 cm. The width of the pillar part is set as 10 cm, the ratio of radius is set as 1:3, and then the size of the 'T' type system can be determined. Considering the effect of interaction of the interface, the height of suspended type of the system is laid at 100 cm above the water level. Based on the same assumption of the maximum effective depth of evaporation, and then the thickness of fine layer is determined as 150 cm. in order to keep the consistency with the 'T' type system, the width of the finer layer is set as 30 cm. Figure 6 shows the grain size distribution of soils used in this study.

3.2 *Numerical Verification*

Figure 7 shows the FEM mesh of the numerical model. As shown in the figure, the model set-up follows the experiment work described above, in which the upper boundary is atmospheric condition. The lower boundary was assigned to condition of constant saturated water content. The FEM column was discretized uniformly, except the area, where fine layer exits, was discretized in to small triangular mesh. A number of observation points were located at different elevations as the location of water content sensor in physical model.

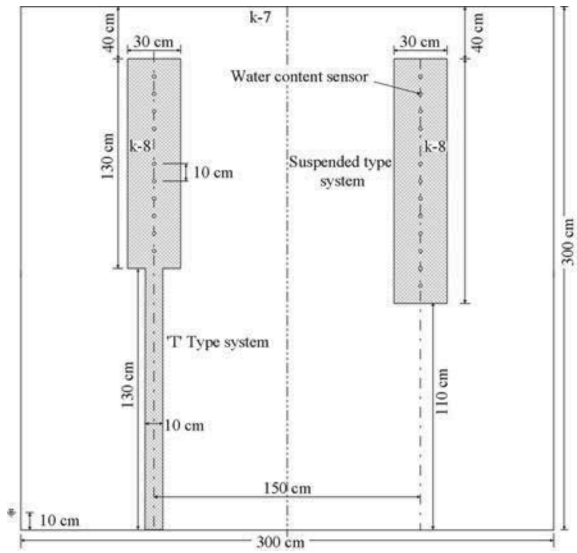

Figure 5 Profile of the model test.

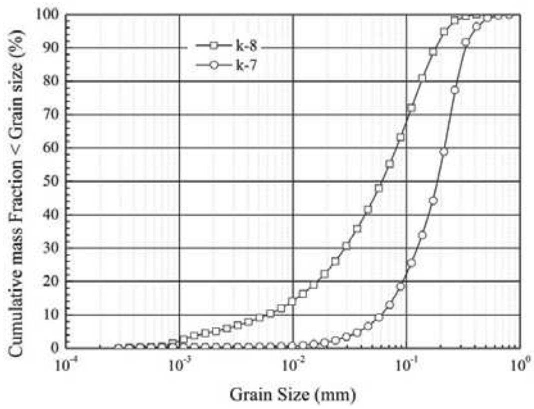

Figure 6 Grain size distribution of the soils

Figure 8 shows the comparison between test result and numerical result. As shown in the figure, several observations can be obtained. First of all, the self-watering system in both 'T' type and suspended type can absorb the water from the bottom and store the water in higher part of the system. Secondly, there is a good consistency between the test result and numerical result. It means that the numerical method can be used as one tool to predict the unsaturated water flow in the self-watering system.

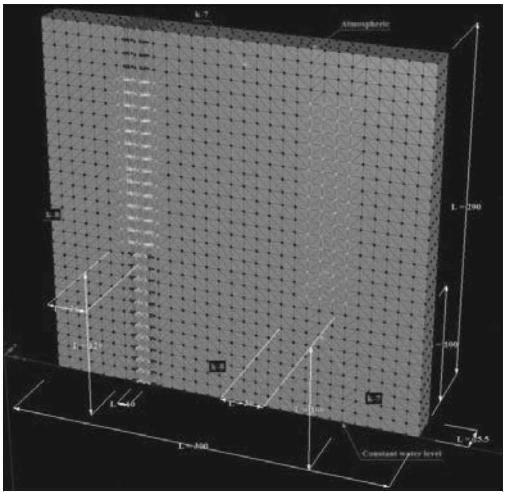

Figure 7 FEM mesh of the numerical model

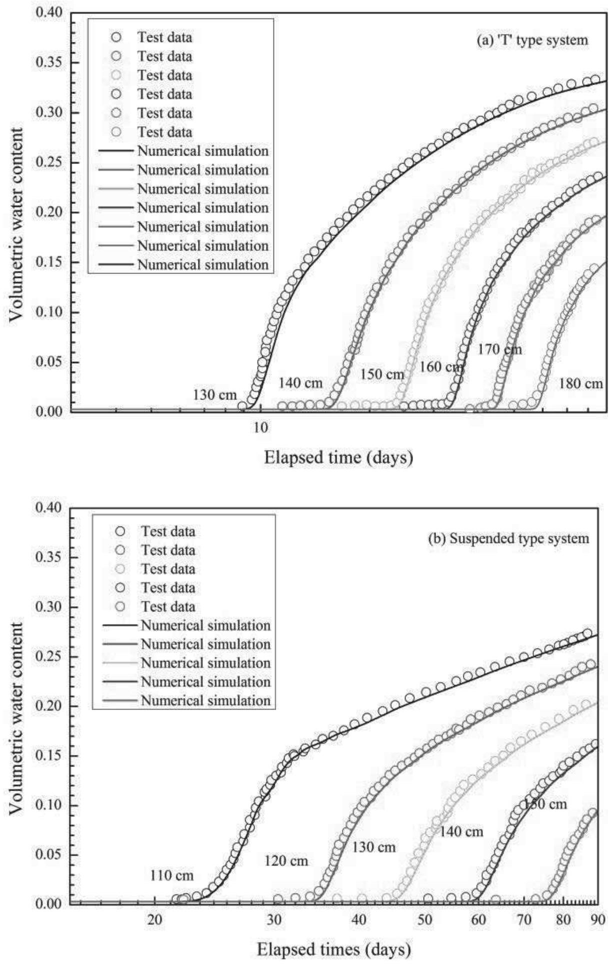

Figure 8 Comparison between test results and numerical results. (a) 'T' type system. (b) Suspended type system.

Figure 9 shows the performance of the self-watering system. First of all, it is easily to be observed that both 'T' type system and suspended type system have larger storage capacity than the original sandy ground (k-7 soil). Secondly, the height of capillary rise of 'T' type system is higher than that of the suspended type system. At the same height, the volumetric water content of 'T' type system is larger than that of the suspended type system. These indicate that the rate of water supply of 'T' type system is quicker than that of the suspended type system.

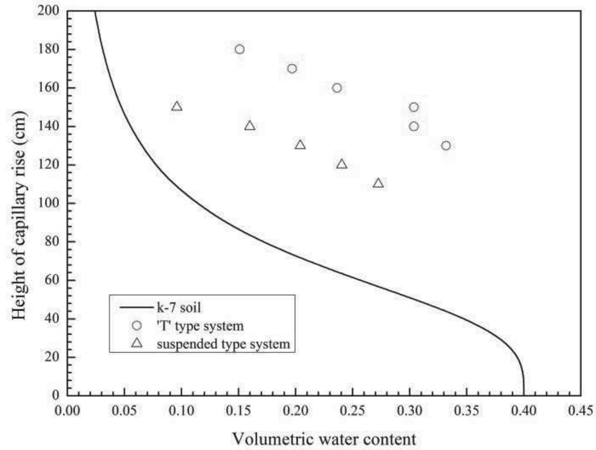

Figure 9 Performance of the self-watering system

4 CONCLUSIONS

In this paper, the self-watering system has been proposed. The design methodology has also been given out. Based on the verification of the system, the conclusions can be drawn as follows,

1) Based on the information of the follows, the soil water retention curve and unsaturated hydraulic conductivity of sandy ground, the maximum influence depth of evaporation, the target planting density and effective depth of roots of the plants, the monthly quantity of evaporation, transpiration, capillary water and irrigation, the self-watering system can be designed.

2) The self-watering system works under the condition of no extra energy input. Even though, the system can raise the ground water up to the certain depth of the unsaturated sandy ground. The system can absorb and store some quantity of water. The system can minimize the quantity of evaporation of the water in the system.

3) Numerical method is proven to be a useful tool to predict the unsaturated water flow within the system.

4) Both the two types of the self-watering system can fulfill the requirement of designed functions. However, in the case study, the efficiency of water supply of 'T' type system is higher than that of the suspended type system. Because the pillar part in the 'T' type system has higher efficiency of absorbing water. It can be predicted that when the critical height of the suspended system decreases, the opposite tendency will occurs.

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