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INFLUENCE OF RAINFALL PATTERN ON THE INFILTRATION INTO LANDFILL EARTHEN FINAL COVER

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ABSTRACT: Rainfall pattern is an important factor that affects the infiltration process into earthen final covers of landfills. In this paper, six typical rainfall patterns present in nature were sorted out. Then the rainfall patterns were used as the infiltration boundaries of an earthen final cover model, and numerical simulations of the infiltration process were carried out by the use of the commercial software SVFlux. The numerical simulation model was firstly verified by experimental data. A parametric study was performed to investigate the influence of rainfall patterns on the infiltration process in the silty soil cover. The numerical simulation results indicate that the rainfall pattern can significantly affect the infiltration process and cumulative infiltration under the same total amount of precipitation. The peak rainfall intensity occurs earlier, the cumulative infiltration will be larger. The advanced pattern (A1) will generate the largest amount of infiltration compared to other patterns. The numerical analyses also suggest that rainfall pattern should be taken into account in the performance assessment of earthen final covers.

KEYWORDS: Rainfall pattern, Earthen final cover, Infiltration, Numerical simulation

1 INTRODUCTION

Landfill covers were primarily designed to prevent or control the infiltration of precipitation into the waste, so the generation of leachate can be reduced. The earthen final cover is an alternative cover for the traditional landfill covers, such as compacted clay covers and composite covers. The earthen final cover systems use water balance to minimize percolation into the waste. These cover systems can store the infiltrated water until it is either transpired through vegetation or evaporated from the soil surface. The amount of infiltration should be accurately calculated in the design of earthen final covers to carry out the water balance analysis.

When rain falls on the ground surface, a portion of the total rainfall infiltrate into the soil, and the deficit will be the runoff on the surface. The infiltrated water will increase the water content and then reduce the matric suction at the ground surface. The infiltration capacity will decrease as the rainfall advances. There have been numerous rainfall-runoff models to predict the amount of runoff during rainfall event, such as the Green-Ampt (1911) model, Horton model (1938), Holtan model (1961), Mein-Larson model (1973). The parameters for these models used in geotechnical engineering are mostly obtained empirically. The predicted infiltration capacity of these models can't vary with the rainfall pattern, so it is not in accordance with the practical situation. These rainfall-runoff models are not suitable in the accurate analysis of the infiltration into the earthen final covers.

Numerical simulations are widely used in the analysis of earthen final cover. The commercial software used in numerical simulations includes SEEP/W, HYDRUS, UNSAT-H, Vadose/W and SVFlux (Scanlon 2002). The software use different ways to deal with the ground surface boundary conditions. It is assumed that when the rainfall intensity is smaller than be saturated permeability, all the rainfall will infiltrate into the ground surface and when the rainfall intensity is larger than the saturated permeability of the soil the flux boundary switches to zero pressure head boundary in

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SEEP/W (GEO-SLOPE 2004). For SVFlux, if the pore water pressure at the surface is negative, all the rainfall will infiltrate into the ground, if the pore water pressure at the surface reaches zero, the infiltration flux will be equal to the saturated permeability when the rainfall intensity is higher than the saturated permeability (SoilVision 2006). Runoff may take place when the value of the rainfall intensity is larger than the saturated permeability, so runoff must be computed in an interactive manner. The upper boundary condition switches between the flux boundary and hydraulic head boundary depending on the rainfall intensity and the matric suction at the ground surface.

In the previous numerical analysis, it is assumed that the rainfall intensity is uniform in one day (Scanlon 2002). But in fact, the rainfall intensity varies with time. The assumption will affect the process and the amount of infiltration. This paper will perform numerical analysis focus on the influence of rainfall pattern on the process and the amount of infiltration.

2 THE NUMERICAL MODEL AND ITS VERIFICATION

2.1 The Geometry and Boundary Condition of the Numerical Model

The commercial software SVFlux is employed to do the numerical analysis. One dimensional analysis was conducted to investigate the influence of rainfall pattern on the process and the amount of infiltration. Albright et al (2004) summarized the covers used in the Alternative Cover Assessment Project (ACAP). The thickness of earthen final covers in ACAP project is around 1.5m, so the thickness of 1.5m was chosen as the vertical depth of the numerical model (Figure 1).

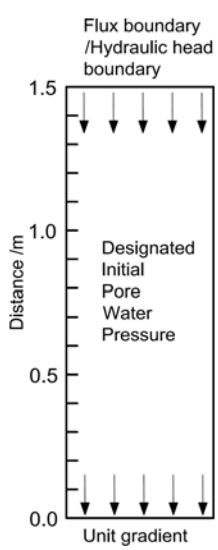

Fig. 1 The geometry and boundary condition of the numerical model

The lower boundary condition of the numerical model is unit gradient boundary. The unit gradient boundary means that there's only gravity gradient acting at the lower boundary and velocity of flow is equal to the soil permeability at the lower boundary. As mentioned previously, for the upper boundary condition, if the pore water pressure at the surface is negative, all the rainfall will infiltrate into the ground, if the pore water pressure reaches zero, the infiltration capacity will be equal to the saturated permeability. The upper boundary condition switches between the flux boundary and hydraulic head boundary.

2.2 Rainfall Patterns and Soil Properties

Figure 2 shows six representative rainfall patterns of 24h duration considered in the paper. They consist of four basic types of rainfall patterns: advanced type (A1 and A2), central-peaked type (C), delayed type (D1 and D2), and uniform type (U) (Ng et al. 2001; Tsai 2008). The advanced patterns have relatively high rainfall intensity during early part of the rainfall event, whereas the delayed type is just the opposite. The central-peaked pattern has relatively high rainfall intensity in the center part, while the uniform type reveals constant rainfall intensity throughout the rainfall duration.

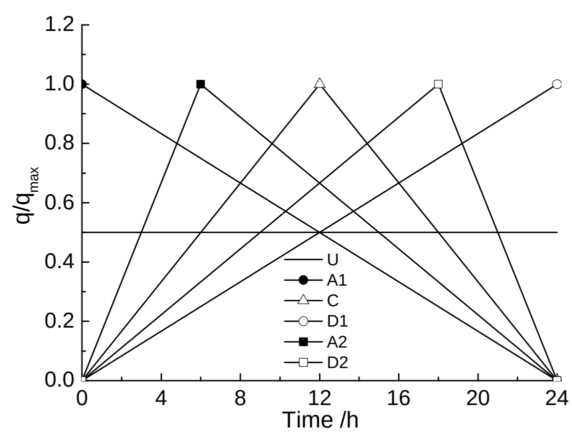

Fig. 2 Representative rainfall patterns used in the analysis

Roesler et al (2002) summarized the hydraulic properties of soils used in the ACAP project. Silt with sand was chosen as the soil used to construct the earthen final cover in the paper. Figure 3 shows the soil-water characteristic curve of silt with sand. Figure 4 shows the soil permeability of silt with sand. The soil-water characteristic curve and permeability function were described by van Genuchten equation (van Genuchten 1980).

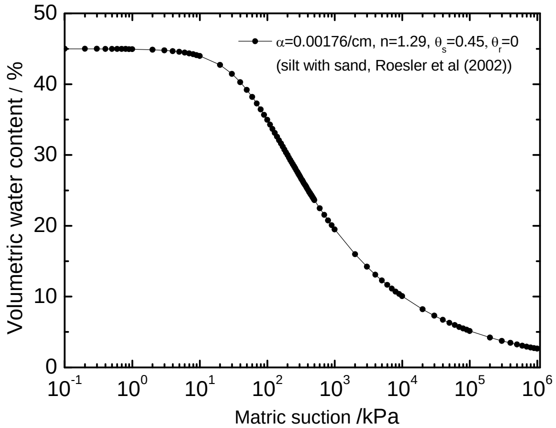

Fig. 3 The soil-water characteristic curve of silt with sand

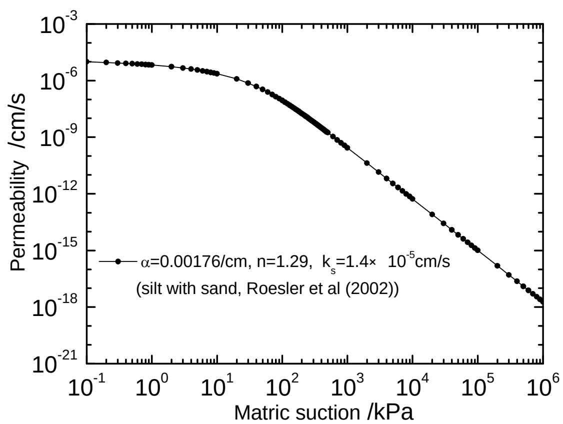

Fig. 4 The permeability curve of silt with sand

2.3 Verification of the Numerical Model

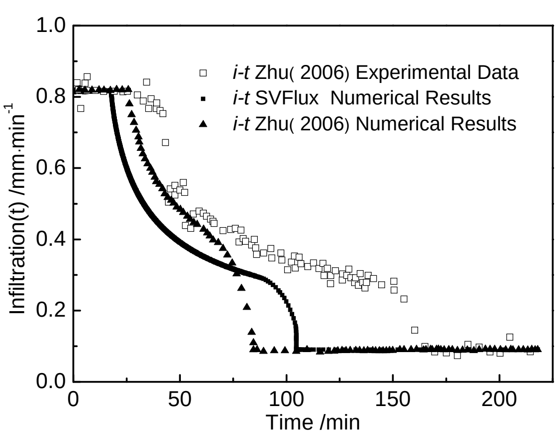

Fig. 5 Infiltration results between the column test and numerical simulations

Zhu (2006) conducted column infiltration tests to study the process of rainfall infiltration. A numerical analysis was performed by SVFlux to simulate Zhu's column test. The simulation results are shown in Figure 5. The trend of the numerical results is consistent with the experimental data obtained by Zhu (2006). It indicates that the numerical model is reasonable and can be used in the parametric studies.

2.4 The Program of Parametric Study

The saturated permeability of silt with sand is 1.4×10^{-5}cm/s (i.e. 0.012m/d). In the analysis, it is assumed that the total amount of rainfall in one day is 0.048m, which is four times of the saturated permeability. The total amount of rainfall will distribute according to the six typical rainfall patterns. The initial matric suction of the one dimensional column is 100kPa.

3 RESULTS AND DISCUSSION

3.1 The Influence of Rainfall Pattern on Infiltration Process

The infiltration process is controlled by many variables, including the soil types, rainfall characteristics, and the initial conditions and so on. Figure 6 shows the rainfall intensity and the corresponding infiltration rate under six representative rainfall patterns. The rainfall intensity minus the infiltration rate is the runoff rate. The peak rainfall intensity occurs earlier, the runoff will occur earlier. As time elapsed, the rainfall intensity tends to be smaller, there will be no runoff generated and all the rainfall will infiltrate into the ground surface.

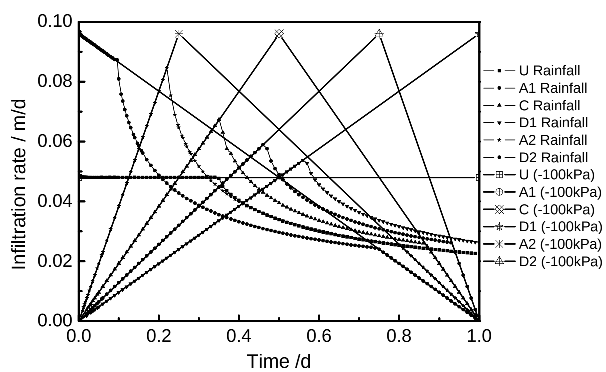

Fig. 6 Rainfall intensity and the corresponding infiltration rate under six representative rainfall patterns

The infiltration process is quite complex. It is primarily influenced by both the hydraulic conductivity and the hydraulic gradient at the ground surface zone. If the ground surface zone is dry, when rainfall on the ground surface, the surface becomes wet, then there will be a great matric suction gradient between the surface and the dry zone, so all the rainfall will infiltrate into the ground. As rainfall advances, the wetted zone deepens. Then when rainfall falls on the surface, the matric suction gradient becomes smaller. If the surface zone is saturated, the matric suction gradient will diminish and only the gravity gradient act. The infiltration capacity continues to decrease during the rainfall period as the infiltrating water reduces the ground surface matric suctions. Eventually, the infiltration capacity is equal to the saturated permeability of the soil.

The peak rainfall intensity of A1 pattern occurs earliest and the peak rainfall intensity of D1 pattern occurs latest. When the ground surface is dry, the infiltration capacity can be high because of the steep matric suction gradient, so all the rainfall infiltrate into the ground surface though the rainfall intensity is high. Therefore for A1 pattern, when the rainfall intensity is high, the infiltration capacity still exceeds the rainfall intensity and there's no runoff generated. For other non-uniform rainfall patterns, since the rainfall intensity is small in the initial period, when the peak rainfall intensity occurs, the infiltration capacity is less than the rainfall intensity, so runoff occurs. Because the peak rainfall intensity can infiltrate into the ground for A1 pattern, the ground surface can absorb more water during the rainfall period.

3.2 The Influence of Rainfall Pattern on Cumulative Infiltration

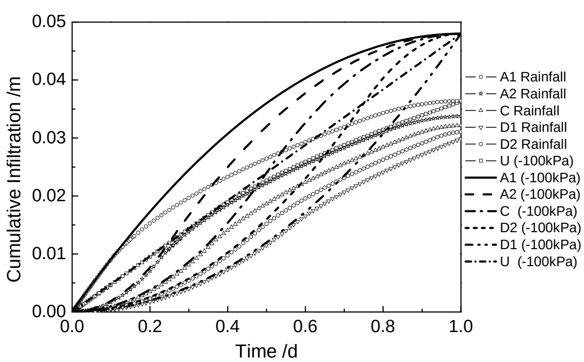

Fig. 7 The cumulative infiltration under six representative rainfall patterns

Figure 7 shows the cumulative infiltration under six representative rainfall patterns. It indicates that the rainfall pattern significantly influence the cumulative infiltration under the same total amount of rainfall. The total amount of rainfall is 0.048m. The cumulative infiltration of A1 pattern is 0.0364m and the cumulative infiltration of D1 pattern is 0.03108m. The infiltration of uniform pattern is 0.03623m. Figure 7 shows that the advanced pattern (A1) will generate the largest amount of infiltration compared to other patterns. The delayed pattern (D1) will generate the smallest amount of infiltration compared to other patterns. The difference of infiltration between the A1 pattern and D1 pattern is 0.00532m, which is up to 11% of the total amount of rainfall depth. The difference of infiltration between different rainfall patterns is quite high. Therefore, the rainfall pattern should be taken into account to calculate accurate infiltration and then percolation.

4 CONCLUSIONS

The numerical simulation results indicate that the rainfall pattern can significantly affect the infiltration process and cumulative infiltration under the same amount of precipitation. The peak rainfall intensity occurs earlier, the cumulative infiltration will be larger. The advanced pattern (A1) will generate the largest amount of infiltration compared to other rainfall patterns. The rainfall pattern should be considered in the numerical analysis of landfill earthen final cover to obtain accurate amount of infiltration. If the real time metrological data is available, it will be much better to be used in the landfill earthen final cover design analysis.

5 ACKNOWLEDGEMENT

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