Numerical simulation of seepage in the landfill leachate layers

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Abstract. In order to control the environmental pollution caused by landfill leachate, the numerical simulation of landfill leachate seepage was carry out, which considered the influence of anisotropy of permeability coefficient, the permeability coefficient, matrix suction, infiltration amount of leachate, slope of drainage layer, drainage distance and initial water head on the maximum saturation depth. The results showed that when the horizontal permeability coefficient is fixed and the vertical permeability coefficient is reduced, the maximum saturation depth of leachate increased sharply. The maximum saturation depth linearly increased with the infiltration of leachate, whereas sharply decreased with the increasing of drainage slope. The maximum saturation depth is less affected by small drainage distance, whereas more affected by the large drainage distance. The initial head has a great effect on the maximum saturation depth, and whether the drainage pipe can discharge the leachate or not has an important influence on the maximum saturation depth.

1. Introduction
With the development of economy and the increase of urban population, the output of MSW is increasing rapidly. The pollution of MSW has become a very serious social and environmental problem. More than 90% of MSW in China is treated by landfill. However, landfill treatment of municipal solid waste will produce a large number of leachate with complex components, high pollutant concentration, great water quality change and long duration. If the leachate is not treated, it will cause secondary pollution to the surrounding water body, which is very harmful. In order to control the landfill leachate, it is urgent to study the migration law of landfill leachate. Kjeldsen and Christensen [1] described the distribution of organic chemicals in landfill leachate, landfill gas and solid waste, and established MOCLA model to predict the discharge of chemicals with leachate and their degradation and transformation in landfill. Dho et al. [2] used water balance method to predict the level of leachate in a landfill through help model. Koriatis et al. [3] established a one-dimensional unsaturated seepage numerical model based on Richard's unsaturated seepage equation. Ahmed et al. [4] combined saturated seepage theory and unsaturated seepage theory to established a two-dimensional unsaturated saturated unsteady flow model fill, considering vertical and lateral movement. McDougall et al. [5] considered the change of permeability coefficient with the change of saturation and compressibility, the method of variable saturation permeability coefficient was used to simulate the percolation of leachate, and the influence of different rain patterns and the permeability
coefficient of capping layer on the production of leachate was analyzed. Santiago and De Andres [6] established a model to simulate the water flow in the overburden system. Bedariol et al. [7] studied the influence of bending deformation of compacted clay on seepage. Warith [8] studied the proportion and change of rainfall infiltration rate and outflow rate under different slope ratios (0-2.5%). Peyton and Schroeder [9] established a model to study the influence of the gradient of the impervious layer and the transverse permeability coefficient of the drainage layer on the leakage and the transverse drainage. In order to improve the efficiency of leachate collection and drainage and reduce the head of the drainage pipe, Ho et al. [10] combined with the multi-point comprehensive drainage system of the slope drainage facilities was studied. It was concluded that the multi-point comprehensive drainage system with the combination of the leachate collection pipe network above the landfill liner and the geotextile drainage layer on the slope could effectively lead to the leachate and promote the waste degradation. Jessberger [11] simply estimated the relationship between the maximum water head of leachate and the upper seepage strength, the slope ratio of impervious layer and the permeability coefficient, and estimated the seepage strength of impervious layer.

In this paper, SEEP/W software was used to analyze the seepage problem of landfill leachate, considering the influence of anisotropic permeability coefficient, matrix suction, infiltration amount of leachate, gradient of drainage layer, drainage distance and initial water head on the maximum saturation depth, which provide a theoretical basis for engineering application.

2. Model Establishment

2.1. SEEP/W software

Based on Frediund unsaturated theory, SEEP/W software regarding the water content and permeability coefficient as continuous functions of pore water pressure, which are expressed as soil-water characteristic curve and water conductivity curve, respectively. The unsaturated permeability coefficient can be derived from the saturated permeability coefficient and soil-water characteristic curve by Frediund and Xing, Green and Corey, and Van Genuchlen. The boundary conditions can be set as flow boundary and head boundary, in which both flow boundary and head boundary can be set as a function of time.

2.2. Model building

In the landfill leachate collection system, the leachate mainly includes the liquid produced in the physical and chemical reaction of the landfill body, atmospheric rainfall infiltration and leachate reinjection. In order to simplify the calculation, it is assumed that the leachate is produced in the form of rainfall. As the efficiency of zigzag drainage structure is higher than that of continuous drainage structure, only the seepage of zigzag drainage structure under steady flow is considered. The drainage layer is adopted 0.9 m sand gravel, and the horizontal distance of drainage layer is 30-100 m. The drainage gradient is 0.5-10%.

If the drainage system can work normally, the water head in the drainage pipe should be lower than that in the sump, and the boundary has no effect on the depth of saturated leachate on the liner layer. Under the condition of free drainage and stable seepage, the hydraulic gradient at the drainage boundary is -1, and the corresponding initial head at the drainage boundary is $y_0$.

$$y_0 = \frac{PL}{k}$$  
(1)

Where $P$ is the infiltration rate of leachate; $L$ is the horizontal distance of drainage layer; $k$ is the permeability coefficient of drainage layer.

Considering the influence of anisotropy of permeability coefficient on the maximum saturation depth, the ratio of permeability coefficient in $y$ direction and $x$ direction be

$$K_{ratio} = \frac{k_y}{k_x}$$  
(2)
When $K_{\text{ratio}}$ takes different values, compared with the maximum saturation depth of soil in isotropy, parameters $y'_{\text{max}}$ are introduced

$$y'_{\text{max}} = \frac{y_{\text{maxa}} - y_{\text{maxo}}}{y'_{\text{maxo}}} \quad (3)$$

Where $y_{\text{maxo}}$ is the maximum saturation depth of leachate in isotropic condition, and $y_{\text{maxa}}$ is the maximum saturation depth of leachate in anisotropic condition.

3. Results and discussion

Figure 1 shows the relationship between the maximum saturation depth and $K_{\text{ratio}}$ when the drainage distance is 30 m, the drainage layer slope is 1.5%, the permeability coefficient is $1 \times 10^{-4}$ m/s, and the infiltration rate of leachate is 5 mm/d. It can be seen that when the horizontal permeability coefficient is fixed and the vertical permeability coefficient is reduced, the maximum saturation depth of leachate increases sharply. When the vertical permeability coefficient is increased, the maximum saturation depth of leachate decreases slowly. In the drainage sand gravel layer of the landfill, due to the large pores and the backfilling compaction, thereby the difference of permeability coefficient in each direction is not great. In the following analysis, the isotropy is considered, i.e. $K_{\text{ratio}}=1$.

![Figure 1](image1.png)

Figure 1. Relationship between maximum saturated depth and anisotropy of permeability coefficient.

Swanson unified sand is used for drainage sand layer with saturated permeability coefficient of $1.0 \times 10^{-4}$ m/s. Figure 2 shows the relationship between permeability coefficient and matric suction ($s$). The influence of infiltration rate, drainage slope, boundary condition and drainage distance on the maximum saturation depth is considered during calculations.

![Figure 2](image2.png)

Figure 2. Relationship between permeability coefficient and matric suction.
Figure 3 shows the relationship between the maximum saturation depth and infiltration rate when the drainage distance is 30 m, the drainage layer slope is 2%, the permeability coefficient is $1 \times 10^{-4}$ m/s, and the infiltration rate of leachate is 0.5-10 mm/d. It can be seen that the maximum saturation depth increases linearly with the infiltration amount. Therefore, it is necessary to determine the infiltration rate of drainage system accurately in the design of landfill.

Figure 4 shows the relationship between the maximum saturation depth and drainage slope when the drainage distance is 30 m, the infiltration amount is 3 mm/d, 5 mm/d and 10 mm/d, and the permeability coefficient is $1 \times 10^{-4}$ m/s. It can be seen that the drainage slope has a great influence on the maximum saturation depth. When the infiltration rate is 2 mm/d and the drainage slope is less than 2%, the maximum saturation depth decreases sharply with the drainage slope. When the infiltration rate is 3 mm/d and the drainage slope is less than 3%, the maximum saturation depth decreases sharply with the increasing of drainage slope. When the infiltration rate is 10 mm/d and the drainage gradient is less than 5%, the maximum saturation depth decreases sharply with the increasing of drainage gradient, and then the drainage distance changes little with the increasing of drainage gradient.

Figure 5 shows the effect of horizontal distance on the maximum saturation depth at a permeability coefficient of $1 \times 10^{-4}$ m/s, an infiltration rate of 5 mm/d, and a drainage slope of 3%. It can be seen that the maximum saturation depth is less affected when the drainage distance is small, and the maximum saturation depth is more affected when the drainage distance is large. In order to consider the influence
of the initial water head on the maximum saturation depth, the parameter $\delta y_{\text{max}}$ is introduced

$$\delta y_{\text{max}} = \frac{y_{\text{max}2} - y_{\text{max}1}}{y_{\text{max}1}}$$  \hspace{1cm} (4)$$

Where $y_{\text{max}1}$ is the maximum saturation depth of leachate in drainage layer when the boundary condition is $y_0$, and $y_{\text{max}2}$ is the maximum saturation depth of drainage layer when the boundary condition changes.

Figure 6 shows the relationship between the calculation error of the maximum saturation depth and the initial water head when the drainage distance is 60 m, the drainage slope is 3%, the infiltration rate is 5 mm/d, and the permeability coefficient is $1 \times 10^{-4}$ m/s. As shown in Figure 11, it can be seen that the boundary conditions have a great influence on the change of the maximum saturation depth. When the initial water level change double, the maximum saturation depth increases by 7%, and the maximum saturation depth increases by 27% when the initial water head changes 6 times. When the initial water level increases 9 times, the maximum saturation depth increases more than 50%, thereby the accurate boundary conditions have a great influence on the maximum saturation depth.

![Figure 6. Relationship between calculation error and initial water head.](image)

4. Conclusions

1. When the horizontal permeability coefficient is fixed and the vertical permeability coefficient is reduced, the maximum saturation depth increases sharply. When the vertical permeability coefficient increased, the maximum saturation depth decreases slowly.

2. The maximum saturation depth increases linearly with the infiltration amount. Therefore, it is necessary to determine the infiltration rate of drainage system accurately according to local conditions.

3. The drainage slope has a great influence on the maximum saturation depth, which decreases sharply with the increase of drainage slope.

4. The maximum saturation depth is less affected when the drainage distance is small, whereas the maximum saturation depth is more affected when the drainage distance is large.

5. Accurate boundary conditions have great influence on the maximum saturation depth. In practical engineering, whether the blind ditch (drain pipe) can discharge the leachate or not has an important influence on the maximum saturation depth.

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