Research on optimal design of slope anti-seepage

Zhenyu Wang, Lingqiang Yang* and Naidong Sun
School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, 250022, China

*Corresponding author’s e-mail: cea_yanglq@ujn.edu.cn

Abstract. In order to study the seepage problem of the slope, the seep/w module in geo-studio is used to analyze the sluice of the Tanzhuang reservoir dam in Liaocheng, and the finite element simulation analysis of the slope seepage under different working conditions is obtained. A series of physical quantities such as seepage velocity, seepage flow and saturation line under working conditions. At the same time, the influence of different anti-seepage materials on the seepage of the slope is analyzed. The best combination of anti-seepage effect and economic benefit is obtained. The analysis results show: (1) In terms of anti-seepage effect: Compared with no anti-seepage measures, horizontal anti-seepage can reduce the seepage velocity to 81% before, and the anti-seepage effect is ideal. The vertical anti-seepage effect in the joint action with horizontal anti-seepage is extremely significant, and the seepage velocity can be reduced to 78% before. (2) In terms of project cost: The price of the anti-seepage film is relatively low, but the laying area is large, which requires a lot of manpower and material resources. The pouring concrete anti-seepage wall has a higher cost and the construction is more complicated. For this project, laying an anti-seepage film is more economical. (3) Comprehensive view: In order to combine the anti-seepage effect with the economic benefit, the combined action of the anti-seepage membrane and the anti-seepage wall is the best choice, and joint anti-seepage can be carried out at important parts, and only horizontal anti-seepage can be performed at the secondary position. The results of this study can provide reference for the same type of project, reduce construction costs, and further improve the stability of the slope.

1. Introduction
In recent years, the rapid growth of China's population has intensified the excessive exploitation and utilization of land resources, triggering a series of geological disasters. Seepage is an important part of the slope stability problem. On the one hand, the seepage field generated by seepage creates pore water pressure, and the pore water pressure acts on the slope to change the stress state of the slope, causing the porosity and permeability coefficient of the soil to change; on the other hand, changes in soil porosity and permeability coefficient will in turn lead to changes in the seepage field [1]. Therefore, anti-seepage research is of great significance for slope stability and provides a reference for slope safety control.

At present, geomembrane and anti-seepage wall are common methods for anti-seepage of slopes. In the anti-seepage construction work of slopes, both safety factors and economic benefits should be considered. So how to combine the anti-seepage effect and the reasonable construction cost to achieve the effect of high quality and low price, which is the focus of our research. This article uses geo-studio's seep/w module for seepage analysis. According to Darcy's law and seepage control differential equations as the basic theory, to study the anti-seepage effect of geomembrane and concrete anti-seepage wall under different working conditions, to seek the best combination of
economic benefits and anti-seepage effects, so as to provide reference for the same type of project, and reduce construction costs and further improve the stability of the slope [2].

2. Basic theory

2.1. Darcy's law
In 1856, French engineer Darcy experimental study of water flow through the sand, come to the following relationship:

\[ v = \frac{Q}{A} = kJ = -k \frac{dH}{ds} \]  \hspace{1cm} (2-1)

Where \( k \) is the permeability coefficient; \( Q \) is the seepage flow; \( J \) is the penetration slope; \( A \) is the cross-sectional area of flow perpendicular to the direction of flow rate; and \( v \) is the section average flow rate.

2.2. Seepage control differential equation
(1) Continuous equation of seepage
The model assumes that continuous water fills the entire seepage field. It is known from the principle of mass conservation that the rate of filling or loss of the seepage medium in any unit in the seepage field is equal to the difference between the rate of flow into and out of the unit, as shown in Figure 1:

![Figure 1. Unit body schematic](image)

That is:

\[ \frac{\partial M}{\partial t} = \frac{\partial (n\rho dxdydz)}{\partial t} = \frac{\partial (n\rho V)}{\partial t} \]  \hspace{1cm} (2-2)

Where \( M \) is the water quality in the unit body; \( n \) is the soil porosity; \( \rho \) is the density of water; and \( V \) is the volume of the unit body.

This formula is the continuous equation of seepage.
(2) Basic differential equation of seepage
Stable seepage basic differential equation
Substituting \( v_x = -k_x \frac{\partial h}{\partial x}, v_y = -k_y \frac{\partial h}{\partial y}, v_z = -k_z \frac{\partial h}{\partial z} \) into (2-2) can be obtained:

\[ \frac{\partial}{\partial x} \left( k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( k_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( k_z \frac{\partial h}{\partial z} \right) = 0 \]  \hspace{1cm} (2-3)

Where \( k_x, k_y, \) and \( k_z \) are the permeability coefficient along the x, y and z directions.

Without considering the deformation and fluid compressibility and conforming to Darcy's law of seepage, it comes down to solving the Laplace equation problem.

3. Case analysis

3.1. Seepage calculation
The seepage portion of this project is calculated by the seep/w module in geostudio. Based on seep/w, the immersion line, equipotential line, overflow point elevation, single flow width and permeability ratio of the dam can be obtained under various working conditions. Moreover the grid diagrams of the
The specific seepage calculation content can be divided into the following points: (1) Calculate the immersion line of stable seepage under various working conditions; (2) Determine the penetration velocity and seepage flow of the dam under different anti-seepage materials; (3) Analyze the combination of different anti-seepage materials to achieve the most economical and safe state.

3.2. Project Overview
Taking the dam of Tanzhuang Reservoir in Liaocheng as an example, the seepage calculation is carried out. The dam height is 7.9m, the dam crest top elevation is 40.7m, the upstream Normal water level is 29.00m, and the downstream corresponding water level is 24.00m. The weight of the dam is 16.7kN/m$^3$, the saturated bulk density is 20kN/m$^3$, the permeability coefficient is $3 \times 10^{-5}$cm/s; the foundation density is 16.7kN/m$^3$, the saturated bulk density is 19kN/m$^3$, and the permeability coefficient is $3 \times 10^{-4}$cm/s. The permeability coefficient of geomembrane is $1 \times 10^{-6}$cm/s; the permeability coefficient of impervious wall is $2 \times 10^{-7}$cm/s [4]. The working conditions are divided into the following categories: (1) no geomembrane, no impervious wall; (2) only geomembrane is effective; (3) only anti-seepage wall is effective; (4) geomembrane and anti-seepage wall are effective.

3.3. Finite element model
The finite element model is shown in Figure 2. The mesh is encrypted in order to improve the calculation accuracy. The model has a total of 4675 units and 4843 nodes [5].

3.4. Boundary conditions
The boundary conditions are: upstream water level 29.00m, downstream water level 24.00m, 14~15 are the downstream water level boundary, and 1~2~16~17, 10~11 are impervious boundaries.

3.5. Calculation results of various working conditions
(1) Working condition 1: no geomembrane, no impervious wall:

(2) Working condition 2: only geomembrane is effective:
(3) Working condition 3: only the seepage prevention wall is valid:

![Figure 5](image)

(4) Working condition 4: geomembrane and anti-seepage wall are effective at the same time:

![Figure 6](image)

Take the top section of the upstream slope as the flow section 1. The immersion line, seepage velocity and seepage flow result of each working condition are shown in Table 1:

| Working Condition | Seepage Velocity (v) | Seepage Flow (Q) | Immersion Line |
|-------------------|----------------------|------------------|----------------|
| 1                 | 24.034               | 0.0424           | In Figure 3    |
| 2                 | 19.495               | 0.0344           | In Figure 4    |
| 3                 | 24.034               | 0.0424           | In Figure 5    |
| 4                 | 18.941               | 0.0334           | In Figure 6    |

The price is calculated according to the polyethylene anti-seepage geomembrane used in the actual project. The polyethylene anti-seepage membrane is 6 Yuan per square meter. The impermeable membrane to be laid in this project is 36.26 m² per unit width; the anti-seepage wall adopts the pile-column anti-seepage wall cast by ordinary concrete. The casting cost is 7.4 m³ per unit length, and the price of ordinary concrete is 300 Yuan per cubic meter. The specific parameters are shown in Table 2.
4. Conclusion
The anti-seepage effects produced by different anti-seepage methods vary widely. Comparing working condition 1 and working condition 2, the seepage velocity is 24.034 cm/s and the seepage flow reaches 0.0424 m³/day/m with no anti-seepage measures. When the anti-seepage membrane is laid, the seepage velocity is reduced to 19.495 cm/s, seepage flow is 0.0344 m³/day/m, only 81% before. Compared with working condition 1 and working condition 3: pouring concrete anti-seepage wall and no anti-seepage measures, there is almost no difference in the permeation speed and the seepage flow at section 1. It can be seen that the simple vertical anti-seepage effect is not good. Comparing the working condition 2 and the working condition 3, the effect of the anti-seepage film is much better than that of the vertical anti-seepage. Comparing working condition 1 and working condition 4, the seepage velocity decreased to 18.941 cm/s and the seepage flow decreased to 0.0334 m³/day/m under the combined anti-seepage. The seepage velocity is only 78% before, it can be seen that vertical anti-seepage plays an important role in joint anti-seepage. Compared with the anti-seepage wall, the geomembrane has higher anti-seepage efficiency.

Different anti-seepage methods have different effects on the cost. Comparing working condition 2 and working condition 3, it can be seen that in the separate anti-seepage, the cost of the anti-seepage film is lower, totaling 217.56 Yuan per unit length; and the anti-seepage wall is 2220 Yuan, which is 10 times the cost of the anti-seepage film. It can be seen from the above that the effect of the anti-seepage wall under the separate anti-seepage mode is almost negligible, and the cost is relatively expensive. Comparing working condition 2 and working condition 4, the anti-seepage speed is reduced from 19.495 cm/s to 18.941 cm/s, which only increases the anti-seepage effect by 3%, but the cost is increased by 10 times.

In summary, if we simply consider the anti-seepage effect and do not consider the cost problem, laying the anti-seepage film and pouring the anti-seepage wall, the anti-seepage effect is the best, able to reduce the anti-seepage effect to less than 80% of the previous; If only the cost problem is considered and the requirements for the anti-seepage effect are low, only laying the impermeable membrane can achieve good results, reducing the anti-seepage effect to less than 85% before; If both the anti-seepage effect and the cost problem are considered, joint anti-seepage can be carried out at important parts, and only horizontal anti-seepage can be performed at the secondary position.

References
[1] Chen, Z.Y. (1985) Calculation steps of total stress method for stability analysis of earth-rock dam slope during sudden water drop in reservoir. Water Resources and Hydropower Engineering., 9:30-33.
[2] Liu, J., Mao, Y.X. (1997) The finite element method for calculation of saturated and unsaturated seepage of dykes. Scientific Research on Water Resources., 19(3): 242-252.
[3] Liu, W.Z. (2005) Coupling analysis of stress field-seepage field of earth-rock dam based on GEO-SLOPE. Prospecting Science and Technology., 23(2):15-18.
[4] Zhao, M.H. (2012) Soil Mechanics and Foundation Engineering. Wuhan: Wuhan University of Technology Press., 26: 84-85.
[5] Sun, Q., Ma, P., Ye, X.P. (2008) Study on swallow tail mutation model of slope evolution. Chinese Journal of Geotechnical Engineering., 30(7):1024-1028.