Study on mechanism of seepage drainage facilities affecting saturated-unsaturated seepage flow field of high tailings dam

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Abstract. This article uses a 300m complex high heap tailings dam as an example. Obtain real parameters through laboratory tests and in-situ tests. Establish a two-dimensional finite element numerical model. Consider normal and flood conditions. Consider the three stages of tailings dam height stacking to 135m, 200m and final 300m. two-dimensional finite element seepage field simulation of simultaneously setting dam surface drainage facilities and reservoir bottom drainage facilities, only reservoir bottom drainage facilities, and only dam surface drainage facilities was performed. Through the analysis of results, the bottom seepage drainage facility is not effective when the dam is high or there are complex geological conditions in the dam. The drainage facilities in front of the dam have a better effect on preventing the infiltration line from overflowing the dam surface, but the ability to control the infiltration line is weak.

Keywords: High Heap Tailings Dam, Drainage facilities, Seepage field, Finite element numerical simulation.

1. Introduction
The tailings dam, as an extremely important link in the construction of mining infrastructure, is related to the safe production and normal operation of the mine. Tailings discharge and storage are long and continuous dynamic processes that exist throughout the life of the mine. As the tailings dam continues to pile up, the area of the reservoir area continues to increase, and the safe operation management of the tailings reservoir is becoming more and more difficult to control. Once a tailings dam breaks, it will cause great casualties and economic losses to the downstream.

Tailing dam seepage damage accounts for most of the safety accidents in tailings ponds. In response to this problem, many experts and scholars at home and abroad have studied it. Chang-Hong Li [1] summarized the research results at home and abroad based on the mechanical characteristics of dam-forming tailings materials, the dam-forming tailings deposition law, and the structure of the dam, and put forward urgent problems in the field of tailing dam disaster research. Fa-Ning Dang and other scholars [2-4] studied the influence of different drainage facilities on the stability of tailings dam seepage from various angles. Jing-You Hu and other scholars [5-7] used the fluid-solid coupling-Morgenstern-Price method to calculate the seepage and stability of tailing dams based on unsaturated fluid-solid coupling theory. Guang-Zhi Yin [8] studied the influence of the lens body on the infiltration line in the tailings dam. Hai-Feng Mei [9] solved the change of permeability coefficient under the consolidation effect and established a formula for calculating the permeability coefficient considering the...
consolidation effect. Ali Pak [10] studied the overall characteristics and heterogeneity of seepage in the tailings dam, and analyzed the stability of the dam based on different stacking methods, material properties and seepage characteristics of the drainage system.

This article takes a typical and complicated 300m high-heap tailings dam in China as an example. Based on the simulation of normal and flood environmental conditions, the mechanism of the influence of different seepage drainage facilities on the seepage field during multi-stage dam construction was studied. It provides a reference for the management and control of influencing factors of the seepage field of high-stack tailings dams at home and abroad.

2. Project background
The morphology of the tailings ditch in this paper is a "V" gully landform near the north-south direction to the middle and low mountains. The reservoir area is surrounded by mountains on three sides, forming a well-closed natural reservoir basin. The tail of the reservoir is divided into three branch ditches, named after 1#, 2#, and 3#. The three ditch valleys converge in front of the initial dam. Affected by topographical factors, a complex confluence area is formed. The catchment area of the tailings pond is 6.87 km². Trench bottom slope is about 8.0%. The total length from the initial dam to the end of the reservoir is 3.3km. Total storage capacity is 14,724,700 m³. The base elevation is 1090m. According to the discharge rate of tailings in the reservoir, it is divided into three phases of dam construction. The dam heights are 135m, 200m and 300m respectively.

![Fig. 1](image)

Fig. 1 The plane profile of a typical profile.

3. Numerical model and material parameters

3.1. Selection of material parameters
According to the engineering survey situation, the tailings in the tailings pond are divided into five types: tailings fine sand, tailing silt, tailing silt, and tailing silt clay based on the engineering geological profile and the size classification of the tailings combined with the reservoir conditions.

| Material                        | Permeability coefficient /cm/sec | Bulk density /KN/m³ | Cohesion C/KPa | Internal friction angle ∅/° |
|---------------------------------|---------------------------------|--------------------|---------------|----------------------------|
| Initial dam                     | 0.15                            | 22.0               | /             | 40                         |
| Tail fine sand                  | 1.65×10⁻⁴                      | 21.4               | 8             | 30                         |
| tail silty sand                 | 4.93×10⁻⁴                      | 20.9               | 10            | 28                         |
| tailing silt                    | 1.34×10⁻⁴                      | 21.5               | 10            | 25                         |
| Tail silty clay                 | 6.01×10⁻⁶                      | 21.8               | 18            | 16                         |
| Moderately weathered dolomitic limestone | 4.2×10⁻⁵  | 27                | 60            | 40                         |

Table 1. Calculation material parameter table of dam seepage and stability.
This paper adopts the soil-water characteristic curve fitting formula of unsaturated soil under different confining pressure conditions proposed by Yong-Le Li [11]. The soil-water characteristic curve of the material is determined according to the relationship between the suction and saturation of the matrix in the soil. The formula is as follows:

\[
\omega = \frac{a + bs}{1 + cs + ds^2}
\]  

(1)

In the formula, \(\omega\) is the mass moisture content; \(s\) is the matrix suction; \(a, b, c, d\) are the fitting parameters under different confining pressures.

The in-situ method was used to measure the permeability coefficient of unsaturated soil. The material permeability coefficient curve is determined according to the relationship between the permeability coefficient and the matrix suction.

![Fig. 2 Soil-water characteristic curves.](image1)

![Fig. 3 Permeability coefficient curves.](image2)
3.2. Establishment of Numerical Model
According to the hydrogeological conditions of the tailings reservoir, three typical sections 1-1, 2-2, and 3-3 located in the gullies 1 #, 2 #, and 3 # were selected for two-dimensional finite element numerical simulation analysis. Numerical simulation models of different dam heights in the 1-1 section are shown in the figure.

![Typical section model diagram.](image)

4. Analysis of saturated-unsaturated seepage field
In this paper, the percolation field calculation is carried out based on the basic parameters of material percolation obtained from field measurements and laboratory tests, based on the basic principles of two-dimensional saturated-unsaturated percolation fields and the two-dimensional stable percolation basic differential equation. According to the assumption of incompressible fluid and continuous flow conditions, under the condition of constant volume, the amount of water flowing into the micro-unit for saturated soil is equal to the amount of water flowing out. The formula is as follows:

\[
v_x \, dz + v_z \, dx = \left( v_x + \frac{\partial v_x}{\partial x} \, dx \right) \, dz + \left( v_z + \frac{\partial v_z}{\partial z} \, dz \right) \, dx
\]

Finishing can be obtained:

\[
\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} = 0
\]  \(2\)

According to Darcy’s Law:

\[
v_x = -k_x \frac{\partial h}{\partial x}; v_z = -k_z \frac{\partial h}{\partial z}
\]  \(3\)

\(H=h+z\) is the total potential energy; \(k_x, k_z\) are permeability coefficients in the x and z directions.

Putting formula (3) into formula (2), we get:

\[
\frac{\partial}{\partial x} \left( k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial z} \left( k_z \frac{\partial h}{\partial z} \right) = 0
\]  \(4\)

Equation (4) is the basic differential equation for two-dimensional stable seepage.

In this paper, the variation of seepage fields with different drainage and seepage settings at different dam heights of 300m high dams is studied. Under the conditions of the prescribed controlled infiltration line, the stability calculation of drainage and drainage before the dam and the bottom of the reservoir is set according to the dam height of 135m, 200m, and 300m. The calculation results show that the 1-1 section is the most unfavorable section. The results of the minimum safety factor of 300m dam height in three sections are shown in the table below.

| Profile | Elevation of dam top | Condition       | Minimum anti-sliding stability safety factor | Specification regulated data |
|---------|----------------------|-----------------|---------------------------------------------|-----------------------------|
| 1-1     | 1390m                | Normal condition| 1.459                                       | 1.30                        |
|         |                      | Flood condition | 1.419                                       | 1.20                        |
| 2-2     | 1390m                | Normal condition| 1.605                                       | 1.30                        |
|         |                      | Flood condition | 1.553                                       | 1.20                        |
| 3-3     | 1390m                | Normal condition| 1.657                                       | 1.30                        |
|         |                      | Flood condition | 1.547                                       | 1.20                        |
4.1. Analysis of seepage field of tailings dam when seepage drainage facilities are installed on the dam surface and the reservoir

The initial dam was a fully permeable rockfill dam. Inner dam slope is laid with anti-filtration layer and drainage cushion. Geotechnical fabric are laid in the stacked dam. Blind drainage ditches is set in 200m away from the top of the dam beach. The geotechnical fabric is connected to the blind drainage ditch through a drainage pipe. At a distance of 30m from the dam top, a horizontal drainage layer in front of the dam is laid every 3m.

The bottom seepage layer of the reservoir is laid with a 0.3m thick gravel layer, a 400g/㎡ geotextile and a 0.2m gravel layer in order from bottom to top. Three drainage steel pipes of DN159 × 6mm are buried in the drainage layer to direct the water in the reservoir area to a nearby drainage well for discharge.

Considering the drainage in front of the dam and drainage in the bottom of the reservoir. When the dam is piled up to a height of 135m, the burial depth of the dam under normal operating conditions is between 37-47m. The infiltration line has a large burial depth, and the infiltration line is evenly distributed from the dam top to the dam foot. Basically distributed along the 1:5 stacking slope ratio. Under flood conditions, the burial depth of the dam is between 30-38m. The overall infiltration line is deep. Affected by the flood, the length of the dry beach of the dam was shortened from 400m to 200m, which caused the infiltration line to rise significantly from the dam top to the middle of the dam. The infiltration line in some areas is located close to the drainage area in front of the dam. The infiltration line between the middle and early stages of the dam was hardly affected by the flood. Due to the good permeability of the initial dam and the role of drainage facilities in front of the dam, the infiltration line of the dam can still be well controlled under flood conditions. The geological conditions in the middle of the dam are complicated, and the seepage performance is poor, which causes the infiltration line between the dam and the dam top to rise slightly.

When the dam is piled up to a height of 200m, the burial depth of the dam under normal operating conditions is between 30-45m. As the dam height increases, the dam infiltration line rises significantly. Difficulty in controlling dam infiltration lines. The infiltration line at the horizontal distance of 181m to
422m from the initial dam is basically close to the drainage facilities of the dam surface. Under flood conditions, the burial depth of the dam is about 30m. The infiltration line of the dam is arranged close to the drainage facilities of the dam.

When the dam is piled up to a height of 200m, Under normal conditions and flood conditions, the infiltration line except the dam top is in close contact with the drainage area of the dam surface as a whole. The burial depth of the infiltration line is effectively controlled. The water in the dam is effectively discharged from the bottom of the initial dam and the bottom of the reservoir.

In the case of lower tailings dams, the drainage facilities on the dam surface and drainage facilities on the bottom of the reservoir effectively adjusted the burial depth of the dam, thereby ensuring the stability of the seepage flow of the dam. In the case of higher dams, the infiltration line of the dam quickly rises, and the infiltration facilities in front of the dam control the infiltration line more effectively. And the bottom seepage drainage facility effectively shared the burden of dam drainage at the initial stage and prevented water accumulation at the initial stage.

4.2. Analysis of the seepage field with only the reservoir bottom drainage

The calculation and analysis of the seepage field was conducted under the condition that only the reservoir bottom drainage facilities were set up. When the dam is piled up to a height of 135m, the analysis results of normal conditions and flood level conditions are the same as when seepage drainage facilities in front of the dam and seepage drainage facilities at the bottom of the reservoir are set at the same time. It shows that when the dam height is low, the dam's infiltration line is well controlled, and the absence of dam surface drainage facilities has little effect on the dam's infiltration line.

When the dam is piled up to a height of 200m, Under normal conditions, the infiltration line at the waist of the dam increased significantly. The shallowest depth of the infiltration line is about 16m from the dam surface. Under flood conditions, the infiltration line rises more obviously at this location, with the shallowest burial depth of about 9m. The distribution of infiltration lines at the dam top and dam foot is good.

When the dam is piled up to a height of 300m, Under normal and flood conditions, the infiltration line of the dam overflowed from the dam waist and quickly spread to the dam top and dam foot. Due to the good permeable performance of the dam in the early stage, the diffusion speed of the overflow toward the dam foot is relatively slow. The tailings dam has undergone large-scale swamping.

4.3. Analysis of the seepage field with only the dam surface drainage

The calculation and analysis of the seepage field was conducted under the condition that only the dam surface drainage facilities were set up. When the dam is piled up to a height of 135m. Under normal operating conditions, the infiltration line at the stratum junction of the dam waist is obviously raised and a smooth curve is formed along the raised part. Except for locations with poor local geological conditions, the overall infiltration line is deeper. The depth of the infiltration line is between 30-43m. Under flood conditions, the infiltration line rises from the junction of the stratum at the waist of the dam to the top of the dam. The results show that the reservoir bottom seepage drainage facility can effectively make up for the lack of seepage drainage at the initial stage when the dam height is low. When there are complex geological conditions in the reservoir, if there is no seepage drainage facility at the bottom of the reservoir, the tailings dam can only seep through the initial dam and the infiltration line will rise.

![Fig. 8 Location map of infiltration line when the tailings dam is 135m high. (Only dam surface drainage)](image)
Under normal and flood conditions of 200m and 300m dam height, the dam infiltration line fits the drainage facilities in front of the dam. The drainage facilities on the dam surface effectively controlled the uplift of the infiltration line.

5. Conclusion
In this paper, a saturated-unsaturated seepage field analysis is performed based on a 300m high pile tailings dam with different drainage facilities. Draw the following conclusions:

1. The tailings dam continues to increase after reaching a height, and the infiltration line will rise rapidly. After the tailings dam reaches a certain height, the infiltration surface will overflow, resulting in swamping of the dam surface and dam collapse in severe cases.

2. The bottom seepage drainage facility can effectively reduce the infiltration line of the tailings dam under various working conditions. However, its range and efficiency are limited, and the effect is not good when the dam is high or there are complex geological conditions in the dam.

3. The dam surface drainage facilities have an excellent effect on preventing the infiltration line from overflowing the dam surface. But when the infiltration line is not high, the ability to control the infiltration line is weak.

4. For tailings dams with high dam heights and complicated geological conditions, the comprehensive action of various drainage facilities is required to effectively control the seepage field in the tailings dam and prevent disasters such as dam collapse.

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