Effect of horizontal drainage pipes on seepage field of tailings dam based on topographic factors

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Abstract. The site selection of tailings dam is basis to ensure the safe operation in the later stage. Through numerical simulation, the influence degree of multiple topographic factors on the seepage field of tailings dam is analyzed, and it is found that the slope of bank slope on both sides of the valley, the longitudinal slope ratio of gully valley and the bottom width of gully valley will have a certain influence on the seepage field of tailings dam. In order to reduce the seepage line of the seepage field of the dam, the orthogonal optimization method was used to simulate the seepage field distribution of different horizontal drainage pipe diameters, pipe lengths, horizontal spacing, vertical spacing and buried inclination angles under different operating water levels based on the topographic factor analysis model. The results show that the infiltration line can be effectively reduced by the installation of the horizontal drainage pipe, and the pipe diameter, horizontal spacing and buried Angle can effectively reduce the height of the infiltration line. The mathematical model of the optimal horizontal drainage pipe is proposed, which provides a certain reference for the three-dimensional seepage safety analysis of the tailings pond.

Keywords: Tailings dam; Topographic factor; Horizontal drainage pipe

1 Introduction

With the increase of people's demand for mineral products, a large number of mineral resources have been mined[1,2]. After separating concentrate, the remaining tailings are hydraulically deposited into dams, which is not only a potential source of danger, but also has great potential for secondary development[3,4]. A reasonable tailing reservoir location will determine the construction type of the tailings dam[5] and even the drainage mode. The characteristics of high water head of the tailings dam make the analysis of the seepage field particularly important, and it is necessary to study the influence of topography on the seepage field of the dam. Scholars have proposed a variety of definition methods for topographic factors. Literature[6] proposed for the first time that the ratio of average valley width to maximum dam height was used to define the valley shape coefficient. Dang et al.[7] and Yang[8] gave quantitative defi-

Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_40

nitions of steep slope, asymmetric valley and narrow valley, and carried out stability analysis of dam. The site selection of tailing ponds requires long and slow longitudinal slope of gullies, which is rarely considered in previous studies.

To improve the stability of the tailings dam, reducing the saturation line is the most effective way, how to choose the drainage facilities reasonably, scholars have given their answers. Ali[9] studied the seepage field of tailings dam drainage systems under saturated and unsaturated conditions; Jin et al[10] summarized the working principle and advantages and disadvantages of typical seepage discharge facilities of tailings dam; Yang et al[11] carried out a case study on the application of geotextile tubing in tailings dams. The results showed that the method was effective in construction. Hu et al[12] conducted a study on seepage control during the construction of a tailings dam in sections. They concluded that a proper drainage system reduces the diving surface. The paper[13,14] gave a comparison of the magnitude of the influence of different seepage discharge facilities on the seepage elements of tailings dams and pointed out that the horizontal seepage discharge pipe has the most significant influence on the seepage volume. However, research about whether different seepage pipe arrangements have different effects on the seepage field does not have a deep carry out.

In this paper, we are changing the slope of the bank slope, the width of the valley, and the symmetry of the bank slope to study the influence of valley topographic factors on the seepage field, and using orthogonal preference method to discuss the influence of the spacing, inclination, pipe diameter, pipe length, and buried inclination of the horizontal seepage pipe on the seepage field on this basis. At last, we concluded the optimal layout of seepage pipe in different conditions. The results of the analysis can provide references and suggestions for the selection of the site of the tailing pond project and the selection of the seepage system.

2 Numerical calculation model

2.1 Geometric models

We are using Rhino to establish the surface of each stratum combined with the measured data and exporting to Abaqus for pre-modeling processing. It divided the calculation model into five regions, which are the starter dam, tail medium sand, tail silt, tail clay, and bedrock. The stratification of tailings is shown in Fig.1 and material calculation parameters in Table 1.

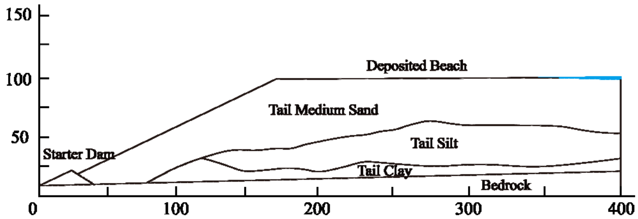

Fig. 1. Section diagram of tailings dam

Table 1. The material properties of the different parts

Sort	$K(m/s)$	$\rho(kg/m^3)$	$c(Pa)$	$\varphi(\circ)$	$E(MPa)$	μ
Tail medium sand	2.96×10^{-5}	1810	11.8×10^{3}	31.6	34	0.33
Tail silt	2.87×10^{-5}	1890	11.0×10^{3}	26	34	0.3
Tail clay	2.18×10^{-6}	1940	16.5×10^{3}	24	29	0.27
Starter dam	2×10^{-4}	1900	1.6×10^{4}	35	70	0.24
Bedrock	3.7×10^{-7}	2450				

The cutting boundary of the model is an impervious boundary $\partial H/\partial n = 0$ .By default, all boundary conditions in Abaqus are impervious, so no additional setting is required. Starter dam boundary and wetting surface boundary:

$$H = H(z) = z \tag{1}$$

$$\begin{cases} H = z \\ \dfrac{\partial H}{\partial n} = 0 \end{cases} \tag{2}$$

2.2 Calculation scheme

The minimum depth of the tailings dam can be a direct response to the dam of the infiltration line location of high and low, but also commonly used in the project to ensure the safety of the dam of the essential control indicators. Under different terrain conditions, the seepage field distribution law of the tailing pond is different, and the height and undulation of the terrain will affect the drainage of the tailing pond, which in turn will affect the form of seepage discharge arrangement of the tailing pond. Therefore, changing the slope of the bank slope α, the slope of the valley θ, the bottom width of the tailing pond B, the study of individual valley topo-graphic factors on the distribution of the seepage field of the tailing pond and the influence of topographic factors on the layout of the tailing pond seepage pipe, through comparing the influence of different spacing of seepage pipes, different pipe diameters, pipe lengths, and burial inclination on the seepage field of the tailings pond, and finally, supposing a formula for calculating the optimal arrangement of seepage pipes. Fig.2 first illustrates the valley geometry used in this article.

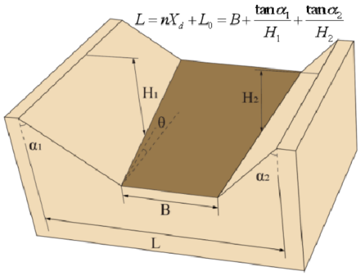

Fig. 2. Simplified valley geometric parameter diagram

3 Analysis of calculation results

3.1 Simplified seepage field distribution

The coordinates of specific zero-pressure points in the model cell were calculated by interpolation. We are keeping α1=18° and changing α2 to 5°, 30° and 63°. The infiltration line through the permeability coefficient of initial dam will be partially elevated; with the two sides of the bank slope at the same time increasing, the tailings dam infiltration line will be gradually elevated. Fig.3(a) shows the buried depth of the infiltration line on α1 side, which the influence of the altered side will slightly lift. Fig. 3(b) shows the comparative distribution of the buried depth of infiltration line on the altered side. When the valley slope is more significant, there will be a more obvious elevation of the dip line. At the same time, the slope of the mountain affects the leach line. The greater the slope, the higher the height of the leach line of tailings dam.

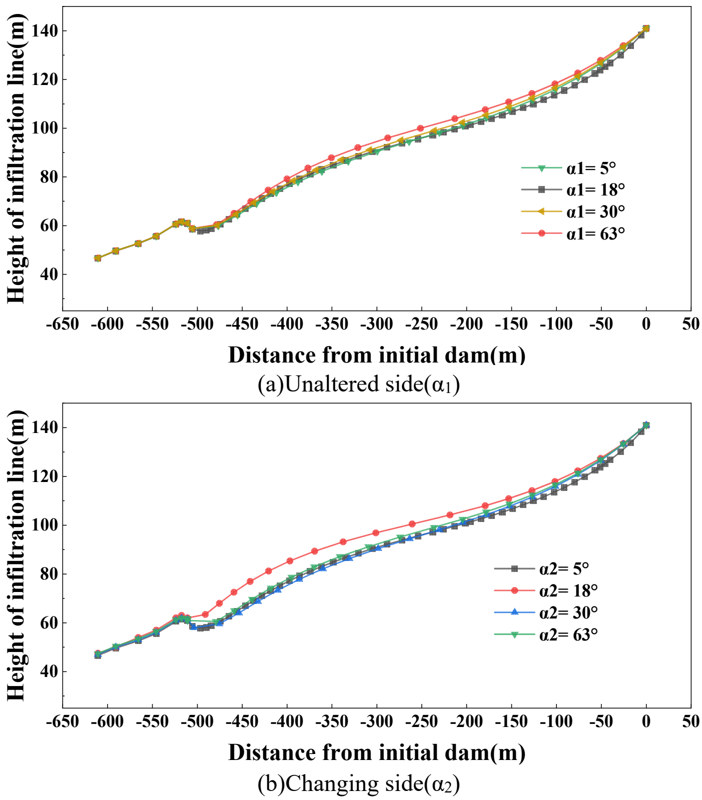

Fig. 3. Elevation of the wetting line when only one bank slope is changed

Keeping $\alpha_1 = \alpha_2$=18° and B=80m, changing θ to 0°, 3°, 5° and 10° respectively. As seen in Fig.4, the effect of the longitudinal valley slope on the dip line of the tailings dam is more concentrated in the portion of the stockpile dam. When θ=0° or 3°, the change of the infiltration line is not apparent, but with a further increase of the valley slope ratio, the depth of the infiltration line of the dam will increase.

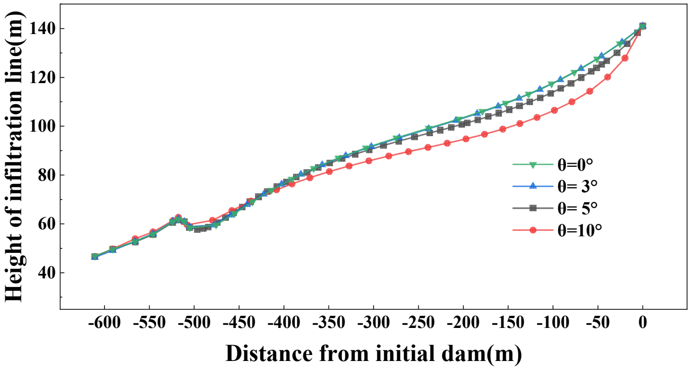

Fig. 4. The height of the infiltration line when the bottom width is different

Keeping α_1= α_2=18° and θ=5°, and changes B to 5 m, 20 m, 40 m, 80 m, 120 m, and 200 m. From Fig.5, it can be seen that the increase of the bottom width of the infiltration line height is gradually reduced when B is increased to 120m and 200m when infiltration line of the difference between the impact has been little.

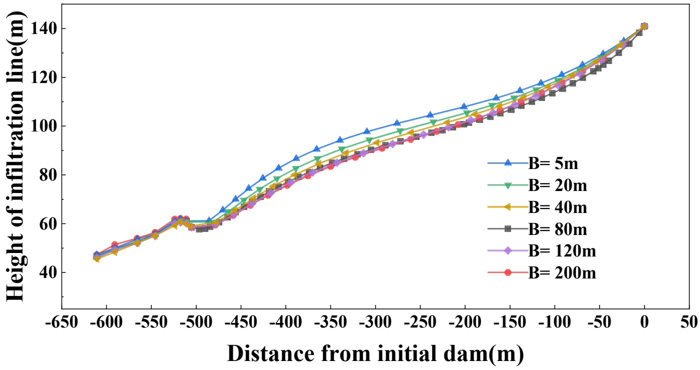

Fig. 5. The height of the infiltration line is distributed when the bottom width is different

Compare calculation of the height of the infiltration line between other conditions and the condition of α_1=α_2=18°, θ=5°, B= 80m can visually reflect the degree of influence of each factor on the infiltration line of the dam. Fig.6 show the results concretely. The larger the area, the greater the difference. It can be found from this different factors caused by the infiltration line difference line is relatively concentrated, and for the tailings dam infiltration line of the degree of influence on the size of α>B>θ, so in the selection of the reservoir site should pay extra attention to the size of the two sides of the slope of the valley.

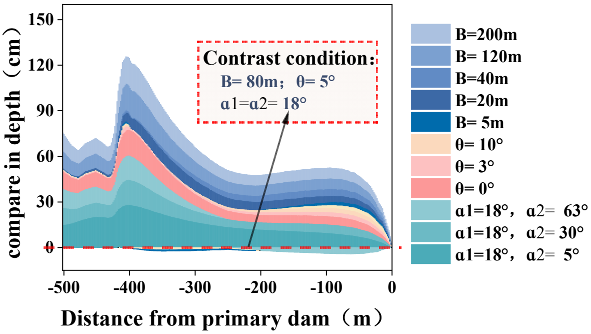

Fig. 6. Cumulative difference area between each working condition and standard

The slope of the valleys on either side, the gully aspect ratio, and the bottom width of the tailings impoundment all impact the extent to which the tailings impoundment seepage field is affected. Specifically, suppose the tailings impoundment lies in terrain with steeper valleys and more excellent gully slopes. In that case, seepage is more concentrated and more propitious to drainage than where it is gentle. The greater the valley slope on either side, the more significant the change in the tailings impoundment seepage field will likely be. The greater the longitudinal slope of the valley, the distribution of the tailings storage seepage field. The bottom width of the tailings pond will also have an effect on the distribution of the seepage field, and the larger the bottom width, the more evenly distributed the seepage field may be.

3.2 The influence of horizontal drainage pipe on seepage field

The position of the horizontal drainage pipe usually depends on the type of dam and the stress of its foundation. In the initial design of the drainage scheme, the geometric requirements should be met first. The horizontal layout of the drainage pipe is determined by the width of the bottom and the slope of both sides of the valley, and the longitudinal slope ratio of the valley determines the buried inclination and vertical layout of the drainage pipe. We can preliminarily deduce the number of drainage pipes laid by formula (3).

$$\begin{cases} m = \dfrac{B + \tan\alpha_1/H_1 + \tan\alpha_2/H_2 - L_0}{X_d} \\ n = \dfrac{H - L_0^{'}}{Z_d} \end{cases} \tag{3}$$

Where: the letters represent had shown in Fig.2 above.

We are arranging the horizontal seepage pipe on the foundation model, connecting the outlet of the seepage pipe and the longitudinal drainage channel, and carrying out the drainage outside the dam by the shoulder drainage ditch on both sides. To analyze the influence of different arrangements of seepage pipe on the leach line of the tailings pond and to discuss how to arrange the seepage pipe in order to achieve the most economical seepage effect scheme. In this case, arrange the horizontal seepage discharge layer from the height of 63.2m of the stacked dam.

The diameter, length, horizontal spacing, vertical spacing, and dip Angle of the buried depth of the horizontal drainage pipe were selected as the six main influencing factors under the operation conditions of three different water levels. The minimum buried depth of the infiltration line was taken as the investigation index. $L_{25}(6^5)$ orthogonal test was carried out by orthogonal optimization method, and numerical simulation was carried out by finite element method. Table 2 shows the specific scheme.

Table 3 reflects the results analyzed by variance analysis. It can be found through ANOVA that the $P \leq 0.01$ of the pipe diameter of the seepage discharge pipe and the horizontal spacing, and the factors have a highly significant effect on the test results, and the $P<0.05$ of the depth of burial inclination and the vertical spacing are significant, which will affect the stability of seepage of the tailings dam. However, compared to others, the significance of pipe length and water level is weak. That is, the length of the seepage discharge pipe and the set water level have a weak effect on the infiltration field of the dam. The ANOVA method considers that it is only necessary to choose the optimal level for the factors with significant effects and to choose the appropriate level according to the actual need for the other factors that have less effect on the test results. Therefore, the best collocation is A4B5C4D4E4F3.

Table 2. Calculated values of infiltration line burial depth under orthogonal analyses

NO.	pipe diameter /mm	pipe rang /m	level interval /m	vertical interval /m	buried inclination /°	water level /m	Minimum burial depth /m
1	50	90	10	20	10	170	13.991
2	30	90	3	5	15	165	6.427
3	50	50	5	5	1	165	13.303
4	90	25	3	3	10	165	7.101
5	50	110	3	15	7	170	14.929
6	70	90	15	15	5	165	21.772
7	30	110	15	3	1	170	6.536
8	70	50	10	3	15	170	18.632
9	90	90	20	10	1	170	14.214
10	110	25	10	15	1	165	18.944
11	110	90	5	3	7	171.8	9.924
12	50	25	15	10	15	171.8	14.644
13	70	25	20	5	7	170	27.053
14	30	25	5	20	5	170	8.689
15	30	70	10	10	7	165	15.719
16	70	70	3	20	1	171.8	17.259
17	90	70	5	15	15	170	11.088
18	30	50	20	15	10	171.8	11.819

19	110	110	20	20	15	165	20.258
20	50	70	20	3	5	165	18.261
21	70	110	5	10	10	165	12.994
22	110	70	15	5	10	170	9.200
23	110	50	3	10	5	170	9.278
24	90	50	15	20	7	165	22.260
25	90	110	10	5	5	171.8	12.286

Table 3. Agent effect test table

Source	sum of squares	DOF	Mean square	F	significance	Significant or not
modified model	720.070a	22	32.730	510.923	.002	
intercept	4416.660	1	4416.660	68944.108	.000	
pipe diameter	266.872	4	66.718	1041.470	.001	YES
pipe range	21.443	4	5.361	83.682	.012	NO
level interval	203.470	4	50.868	794.043	.001	YES
vertical interval	71.427	4	17.857	278.743	.004	YES
buried inclination	122.875	4	30.719	479.521	.002	YES
water level	33.983	2	16.991	265.234	.004	YES
error	.128	2	.064			
total	5743.747	25				
Revised total	720.198	24				

From perspective of the seepage control effect, reasonable arrangement of seepage pipe can effectively control the buried depth and distribution of infiltration line in the dam and improve the state of the seepage field to prevent the seepage damage to the tailings dam, which is conducive to the stability of tailings dam. From the point of view of the minimum buried depth of the infiltration line, the most beneficial way to reduce the infiltration line is to control the horizontal distance of the drainage pipe.

3.3 Optimal seepage pipe placement

Due to the influence of valley topographic factors on the seepage field, it can be seen from the above that the slope on both sides of the mountain has a significant influence on the seepage field, and the inherent limitations of its geometric factors will affect the layout of the drainage pipe. The layout plan of the drainage pipe should meet the economic requirements and restrain the project cost under the premise of meeting the safety of the dam. Therefore, the following mathematical model of horizontal drainage pipe layout is proposed in this paper. The objective function is:

$$\min C = C(k_g, d, m, n, X_d, Z_d, \varphi) \quad (4)$$

$$Q = Q\left(k_g, d, m, n, X_d, Z_d, h_1, h_2\right) \le [Q]$$
$$\text{s.t} \quad P = P\left(k_g, d, m, n, X_d, Z_d, h_1, h_2\right) \le [P] \qquad (5)$$
$$J = J\left(k_g, d, m, n, X_d, Z_d, h_1, h_2\right) \le [J]$$

Where: C is the total project cost of the horizontal drainage pipe layout scheme; k_g is the average permeability coefficient of the drainage pipe; $Q,[Q],P,[P],J,[J]$ is the permissible seepage volume, infiltration pressure, and hydraulic gradient under actual and specific topographic conditions, respectively. d,m,n,X_d,Z_d Are the pipe diameter, the number of each row, the number of rows, and the horizontal and vertical spacing of the drainage pipe, respectively. φ is the average layout Angle of the drainage pipe h_1,h_2 is the upper and lower water levels. The constraint conditions are expressed by the finite element numerical method rather than explicit form.

The average slope on both sides of the bank slope of the tailings dam built in a valley is 18° and 23°, the longitudinal slope ratio of the gully and valley is 0°, the bottom width of the gully is 40m, the initial dam is 30m, the total dam is 65m, and the external slope ratio is 1:2.5. Model data are shown in Fig.7.

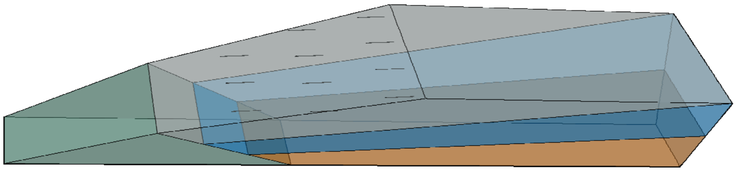

Fig. 7. Horizontal drainage pipe layout

The permeability coefficient of dam body is shown in Table 1. Permeability coefficient $k_g \ge 10^{-3} m/s$. The value range of each parameter in the Technical Specification for Tailings Stacking dam Drainage and Reinforcement Engineering GB1118-2015 and engineering experience is shown in the Table 4.

Table 4. Parameter reference value

Sort	d(mm)	$L(m)$	φ(%)	X_d(m)	Z_d(m)
Value	63~90	5~15	2%~4%	6~25	6~10

First, assume that the aperture is the recommended 63mm, the buried inclination is 2%, the horizontal spacing is 25m, the vertical spacing is 10m, and the drainage pipe length is 15m. According to the model, $M=m_1+m_2+m_3=3+4+4=11$, $n=3$, $C=165c_0$ (c_0 is the unit price) can be calculated to solve the seepage flow, the seepage pressure of the dam foundation, and the maximum hydraulic slope of the dam itself. Then, the three parameters are taken as constraint conditions, and optimized according to the sequence of pipe diameter, buried inclination Angle, horizontal spacing and vertical spacing, and the optimal parameter combination under different constraint conditions is obtained. Table 5 shows calculation result.

Table 5. Calculation result

Plan	s.t.				result						
	$[Q](m^3/s)$	$[P]$	$[J]$	k_g(10^{-3}m/s)	d(mm)	φ(%)	X_d(m)	Z_d(m)	M	n	C(RMB)
1	0.0781	0.8	0.12	1.550	90	2	6	6	66	5	$1138c_0$
2	0.0604	0.83	0.123	1.517	80	2	6	6	66	5	$1089c_0$
3	0.0450	0.85	0.128	1.478	70	2	6	6	66	5	$1039c_0$
4	0.0356	0.88	0.131	1.443	63	2	6	6	66	5	$990c_0$
5	0.0369	0.88	0.132	1.388	63	3	6	6	66	5	$990c_0$
6	0.0377	0.88	0.130	1.409	63	4	6	6	66	5	$990c_0$
7	0.0341	0.89	0.126	1.315	63	4	10	6	41	5	$615c_0$
8	0.0154	0.9	0.126	0.594	63	4	25	6	18	5	$270c_0$

So above scheme, the optimal solution is Plan 7.

4 Conclusion

The finite element software Abaqus was used to calculate the three-dimensional seepage field of a tailing dam with different discharge pipe arrangements for different water level operating conditions. The calculation model assumes that the all-directional permeability coefficients of the tailing sands and tailing soils are the same and constant, and the following conclusions were obtained.

(1) The valley's shape needs to be considered when choosing the address of the tailing pond. The topography has a particular influence on the seepage stability of the tailing pond. Through several comparative analyses, the degree of influence of each topographic factor is the slope of the two sides of the valley > bottom width> gully longitudinal slope ratio. With the increase of the slope of both sides of the bank, the infiltration line of the tailings dam will be gradually raised; under the action of gravity of the tailings pond itself, the larger the slope of the gully valley is on the contrary, it is conducive to the drainage of the dam. Nevertheless, at the same time, the increase of the gully slope is not conducive to the structural stability of the dam; therefore, when selecting the site, the longitudinal slope of the gully is relatively small, and the flatter terrain is more suitable to establish the tailings dam.

(2) With the increase of the bottom width, the height of the leach line gradually decreases, and when we increase the bottom width to 120m, 200m, the influence on the leach line has little difference. There should be a critical value of the bottom width in the design of the tailings pond when approaching this critical value, that is, the most favorable drainage size of the bottom width.

(3) When laying the horizontal seepage pipe, the pipe diameter, burying inclination, and horizontal spacing, compared to other influences on the height of the infiltration line, are more prominent. Therefore, when we design the drainage pipe's laid

method, it needs to be considered first, based on which the vertical spacing can also be adjusted. In the study of this paper, the pipe diameter of 90mm, burial inclination of 10°, horizontal spacing, and vertical spacing of 15m of the deployment of the most significant influence on the infiltration line.

(4) Combined with the above law, the actual production should also consider the unevenness of the distribution of tailings sand caused by changes in permeability coefficient and other impacts, as well as, according to the geological survey report through the seepage pipe spacing and burying inclination of the reasonable design to achieve the purpose of saving money and meet the design requirements.

References

1. Wang X, Zhan H, Wang J et al. The stability of tailings dams under dry-wet cycles: A case study in Luonan, China[J]. Water. 2018,10,1048.
2. Asghari M., Noaparast M., Shafaie S.Z. et al. Recovery of coal particles from a tailing dam for environmental protection and economical beneficiations[J]. Int. J. Coal Sci. Technol, 2018, 5: 253-263.
3. Gao S, Cui X, Zhang S. Utilization of Molybdenum Tailings in Concrete Manufacturing: A Review[J]. Appl. Sci, 2020, 10, 138.
4. Lv X, Shen W, Wang L, et al. A comparative study on the practical utilization of iron tailings as a complete replacement of normal aggregates in dam concrete with different gradation[J]. J. Clean. Prod, 2019, 211, 704-715.
5. Wu Wuhai. Three-dimensional seepage field analysis of a valley-type tailings pond based on GTS [J]. Modern Mining, 2023,39 (04): 81-84.
6. Sergio Giudici, Richard Herweynen, Peter Quinlan. HEC Experience in Concrete Faced Rockkill Dams, past, Present and Future, CFRD 2000, Proceedings of International Symposium on Concret Faced Rockill Dam. Sept. 18，2000，Beijing.
7. Dang Faning, Wang Xuewu, Tian Wei et al. Stress and deformation characteristics of asymmetric high face rockfill dam and its improvement measures [J]. Journal of Hydraulic Engineering, 2012,43 (5): 602-608.
8. Yang Chao. Study on quantitative method of influence of valley shape on stress and deformation characteristics of faced rockfill dam [D]. Xi 'an University of Technology, 2018.
9. Pak, A., Nabipour, M. Numerical Study of the Effects of Drainage Systems on Saturated/Unsaturated Seepage and Stability of Tailings Dams. Mine Water Environ 2017, 36, 341-355
10. Jin S, Xu H, Zhang W, et al. Drainage mechanism and calculation method of slot pipe of fine tailings dam. Metal Mine. 2013, (3):42-44.
11. Yang Y, Wei Z, Cao G, et al.A case study on utilizing geotextile tubes for tailings dam construction in China. Geotext. Geomembr. 2019, 47:187-192.
12. Hu S, Chen Y, Liu W, et al. Effect of seepage control on stability of a tailings dam during its staged construction with a stepwise-coupled hydro-mechanical model. Int. J. Min. Reclam. Environ. 2015, 29:125-140.
13. Dang F, Li Q, Xue H, et al. Analysis of the influence of drainage facilities on seepage stability of a tailings dam. Modern Mining. 2015, (2):126-128.
14. Chen J, Liu X. Three-dimensional analysis of the effect of horizontal drainage pipe on the seepage field of tailings deposit dam. Light Metals. 2020, 2:1-8.