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The Analysis of the Seepage Characteristics of Tailing Dams Based on FLAC^{3D} Numerical Simulation

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Abstract: In this paper, the Guangxi's red mud disposal field is taken as the study area. Appropriate calculating parameters and boundary conditions were selected based on the survey data to build a Mohr-Coul0mb and fluid model under the plane-strain condition. FLAC^{3D} software was adopted to simulate the distribution of pore water pressure, filtrate seepage paths, and leakage of the dam body under conditions with no anti-seepage design, with partial anti-seepage design and with full anti-seepage design respectively, which provided a technical base for the anti-seepage design of this tailing reservoir. The results showed that this software could better simulate the leakage of red mud tailing dams. The reservoir area displayed obvious leakage characteristics, so full anti-seepage measures and appropriate seepage-proofing materials should be employed to deal with the dam body and the reservoir area to prevent environmental pollution and guarantee the stability of the tailing dams. The method not also can provide the technical reference for the evaluation of anti-seepage works, but also gives important guidance for the anti-seepage works.

Keywords: Tailing dams, leakage, FLAC^{3D}, numerical Simulation.

1. INTRODUCTION

Red mud storage area is a place of stockpiling red mud in mining engineering. Red mud is the high alkaline tailings from the production process of alumina, the tailing dam of red mud has adverse environmental impacts and groundwater can be polluted. Leakage is the engineering geological problem which is often met and must be solved, when tailing pond is built in the karst area. The groundwater will be polluted by means of slag and wastewater and the poor stability of the dam body can be produced if the problem of karst seepage happens. Therefore, it is necessary to analyze the characteristics of the tailings dam seepage and take efficient actions to prevent seepage and cure them [1].

There are a lot of methods of seepage analysis. The stability and the characteristics of seepage of tailing reservoirs are studied on numerical simulation technology which can comprehensive and deep analysis the characteristics of seepage [2]. The leakage of tailings dam can be simulated with FLAC^{3D} software, it is significant to fully recognize the character of the flow, analysis and simulate pore water pressure and the path of flow, to research and work out the control measure of the tailings dam leakage.

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2. THE GENERAL SITUATION OF THE ENGINEERING

The Red mud yard is located in Jingxi county, Guangxi Zhuang Autonomous Region which is the transition slope area of the Yunnan-Guizhou Plateau to the low mountains in the southwest of Guizhou province. There are more geotechnical sort and bigger Landform change. In the region, there are various kinds of surface and underground karst forms, for example the karst fissure, water hole and caves. in the area, the hydrological geological conditions is very complex . The prevention and control of seepage and the stability of the dam slope are severely affected by the bad geological phenomenon. Tailings dam is an important part of engineering construction of tailings pond. The earth-rock dam is used as the initial dam of red mud stockpile, the sub dams are built along the upstream of the initial dams. the sub dams are built with red mud which pile up by the wet methods.

3. THE ESTABLISHMENT OF MODEL

In the process of numerical analysis, the development of the stress of red mud yard should be considered. First, the balance of original stress will be calculated, then mechanical properties were obtained according to the red mud body straight into the mud yard, finally pore water pressure and the characteristics of seepage of mud yard is obtained according to the balance of principle of seepage flow. Boundary conditions were selected to establish Moore-Coulomb and fluid model under the plane strain conditions,

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and seepage characteristics of the tailing dam was simulated with software [3-5].

The mud yard can be as symmetrical model of high in the middle and low on all sides. The overall model will be calculated which cut out a part considering the convenient of building model and the speed of calculation on the analysis of seepage. The model of calculation is about 300 meters long, 8 meters wide, 35 meters deep. Automation functions can be sub-grid based on user's request to create the structural model of the unit divided into the number of nodes for the 28000 points. On the different conditions of seepage treatment, the mesh division of the red mud yard is the same. On the different kinds of anti-seepage state, the characteristics of seepage of model will be adjusted. Physical and mechanical parameters and grid model is shown in Table **1** and Fig. (**1**). Numerical simulation was conducted based on different seepage-proofing design conditions of the tailing dam, and pore water pressure distribution as well as seepage path of the tailing liquid was obtained.

4. THE PROCESS OF NUMERICAL SIMULATION

4.1. The Flow Characteristic of the Red Mud Stacking Without Anti-Seepage Measures

The Red mud filtrate liquid as the pollution will flow when local strata cannot satisfy the natural conditions of anti-seepage. In order to know the ways and the path of filtrate liquild without anti-seepage measure, the characteristics of seepage of the red mud stacking is simulated based on the condition of simulation without anti-seepage measure. The simulation results that distribution of pore water pressure and direction of the fluid flow are shown in Figs. (**2**, **3**).

From the figure, the zero potential surface of pore water pressure of red mud filtrate is on the top of the red mud body and at the top of the dam body without anti-seepage measure. The red mud filtrate flows into the external environment not only through the dam body, but also through the soil under the red mud stacking. The direction of

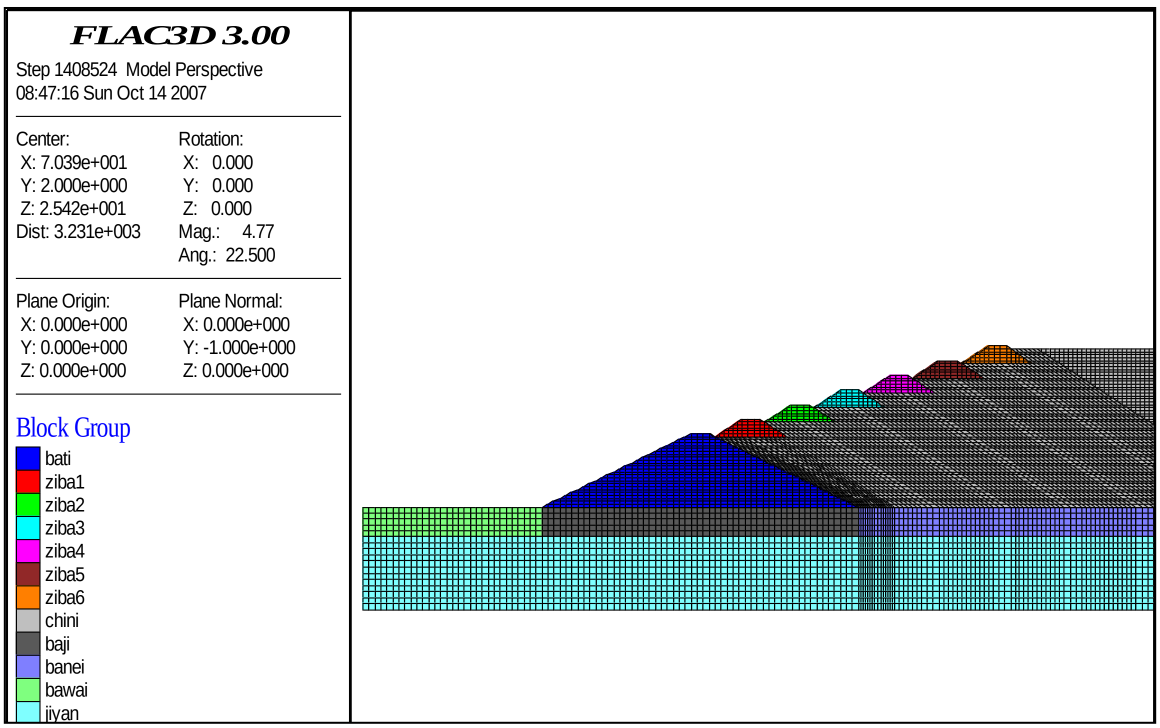

Fig. (1). The seepage grid model of the red mud stacking.

Table 1. Rock and soil physical and mechanical parameters of model.

The type of rock soil	Gravity density (kN/m^3)	Saturated gravity den sity(kN/m^3)	Quick shear test cohesive force(KPa)	Quick shear test internal friction angle φ (°)	Permeability coefficient (m/s)
Clay layer 1	18	18.2	60.4	13.6	3.65×10^{-5}
Clay layer 2	17.8	18.0	28.1	6	3.65×10^{-5}
Limestone layer1	--	26.6	5000	1.37*	2.43×10^{-4}
Limestone layer2	--	26.7	5910	1.46*	2.43×10^{-4}
Red mud	16.9	18.0	60	10	1.0×10^{-5}

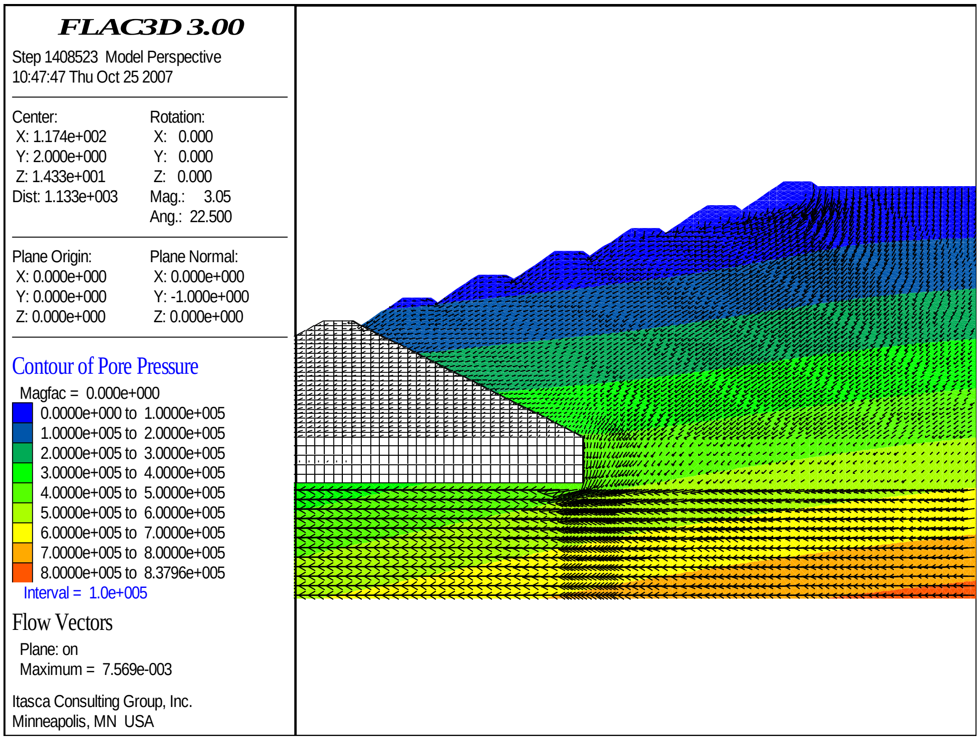

Fig. (2). Pore water pressure profile without anti-seepage measures.

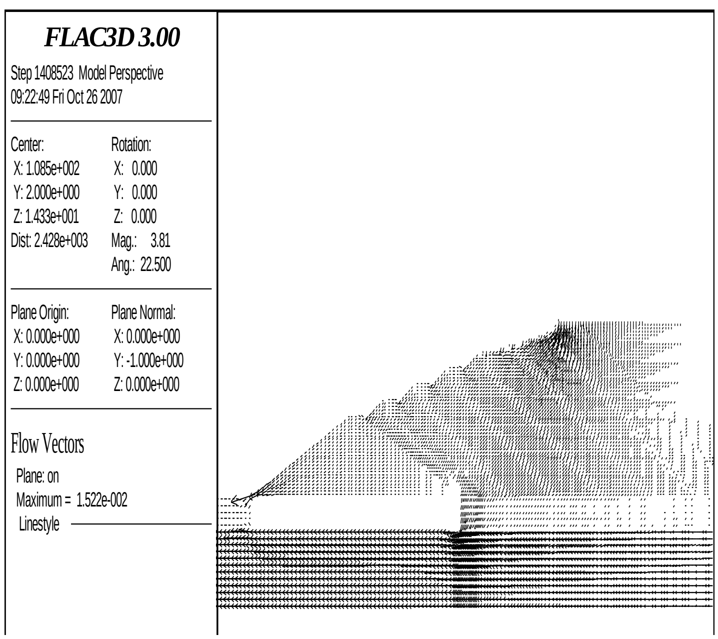

Fig. (3). Red mud filtrate seepage flow without anti-seepage measures.

seepage Filtrate is mainly under the soil of red mud stacking because of different permeability of the dam body and the soil in the red mud stacking. A small amount of filtrate flow into the middle-under parts of the dam body of the red mud stacking [5]. The red mud filtrate has the better hydraulic connection with the surrounding environment. Red mud filtrate will flow into the underground soil layer, the underlying strata and the surrounding environment though the body of dam and underlying formation which will directly affect the surface water of surrounding and groundwater.

4.2. The Flow Characteristic of the Red Mud Stacking with Part of Anti-Seepage Measures

In this situation, the characteristic of seepage that anti-seepage under the red mud stacking is simulated and without anti-seepage on the dam body is simulated. In process of the simulation , the red mud filtrate will not be allowed to flow into the lower soil layer. According to the mechanical balance and the principle of fluid balance, the simulation results that distribution of pore water pressure and direction of the fluid flow are shown in Figs. (**4**, **5**).

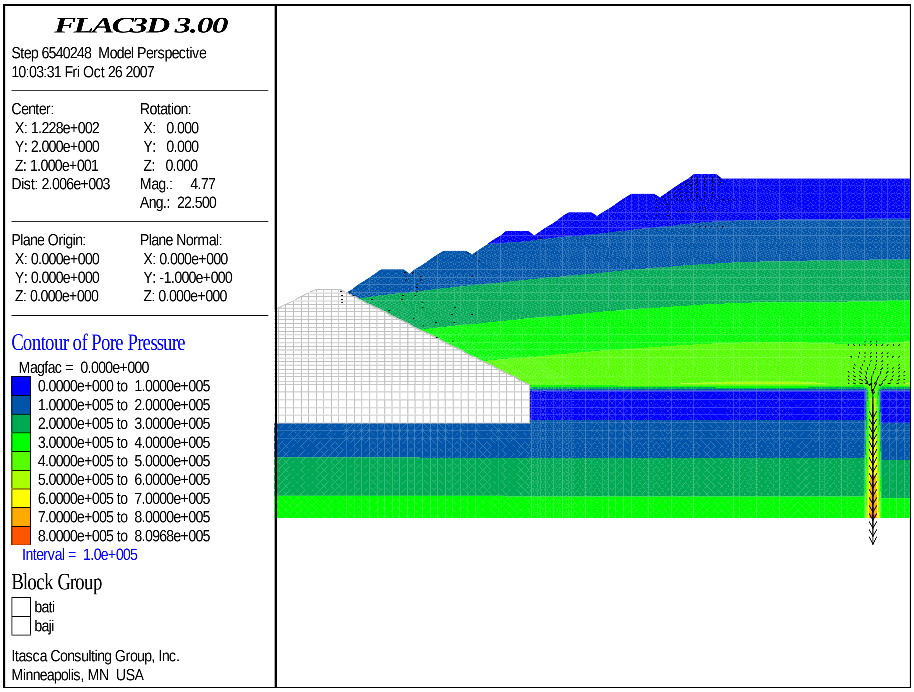

Fig. (4). Pore water pressure profile with part of anti-seepage measures.

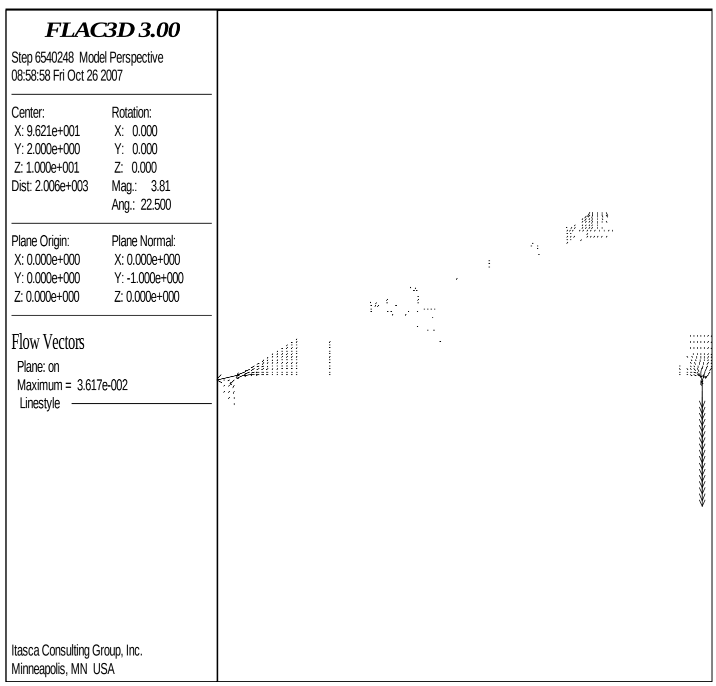

Fig. (5). Red mud filtrate seepage flow with part of anti-seepage measures.

From the figure, the zero potential surface of pore water pressure of red mud filtrate is also on the top of the red mud body and at the top of the dam body with part of anti-seepage measure. There is pore water seeping in the body of the sub dam. Change of pore water pressure is the precursor of change of soil intensity. The red mud filtrate flows into the external environment through the body of dam, because of taking anti-seepage measures at the bottom of Red mud storage. Red mud filtrate will flow into the surrounding environment though the body of dam which will directly affect the surface water of surrounding and groundwater.

4.3. The Flow Characteristic of the Red Mud Stacking with Closed Anti-Seepage Measure

When taking closed anti-seepage measures, not also the characteristic of seepage that anti-seepage under the red mud stacking is simulated , but also anti-seepage on the dam body is simulated. According to the different permeability coefficient under the conditions of different anti-seepage measures, the characteristics of seepage under two different effect of anti-seepage are analyzed. According to two different kinds of anti-seepage effect, two kinds of composite seepage coefficient of impermeable layer is set to 1×10^{-10} m/s, 1×10^{-11} m/s. The simulation results that distribution of pore water pressure and direction of the fluid flow are shown in Figs (**6**-**9**).

The results show that exchange degree of red mud filtrate with surrounding groundwater environment is related to the comprehensive anti-seepage effect, when taking closed anti-seepage measures. As shown in Fig. (**7**), when comprehensive anti-seepage effect is low, there is still a small part of filtrate flow directly into the bedrock through the soil under the red mud stacking except for through drainage well. As shown in Fig. (**9**), when comprehensive anti-seepage effect is good, seepage flow through the soil under the red mud stacking will decrease. The groundwater outside of red mud stacking do not exchange with red mud

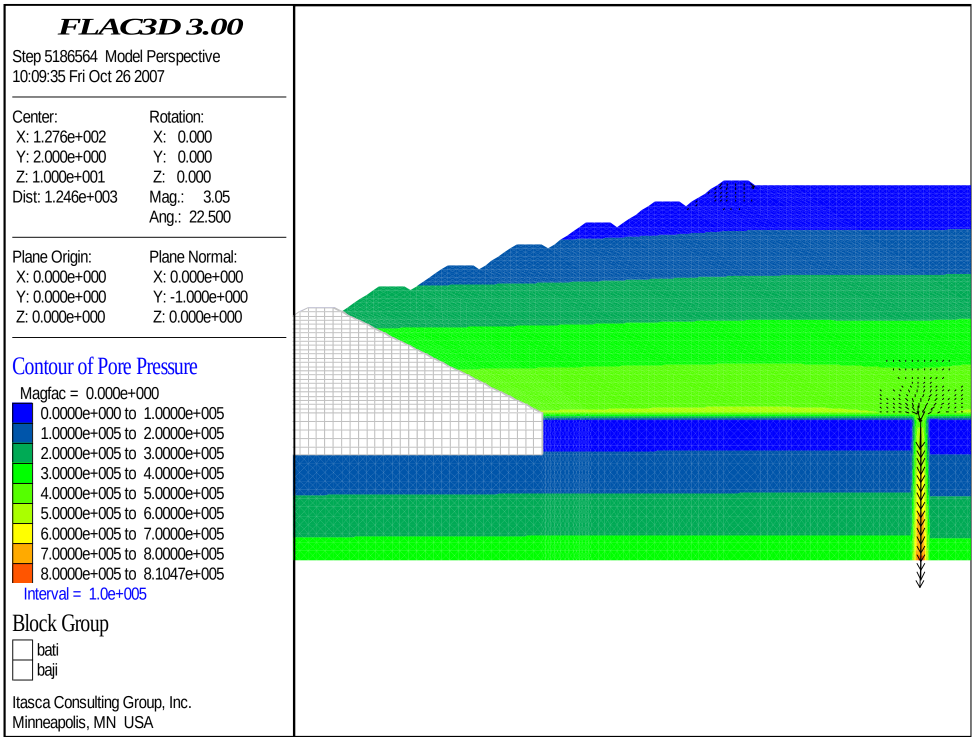

Fig. (6). Pore water pressure profile with closed anti-seepage measures (1).

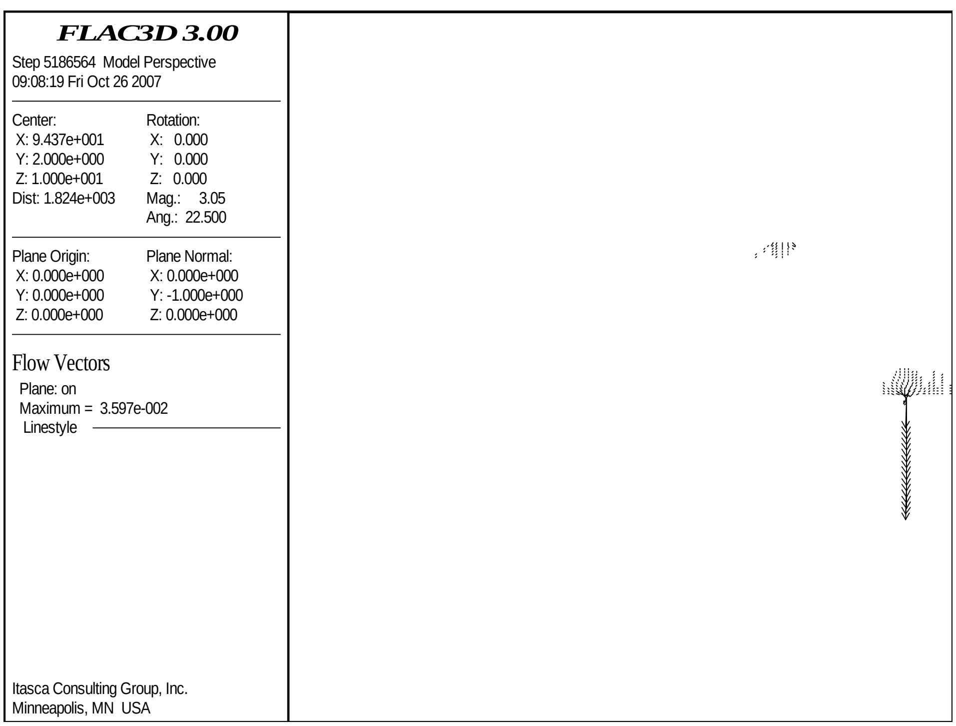

Fig. (7). Red mud filtrate seepage flow with closed anti-seepage measures (1).

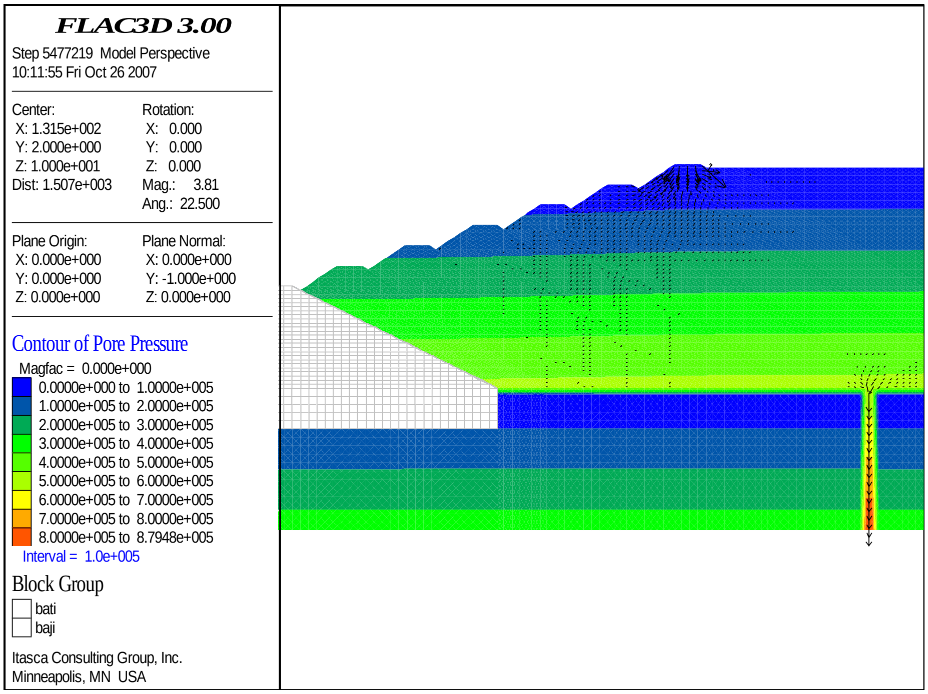

Fig. (8). Pore water pressure profile with closed anti-seepage measures (2).

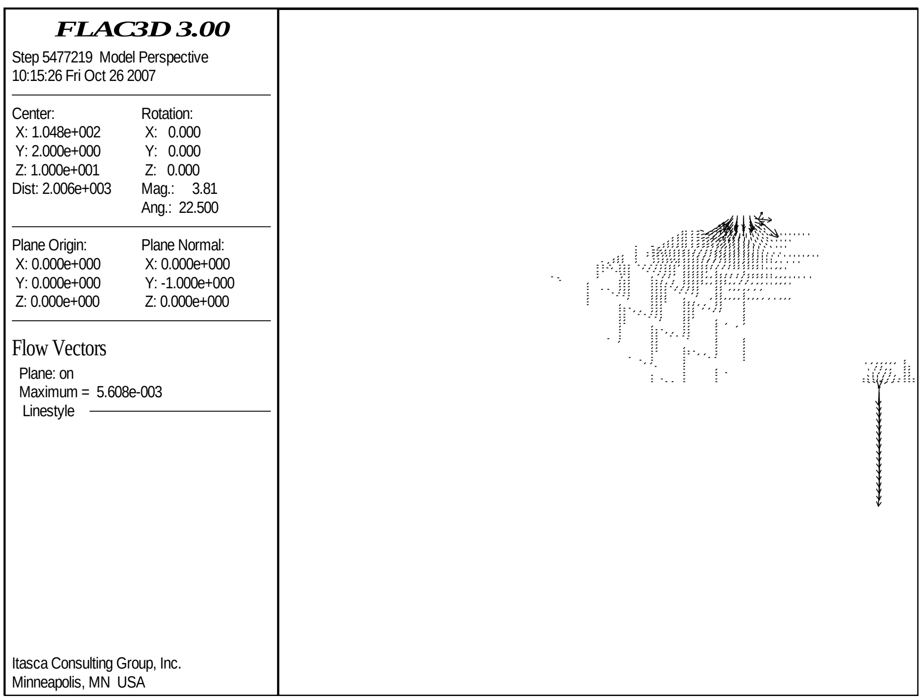

Fig. (9). Red mud filtrate seepage flow with closed anti-seepage measures (2).

filtrate. Under the circumstances, it will not cause pollution to the environment that only a small red mud filtrate seeps into the surrounding environment.

When the distribution of the stress in the dam body is studied, it will consider both the action of pore water pressure and the action of flow drive force. From the figure of pore water pressure (Fig. (**6**), Fig (**8**)), the dam of red mud stacking will bear a certain excess pore water pressure. The penetrating liquid has a tendency to flow outward at all levels of sub dams and at junction between the sub dams and the main dam. The inside of all levels of sub dams have also fluid flow. In order to increase the dam body stability and prevent the penetration of the red mud liquid in the sub dams, the upstream side of the level of sub dams should be taken anti-seepage and drainage measures .

Through the study of the characteristic of seepage,, when taking closed anti-seepage measures, the zero potential surface of pore water pressure of red mud filtrate is also at the top of the red mud body and at the top of the outside of the dam body with closed anti-seepage measures. In this situation, the direction of motion of red mud filtrate is vertical, the red mud filtrate is discharged from emissions well. According to the above conditions, impermeable layer can ensure the safety, environmental protection and the economic effect [6, 7].

4.4. Calculation of Seepage Flow

In the process of seepage calculation under different anti-seepage conditions, calculating plane is set to horizontal ground. The thickness of impermeable layer is taken as 1m, which will be as a whole. The pore water pressure of upper impermeable layer is set to 53m, of lower part of impermeable layer (at the top of the layer of red mud stacking) is set to 0m. Based on the Darcy's law of the infiltration of ground-water, this paper uses the theoretical seepage formula is as follow:

hydraulic slope (i) $i = \Delta h / \sum H_i$ (1)

Seepage flow (Q) $Q = k \bullet i \bullet A$ [8] (2)

daily seepage flow(W) $W = Q \bullet T$ (3)

every symbol is expressed as follows:

i--hydraulic slope, the head loss of per unit length;

Q-- seepage flow, the head loss of per unit length;

k--- coefficient of permeability; W--- the daily seepage flow; T--- time (h)

According to the above formula, when the permeability coefficient of impermeable layer is different, red mud seepage quantity within per unit area of of red mud stacking shown in Table **2**.

The results of calculation show that when the permeability coefficient of impermeable layer is 1 x 10^{-10} m/s, at the bottom of the reservoir area, per unit area of quantity of flow is 0.458 L every day. The above calculation seepage flow is beyond the ability of the environment to absorb pollutants. When the permeability coefficient of impermeable layer is 1 x 10^{-11}m/s, at the bottom of the reservoir area, per unit area of quantity of flow is only 0.0458 L every day. The seepage flow is far below the tolerable minimum. In order to reach the technical requirements of anti-seepage, all the bottom of red mud stacking and the surface of dams should be covered with anti-seepage structure layer. And the materials of anti-seepage should be choose double composite geomembrane. compound geomembrane is a kind of seepage material which is rapidly developed recent years. As discussed above, impermeable layer including all levels of the dam body and the bottom of red mud stacking should be strictly carried out design, construction and supervision by relevant standards of the country.

CONCLUSION

1) As the red-mud storage yard has a number of seepage points, seepage from the tailing liquid will have a strong impact on the environment. Based on survey data, reasonable parameters and boundary conditions were selected to establish Moore-Coulomb and fluid model under the plane strain conditions, and seepage characteristics of the tailing dam was simulated with software.
2) Numerical simulation was conducted based on different seepage-proofing design conditions of the tailing dam, and pore water pressure distribution as well as seepage path of the tailing liquid was obtained. The result showed that, on conditions that no seepage-proofing or partial seepage-proofing measures were taken, obviously the red mud would go through the dam body and seep into the shallow ground and then into the groundwater system, causing pollution to surrounding environment. While fully-enclosed seepage-proofing measures were taken, red-mud filtrate mainly flowed out through the seepage well, and the seepage into the surrounding environment was mild, basically having no influence on the environment.
3) For fully-enclosed seepage-proofing simulation, the anti-seepage body should be based on different seepage coefficients. On conditions of small seepage coefficients, if the seepage discharge is within the allowed values for red-mud filtrate seepage of the dam after calculation, relevant impermeable layer can be applied and strictly constructed according to corresponding specifications.
4) For tailing dam seepage, $FLAC^{3D}$ software performs relatively well in simulating pore water pressure and seepage liquid distribution, and performs even better in simulating seepage of tailing dam with complicated hydrogeological conditions.

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Table 2. Seepage flow of different comprehensive anti-seepage.

The permeability coefficient of impermeable layer (m/s)	Hydraulic slope	Seepage time (s)	Seepage area (m^2)	Seepage flow per unit area W (m^3/d)
1×10^{-10}	53	86400	1	4.5793×10^{-4}
1×10^{-11}				4.5793×10^{-5}

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] L. Yuan, W. Bing and Z. Quan-xiu, "Groundwater tracer experiments on leakage characteristics of a tailings pond, *Bulletin of Soil and Water Conservation*, vol. 32, no. 2, pp. 96-99, 2012.

[2] Y. feng-xia and H. De-yong, "Application of FLAC software in the stability analysis of the tailings", *Journal of Neijiang Normal University*, vol. 23, no. 8, pp. 66-68, 2008.

[3] J. Jiaxu, L. Li and C. Tianyu. "The seepage calculation and the drainage design of tailings dam", *METAL MINE*, vol. 6, pp. 155-157, 2013.

[4] L. Ruili, S. Dongpo and W. Wei, "Influence on seepage field with drain seepage system during filling period in the tailing reservoir", *Journal of Basic Science and Engineering*, vol. 21, no. 3, pp. 532-542, 2013.

[5] L. Houxiang, S. Jun and C. Kejun, "Steady seepage analysis of2d consolidation of tailing dams", *Mining and Metallurgical Engineering*, vol. 22, no. 4, pp. 8-11, 2002.

[6] L. Houxiang, L. Ning, L. Xue, G. Jinlin and F. Fenghua, "Unsteady seepage analysis of tailings dams considering coupling of stress and seepage fields," *Chinese Journal of Rock Mechanics and Engineering*, vol. 23, no. 17, pp. 2870-2875, 2004.

[7] Y. Si-ying, S. Long-tan and L. Shi-yi, "Stability analysis of tailings dam based on finite element limit equilibrium method", *Rock and Soil Mechanics*, vol. 34, no. 4, pp. 1185-1190, 2013.

[8] G. Dazhao, *Soil Mechanics and Foundation Engineering*, China Building Industry Press, Beijing, 1999.

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