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The Stability Analysis of Heituwan Tailings Pond Based on Strength Reduction Method

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Abstract. To analyze the stability of Heituwan tailings pond after vacuum well point dewatering treatment, a unit thickness numerical 3D model was built based on field survey data and physical mechanical properties tests; and the model was analyzed by FEM numerical software according to strength reduction method. The properties of stress and strain, the plastic region, and the deformation properties are acquired by numerical stimulation, and the simulation result was compared withe the in-situ monitoring data. The results show that the safety factor does not meet the requirements of the standard; and most of the landfill made of manganese tailing has developed into plastic status; the deformation is more obvious where the tailing store is higher and closer to roller compacted rockfill dam; the manganese tailing landfill near the roller compacted rockfill dam should be grouted by cement to meet the requirements of continued use.

Keywords. Tailings pond, stability, Numerical analysis

1. Introduction

Tailings pond is typically used to store the mining residue, and security problems was usually happened in tailings pond because of its large capacity, the complexity and toxicity of its contents [1-2], therefore, the safety of the construction and operation of tailings pond is always a hot spot for scholars in engineering field. Previous study show that the stability of tailings pond is concerned with the height of the tailings pond, the construction method of tailings dam and the physical mechanical properties of the embankment material of the tailings pond, etc [3-5]. There are several methods usually used in the analysis of the stability of tailings pond, such as finite element method, limit equilibrium method and Bishop method, etc [6-8]. To improve the efficiency of the analysis, FEM softwares are usually used in the analysis of the stability of tailings pond [9-11]. Some of them can be used in the analysis of the critical slip surface of slope, the safety factor of slope, the distribution of the plastic zone in slope and the characteristic of the deformation of slope, etc [12-13]. To applied FEM in the analysis of the stability of the slope, strength reduction method is the key point, the physical parameters of the soil or rock would be reduced through the simulation process, which is in agreement with the process of the failure of the slope, and strength reduction

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method is always used in the analysis of the stability of slope. So that it is possible to apply strength reduction method and FEM software in the analysis of the stability of tailings pond. To make the soil reach the limit equilibrium state and gain the shear strength of soil when it failure, as it shown in equation 1, the programme would reduce the physical parameters of the soil through control the field variables.

$$c_{\mathrm{m}}=c/F_{\mathrm{r}} \quad (1)$$

$$\varphi_{\mathrm{m}} = 2(\mathrm{a+b})Lf \quad (2)$$

The relationship between the physical parameters before and after the application of the strength reduction method is shown in equation 1 and equation 2. c_m and φ_m respectively means the cohesive force and the internal friction angle of the soil when it reach the limit equilibrium state, F_r means strength reduction coefficient, which is equal to factor of safety numerically. c means cohesive force. In this paper, strength reduction method and a FEM numerical analysis software were applied in the evaluation of the stability and operation status of the Heituwan Tailings Pond, to verified the analysis result, in-situ monitoring plan was conducted, these measurements provide an important reference to the operation and treatment of the tailings pond.

2. Engineering Profile

The design capacity of Heituwan Tailings Pond is 152.10e4 m^3, and the utilizable capacity is 142.24e4 m^3. The Tailings Pond was designed to service the Electrolytic Manganese Plant for 7.71 years. The initial dike was designed as roller compacted rockfill dam with a height of 30m, an axis length of 95m, the width of the top of the initial dike is 4m. The inclination of both upstream and downstream is 1:2. The tailings would be finally raised to a level of 210.0m, and the tailings dam would be raised to a height of 55.0m. The present height of the tailings behind the dam is 42m, and the level of it has been raised to 197m, the inclination of the stored tailings that over the dam is 1:4. According to the field investigation conducted before, the potential risks of the tailings pond are as following: first, the geotechnical condition of this area is not stable enough as there are active fault zone and other adverse geotechnical conditions under this area; second, the landfill consist of tailings have a poor stability and bearing capacity; third, during the raising process of the tailings, it was found that those tailings raised near the compacted dam had partially shifted and uplifted; fourth, part of the manganese tailings was not raised in the correct method based on the adopted code requirement, which had induced local stability failure of the tailings landfill.

3. Numerical Simulation

3.1. Numerical Modelling

As the dam is a long straight section, the unit thickness model was chosen to applied in the simulation. As it shown in figure 1, the body of the tailings near the tailings dam and the body of the tailings dam was respectively simplified to an irregular pentagon and an isosceles trapezoid according to the geological exploration report and the field survey. Because the whole tailings pond lied on the stable rock, the foundation of the dam was assumed as rigid and the rock layer was not included in the analysis, the displacement of the bottom of the model was strictly restrained, and the friction coefficient between the tailings and the surface of the tailings dam was assumed as 0.1. oth the materials of tailings and rockfill was simplified as isotropic and continuous materials.The physical parameters of the material of the model is determined from laboratory test. And the physical parameters of the materials was shown in table 1.

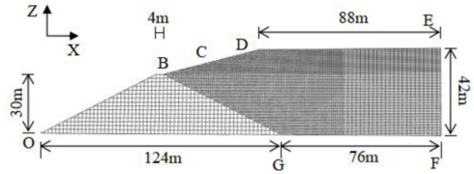

Figure 1. Numerical model of Heituwan tailings pond.

Table 1. Physical parameters of soil layers.

Soil type	Bulk density (kN/m^3)	Elasticity modulus (MPa)	Poisson's ratio	Internal friction angle(°)	Cohesive force (kPa)
Tailings dam	2.45	30.00	0.25	---	---
Tailings	1.91	2.34	0.35	11.8	5.343

3.2. Numerical Simulation Result Analysis

The shear strength parameters have been reduced by strength reduction method as it shown in table 2. Based on the simulation result, the critical dangerous point of the tailings pond is 109m away from 2.5the external slope toe of the tailings dam in horizontal and 41m away from the toe vertically, the total deformation of this point is 6.82mm. And safety factor of the Heituwan tailings pond is 1.15, which is less than 1.30 and not met the requirement of the adopted code(GB 50863-2013). And it means that the stability of the tailings pond is poor and the tailings pond can not operate safely.

Table 2. Shear strength parameters of tailings after strength reduction.

Strength reduction coefficient	Cohesive force(kPa)	Internal friction Angle(°)	Displacement(mm)
1.00	5.343	11.800	0.00
1.05	5.089	11.238	1.25
1.10	4.857	10.727	2.49
1.15	4.646	10.261	6.82
1.20	4.452	9.833	28.46
1.25	4.274	9.440	50.11
1.30	4.110	9.077	71.75

3.3. Stress and Strain Analysis

In the initial stage, the vertical stress of the tailings increased with the increase of depth, the horizontal stress increased with the increase of the distance from the interface B-G, the biggest vertical stress and horizontal stress is 782.3kPa and 773.9kPa respectively. The vertical stress of the tailings dam increase with the increase of depth, the horizontal stress increased with the decrease of the distance from the mid point of the interface B-G, the biggest stress in vertical direction and horizontal direction is 773.9kPa and 212.5kPa respectively.

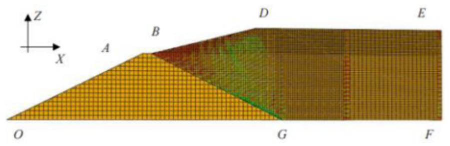

Figure 2. Illustration of distribution of strain in vertical direction.

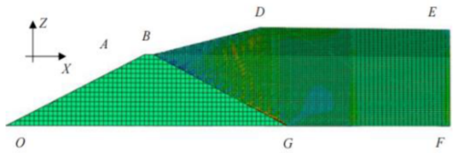

Figure 3. Illustration of distribution of strain in horizontal direction.

Figure 2 and figure 3 depict the variation of the vertical strain and horizontal strain of the tailings pond respectively. The tailings landfill near the roller compacted rockfill dam had a larger strain in value, and the range of horizontal strain is larger than the range of vertical strain. On the interface B-G, take the middle point of the interface as a divide, the strain of the tailings in the upper direction along with the interface and the strain of the tailings in the lower direction was on the contrary. The tailings of the middle-lower part have a larger strain, the vertical strain of these tailings is tensile stain, the horizontal strain is compressive strain. The tailings of the middle-upper part have tensile strain in vertical direction and compressive strain in horizontal direction.

3.3.1. Plastic Zone and Deformation Analysis

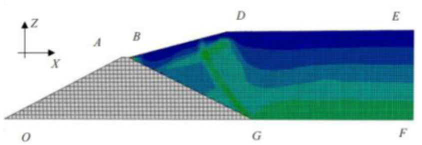

Figure 4. Illustration of the plastic deformation of the tailings pond.

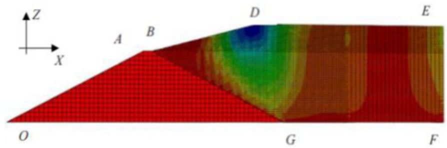

Figure 5. Illustration of settlement of Heituwan tailings pond.

As it shown in figure 4, most of the tailings have remarkable plastic deformation, and the plastic deformation is more and more obvious with the increase of the depth and the decrease of the distance from the interface B-G. The point B, the highest point of the interface B-G, have the largest plastic deformation, the reason is that the friction coefficient between the tailings dam and the tailings is very small, and the tailings would slide along with the interface in deeper direction, when the tailings slid to the toe of the dam, with the accumulation of these tailings, the tailings at the toe would be squeezed to moved in horizontal direction, the displacement of these tailings would influence the tailings above.

As it shown in figure 5, there are 2 settlement area in the tailings landfill, the settlement area D with the point D as center and a radius of 34.2m, this area grew as an irregular circle and had extended to the interface E-G; the settlement area E with the point E as center and extended to the deeper area as a elliptical. The point have largest settlement is 109m away from point O horizontally and 41m away from point O vertically, and the settlement of this point is 5.67mm.As it shown in figure 6, there are

4 horizontal area in the tailings landfill, the horizontal deformation area B with the point B as center and have a radius of 21.2m; the horizontal deformation area D with the point D as center, which had connected with area B; the area G which had a center point on the interface and 12.9m away from point G and had a radius of 11m;and the area F with a center point above point F. The point have largest horizontal deformation was in the area G and have a horizontal deformation of 4.68mm.

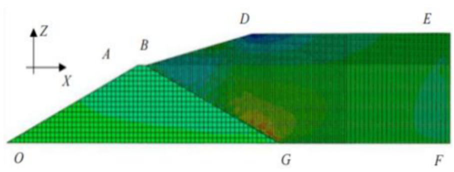

Figure 6. Illustration of horizontal deformation of Heituwan tailings pond.

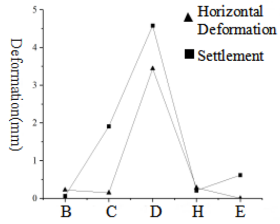

Figure 7. Settlement and horizontal deformation of the representative points.

For analysis the deformation of the surface of the tailings landfill, The settlement and horizontal deformation of point B, point C which is the mid point between point B and point D, point D and point H which is the mid point between point D and point E was extracted as representative point and shown in figure 7. Point D had both the largest settlement and largest horizontal deformation, and the deformation decreased with the increase of the distance away from point D.

4. Field Monitoring

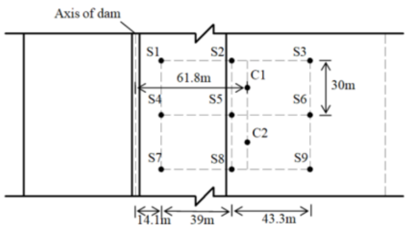

Figure 8. Layout of the monitoring point.

To verified the numerical analysis result, a field monitoring scheme was conducted on the Heituwan tailings pond after the tailings pond was treated with Vacuum well point dewatering method as it shown in figure 8. There are 9 subsidence monitoring point numbered with S1 to S1 and 2 horizontal monitoring point numbered with C1 to C2 set on the tailings pond. Figure 9 shown the data of the subsidence monitoring and horizontal deformation monitoring during Nov. 14, 2019 to Dec. 31, 2019. The subsidence of the points 53.1m away from the axis of the tailings dam which were very close to the point D in the model were bigger than others points. Compared the horizontal deformation in different depth, the order of the value size of different depth is 0m>30m>20m>10m>40m.

(a)Variation of vertical deformation with time. (b)Variation of horizontal deformation with time.

Figure 9. Monitoring result.

(a) Difference in vertical deformation. (b) Difference in horizontal deformation.

Figure 10. Difference of deformation between numerical simulation and field monitoring.

As it shown in figure 10, compare the subsidence and horizontal deformation of numerical analysis result and monitoring result, it was found that the difference between the numerical simulation and field monitoring was small enough to meet the demand of engineering, and the horizontal deformation in monitoring result was slightly bigger than in the numerical simulation due to the difference of the tailings pond along the axis of the tailings dam was not considered in numerical simulation.

According to the numerical analysis and field monitoring result, it was clear that the stability of the tailings pond was poor, and the strain of the tailings landfill near the roller compacted rockfill dam was very big and the subsidence and horizontal deformation of the tailings slope above the tailings dam were obvious and it is likely to increase continuously with the operation of the tailings pond. To make sure the safety of the operation of the tailings pond, strengthen the tailings pond and improve its stability, the part of the tailings landfill near the roller compacted rockfill dam need to be strengthen. Based on engineering experience in similar projects and the analysis result mentioned above, grouting method was suggested because it would probably improve the shear strength of the tailings landfill and modify the deformation trend of the tailings landfill while it would not waste the land resources.

5. Conclusion

In this paper, based on strength reduction method, a unit thickness 3-dimension numerical model was established through ABAQUS to analyze the stress-strain distribution, plastic zone and deformation of the Heituwan tailings pond been treated with vacuum well point dewatering method, the conclusions are as following:

(1)The numerical analysis result shown that the factor of safety of the Heituwan tailings pond was 1.15 which was lower than 1.3, the safety factor required by the adopted code, and the Heituwan tailings pond need further maintenance.

(2) The deeper the depth is, the closer it is to the midpoint of the interface between the tailings dam and the tailings landfill, the greater the horizontal stress of the tailings dam, while the horizontal stress of the tailings landfill increased with the increase of the distance away from the tailings dam.

(3)The strain, subsidence and horizontal deformation of the tailings landfill that near the tailings dam were bigger than other area, thus, to strengthen the tailings pond, this part of tailings landfill need to be grouted with cement.

(4) The numerical analysis result is close to the field monitoring result, which means that it is appropriate to adopted strength reduction method and FEM numerical software in the analysis of the stability of the tailings pond.

Acknowledgments

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