Bulgarian Chemical Communications, Volume 47, Number 4 (pp. 1077 – 1083) 2015

Study of the influence of acidic tailings water with a large number of chemical substances on the granular medium and slope stability in the dump

Guangjin Wang[1,2]*, Xiangyun Kong[2], Chunhe Yang[1]

[1]*State Key Laboratory of Geomechanics and Geotechnical Engineering，Institute of Rock and Soil Mechanics, Chinese Academy of Sciences，Wuhan,430071, China*

[2]*Kunming University of Science and Technology, Kunming 650093, China*

Received April 5, 2015

The long-term soaking of the granular medium with acidic tailings water which contains a large number of chemical substances is an important factor that affects the structural composition of copper waste ore with copper compounds and the slope stability in the dump. Therefore, based on the project example that part of the granular material of the mine dump at the bottom is soaked by the acidic tailings water for a long time, in the present work indoor direct shear tests of the granular medium under long-term soaking were performed and the influence of long-term soaking on the particle breakage of granular medium and strength parameters was analyzed. The dump slope stability was studied at different water levels of the tailings pond and was compared to the indoor test results. The research results show that the breakage rate of the soaked samples is obviously higher than that of saturated and *on-situ* samples when the granular medium is soaked by the tailings water for a long time. The change in the value of the safety coefficient is small as the water level of the tailings pond is below 230 m. But the safety coefficient obviously decreases after the water level of the tailings pond is up to 230 m and it increases with the increase of the water level of the tailings pond. Moreover, the slope sliding surface moves down with the increase in the water level of the tailings pond.

Key words: acidic tailings water, copper and iron compounds, chemical reaction, slope stability

INTRODUCTION

The long-term soaking of the granular medium is an important factor that impacts the dump stability. However, in the process of experiment, the decrease in strength parameters mainly results from particle breakage. Based on a number of tests, the articles [1-3] point out that the particle breakage can change the particle size, gradation curve and density degree, resulting in changes of the physical and mechanical properties of the soil samples. Hall and Gordon [4-5] find that under a certain amount of stress, the breakage rate of sands with good grading is smaller than that of sands with poor grading. The articles [6-8] find that by the triaxial test the increment of the particle breakage leads to the reduction of the shear strength of the coarse aggregates, and the peak friction angle within the peak values is a power function of the particle breakage rate. Wei Song [9] points out through the triaxial test of wet particle breakage that the particle breakage caused by wetting increases with the increment of the confining pressure and the wet stress, and a linear relationship approximately presents between the wet- axis variation and the wet particle breakage. Therefore, the long-term soaking of tailings water can affect the breakage of the dump granules and then the granular strength parameters. In fact, the particle breakage test is of actual engineering significance in the dump and rockfill dam. In particular, when the bottom granular medium of the dump is soaked in the tailings water, the particle breakage is quite obvious because of the long-term soaking of the granular medium in the acidic tailings water which contains a lot of chemicals.

The XRD patterns of the original tailing sample and after leaching at pH=2, 4.5, and 7.0 are shown in Fig. 1. XRD data were collected in the angular range (10°−90°). The tailings mainly consist of quartz, despujolsite and muscovite-3T, with trace palygorskite O, pectolite and manganoan [10].

The previous studies were rarely related to the influences of the particle breakage in the long-term soaking of the tailings water on the shear strength. However, the large-scale direct shear test is one of the conventional indoor test methods for coarse grained soil because the large-scale direct apparatus is characterized by a large specimen size used in it that can retain the original grading of the soil samples to a maximum extent and weaken the size effect. As the direct shear test is easy to operate and applicable in a wide range, it is the most widely used method [11] that is economical and practical for small and medium-size engineering projects. Therefore, in our work, the modified large-scale strain-controlled direct dual-purpose shear apparatus of indoor and field use, developed jointly by Wuhan Institute of Rock and Soil Mechanics,

* To whom all correspondence should be sent:
E-mail: wangguangjin2005@126.com

Chinese Academy of Sciences and Hongkong University, was used to test the particle breakage of the dump granules and its influences on the strength parameters. On the basis of the experimental results, the slope stability of the mine dump was studied by means of FLAC software.

DIRECT SHEAR TEST

Test equipment

The dual-purpose direct shear apparatus used in this test is of assembled structure, and mainly composed of an overall removable outer frame, horizontal loading system, vertical loading system, a shear box, etc. The clearance dimension of the shear box is: L×W×H = 500 m×500 m×410 mm. The lower shear box is connected with the overall framework, and the largest slit width between the upper shearing box and the lower one is 10 mm. Since the lower shear box is fixed in the shearing process of the direct shear apparatus, the upper shear box can only be moved in the horizontal plane and then the shear slits do not change due to the dilatation of the specimens. The deformation of the specimens by the above dual-purpose direct shear apparatus is more uniform than that by using the conventional one. Compared with the stress-controlled field-use direct shear apparatus, this device can show the whole process of rock mass deformation, and the maximum shear displacement can be up to 140 mm.

Test method and test grading

A large number of experimental studies performed by Yangtze River Scientific Research Institute [12] has shown that the sample size effect can be almost eliminated only when the D/dmax is 4-6mm (D is the size of the shear box and dmax is the largest tested particle diameter). According to the designed size of the above direct shear apparatus, the maximum particle diameter of the samples is selected to be 60 mm. The tested grain size range groups are shown in Table 1.

Table 1. Test grading of coarse grained soil.

Range of grain size(mm)	40-60	20-40	10-20	5-10	2-5
Percent (%)	22.5	14.5	9.5	7.5	10.0
Range of grain size(mm)	1-2	0.5-1	0.25-0.5	0.074-0.25	<0.074
Percent (%)	6.0	5.1	6.9	12.0	6.0

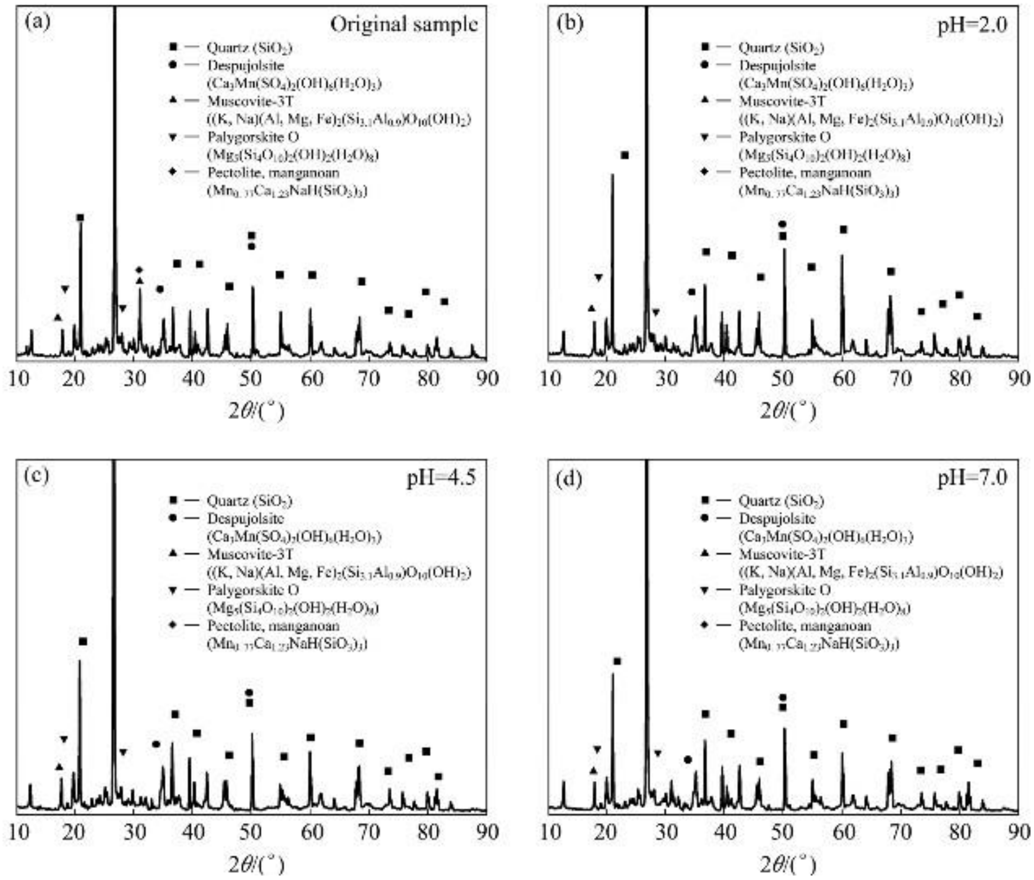


Fig. 1. XRD patterns of tailings samples before (a) and after leaching at pH 2 (b) [10].

In order to study the effect of the tailings water on the particle breakage of the coarse grained soil, the *on-situ* samples (with water content of 4%), saturated samples and soaked samples with a dry density of 1.90 g/cm^3 were selected for each group's tests under different vertical pressures (0.05, 0.1, 0.2, 0.4, 0.7, 1.0, 1.3MPa, respectively). The granular samples soaked in the tailings water and the pictures of their direct shear tests are shown in Figures 2(a) and 2(b).

(a)

(b)

Fig. 2. (a) Samples soaked in the tailings water and (b) Direct shear test of the soaked samples.

The soaked samples refer to the soil samples that were put into the water containers after weight proportioning and air drying and maintained to be in fully-saturated state without external forces and sealed for a month. Before the test, the soil samples were taken out from the site, dried at ambient temperature, separated by sieving, weighed, then added water as required, mixed evenly (saturated samples needed to add water to maintain the full saturation state), and loaded in 3 tiers for compaction. Then artificial consolidation was conducted for the samples and the consolidation stability was controlled to be 0.0025 mm/min. After the deformation was stable, the direct shear test was operated at a horizontal shear rate of 1.4 mm/min and it was stopped when the shear strain was 20%. After finishing the test, the soil samples were dried again at ambient temperature and then screened. The pH value of the tailing water is 2.1~2.5 and its physicochemical composition is shown in Table 2.

Table 2. Physical and chemical composition of the tailing water

Item	COD	Fe	Ca	Zn	Mn	Al
Concentration (mg/L)	19.50	0.82	498.80	0.18	4.70	0.42
Item	Mg	Cu	Na	K	Cd	As
Concentration (mg/L)	67.30	≤0.02	54.80	23.40	≤0.02	≤0.02

The main ingredients of mine waste rock which can participate in chemical reactions were chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), oxidized copper ore ($CuCO_3 \cdot Cu(OH)_2$) and pyrite (FeS_2). The chemical reaction is as follows:

① Chalcopyrite

$$2CuFeS_2+H_2SO_4+O_2 \rightarrow 2CuSO_4+Fe_2(SO_4)_3+H_2O$$

$$CuFeS_2+2Fe_2(SO_4)_3 \rightarrow CuSO_4+5FeSO_4+2S$$

$$2FeSO_4+H_2SO_4+O_2 \rightarrow Fe_2(SO_4)_3+H_2O$$

② Chalcocite

$$Cu_2S+Fe_2(SO_4)_3 \rightarrow CuS+CuSO_4+2FeSO_4$$

$$CuS+Fe_2(SO_4)_3 \rightarrow S+CuSO_4+2FeSO_4$$

③ Oxidized copper ore

$$2CuCO_3 \cdot Cu(OH)_2+H_2SO_4 \rightarrow 3CuSO_4+4H_2O+2CO_2$$

$$CuO+H_2SO_4 \rightarrow CuSO_4+H_2O$$

$$Cu_2O+H_2SO_4 \rightarrow CuSO_4+Cu+H_2O$$

④ Pyrite

$$2FeS_2+3O_2+2H_2O \rightarrow 2FeSO_4+2H_2SO_4$$

$$4FeSO_4+H_2SO_4+O_2 \rightarrow 2Fe_2(SO_4)_3+2H_2O$$

⑤ Other reactions

$$Fe_2O_3+3H_2SO_4 \rightarrow Fe_2(SO_4)_3+3H_2O$$

$$Al_2O_3+3H_2SO_4 \rightarrow Al_2(SO_4)_3+3H_2O$$

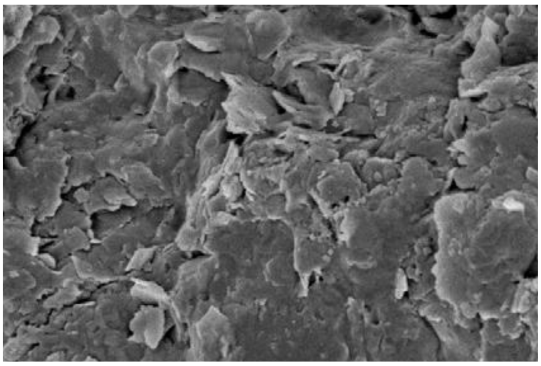
ANALYSIS OF TEST RESULTS

According to Hardin's definition, the relative particle breakage rate Br is the area Bt between the grading curve before and after the test divided by the initial crushing potential Bp, i.e., Br=Bt/Bp. As the relative particle breakage rate can reflect the variation of the various particle sizes of the sample before and after the test, the direct shear tests were conducted in our work for the *on-situ* samples (with water content of 4%), saturated samples and soaked samples to obtain the relative particle breaking rate Br as shown in Table 3.

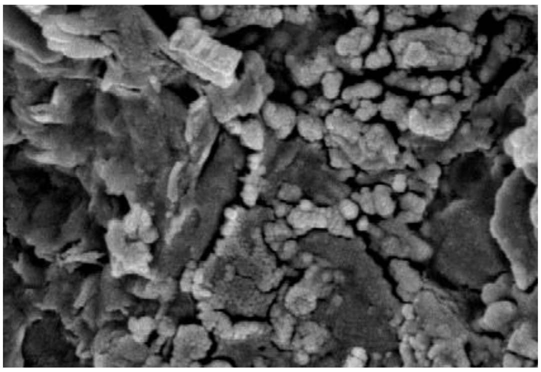
From Table 3, it can be seen that the breakage rate Br of the saturated samples increases but not clearly, compared with the *on-situ* samples. On the contrary, that of the coarse-grained samples soaked in the tailings water for a month increases obviously and is much higher than that of *the on-situ* samples and the saturated ones. In the long run, tailings water has a striking softening effect on the coarse-grained soil while not in the short-term water flow. The typical SEM images of the granular medium before and after soaking are shown in Figure 3.

Table 3. Relationship between σ and Br at different water contents

Sample	Breakage rate (Br)at different vertical pressures(MPa)						
	0.05	0.1	0.2	0.4	0.7	1.0	1.3
Soaked sample (%)	1.34	2.04	4.56	7.57	9.14	11.19	11.91
Saturated sample (%)	0.34	0.46	0.788	1.87	5.15	6.60	7.23
On-situ sample (%)	0.24	0.23	0.77	1.50	4.33	5.29	6.56



(a) SEM images before soaking



(b) SEM images after soaking

Fig. 3. Typical SEM images of the granular medium before and after soaking.

ANALYSIS OF DUMP SLOPE STABILITY

Slope model

A mine dump is very close to the tailings pond and its bottom granular medium is under the water surface of the tailings pond. See Figure 4 for the site photos. Landslides of the dump may affect the safety of the tailings dam of the mine. Therefore, the dump slope stability was analyzed by means of the ANSYS and FLAC software based on the results of the indoor direct shear test for the dump granular medium.

Fig. 4. *On-site* dump granular in the tailings pond.

According to the original and current topographic maps of the dump, the three-dimensional geological model was created and shown in Figure 5, which was divided into 6 layers with 20 m each and 120 m in total.

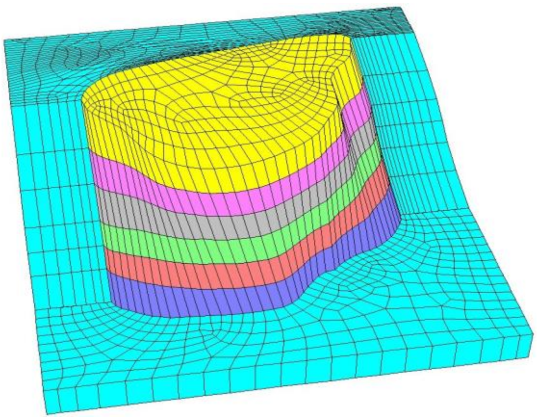


Fig. 5. Three-dimensional geological model of the dump.

Table 4. Material parameters of granular accumulation.

Sample	Density (kg.m^{-3})	Bulk modulus K (Gpa)	Shear modulus G (Gpa)	Cohesion C (Mpa)	Internal frictional angle φ(°)	Dilation angle ψ(°)	Tensile strength σ_t(Mpa)
Long-term soaked sample	1900	0.03	0.02	0.03	22.90	4.80	0.03
On-situ sample	1900	0.15	0.10	0.09	33.89	7.60	0.05
Rock	1900	13.600	9.800	0.40	46.00	14.00	2.15

Calculation parameters and schemes

The Mohr-Coulomb criterion was used for the calculation of the model. The top surface was set to be a free boundary, the bottom - a fixed restricted boundary and the four sides - roller bearing boundary. Under the initial conditions, only the dead weight was considered in the entire process of the calculation. The parameter values of the dump materials are shown in Table 4.

Based on the indoor experimental research of the long-term soaking of the dump granules in the mine tailings water, five schemes were selected to make the analysis of the dump stability, i.e., Scheme 1 for the dump granules which are not soaked in the tailings water (i.e., the water level of the tailings pond is <190m), Scheme 2 for the current water level of the tailings pond and the rest schemes for the water level of 230 m, 250 m and 270 m, respectively. See Table 5 for the specific calculation schemes.

Table 5. Calculation schemes.

Calculation scheme	1	2	3	4	5
Water level of tailings pond (m)	<190	210	230	250	270

RESULTS ANALYSIS

Table 6 shows the computed results of the slope safety coefficient of the dump in the different schemes, from which the slope safety coefficient follows the order: Scheme 1 > Scheme 2 > Scheme 3 > Scheme 4 > Scheme 5. The value of the safety coefficient changes little in Scheme 1 and Scheme 2 while it obviously decreases after the water level of the tailings pond increases up to 230 m. It is not obvious for the long-term soaking of the dump granular medium at the bottom of the dump to impact the safety coefficient of the dump slope because the slope sliding surface is still above the water level of the tailings pond when the water level of the tailings pond is 210 m. However, when the water level of the tailings pond is up to 230 m, the slope sliding surface has already been below the surface of the tailings pond partly and then the change value of the safety coefficient increases. In addition, with the increment of the water level of the tailings pond, the change value of safety coefficient continues to increase.

Figure 6 indicates the displacement vector cloud in Scheme 1 and Scheme 5, from which it can be seen that the slope sliding surface moves downward with the increment of the water level of the tailings pond and as a result the change value of slope safety coefficient also increases. The above analysis shows that long-term soaking of the dump granular medium is adverse to the stability of the dump slope. In particular when part of the slope sliding surface is under the water level of the tailings pond, the long-term soaking of the dump granular medium greatly affects the stability of the dump slope. Thus, separate tailings dam and dump should be built as far as possible.

Table 6. Calculation results of slope reliability.

Calculation scheme	1	2	3	4	5
Safety coefficient	1.26	1.24	1.19	1.10	0.98

CONCLUSION

Compared with the *on-situ* samples, the breakage rate Br of the saturated samples increases but not distinctly. On the contrary, that of the coarse-grained samples soaked in the tailings water for a month obviously increases and is much higher than that of the *on-situ* samples and the saturated ones. The tailings water has a striking softening effect on the coarse-grained soil in long term while it has not in short term. The safety coefficient of the slope calculated for the dump decreases with the increment of the water level of the tailings pond.

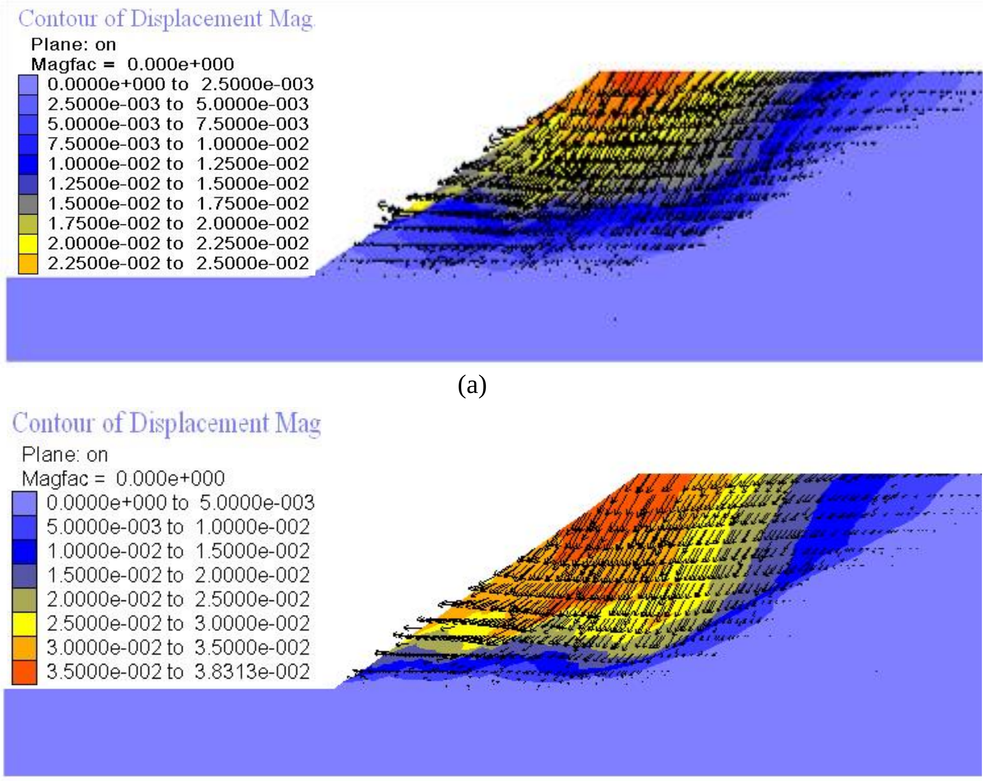


Fig. 6. (a) Displacement vector cloud of Scheme 1; (b) Displacement vector cloud of Scheme 5.

It changes little when the water level of the tailings pond is below 230 m; while it obviously decreases when the water level is above 230 m. The value of the change continues to increase with the increment of the water level of the tailings pond. Meantime, with the increment of the water level of the tailings pond, the slope sliding surface moves downward, resulting in increased change value of the slope safety coefficient of the dump. It is concluded that long-term soaking of the dump granular medium is unfavorable to the stability of the dump slope; in particular, it affects the stability of the dump slope significantly when part of the slope sliding surface is under the water level of the tailings pond.

Acknowledgments: *This research is Supported by Open Research Fund of State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, (Grant No. Z014012), Key project of national natural science funds (No.51234004), School-enterprise funds(No. KKZ4201221008), Yunnan Provincial Fund project (No. KKSY201221070), Yunnan Province Project Education Fund(No. KKJD201521003).*

REFERENCES

1. R J. Marsal, *Journal of the Soil Mechanics and Foundations Division*. **93**(SM2), 27 (1967).
2. L.Xiaoli, L.Hongyan, L.Zhonggang. *Disaster Advances*, **6** (S2) , 46 (2013).
3. Z. Qing, G. Yue, C. H. Ming, C. Jing, Y. ZhiHua, *Research Journal of Chemistry and Environment*, **16**(S2), 1 (2012).
4. E. B. Hall, B. B. Gordon, American Society for Testing and Materials, Philadelphia, Penn. Special Technical Publication STP-361, 1964, p. 315
5. W. Guangjin, K. Xiangyun, Y.Chunhe, R.Zhaoying. *Disaster Advances*, **6** (S4), 102 (2013).
6. L. Hanlong, Q. Hongyu, G. Yufeng, Y. D. Zhou, *Rock and Soil Mechanics*, **26**(4) ,562 (2005).
7. Wang Feiyue. *Research Journal of Chemistry and Environment*, 17(S1), 163 (2013).
8. Y. Gui, L. Kunlin, L. Yanchen. *Disaster Advances*, **6** (S1), 9 (2013).
9. W. Song , Z. Jungao, *Chinese Journal of Rock Mechanics and Engineering* , **25**(6), 1252 (2006).
10. Y. Guo, P. Huang, W. Zhang, X. Yuan, F. Fan, H. Wang, J. Liu, Z. Wang, *Transactions of Nonferrous Metals Society of China*, **23**, 3068 (2013).
11. W. Houzhen, W. Ren, H. Mingjian,et al. *Rock and Soil Mechanics*, **29**(1), 48 (2008).
12. Z. Xiaowen, G. Biwei, D. Hongshun, R. Xibao, *Chinese Journal of Geotechnical Engineering*, **27**(8), 876 (2005).

ИЗСЛЕДВАНЕ НА ВЪЗДЕЙСТВИЕТО НА КИСЕЛИННИТЕ ОСТАТЪЧНИ ВОДИ В ДЕПО ЗА ОТПАДЪЦИ, СЪДЪРЖАЩИ РАЗЛИЧНИ ХИМИЧЕСКИ ВЕЩЕСТВА ВЪРХУ ГРАНУЛИРАНА СРЕДА

Гуангджин Ванг[1,2] , Ксиангюн Конг[2] ,Чунхе Янг[1]

[1]*Държавна лаборатория по геомеханика и геотехническо инженерство,*
Институтпоскална и почвенамеханика, Китайска академия на науките, Ухан, Китай
[2]*Научно-технологичен университетв Кунминг, Китай*

Постъпила на 5 април, 2015 г.

(Резюме)

Продължителното промиване на гранулирана среда с киселинни отпадъчни води, съдържащи голям брой химически вещества е важен фактор, който влияе на структурата на отпадъци, съдържащи медни съединенияи на ъгъла на откоса на депото.В тази работа са направени изпитания в лабораторни условия върху срязващото напрежение в гранулирана среда при продължително промиване и върху разрушаването на твърдите частици и здравината на средата. Стабилността на насипа и ъгъла на откоса са изследввани при различни нива на водите в хвосто-хранилището. Изследването показва, че скоростта на разрушаване при продължително промиване очевидно е по-висока отколкото при реални проби от хранилището. Промяната на коефициента на сигурност е малка, когато нивото на водите е под 230 м. Този коефициент намалява значително, когато нивото на водите достига 230 м. и продължава да намалява, когато нивото на водите в хвосто-хранилището се покачва. Освен това наклона на насипа от твърди отпадъци започва да се свлича с повишаване на водното ниво в хвосто-хранилището.