ON THE POSSIBILITIES FOR IMPROVING DRAINAGE SYSTEMS AND SAFETY FACTOR WITH COMBINED MINE WASTE DUMP FACILITIES

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ABSTRACT. The information about the phreatic surface and moisture content of the depositing tailings from the processing plant has a crucial role in the design, construction, and maintenance of a tailings storage facility (TSF). This problem does not exclude the combined mine waste dump facilities (CMWDF). A CMWDF was designed with publicly available information for the integrated mine waste facility (IMWSF) that is under construction in the *Ada Tepe* mine in the town of Krumovgrad, Bulgaria. In this paper, the level of the phreatic surface was considered while calculating the factor of safety (FS). The FS was calculated on a high phreatic surface passing throughout the starting platform, and a low one which ends in the back end. The data about the material was from the publicly available data about the overburden and tailings produced from the mine and processing plant. The version with the higher phreatic surface has lower FS, than the one with the lower phreatic surface. The results were compared with the FS calculated by Dimitrov and Koprev (2023) on the same designed facility, but with fully drained and consolidated tailings. Various drainage systems were discussed, and recommendations were given. The calculations were made using the *Slide 2* program from *Rocscience*.

Key words: tailings storage facilities, tailings deposition, co-disposal, safety factor, drainage systems

ВЪЗМОЖНОСТИ ЗА ПОДОБРЯВАНЕ НА ДРЕНАЖНИТЕ СИСТЕМИ И УСТОЙЧИВОСТТА ПРИ КОМБИНИРАНИТЕ СЪОРЪЖЕНИЯ ЗА ДЕПОНИРАНЕ НА МИННИ ОТПАДЪЦИ

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РЕЗЮМЕ. Информацията за водното ниво и влага в отпадъка от обогатителните фабрики са от много съществена важност при проектиране, конструкция и поддържане на отпадъкохранилищата. Същият проблем важи и за комбинираните съоръжения за депониране на минни отпадъци (КСДМО). Проектирано е КСДМО с публично достъпните данни за интегрираното съоръжение за съхранение на минни отпадъци (ИССМО), което в момента е в експлоатация в рудник „Ада Тепе“ в Крумовград, България. За изчисляване коефициента на устойчивост (КУ) бяха разгледани различни нива на водното ниво в съоръженията. КУ беше определен при по-високо водно ниво, което минава през стартовата платформа, и с по-ниско водно ниво, което минава под стартовата платформа по дренажната система. Данните за откривката и отпадъка са също така от публично достъпните данни за материалите. Вариантът с по-високо водно ниво даде по-ниски резултати от варианта с по-ниско водно ниво. Резултатите са сравнени с КУ, изчислен от Димитров и Копрев (2023) при вариант на същото проектирано съоръжение, но с изцяло консолидирал отпадък. Бяха разгледани възможности за дренажни системи и са предложени решения. Изчисленията са направени с софтуерен продукт Slide 2 на Rocscience.

Ключови думи: Отпадъкохранилища, депониране на отпадък, комбинирано депониране, коефициент на устойчивост, дренажни системи

Introduction

The mining industry generates large volumes of waste materials that need to be properly managed to prevent negative environmental impacts. Plenty of authors (Tayebi-Khorami et al., 2019), (Yankova, 2020; 2021) emphasise the key problems with mining and processing waste, along with tailings storage, mining waste amount reduction and safe storage. Effective waste management is the basis of sustainable development (Yankova, 2020; 2021). Many experts contend the present stage of the mineral-raw material industry evolution is described by mineral deposits with complex mining-geological conditions, difficult for mining, and low-grade ores with complex processing, which leads to considerable waste quantities formation. Proper waste storage is critical to the planet and human health (Grigorova, Nishkov, 2016).

One common practice is the construction of Tailings Storage Facilities (TSFs) to store mine waste. However, these facilities require significant amounts of land and can pose a risk of catastrophic failure, leading to environmental damage and potential harm to nearby communities.

An alternative approach is the use of an Integrated Mine Waste Storage Facility (IMWSF), also known as a Combined Mine Waste Dump Facility (CMWDF), which combines mine waste materials in a single location. This method has the potential to reduce the required land area, decrease construction costs, and improve environmental management.

The great challenge which TSF and CMWDF face is the control of the water from the tailings consolidation and the runoff inflow. In the process of consolidation, a great amount of water is released, which needs to be safely transported out of the facility. This is done by internal or external drainage systems. The drainage systems in the TSF depend on the design method and can be designed to be constructed in the embankment from the inside of the embankment or in another place. In the Evaluation of Liner Requirements report by *AMEC Earth and Environmental UK Ltd.* (Diaz M., 2014) is given that the drainage system in the IMWFS in the *Ada Tepe* mine is designed under the facility, and this is possible because of the bench-by-bench construction of the facility. In that way, the cells will be in direct contact with the drainage system allowing it to drain and consolidate faster.

The control of the phreatic surface is crucial in the construction and operation of a CMWDF. In this study are presented results considering the change in heights of the phreatic surface and calculating the FS. Discussion about the possibilities of the drainage system is made.

Background

Facilities such as the CMWDF are great but expensive and complex to construct. Such a facility is great because it offers a storage capacity for less impacted area. The IMWSF currently under construction in Krumovgrad, Bulgaria saves approximately 55 % of surface area, concluded Eldridge et al. (2011). To build a separate waste dump and tailings storage facility, 96 ha of land was needed. With implementing this technology, the construction area decreased to 41 ha (Eldridge et al. 2011). One more positive characteristic of IMWSF is that it is relatively easy to monitor their stability and water drainage. According to Grigorova (2020), electrical resistivity measured is directly related to the geological characteristics of the study area, such as lithological composition, fluid saturation, porosity, and others. This information is very important for monitoring the effect of internal water drainage into constructed cells (ibid).

Other than the positive sides, this design has its negative sides, such as the expensive construction materials and technology, and the difficult operational sequence. Aleksandrova et al. (2021) suggest that the operational sequence can be managed by using the critical path method (CPM), which will give information about the important and urgent tasks that need to be started earlier and the ones that can be delayed. Dimitrov et al. (2023) have designed two variants of a CMWDF. The first one was with a wider body, and the second was with a narrower. The authors have concluded that the wider body has a better operational sequence because of the greater number of available cells, which can accumulate thickened tailings.

Methodology

Dimitrov and Koprev (2023) designed a CMWDF in AutoCAD Civil 3D. The CMWDF is designed using the publicly available data for the IMWSF which is used to store the tailings and waste rock from the *Ada Tepe* mine in Krumovgrad, Bulgaria. The same design was used to evaluate how the change in the phreatic surface influences the FS.

In the design, there are two facilities designed. The facilities are named by the side on which they belong, hence the names: “East” and “West” facilities.

The design has four variants which differ by the thickness of the tailings layer. The four variants are with 3 m, 5 m, 7 m, and 9 m thick layers of tailings (LOT) on every bench.

The phreatic surface was added using the command “Piezometric Line” in the *Slide 2* software from *Rocscience*.

For the calculation of the factor of safety (FS), 2D central profiles of all the variants were designed. The profiles were extracted as DXF files from *AutoCAD Civil 3D* and imported into *Slide 2* from *Rocscience*.

In the program, all the material properties were set using publicly available data for the overburden and tailings stored in the IMFDF in the *Ada Tepe* mine in Krumovgrad, Bulgaria.

The friction angle for the tailings and the overburden used for the construction are taken from the environmental impact statement (EIS) made by *Balkan Mineral and Mining EAD* in 2010 (Petkov G. 2010). As stated in the EIS (2010), the angle of friction is 40^{o} for the waste rock (overburden) and 30^{o} for the thickened tailings (at 56% w/w solids). The material density of the overburden is given at 2.00 g/cm^3 in the "NI 43-101 Technical Report" made by *CSA Global* (White G. et al. 2014). The material density for the tailings is given to be 1.45 g/cm^3 in the Evaluation of liner requirements report by *AMEC Earth and Environmental UK Ltd.* (2014). For the drainage system and the base, the same friction angle was used. For the base, a material density was used for fresh breccia conglomerate given in Table 44 in the report from "CSA Global" (White G. et al. 2014).

For all the materials, cohesion was given as 1 kPa, which was done because the calculations could not be performed with 0 kPa of cohesion. The base was given as "Infinite strength," which means that it will not fail under any circumstances, but the option was chosen for the failure surface to be allowed to pass through it.

The water level is added above the drainage system because it is meant to be ~~also~~ used for atmospheric water, too, so it will have water running through and near it.

The calculations were made using the option "Circular" surface type and the *Eurocode 7 - Design approach 3* design standard.

Calculations were not made for the 7 and 9 m variants because the facilities were not as high.

Results

The results given in Tables 1 and 2 show that the phreatic surface influences the FS; but when it ends in the back end of the starting platform, the results are approximately the same as the results in the case of consolidated tailings given in the paper published by Dimitrov and Koprev (2023). In the case when it passes through the starting platform, the FS decreases by approximately 0.3. The models from the calculations are given in Figures 1 to 6. Only the models with high phreatic surface are given.

Table 1. *FS for the well-controlled phreatic surface*

Thickness of the Tailings layer, m	**West CMWDF**				**East CMWDF**			
	3 m	**5 m**	**7 m**	**9 m**	**3 m**	**5 m**	**7 m**	**9 m**
Method Name	**Factor of safety**							
Janbu corrected	1.83	1.78	1.63	1.55	1.83	1.80	-	-
Spencer	1.80	1.76	1.64	1.54	1.80	1.78	-	-
Corps of Engineers #1	1.80	1.76	1.64	1.54	1.80	1.78	-	-
Corps of Engineers #2	1.80	1.75	1.64	1.53	1.80	1.77	-	-
GLE / Morgenstern-Price	1.80	1.76	1.64	1.53	1.80	1.77	-	-
Sarma	1.80	1.75	1.64	1.53	1.80	1.77	-	-

Table 2. *FS for high phreatic surface*

Thickness of the Tailings layer, m	West CMWDF				East CMWDF			
	3 m	5 m	7 m	9 m	3 m	5 m	7 m	9 m
Method Name	Factor of safety							
Janbu corrected	1.46	1.44	1.43	1.33	1.69	1.48	-	-
Spencer	1.45	1.43	1.43	1.34	1.70	1.48	-	-
Corps of Engineers #1	1.46	1.44	1.44	1.34	1.70	1.48	-	-
Corps of Engineers #2	1.45	1.43	1.43	1.34	1.68	1.49	-	-
GLE / Morgenstern-Price	1.45	1.43	1.43	1.33	1.70	1.48	-	-
Sarma	1.45	1.43	1.43	1.33	1.70	1.47	-	-

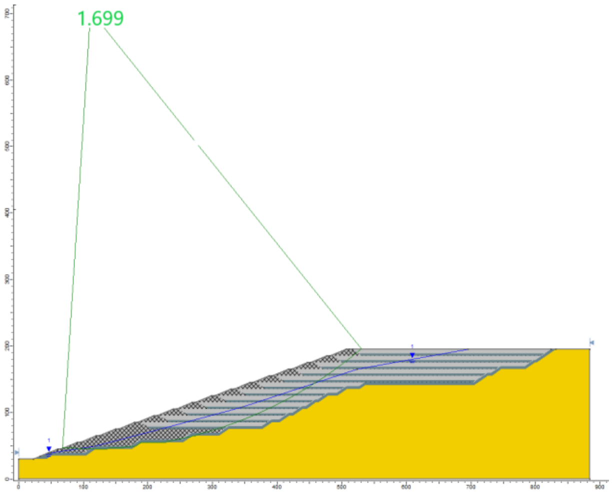

Fig. 1. East CMWDF with 3 m LOT with high phreatic surface

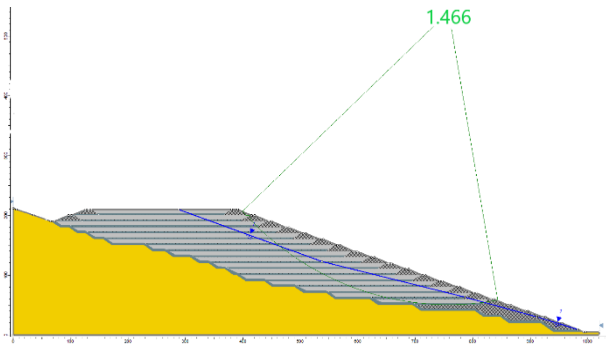

Fig. 2. West CMWDF with 3 m LOT with high phreatic surface

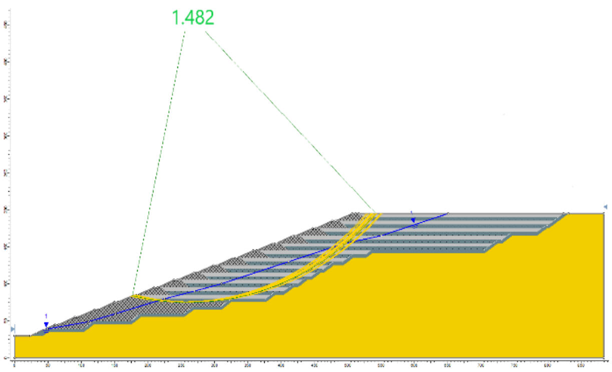

Fig. 3. East CMWDF with 5 m LOT with high phreatic surface

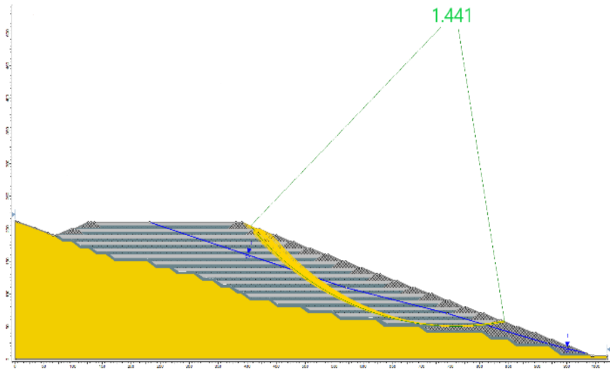

Fig. 4. West CMWDF with 5 m LOT with high phreatic surface

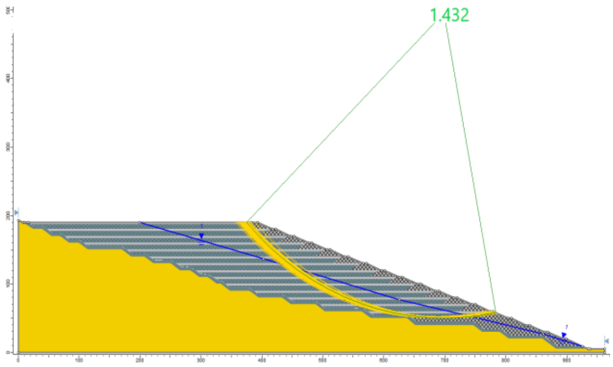

Fig. 5. West CMWDF with 7 m LOT with high phreatic surface

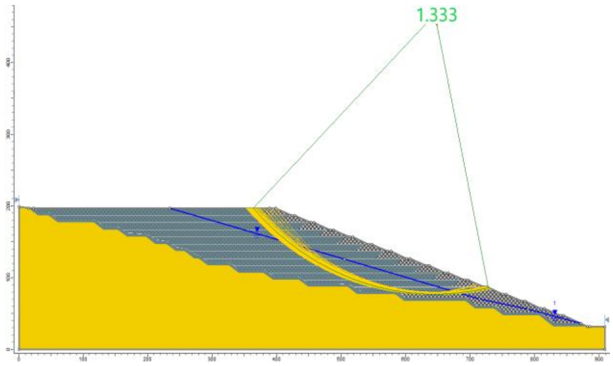

Fig. 6. West CMWDF with 9 m LOT with high phreatic surface

Discussion

The calculations have shown that the higher phreatic surface also influences the stability of the CMWDF. Considering that fact, greater attention needs to be given to the drainage systems.

Waiting for the full consolidation and removing the water from the cell is by itself a great challenge as time is not in abundance. Removing the water from a cell with a 3 m-thick layer of tailings is for sure easier than from a 7 or 9 m-thick layer. So, considering that, a different approach should be applied for a thicker layer.

For the cells with the thicker layer, internal drainages are recommended. The internal drainage can be placed in the LOT itself and on the bottom and walls. An option can be perforated pipe as the one suggested for draining the TSF in China by Wei et al. (2016). Another option can be adding prefabricated drainage systems (PDS) as the one given in Fig. 7. This will provide a free way for water to escape. The PDS can be placed at an angle of approximately 5^o, and pointed to the main drainage system. That will provide a faster route to the drainage system and in case of bending of the PDS, it will not block passage of the water as one point will be higher from the other. Such drainage veins can be added in the cells, so the tailings can be in direct contact with the drainage system, hence ensuring faster consolidation.

Fig. 7. Prefabricated drainage system

The starter platform can be protected with geomembrane or geocomposite to prevent water from entering. In addition to that, the top of the starting platform can have a slight incline, e.g. 1-2 degrees. In that way, the possibilities for the phreatic surface to end behind the starter platform will be greater.

In case of improper work of the drainage system, a new drainage system can be constructed; or if the facility is already at its end phase, a two-way slotted drainpipes can be inserted to maintain low phreatic surface. The technology can be implemented in a similar manner as given from Wei et al. (2016).

Conclusions

Taking into consideration the results, the following conclusions can be made:

- Internal drainage systems that lead to the main drainage are needed to shorten the consolidation time.
- The FS greatly depends on the water content in the CMWDF.
- The height of the facility does not greatly influence the FS as it is from the phreatic surface and the thickness of the tailings layer.

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