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The use of seepage dams in mine waste disposal

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Abstract

The Swedish iron mining company LKAB has, for several years, worked with the development of alternative methods for mining waste disposals. LKAB in co-operation with the Swedish mining waste research program (MiMi) and the Dept. of Civil and Mining Engineering at Luleå University of Technology, has started a project with the purpose to find out how a seepage dam should be designed in order to manage to drain out pumping water but at the same time being able to keep all particles inside the dam. This results in considerably smaller tailing dams. Such a technique will be much safer and cheaper than that used today. To test this, four different types of drained test cells situated in Malmberget were constructed during the summer 2000. In each cell a seepage dam was built by mixing two different types of dry waste rock. The size of each cell was large enough for the production during five days. Measurements were performed in the dams and cells, in order to find out the efficiency and stability of the different dam types, i.e. how well the water was drained away and the amount of particles being kept in each cell. Preliminary results are presented here. The efficiency of particle separation is calculated as the relation between the quantity of incoming tailings and outgoing tailings through the seepage dam. The efficiency was found to vary between 35 – 100 %. The efficient values for cell 1, where the seepage dam was constructed by primary sorting waste rock, were surprisingly high due to the fact that the material in the seepage dam did not fulfil the filter criteria. The filter material used in the seepage dam in cells 2 and 4 did not fulfil the filter criteria and therefore were flushed away. The permeability of material that been used in the seepage dam in cell 3, was too low. Water level in the cell increased until instability in seepage dam occurred and the dam collapsed. During the test-period several interesting observations were made. A lot of data are not yet analysed. Future work will form a better basis for the evaluation of the performance of the studied seepage dams. LKAB regards the results as promising and the method to have a potential to be more efficient than the one used today, even though the values obtained in this test are too low to be highly interesting. Additional tests are therefore planed

Introduction

LKAB, operates in northern Sweden, is one of the major mining companies in Sweden with magnetite and hematite mines in Malmberget and Kiruna. When crude ore is refined in Malmberget, two major types of mining waste are generated. One type is a coarse and dry material (waste rock), and the other is a wet and fine-grained material (tailings). The tailings are pumped into a tailings pond in which the particles settle. Water is thus cleared and ultimately drained away. Large quantities of water are used to pump the tailings into the dam. Most presently minerals in tailings in Malmberget, are magnetite, hematite, apatite, calcite, pyrite, quartz, amphibole and biotite (Geijer, 1930).
There are a number of advantages with the current disposal system, but, however, also some disadvantages, like:

- A tailings dam is often built like a hydropower dam, with same demands on materials used in the dam body. A tailings pond is therefore an expensive construction with significant demands of maintenance.
- The life length of a tailings pond is limited.
- A tailings pond is related to great environmental risks in case of a dam failure.
- A tailings pond needs an extensive area in order to create good sedimentation conditions.
- The tailings pumped into the construction will form a layered structure and thus the geotechnical properties will vary due to segregation during sedimentation.
- The restoration costs are expected to be high at the end of lifetime.

LKAB has, for several years, worked with the development of alternative methods for mining waste disposals. One of the latest projects was a large-scale field-testing of joint disposal of coarse waste rock and tailings. For transportation, pumping was used (Sundqvist and Sundqvist, 2001). The test showed, among many things, that a deposit with good properties in stability and landscaping possibilities was obtained. However, during pumping, the friction between the pipe and the material was so extensive that maintenance costs seemed to be too high for an immediate use of the technique.

The major goals with the current project is to find out a good design of dams, which are impervious enough to hinder the tailings to pass the dam but at the same time, permeable enough to drain the water away. This type of construction is referred to as seepage dams. Another goal is to investigate and try to understand the processes that control the deposition of tailings under these conditions. If this is possible to obtain, such a technique will be much safer and cheaper than that used today. A hypothesis that is used for construction of the test plant, is that waste rock from the refining process can be used for construction of dams. The whole flow of tailings from production is led to the test plant.

The project is run by LKAB in co-operation with the Swedish mining waste research program MiMi (Mitigation of the environmental impact of mining waste) and the Dept. of Civil and Mining Engineering at Luleå University of Technology.

**Design**

It was decided to test four different types of dam layouts. For this reason four different drained test cells were constructed during the summer 2000. In each cell, the seepage dam used, had its specific layout. The test plant with the four test cells was situated within the area of the ordinary pond for tailings disposal. The layout of the four test cells is schematically shown in Figure 1.

![Sketch of test plant design](image1)

**Figure 1**: Sketched picture of the test plant design. The test plant with four different cells is situated inside the ordinary tailing pond.
Each cell was constructed in a traditional way to hold water, but one of the sides was used for the test of seepage dams. Four different types of design were used, one in each cell (Figure 2).

**Cell 1**

The seepage dam was homogeneous and constructed by a coarse material (primary sorting waste rock). The grading is shown in Figure 3. The waste rock is classified as a gravelly cobble deposit. Field B in Figure 3 represents the area in which all the grading curves were located.

**Cell 2**

In addition to the type of dam used in cell 1, a filter layer was placed on the upstream slope in cell 2. The filter was a fine-grained sorting waste rock material, classified as coarse-grained gravel. The typical grading curve is shown in Figure 3 as field A. Furthermore, a coarse layer and a filter were placed at the bottom of the cell. The idea with this layer was to improve the drainage of water from the cell.

**Cell 3**

In cell 3 a homogenous dam constructed by sorting waste rock (field A in Figure 3) was tested.

**Cell 4**

Cell 4 was designed as cell 2 but in addition the cell was also partly filled with primary sorting waste rock. This was used in order to study the penetration of tailings into the coarse material. If the results from the tests in cell 4 are good, this technique might be possible to use and thus tailings can be pumped directly to the big heaps of waste rock situated close to the mining area.

![Diagram](image.png)

*Figure 2. The different seepage dams were constructed of two different types of waste rock. In cell 2 and 4 filter layers were also used. In cell 4 direct disposal of tailings into coarse materials were tested.*
Figure 3. Particle size distributions of the two different types of dry and coarse waste-rocks used. Field A represents the area in which all the grading curves were located for the fine-grained sorting waste rock. Field B represents the area in which all the grading curves were located for primary sorting waste rock.

The following conditions were considered when the test plant was designed:
- Usually about 900 m$^3$/h is pumped to the cell. The concentration of solids is approximately 10–15% by mass.
- Bulk density of tailings settled in water, is approximately 2 ton/m$^3$.

The following assumptions were made when the test plant was designed:
- Minimum width of the dam crests are 4m, due to the transportation needs
- Natural slope of the waste rock used is 1:1.5
- The heights of the dams were 5 m.

The size of each cell was 40 x 100 m and large enough for deposition of tailings during five days of production.

Test program

Three major questions related to the performance of the seepage dams were identified as highly important and were therefore studied in detail during the field-test. They were:
- To what degree can the particles be kept in the cell?
- How efficient is the drainage capacity of the seepage dam?
- What is the shear strength of the seepage dam and of the deposited tailings?

Measurements and analysis were concentrated on these three issues.

The seepage capacity and the corresponding efficiency in particle sedimentation have been measured in two different ways. One way was by comparing the concentration of solids in the incoming and outgoing water and assuming negligible difference incoming and outgoing flows. This assumption is based upon the observation of a constant water level in the cell during the pumping period. The difference in concentration will therefore reflect the the amount of solids stored in each cell. A second way was to estimate and compare the quantity of tailings pumped into the cell with the quantity of tailings disposed. This was obtained by levelling.
All data of water and tailings came from conveyor scales in the refining plant as well as from flow measurement gauges located in the pipeline between the refining plant and the test plant. By using a total station, it was possible to estimate the volume of disposed tailings. With the help of sampling tubes, shown in Figure 4, located in the bottom of the seepage dam, samples of water were taken continuously. Four different tubes were used in each cell having the length of 2, 4, 6 and 8 metres, respectively. This construction made it possible to take water samples from different places in the seepage dam.

Figure 4. Different lengths of the water sampling tubes located in the bottom of the seepage dams. In the figure to the left, the tubes shown have the length of 4 m and to the right 2 m.

Samples of the out-flowing water were taken three times during the one week long filling period for each cell, see Figure 5. The samples can be considered as random samples. The analyses were focused on the concentration of solids and on the particle size distribution.

During filling operations pore pressures were measured with piezometers and data were stored in a data logger (Tremblay 1990). Pore pressures were measured in order to have the possibility to compute the shear strength in the disposed tailings and in the seepage dams. Pore water pressures are not yet analysed and therefore not presented herein.

To calculate the shear strength in the seepage dam and in the disposed material, it is necessary to know the angle of internal friction. It was found necessary to identify the changes in internal friction due to penetration of tailings in the coarse grained material in cell 4, as well as in the seepage dams. Samples were therefore taken before and after the
experiment. In Figure 6, it is shown how sorting waste rocks and tailings are sampled before the test.

Figure 6. To the left waste rock are prepared for sampling. To the right tailings are sampled at the end on the pipeline.

In Figure 7 it is shown how the disposed tailings were sampled. 3 profiles in each cell were dug out after the test series. One of the profiles was dug out near the seepage dam. The other two were located 30 and 60 metres from the seepage dam respectively. In order to take undisturbed samples, half-meter long tubes were pushed horizontally into the soil profile, which is shown in Figure 7.

Figure 7. Sampling of the disposed tailing in a profile. The arrows show where the samples were taken in the profile.

Results and discussions

The efficiency of the particle sedimentation has been calculated in two different ways. One was to compare the concentration of solids in the incoming (to the cell) and outgoing (through the seepage dam) water respectively. Knowing the water flow in and out of the cell it was possible to calculate the amount of solids stored within the cell ("Method I"). Another way was to calculate the quantity of tailings that have been pumped into the cell and compare this with the amount being disposed ("Method II"). If the amount of disposed tailings in the cell is the same as the amount pumped into the cell the efficiency is set to 100%. The results of the efficiency for each cell, calculated in the two different ways described, are shown in Table 1.

It is obvious that the differences between the efficiency factors calculated in the two ways are large. The two calculation methods are based upon the same pumping data, but they differ in how the material disposed in the cells is determined. It is not quite clear today, which method should be used in order to evaluate the efficiency in the best and
most reliable way. However, from an analysis of all the data collected it seems to be more reliable to base the efficiency factor on “Method II”, see Table 1.

Table 1. The efficiency of the particle sedimentation counted in two ways.

<table>
<thead>
<tr>
<th></th>
<th>Difference in concentration of solids in incoming and outgoing water (Method I)</th>
<th>Relation between mass pumped into the cell and disposed mass (Method II)</th>
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<tbody>
<tr>
<td></td>
<td>[%]</td>
<td>[%]</td>
</tr>
<tr>
<td>Cell 1</td>
<td>88</td>
<td>35</td>
</tr>
<tr>
<td>Cell 2</td>
<td>59</td>
<td>29</td>
</tr>
<tr>
<td>Cell 3</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Cell 4</td>
<td>67</td>
<td>-</td>
</tr>
</tbody>
</table>

In “Method II” the volume of disposed material was determined by using a total station before and after the field test. In this way the total volume stored in the cell was evaluated.

It was not possible to evaluate the volume of disposed material in cell 3 by using “Method II” and therefore no efficiency value is given here. The seepage dam in Cell 3 was constructed out of a sorting material. During the filling operation, the pore pressures below the dam foundation increased to such a level that the effective stress, and thus the strength in the material, was reduced to such a level that instability of the dam occurred. As a consequence, dam failure took place and some of the disposed material was flushed out. Therefore no realistic values of the amount of disposed material in cell 3 can be given.

As can be seen in Table 1, also for cell 4 there is no efficiency value for “Method II”. The reason for this goes back to the construction of the cell. The idea in this cell was to study the penetration of tailings into coarse, primary sorting material. This material was placed as a horizontal layer in the bottom of the cell. During placement of this it was necessary to put a layer of sorting material above the coarse primary sorting in order to protect the tires of the lorries. This protection layer was supposed to be removed before the filling operation, but this turned out to be difficult. Some of the material had penetrated into the coarse grained material and was therefore difficult to remove. As the protection layer has a lower permeability than the coarse grained material, the water was partially hindered to permeate, see Figure 8.

![Figure 8. To the left, the tractor is trying to remove the layer of sorting material at the top in cell 4. To the right it is shown that it did not work out well. Water was partially hindered to permeate.](image)

Water that did not immediately permeate flowed on the surface to areas with openings in the protection layer or where permeability was high enough to let the water in. As a consequence, it was very difficult to evaluate to what degree the pores of the coarse
material was filled up with tailings. This degree was more dependent upon the remaining protection layer than on the properties of the coarse primary sorting.

During the planning phase, the hypothesis for cell 2 was that it would be possible to achieve higher efficiency of the dam with a filter on the upstream side. After the test, all the seepage dams where dug out. It was then possible to see that the filter on the dam in cell 2 had been removed and most likely been flushed away. Therefore, the function of the dam in cell 2 became similar to that of the dam in cell 1.

The efficiency value for cell 3 is very high. During the filling operation, outgoing water with very low solid concentration was sampled. This shows that the dam is very efficient in not letting particles through. However, the material used for the dam in cell 3 was not permeable enough to let all the water being pumped into the cell through. This resulted in a continuous increase of the water level, until the seepage dam collapsed.

In spite of the coarse material used for the dam in cell 1, tailings have been hindered. This was obviously the case even though normal filter criteria were not fulfilled.

The efficiency values are significantly higher for cell 1 than for cell 2 independent of whether method I or II is used. If method I is used for evaluation, the relationship between the efficiency in cell 1 and 2 is 1.49, while the same number is 1.21 if method II is used. This implies that the filter on the upstream side used in cell 2 is of no, or minor, importance for keeping the particles within the dam. This is also logical as the filter was flushed away during filling operations and no change in performance was noticed.

The efficiency values for each cell obtained from “Method I” can be compared. Cell 3 shows the highest value, which is realistic due to the fact that the seepage dam was constructed out of fine-grained material. The permeability was low and the capacity to hinder particles through was good. Cell 4 shows lower value than cell 1 which is surprising, but higher value than cell 2, which was expected. When the seepage dam in cell 4 was dug out, it was found that the filter layer had been flushed away similar to what happened in cell 2. The higher value for cell 4 than for cell 2 is explained by the fact that some of the tailings were deposited in the pore volume of the coarse material inside the cell.

The efficiency values given by the use of “Method I” in Table 1 indicate that the seepage dams worked well. However, the efficiencies given from “Method II” are too low in order to clearly show, that seepage dams are a realistic alternative to the system used today. The uncertainties in the evaluation are a complicating factor. To achieve higher efficiency values for this type of seepage dams, a different type of filter must be developed. However, LKAB regards the results as promising and the method to have a potential to be more efficient than the one used today, even though the values obtained in this test are too low to be highly interesting. Additional tests are therefore planned.

There is still a lot of material to be analysed from the field test presented in this paper. This includes analysis in laboratory of basic soil mechanical parameters such as permeability, shear strength, compaction properties etc. Pore pressure data is also to be analysed in detail.

The seepage dams in cell 1 and 2 worked well, even though there is an uncertainty about the efficiency in keeping the particles within the cell, see Table 1. During the sampling procedure in these dams after the test, a number of interesting observations were made. One of them was how well the pore space in the coarse material in the seepage dams in cell 1, 2 and 4 was filled with tailings. It was also obvious where the free water table was located in the dams during the test. Below this surface, the pore space was almost completely filled with tailings. Immediately above the free water table, an area with the height of about 0.2 m in the coarse material was washed clean. Above this layer the material was in its original condition. This is illustrated in Figure 9.
Figure 9. In the sampling profile of the seepage dams in cell 1, 2 and 4 it was possible to identify the location of the free water surface. The photo is taken from cell 1. The area, which was washed clean just above the free water surface, is marked.

Conclusions

The seepage dams in cell 1, 2 and 4 worked well enough to be interesting for further studies.

The efficiency value for cell 1 was surprisingly high due to the fact that the material in the seepage dam did not fulfil any common filter criteria.

The permeability of the material used in the seepage dam in cell 3, was too low. The water level in the cell therefore increased until instability in the seepage dam occurred and the dam finally collapsed.

There were some difficulties with taking samples on the outgoing water. The cells were situated on tailings that already had been deposited. During the test period tailings were flushed away with settling in the seepage dam as a consequence. Taking samples from the tubes was related to some risks due to the settling of the seepage dams. The sampling tubes finally disappeared under the seepage dam.

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References

