OPERATIONAL SEQUENCE FOR CONSTRUCTING AN COMBINED MINE WASTE FACILITY

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ABSTRACT
The different stages and processes of the construction and exploitation of combined mine waste facilities are treated in this paper. Based on technological operations, required for finalizing each operational stage, a CPM (critical path method) approach is introduced for the construction planning of a combined mine waste facility. The CPM chart can be used for applying different when certain activities lie on the critical path. Nevertheless, periodic monitoring of this facility is mandatory in order to fulfill the geotechnical and production requirements, necessary for its successful exploitation. Furthermore, monitoring can provide information, which is used for updating the CPM chart.

INTRODUCTION

Mineral resources mining is imminently related to the excavation of large volumes of overburden and sterile rock masses. Annually over 120 billion tons of ores, coal, oil, gas and non-metallic mineral resources are extracted on a world-wide scale (approximately 20 tons of mineral resources per capita). According to some authors only 5 to 10 % of the excavated volumes of rock material is considered to be a mineral resource, while the remaining volumes are considered to be waste material. Waste material can be generally divided to the following different types of groups: tailing, slag, coal ash, sterile rock, overburden, etc. which are stored in technogenic depots and waste dumps. Despite their potential and the efforts which are put into the utilization of such waste materials, so far the extent at which they can be successfully used as a mineral resource remains relatively low. Open-pit mining is generally more ecologically harmful than underground mining, due to the fact that large scale pits are formed on the surface (Morin, Hutt 2001). Therefore, the problems related to occupying areas for mining purposes and waste storage remains intact.

COMBINED MINE WASTE DUMP FACILITY

Purpose of the facility

In recent years a new technology for waste dumping and storing is starting to show considerably better acceptance from an ecological standpoint – the technology of constructing a combined mine waste dump facility. The main purpose of the facility is to accumulate both the volumes of mine waste during the exploitation of an open-pit mine and the tailing material which remains after the dewatering of the slurry generated by the processing plant. The main advantage of the construction of such a complex facility is to minimize the ecological impact of mining operations on the environment by reducing the areas which have to be used for the purpose of waste storage, as well as minimizing the amounts of fine particles which fall onto the environment.

This technology is based on the placement of waster rock material on top of the consolidated and dewatered tailing and vice versa. The main advantage of this technology is that the stability of such waste dump facilities has drastically improved, as well as the areas required for storing mining wastes has significantly decreased (Driussi, Jansz, 2006). They key factor for these facilities is that the tailing is dewatered to a minimal level of moisture and the water is reused for the beneficiation process. This also leads to other advantages such as the lower need of water for technological purposes (Bussiere, 2007). This leads to the reduced negative impact on the environment as well as the reduction of monitoring costs due to the lower risk during and after the exploitation of the facility. The main drawback of this technology is the relatively higher levels of exploitational costs, as well as sealing away potentially feasible ore volumes which are with contents below the cut-off grade during the whole period of the facility's exploitation. Nevertheless, the utilization of the combined mine waste dump facility proves to be feasible and dependable in the ever-changing problem of waste materials storing, which nowadays has even a higher priority in terms of global policies.

TECHNOLOGY FOR BUILDING A COMBINED MINE WASTE DUMP FACILITY

Operational sequence

The technology for construction and exploitation of such a combined mine waste facility is achieved by sequential building of cells from the overburden and sterile rock, which are further used for accumulating the tailing volumes (Grigorova, 2011). By doing so, the stability parameters of the facility are improved significantly. Another advantage is that such a facility enables the possibility for the surface water from rainfall and snow melting to drain along with the water in which the tailings is dispersed. While the water is draining, the waste materials are consolidating. The expected result is that the waste facility is fully dewatered, while the material which remains in the facility is of higher density and cohesion. This is considered to be a better outcome than the construction of conventional overburden dumps and tailing ponds separately in terms of stability management.

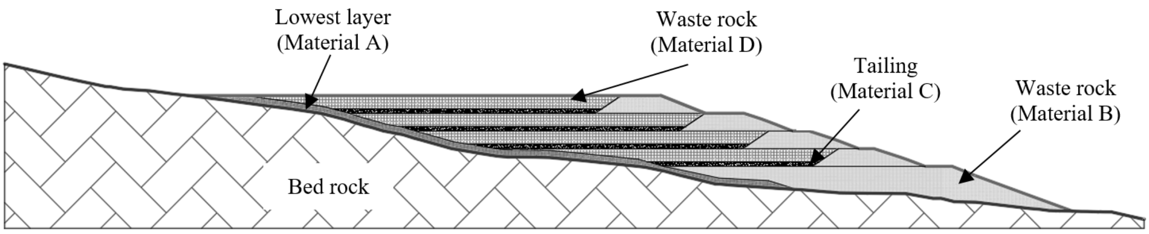

Figure 1. A simple overview of a combined mine waste dump facility

The lowest layer of the depot (material A) serves as a drainage system of the waste dump and it must suit the conditions for permeability and thickness so that it protects the top soils and the underground water surface from the harmful impact of the waste material. At the same time the drainage layer should be suitable stability-wise. The drainage layer includes a geotextile, mineral sealing layer (over the geotextile), an isolation geomembrane (below the drainage system) and coarse material layer.

The overburden and waste rock (material B) is initially used for creating berms and the starting platforms, which form the outer surface of the facility. The combined mine waste facility has a continuous surface of sterile rock. If the sterile rock and overburden do not have the required properties for the construction of the starting platform or the berms, they are used for the construction of haulage roads, which provide access of the mining equipment to the place where the drainage system is built. Inner roads can be placed on the centerline of the bench cell, or they can follow the shape of the landscape around the cell. The sterile rock volumes are transported by dumper trucks and dumped into the facility.

The tailings (material C) is transported via a slurry pipeline for dumping the waste volumes into the cells of the facility. A filtering system will be placed for filtering the material in two zones in order to prevent the blend of tailing outside the outer wall. The filter is built from a layer of nonwoven geotextile, which is placed directly on the rock slope and covered with a layer of sand.

The work platforms of the combined waste dump facility are separated into cells. The slurry pipes from the processing plant require multiple points for unloading the waste and therefore the slurry pipe is moved between the cells, whenever they have to be filled partially with tailing material.

In order to ensure that the dewatering process of the tailings material is achieved, the height of the tailings volume inside the cell is controlled by the addition of horizontal drainage layers (in cell drainage pipes) between the tailing volumes. The cell is filled with tailings until it reaches the desired height (30 ÷ 50% of the cell's height). After that, the tailing dumping pipeline is prolonged for the adjacent cell and the process is repeated until all cell for the current bench are filled.

After the tailing material is dewatered and consolidated, the remaining volume of the cell is filled with overburden and sterile rock (material D). A drainage layer is built over the bench (material A) in order to star the construction of the next bench.

Technological constraints

Depending on the work schedule of the open-pit mine and the processing plant, the volumes of sterile rock and tailing volumes follow a rotation during the years of exploitation of the mine.

The parameters of the combined mine waste dumping facility (volume capacity, bench height, slope angles, required area, etc.) are determined by the output volumes of waste volumes the open pit mine and tailing volumes from the processing plant. This leads to following the requirement of using as less terrain as possible in order to minimize the area of impact. This can be achieved by using the topography features, as well as utilizing the possibility of progressive reclamation of lower benches of the facility while the upper ones are still under exploitation.

In order for the combined mine waste dumping facility to operate as intended, there has to be at least one fully prepared cell, ready to be filled with tailing. Therefore, the time which a cell is being built and the prerequisite operations for its construction has to be equal to the time required for filling the previous cell to the optimum height. At the same time the volumes of overburden and sterile rock which are generated from the mine and their respective times of excavation and transportation have to be equal to the time of tailing consolidation in order to continue filling each cell, or to the time between the building of the safety berms and cell slopes. Unlike tailing volumes generated from the processing plant, excess waste rock volumes can be accumulated in temporary waste dump, whose volumes can be used when needed.

Principles of estimating the critical path for the construction of a combined mine waste dumping facility

The Critical path method (CPM) is widely used approach for estimating which technological operations are critical for a technical project to be fulfilled in a desired time constraint. It can also provide a better understanding how long a certain operation can be prolonged or how long can it be delayed without affecting the duration of the technical project (Zlatanov, 2010). For the construction of integrated mine waste facilities, the CPM chart can be especially useful due to the number of operations which have to be fulfilled parallel to one another in order to fulfill the technological constraints for its construction. The building of the integrated mining facility needs near-perfect coordination of the procedures that are including the disposal of tailings and waste rock. Therefore, the purpose of the CPM is not only to maintain the ultimate time required for its construction and reclamation, but at the same time to maintain the operations within time boundaries during its different construction stages.

As a simplified example of the combined mine waste facility and the critical path method, we have assumed that combined mine waste facility will be build upstream and there will be a total of 4 benches. During the construction of the facility, the mandatory operations are as follows:

A. Removal of top soil and vegetation
B. Preparing the surface terrain, required for the new bench and drainage system;
C. Building a water collector;
D. Placing geomembrane on the pre-prepared surface;
E. Starting a main drainage system with a length from the water collector to the top ending of the first bench. It is composed of perforated pipe surrounded with gravel;
F. Hauling material for building and building the 1-st bench;
G. Building the dyke which is the front of the 2-nd bench;
H. Building the rest of the bench which includes forming of the cell for future tailings placement;
I. Prolonging the main drainage system;
J. Placing geotextile, which lets water pass thru but keeps the tailings in its border;
K. Placing of in cell drainage pipes. They are not perforated;
L. Placing the tailings pipeline over the bench, surrounding the cell;
M. Partially filling the cell with tailings (30 ÷ 50 %);
N. After the tailings have consolidated, the remaining volume of the cell (50 ÷ 70 %) are filled with waste rock;

O. Construction of a base for the tailings pipeline;
P. Building the pipeline for transporting tailings;
Q. Building the first cell;
R. Building the second cell;
S. Building the third cell;
T. Preparing and moving the tailings pipeline to the next cell;
U. Period when the tailings are consolidating;
V. Building a dyke for the new bench enough to fit one minimum size cell behind it;
W. Prolonging the dyke;
X. Bench reclamation;
Y. Filled and consolidated cell reclamation.

Due to the site specific features of each project, the critical path can vary for each of the technological complex of operations. The following cases can occur depending on which types of processes fall onto the critical path:

1) **The tailing filling process of the next available cell lays on the critical path (acceptable)**
This case is the most favorable one, due to the available time with which other operations parallel to filling process can be delayed with. Therefore, all the other technological processes are time-bound to the time required for filling the cells with tailing, which leads to better operational flexibility.
2) **The time for the preparation of the next available cell lays on the critical path (unacceptable)**
This case can occur when time for the preparation of a cell (including the preparation of the bench, dykes, berms, cell slopes, geotextile placement and tailing pipes installation) exceed the time for filling a previous cell. A suitable strategy for this case is to either change the choice of mining equipment, alter the processing plant and the mine's annual output of ore volumes for the specific stage from the mine's strategic plan. Either way, a reevaluation of the CPM should be made.
3) **The reclamation process of the lower benches lay on the critical path**
If the reclamation processes occur on the critical path (except for the operations on the benches constructed lastly), the only viable strategy is to review the CPM chart and delay the start of the reclamation activities of the combined mine waste dump facility in the future, which can, however, prolong the time required for its reclamation and monitoring.

The operational sequence and the different phases of building the facility is introduced in table 1.

Table 1. Operational sequence for building a combined mine waste dump facility

Construction stage	Event №	Following event (Activity in brackets)	Previous event (Activity in brackets)	Construction stage	Event №	Following event (Activity in brackets)	Previous event (Activity in brackets)
Bench 1 construction	**1**	2 (A)	-	**Bench 3 construction and Bench 1 reclamation**	**45**	49 (U)	44 (M)
	2	3 (B)	1 (A)		**46**	47 (J)	37 (S)
	3	4 (C) 5 (D)	2 (B)		**47**	48 (K)	46 (J)
	4	5 (fictitious)	3 (C)		**48**	50 (T)	47 (K)
	5	6 (E)	3 (D) 4 (fictitious)		**49**	56 (N)	45 (U)
	6	7 (A) 8 (F)	5 (E)		**50**	51 (M)	48 (T)
	7	8 (fictitious)	6 (A)		**51**	61 (U)	50 (M)
	8	9 (B)	6 (F) 7 (fictitious)		**52**	53 (N)	43 (U)
	9	10 (D) 11 (O)	8 (B)		**53**	54 (B)	52 (N)

Bench 2 construction	**10**	12 (I)	9 (D)	**Bench 3 and Bench 4 construction and Bench 2 reclamation**	**54**	55 (D)	53 (B)
	11	13 (fictitious)	9 (O)		**55**	57 (I)	40 (fictitious) 54 (D)
	12	14 (Q)	10 (I)		**56**	58 (fictitious) 61 (fictitious)	49 (N)
	13	14 (fictitious)	11 (P)		**57**	58 (Q)	55 (I)
	14	15 (fictitious)	12 (Q) 13 (fictitious)		**58**	59 (J) 63 (R) 64 (V)	55 (V) 56 (fictitious) 57 (Q)
	15	16 (R) 17 (J) 20 (A)	12 (G) 14(fictitious)		**59**	60 (K)	58 (J)
	16	21 (J)	15 (R)		**60**	65 (T)	59 (K)
	17	18 (L) 19 (K)	15 (J)		**61**	62 (M)	56 (fictitious)
	18	19 (fictitious)	17 (L)		**62**	65 (fictitious) 69 (fictitious)	61 (M)
	19	25 (M)	17 (K) 18 (fictitious)		**63**	72 (S) 73 (fictitious)	58 (R)
	20	27 (fictitious)	15 (R)		**64**	66 (J)	58 (V) 63 (fictitious)
	21	22 (K)	16 (J)		**65**	68 (M)	60 (T)
	22	23 (T)	21 (K)		**66**	67 (K)	64 (J)
	23	24 (M)	22 (T)		**67**	70 (T)	66 (K)
	24	36 (U)	23 (M)		**68**	69 U)	65 (fictitious)
	25	26 (U)	19 (M)	**Bench 4 construction and Bench 2 reclamation**	**69**	70 (fictitious) 80 (N)	62 (fictitious) 68 (U)
	26	27 (N)	25 (U)		**70**	71 (M)	67 (T) 69 (fictitious)
	27	28 (B)	20 (fictitious) 26 (N)		**71**	77 (U)	70 (M)
Bench 2 and 3 construction	**28**	29 (D)	27 (B)		**72**	73 (fictitious)	63 (S)
	29	30 (I)	28 (D)		**73**	74 (X) 75 (J)	63 (W) 72 (fictitious)
	30	31 (Q) 32 (V)	29 (I)		**74**	82 (X)	73 (X)
	31	32 (fictitious)	30 (Q)		**75**	76 (K)	73 (J)
	32	33 (J) 37 (R) 39 (V)	30 (V) 31 (fictitious)		**76**	78 (T)	75 (K)
	33	34 (K)	32 (J)		**77**	78 (fictitious)	71 (U)
	34	35 (T)	33 (K)		**78**	79 (M)	76 (T) 77 (fictitious)
	35	43 (M)	24 (fictitious) 34 (T)		**79**	85 (U)	78 (M)
	36	38 (N)	24 (U)		**80**	83 (Y)	69 (fictitious)
	37	39 (fictitious)	32 (R)	**Bench 4 construction and Bench 3 and 4 reclamation**	**81**	84 (Y) 85 (fictitious)	77 (N)
	38	39 (fictitious)	36 (N)		**82**	88 (fictitious)	74 (X)
Bench 3 construction and Bench 1 reclamation	**39**	40 (X) 41 (J)	32 (V) 37 (fictitious) 38 (fictitious)		**83**	84 (fictitious)	80 (Y)
	40	55 (fictitious)	39 (X)		**84**	87 (fictitious)	81 (Y) 83 (fictitious)

	41	42 (G)	39 (J)		**85**	86 (N)	79 (U) 81 (fictitious)
	42	44 (T)	41 (G)		**86**	87 (Y)	85 (N)
	43	44 (fictitious) 52 (U)	35 (M)		**87**	88 (X)	84 (fictitious) 86 (Y)
	44	45 (M)	42 (T) 43 (fictitious)		**88**	-	87 (X)

Figures 2 represents the CPM approach used for the construction of the combined mine waste facility.

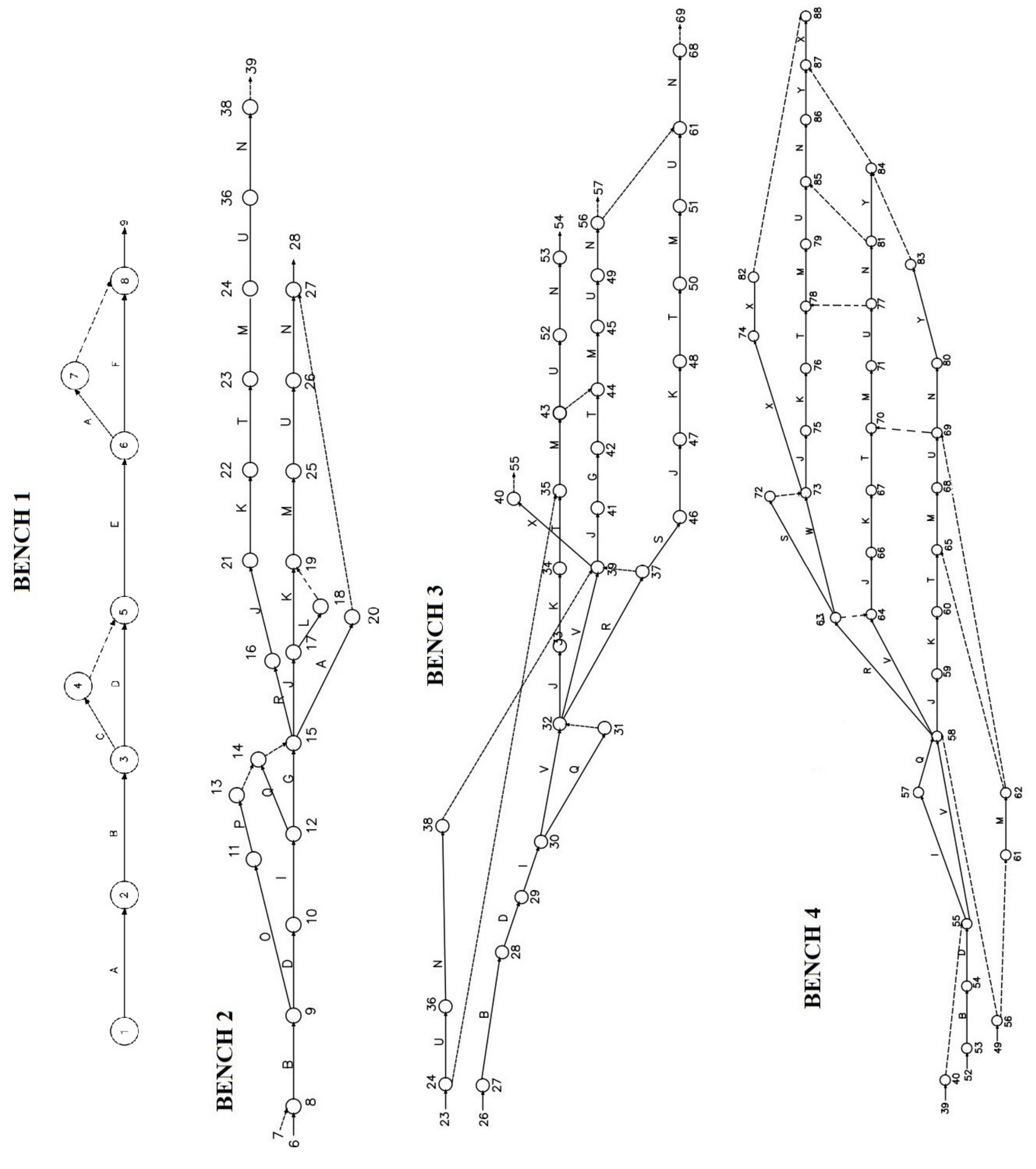

Figure 2. Stages for the construction of the combined mine waste facility (CPM approach)

Despite the fact that the operations required for building such a facility can be scheduled properly, the construction and filling of the cells requires active control. The dumped mine wastes undergo significant deformations, which are related to the process of consolidation. Therefore, the facility requires long-term monitoring not only during its construction and exploitation, but also during its reclamation. The activities required for proper monitoring include these key elements:

1) Dumping operations control – initial control and control of the technology for waste dumping of the isolated drainage system and the overall stability of the facility. The operator of the facility logs the information from the monitoring;
2) Self-monitoring system – it includes observations and researches during the period of exploitation of the depot, as well as after its reclamation. The monitored elements include: meteorological data (the amount of precipitation, air temperature, wind direction and strength, water evaporation), ground water, facility state (stability monitoring through deformation observations).

Following the monitoring activities, the CPM chart may have to be reevaluated at certain periods of time.

CONCLUSIONS

1. By using the critical path method, the activities that need to be prioritized and started earlier can be identified.
2. By using the critical path method, the best time for starting the reclamation process of the combined mine waste facility can be identified. Either the reclamation of lower benches takes place parallel to the construction of upper benches, or the reclamation process is postponed at later stage when the waste dump is consolidated and no more subsidence occurs.
3. By using the CPM chart, possible delays can be detected ahead of time, which gives time to manage the activities in order to avoid unnecessary delays.
4. Despite the reliability of the critical path method, constant monitoring needs to be carried out so that adjustments in either short-term or long plans can be applied.

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