UDC 622.882

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TOWARD A RECLAMATION EFFORT ESTIMATION PROCEDURE FOR OPEN PIT MINES

The present imposes increasingly more environmental requirements on the mining industry, including CO_2 emission standards. For another thing, technological complication of mining processes and the mineral quality degradation results in the closure of coal mines, which implies ecological recovery of the post-mining areas and their return in the economic activity in what follows.

Experience proves that post-mining land reclamation is a very complex challenge as there is no universal methodical approach to reclamation planning. Reclamation of mining-disturbed land includes a set of geotechnical, engineering and other activities aimed at recovery of economic value of such land.

The Federal Law on the Subsoil [1] dictates reclamation effort estimation to be carried out at the stage of mine planning and design.

The main open pit mining parameters to be defined in this regard are:

–the volume of an open pit void after mining;

–the volume of overburden and waste rocks produced at an open pit and usable in backfill of this very open pit void.

The present study focuses only on evaluation of overburden rock volume with regard to their disintegration and swelling which increase the rock volume.

Keywords: *Open pit mining, coal, overburden, reclamation, rock, soil, disintegration, moisture, swelling, shrinkage*

DOI: *10.17580/em.2023.01.18*

Introduction

Open pit coal mining dramatically affects the subsoil, ground surface, underground and surface water, and flora and fauna, i.e. all components of the environment.

One of the critical problems in the mining sector of Russia is a substantial retardation of land reclamation after the land disturbance by open casting [2].

Some mining companies demonstrate the environmental and social responsibilities while doing their businesses. Unfortunately, most companies violate their obligations, elude reclamation and endamage the environment without any punishment.

The present-day coal mining industry faces increasingly more environmental standards to adhere to, including reduction of CO_2 emission, which is also feasible during surface mine reclamation. Technological complications and drop in the application properties of coal at some mines result in the mine closure, and the mining-disturbed land is to be returned into economic management after due rehabilitation. The reclamation problems and activities are the subject of many studies [3–6].

Reclamation (recultivation) of land after mineral mining is an extremely complex challenge as there is no universal technique of reclamation planning and design [5, 6].

The best way is to find a technology of reclamation implementable while mining.

The causes of reclamation retardation also include the lack of procedures to estimate the scope and size of the mined-land reclamation at the stage of mine planning and design.

Grounds for effort estimation procedure in open pit mining-disturbed land reclamation

Mining-disturbed land reclamation includes a package of geotechnical, engineering and other activities aimed at recovery of the national economic value of the post-mining land.

The feasibility of the land use to be continued should be the governing factor of choice of a mining method and reclamation technique later on.

The reclamation effort estimation requires evaluating the volume of the post-mining pit and the overburden volume returnable into the pit at the stage of the open pit mine planning [1].

Reclamation planning needs a procedure of reclamation effort estimation after coal mining using the open pit method.

Figure 1 depicts this task at the early mine planning stage.

We limit our present research to the assessment of the overburden volume as the waste rock volume can be determined during processing with regard to the physical, mechanical and chemical properties of coal.

Pit void volume estimate

Let us discuss the reclamation effort estimation in open pit coal mining.

The main tasks in the open pit mining design and planning is the delineation of the open pit mining boundaries, substantiation of the schemes of getting access to mineral and mineral extraction, determination of mining advance directions, and evaluation of volumes of mineral, overburden and waste. The main parameters of an open pit are its limit and depth.

Reclamation planning needs information on the mined-out pit volume, the composition and volume of rocks usable in backfill of the pit void and some technological features of reclamation process.

The use of an open pit void is possible in truck-and-shovel mining with re-handling of overburden and its placement in the mined-out void, or in mixed-type mining with internal and external overburden dumping [7].

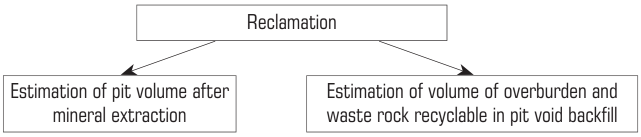

Fig. 1. Reclamation effort estimation procedure at early stage of mine planning

Parallel reclamation of a mined-out pit void includes filling of the void with current overburden rocks or with a reclamation agent composed of processing products of a mineral or waste. In this case, it is necessary that at least one pitwall is in the limit position and is free from any roads in operation. While backfilling the mined-out void and recovering the initial elevation of the terrain, the height of the fill may be increased to ensure the angle of slope in consistency with the chosen direction of reclamation [8].

The reclamation design uses the data from the mining project which is the basis for acquiring the mining lease, and for the mine construction and operation [1]. The total volume of rocks within the limits of an open pit is an important characteristic of the mine capacity and service life.

On the other hand, this volume of rocks is the volume of the pit. This information is important in reclamation as it defines the volume of rocks necessary to fill the mined-out void of an open pit mine after mining completion.

Rock volume (m^3) within an open pit limit, or the open pit volume can be expressed by Academician Rzhevsky in terms of elementary geometric figures of the known volume [9, 10].

$$V_{rock} = SH_{pit} + 0.5\frac{1}{2}\sum_{1}^{n} l_n H_{pit}^2 ctg\beta_n + \frac{1}{3}\pi H_{pit}^3 ctg\beta_{av}, \quad (1)$$

where S is the pit bottom area, m^2; H_{pit} is the pit depth, m; b_n is the slope of an n-th site in the pitwall, deg; l_n is the length of the n-th site in the pitwall, m; b_{av} is the average slope of the pitwall, deg:

$$\beta_{av} = (\beta_1 l_1 + \beta_2 l_2 + ... + \beta_n l_n)/(l_1 + l_2 + ... + l_n). \quad (2)$$

When the terrain is even, and the pitwall slopes are equal everywhere, or differ insignificantly, it is possible to find a sufficiently accurate general rock volume in an open pit, or the pit volume, from formula (3):

$$V = S_{pit}H_{pit} + \frac{1}{2}P_{pit}H_{pit}^2 ctg\gamma_{av} + H_{pit}^3 ctg^2\gamma_{av}, \quad (3)$$

where S_{pit} is the pit bottom area, m^2; H_{pit} is the pit bottom depth, m; P_{pit} is the pit bottom perimeter, m; γ_{av} is the average pitwall slope, deg.

Physical balance of rock

The calculated mass and volume of overburden rocks help estimate which part of an open pit will be occupied by overburden in backfill.

The physical rock balance procedure [1] favorably measures all rock components (mineral, overburden) using the same measures—kg/m^3 or t/m^3. All proposed criteria correlate with the stripping ratio.

Rock is a complex natural material. Rocks have a complex structure and a complex composition, and possess many properties that show up under various external impacts.

Only a part of extracted rock participates in the further technology process. Waste or overburden rocks can be left inside the pit or dumped externally, or both. The mineral itself can also comprise some waste rocks (host rocks) to be separated during processing and placed in tailings ponds, and can also be placed in the open pit void.

The modern science explores complex and multicomponent object, either natural or manmade, as well as complex natural and anthropogenic processes commonly using modeling.

The modeling method replaces a real-life object by its schematic representation created by a researcher's intelligence to image the most essential features of the original. Regarding processes, the approach is the same.

An object of the modeling is rock. The rock is a complex natural material composed of a mineral including a valuable component represented by coal, metal, etc. and waste represented by overburden and dirt rocks.

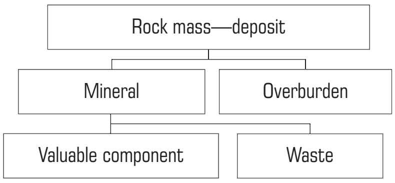

Fig. 2. Structural model of rock mass at mineral deposit

Figure 2 depicts a typical model structure of a deposit as a rock mass [11].

This model has three levels. The first (bottom) level is the waste rock and valuable component that can be coal, metal, etc. The second (medium) level is the mineral and overburden. The third (top) level is the rock mass at the deposit being mined, which integrates the matter from the first and second levels of the model.

The four basic tasks addressed by a mining company in its production activity include:

1) stripping to get access to a mineral and, thereby, to a valuable component;

2) extraction of a mineral (coal, ore, etc.);

3) separation of a valuable component and waste rocks;

4) removal of impurities from a valuable component, its treatment and conversion into an end product.

The first and second tasks are to be solved by the mining services of a company, and the third and fourth points are the tasks for the processing services.

Separation of rocks at a deposit to a mineral and waste should be undertaken with regard to the occurrence features and process properties of the mineral and waste rocks.

We use the structural model of a rock mass at a mineral deposit (see Fig. 2) as a framework for writing the equations below:

$$M_{rock} = M_{min} + M_{over} \quad (4)$$

and

$$M_{min} = M_{end} + M_{waste}, \quad (5)$$

where M_{rock} is the rock mass, t; M_{min} is the mineral mass, t; M_{over} is the overburden mass, t; M_{end} is the end product mass (size), t (the range of the end product may be very wide); M_{waste} is the waste rock mass.

The overburden rock mass can be set as a sum of masses of different rocks composing the overburden. A part of overburden rocks ($M_{over1\ i}$) can be used in backfill of the pit, and the other part ($M_{over2\ j}$) can serve the other economic purposes:

$$M_{over} = \sum_{i=1}^{n} M_{over1\ i} - \sum_{j=1}^{m} M_{over2\ j}, \quad (6)$$

where $M_{over1\ i}$ is the mass of an i-th rock returnable in the pit; i is the number of rock returnable in the pit; n is the quantity of rocks returnable in the pit; $M_{over2\ j}$ is the mass of a j-th rock serviceable for the other economic purposes; j is the number of rock serviceable for the other economic purposes; m is the quantity of rocks serviceable for the other economic purposes.

Then the general volume of overburden for backfilling is:

$$V_{over} = \sum_{i=1}^{n}(M_{over1\ i}/\rho_{over\ mass1\ i}), \quad (7)$$

where $\rho_{over\ mass1\ i}$ is the mass density of the i-th overburden rock returnable in the pit, t/m^3

or

$$V_{over} = \sum_{i=1}^{n}(M_{over1\ i}/\rho_{over\ bulk1\ i}), \quad (8)$$

where $\rho_{over\ bulk1\ i}$ is the bulk density of the *i*-th overburden rock returnable in the pit, t/m^3.

Usually, $\rho_{over\ bulk1\ i} < \rho_{over\ mass1\ i}$ owing to pores and voids generated in disintegrated overburden.

The disintegration factor is presented in **Table 1** for some potential rocks in coal fields [12, 13].

The values of the disintegration factors reduce with time.

The analysis of these data shows that in long storage (a conditional minimum is assumed as 4 months), the volume of a dump (a fill) composed of sand and gravel shrinkages by self-compaction by 10% approximately, and the volume of a strong rock dump reduces by 25% [12, 13].

For a more accurate estimate of the rock volume returnable in the pit, it is necessary to take into account the other properties of rocks, for example, rock alteration due to moisture [13].

Water-soaking rocks are sandstone, siltstone and coal, and the main water accumulators are sandstone and thick coal seams [12, 13].

Water-swellability of rocks is the highest in coherent (clayey) rocks as follows from the data in **Table 2** [12, 13]. After total water saturation of clayey rocks, their volume can increase by 1.5–2.0 times. Sandstone, siltstone, mudstone and their partings swell poorly. The swelling factor of these rocks is as a rule under 0.8–1.0% by volume.

Hard and strong rocks display almost no swelling in moistening under positive temperatures. Under negative temperatures, these rocks may swell as the total volume of moisture (unfrozen water and ice) during freezing grows (water has the specific volume $V_w \approx 10^{-3}$ m^3/kg and ice—$V_{ice} \approx 1.1 \cdot 10^{-3}$ m^3/kg) [12, 13].

Table 1. Initial and residual disintegration factors for some rocks

Rocks	Disintegration factor	
	Initial	Residual
Sand and gravel	1.1 – 1.15	1.01 – 1.015
Loam	1.20 – 1.25	1.02 – 1.04
Chalky clay	1.25 – 1.30	1.04 – 1.05
Hard clay	1.30 – 1.35	1.06 – 1.07
Strong rocks	1.35 – 1.40	1.08 – 1.15

Table 2. Swelling ratios of sandy–clayey rocks

Rocks	Swelling ratio
Heavy viscous clay	2.0–1.5
Ordinary plastic clay	1.5
Heavy loam	1.5–1.45
Medium loam	1.45–1.20
Light loam	1.20
Medium sandy clay	1.5
Sandy clay	1.15–1.05
Sandy silt	1.10
Clayey sand	1.10–1.05
Sand	1.0

Conclusions

The coal mining industry is booming in Russia, and it is necessary to plan the post-production future for a few dozens of years ahead. In this case, the industry will stand to win and succeed in fruitful transformation.

This approach to be effective calls for the long-term planning. A reclamation plan and, accordingly, the reclamation scope should be elaborated before starting mining operations, in accord with the needs of a certain region, to be successively implemented later on. Unfortunately, as experience shows, such approach is absent in the Russian reality [14, 15].

The structural rock mass models described in this study enable the maximum possible use of overburden and waste rocks in reclamation of the open pit mine areas.

The reclamation effort estimation at the stage of a technical design of mineral mining can help select the most rational decisions concerned with both mineral mining itself and with the mining-impacted land reclamation conformable to the Federal Law on the Subsoil [1].

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