EVALUATION OF THE POSSIBILITIES FOR SUSTAINABLE EXPLOITATION OF A DEPOSIT FOR KAOLIN AND SILICA SANDS

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ABSTRACT. The article reviews the development of an existing open-pit mine for kaolin and silica sands. The possibilities for the development of the pit have been considered for a period of 10 years. The key parameters for the efficiency of the open-pit mine have been determined according to the specific conditions of the deposit and the location of the pit. A solution for the development of the open-pit mine has been proposed.

Keywords: open-pit mining, kaolin-silica sands

ОЦЕНКА НА ВЪЗМОЖНОСТИТЕ ЗА УСТОЙЧИВО РАЗВИТИЕ НА МИИНИТЕ РАБОТИ В НАХОДИЩЕ ЗА КВАРЦ-КАОЛИНОВИ ПЯСЪЦИ

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РЕЗЮМЕ. В настоящия материал е разгледан съществуващ открит рудник за добив на кварц-каолинови пясъци. Разгледани са възможностите за продължаването на неговото разработване за период от 10 години. Формулирани са ключовите показатели, определящи ефективността на откриния рудник, съобразени с неговите специфични условия. Предложено е крайно решение за развитие на минните работи.

Ключови думи: открит добив, кварц-каолинови пясъци

Introduction

In order to choose a suitable mining technology for extracting certain mineral resources the key factors which determine the efficiency of the mining process must be considered. In the current paper the possibilities for maintaining a stable mining process in an open-pit mine for kaolin and silica sands for the next 10 years has been researched. The deposit is situated in the northern part of Bulgaria and has certain important limiting conditions which lead to a unique problem and a unique solution which can, however, be considered as typical for a conventional non-metallic open-pit mine.

Factors which affect the choice of mining technology

The main goal for achieving an optimal mine design is to establish a link between the surface and the layers of kaolin and silica sands while maintaining the volume of excavated overburden as low as possible. In order to achieve the goal, several main factors which affect the choice of the mining technology for extraction have to be pointed out:

- the terrain of the mined area;
- the area which is planned for mining;
- the annual output for the pit;
- the shape of the deposit;
- the mechanical properties of the rocks;
- the height of the benches;
- the climate conditions;
- the annual strip ratio.

First of all, the terrain has a mild slope of around 4°and stretches over 72000 m^2. Therefore, this does not require any special preliminary preparations for the utilisation of the conventional mining equipment for similar non-metallic deposits (excavator, mining trucks and bulldozer). Furthermore, the shape of the deposit is near-horizontal and stretches all around the boundaries of the deposit. However, the depths of the overburden and the silica sands vary from 9 m to 15 m across the boundaries of the deposit. According to the geological surveying some neighbouring layers of silica sands vary in their depth due to the inclusions of sandstones.

Based on the overall geological report on the deposit, an annual production of 30 000 m^3 kaolin and silica sands has been established for a period of over 30 years. Until this moment the open-pit mine has been in exploitation and will further be exploited. In the current paper a different part of the deposit is considered to be mined in order to open up a new mining surface and to maintain the level of the annual output.

The mechanical properties of the rocks are as follows:

- cohesion – $C = 35.10^5$ Pa;
- angle of internal friction – $\varphi = 25°$;
- density (kaolin and silica sands) – $\gamma = 1900$ kg/m^3.

For that purpose, the current height of the benches is 6 m and the slope angle is 55°.

According to the past experience of exploiting the deposit, two more key factors which influence and limit the further development of the pit can be pointed out:

- Slope stability;
- Limited area for overburden storage.

Maintaining a low volume of overburden due to the limited storage also achieves another benefit from the technological solution – lower costs for overburden extraction and storage.

For maintaining the desired level of stability it is recommended that the highest value of the slope angle for the pit should be 55°. Although the stability coefficient is greater than 1.5 this slope angle is based on the experience in similar pits and on past experience. Furthermore, this slope angle guarantees the stability on a longer-term scale, including during the winter season and during snow meltdowns.

For each case the width of the working bench is considered to be 20 m. In addition, the width of the transport ramps is 7 m which ensures the safe passage of one truck as the truck fleet for each shift consists of only up to three trucks.

Parameters of efficiency

In order to make a grounded decision for the further development of the pit, certain parameters of efficiency have to be established (Bosnev et al., 2018). In order these parameters to be established in an adequate manner, they have to reflect the economic and technological side of the problem. For this reason, the three key parameters of efficiency, which should be considered when choosing the mining technology, are:

- The volume of overburden required for extraction, m^3;
- The volume of estimated loses of the mineral resource, m^3;
- Transportation distances for overburden storage, m.

In addition, a secondary parameter of efficiency can be added in order to measure how the mining fleet is utilised fora period of 10 years by applying the variance coefficient for the overburden ration for the different years (Bosnev, Kaykov, 2018). It is important to notice that this parameter gives only a basic information how stable the volumes of overburden are during the open-pit mine development and it has to be used only as a further argument for the decision.

The specific conditions for the deposit have shown that very little can be achieved via interchanging the values of the slope angles for the pit or the overburden storage facility due to the smaller size of the pit. Hence, this requires a different type of solution regarding the choice of a mining technology. For this purpose, three scenarios have been considered for establishing the desired results.

The first scenario utilises the area of the previously used pit for storing the overburden, while the second and third scenario utilise the old pit for removing the overburden and reaching the silica sands.

Scenario 1

The first scenario deals with the problem of the limited space for dumping the overburden.

The utilisation of the old open-pit mine ensures an area of about 17 000 m^2 for overburden storage. The entry point to the pit is situated as close as possible to the road leading to the overburden dump. Table 1 shows the four parameters of efficiency.

Table 1. *Parameters of efficiency for Scenario 1*

Total volume of overburden, m^3	Volume of estimated loses, m^3	Average distance to overburden stockpile facility, m	Variation coefficient of the overburden
429 600	13 500 (4.5%)	250	0,285

Furthermore, the direction of development of the pit is situated perpendicularly to the direction of the slope. Table 2 shows the different volumes of extracted silica sands and overburden, as well as the strip ratio.

Table 2. *Volumes of overburden for Scenario 1*

Year	Volume of overburden, m^3
1	62 280
2	41 520
3	48 600
4	32 400
5	36 720
6	24 480
7	46 080
8	30 720
9	64 080
10	42 720

Figure 1 is a general representation of the designed position for the 10th year of exploitation. The light-coloured lines represent schematically the position of the toe of the bench level 36.

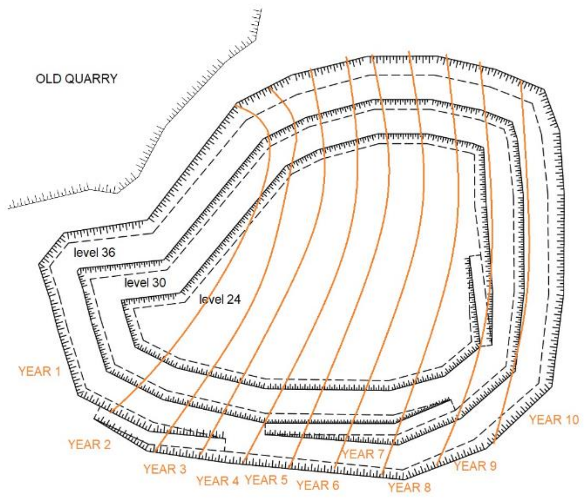

Fig. 1. Approximate annual development of the open-pit mine for reaching the design contour at year 10 in Scenario 1

The most important conclusion of this scenario is that the volume of overburden from the initial stages of the period of 10 years is the biggest as the closest entry point to the overburden dump is situated where the higher parts of the terrain are situated.

The variation coefficient has a low value, which means that the mining fleet will be utilised in an efficient manner during the 10-year period.

Scenario 2

The second scenario deals with the problem of reducing the required area for storing the overburden, especially during the later stages of the development of the pit. Furthermore, the direction of the pit development is parallel to the direction of terrain rising. The old open-pit mine is utilised as an entry point to the new boundaries of the pit. During the initial stages the volumes of overburden are slightly lower than the ones from Scenario 1, leading to a lower required space for the dump. Furthermore, the extracted space in the pit is used for storing a bigger part of the overburden. Table 3 shows the four parameters of efficiency.

Table 3. *Parameters of efficiency for Scenario 2*

Total volume of overburden, m³	Volume of the blocked mineral resource, m³	Average distance to overburden stockpile facility, m	Variation coefficient of the overburden
676 500	16 200 (5.4%)	70	0,288

Table 4 shows the volumes of overburden, extracted sands and the strip ratio for the period of 10 years. The variation coefficient is also high in this scenario and slightly differs from scenario 1.

Table 4. *Volumes of overburden for Scenario 2*

Year	Volume of overburden, m³
1	114 135
2	76 090
3	73 900
4	49 265
5	70 615
6	47 075
7	72 805
8	48 535
9	74 450
10	49 630

Figure 2 is a general representation of the designed position for the 10th year of exploitation. The light-coloured lines represent schematically the position of the toe of the bench level 36.

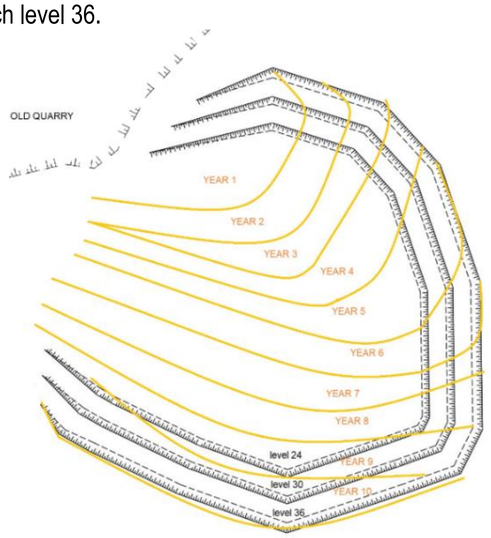

Fig. 2. Approximate annual development of the open-pit mine for reaching the design contour at year 10 in Scenario 2

Scenario 3

The third scenario is a modification of Scenario 2, however, they differ in the direction of the pit development. In Scenario 3 it is parallel to the direction of the slope. Table 5 presents the parameters of efficiency for this scenario.

Table 5. *Parameters of efficiency for Scenario 3*

Total volume of overburden, m³	Volume of estimated loses, m³	Average distance to overburden stockpile facility, m	Variation coefficient of the overburden
676 500	10 200 (3.4%)	70	0.466

Table 6 presents the volumes of overburden, silica sands and the strip ratio for the 10-year period.

Table 6. *Volumes of overburden for Scenario 3*

Year	Volume of overburden, m³
1	140 580
2	93 720
3	74 520
4	49 680
5	46 260
6	30 840
7	54 000
8	36 000
9	90 540
10	60 360

Figure 3 is a general representation of the designed position for the 10th year of exploitation. The light-coloured lines represent the position of the toe of the bench level 36.

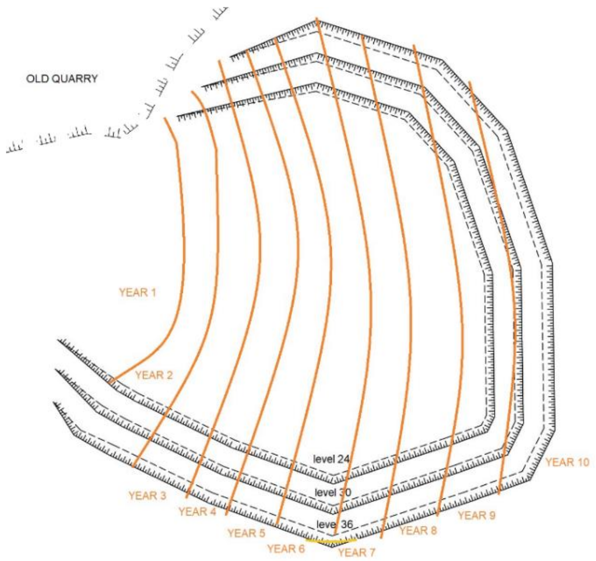

Fig. 3. Approximate annual development of the open-pit mine for reaching the design contour at year 10 in Scenario 3

It is important to notice that the slope of the old quarry ceases to exist after the 10th year due to the mining operations starting for the old mining site. The slope of the quarry on figures 2 and 3 is just for illustration.

Conclusions

From the consideration of the three scenarios, the following conclusions can be made:

- The direction of the pit development leads to the different volumes of overburden during the 10-year period.
- The variation coefficient indicates that in each scenario the utilisation of the mining equipment will be different during the different years. This could be further adjusted in order to maintain a more stable work flow on an annual level.
- The variation coefficient can prove to be an informative parameter for the steadiness of the process on a strategic level as the total volume of overburden will be excavated. The differences that occur apply only to the mining sequence which leads to the bigger variations in the output flows.
- Scenario 1 may not be entirely better than Scenario 3, but it provides a good short-term solution for the development of the pit.
- However, if the open-pit mine is to be exploited during a full 30 to 35-year life span, then it would be wiser to adjust the output of overburden for Scenario 3 in order to minimise the transportation costs, as well as to limit the volumes of loses.
- The scenarios which utilise the extracted space within the current pit for storing the overburden are related not only to shorter distances for dumping the overburden, but also to the lesser environmental impact.

References

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