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BENCH HIGHT AND SLOPE ANGLE ON LITHIUM ORES OPEN PIT MINES

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ABSTRACT

The fundament of the open pit geometry, both, on metallic and non-metallic mineral raw materials, consists of benches that allow mining operations to be carried out in the contour of the open pit mine. On lithium pit mines, formed benches of a certain height and slope angle, must ensure physical stability of the open mine pit and smooth running of mining work to excavate, load and transport the overburden and mineral resources out of the contour of the lithium open pit mine. The bench height and slope (bank) angle depend on the geotechnical situations, water impact and conditions of utilizing mining mechanization in digging, loading and transporting the overburden and mineral raw material.

Key words: lithium, open pit mine, bench height, bench slope angle

1. INTRODUCTION

Open pit mine geometry is based on the concept of stability of the working area in which the mining operations take place, regardless of the type of ore being excavated. Surface mines are mining facilities that develop in all directions - horizontally and vertically, according to a certain procedure. The basic rule is that works on pit deepening (vertically) can only be realized if the prerequisites for expanding the works at higher levels – benches (horizontally, regardless of the advancing direction) have been met. The open pit development creates the open pit crater (inverted truncated cone) and its contour. The expansion of the works involves the construction of working benches where overburden and mineral raw materials are dug with mining machinery, and the excavated material is transported either to the overburden waste dump or to the mineral raw material landfill or to mineral processing plants. Depending on the characteristics of the rock mass where the lithium ore is integrated, technological processes, among other aspects, impact on the calculation of the bench height and slope. In the case of a loose rock working environment, the material on the bench is dug and loaded with mining machinery, and in the case of solid rocks, the process of drilling and blasting the rock mass is applied, followed by loading into the heavy trucks. Since the diversity of the geological structure of the lithium ore deposit, it is applied surface mining with the deepening to the ultimate pit depth, i.e. to an economically profitable digging depth. The deepening of the surface mine is designed and worked out according to the geometrical analysis results, with primary emphasis on the characteristics of the benches, as well as the characteristics of the ultimate pit slopes, transport paths, mine drainage and other elements in the contour of the open pit mine.

2. BENCH CHARACTERISTICS AT THE LITHIUM ORE OPEN PIT MINE

The surface mine floor represents the area where overburden and lithium ore are dredged. It is characterized by the volume of the block that is excavated at the floor level, and the block (in m3) is defined by the height of the floor, the angle of inclination of the floor and the width of the catch, i.e. the digging radius of the excavator digging the material.

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The layout of floors in the open pit contour is determined by geometric analysis or software methods based on the Lerchs-Grossmann, or similar, algorithm. The prerequisite for surface exploitation is that the floors are stable and that the slope of the floors does not collapse. There are three global influencing factors on slope stability: geological and engineering geological, hydrogeological and mining-technical.

2.1 Geotechnical stability of bench slope

The geotechnical stability of the bench slope primarily depends on the lithological composition of the rock mass, rock strength, fractures and distribution layer structure of the material. Disturbance of geotechnical stability results in the bench failure by sliding of material in the bench slope, which can cause human casualties, injuries to workers, damaging mining machinery and stoppage of production processes until the bench / benches are reconstructed and the collapsed material is replaced. The duration of the reconstruction mining works depends on the number of destabilized benches and the sliding surface width. For failure of one bench, reconstruction takes about 7 days, and in case of sliding of several benches (which also happens during the exploitation of lithium ores), reconstruction takes several months.

At Rio Tinto's borates and lithium open pit mine (picture 1), located 145 km from Los Angeles, USA, in 1998, the sliding of benches caused collapse of about 39 million tons of rock material, which had significant multi-year negative impacts on mining operations in the open pit mine. The causes of bench sliding were the bench geological structure, the influence of underground and surface water and to steep bench slopes[3].

Figure 1. Landslide at the Rio Tinto open pit mine in the Mojave Desert in the Kern region near Los Angeles in 1998

In the literature, authors specify a number of mineral deposit groups and subgroups classifications in accordance to the slope stability, and lithium ore deposits (suitable for open pit mining) are composed of hard rocks[4] with the strength from 800 N/cm^2 to 8000 N/cm^2 and unconsolidated rocks whose strength is less than 800 N/cm^2. Data of the rock strength are obtained through laboratory testing of the physical and mechanical rock properties. As a result of the disturbance of the bench slope stability, sliding of the rock mass of the bench slope occur, and the sliding types are classified according to the spatial movement of masses - sliding surfaces from the higher level of the bench to the lower one, and all the way to the bench floor where digging and transport are carried out. In order to preventively act, slope stability monitoring and analyses are carried out for different types of fracture surfaces and for the designed bench height and slope angle.

[3] Nutakor D., Asbury N., Zavodni Z., Back analysis of Rio Tinto Borates and Lithium Mine north wall failure, konferencija Slope Stability 2022, Tucson, SAD, 2022.

[4] Popović N. Naučne osnove projektovanja površinskih kopova, poglavlje 2, Sarajevo, 1984.

2.2 Mining machinery

The sequence of technological processes at the open pit mine is determined with the aim of extract the considered mineral raw material or dig-out the overburden. Technological processes include drilling and blasting (in case of hard rocks that cannot be excavated by mining machinery), digging, loading and transportation. Digging is done with dig bucket excavators (hydraulic bucket excavators or rope electric shovels), which at the same time load the excavated material into transport vehicles (most often a truck).

Bucket shovels are produced with an electric drive, and in rare cases they have a diesel drive engine - if they are smaller excavators with a bucket volume of 3 to 4 m^3. They can dig in material from loose to very hard and abrasive rock. At lithium ore open pit mines, it is expected that the same mining machinery (excavators and trucks) will be utilised for digging and transporting overburden and for digging and transporting mineral raw materials.

Digging is usually done from the ground standing level of the excavator, i.e. on the bench ground, and in such case, hydraulic bucket excavators with a shovel loading bucket - classic or bottom dump buckets are applied - picture 2. If digging is done below the ground level (so-called downward digging), then hydraulic bucket excavators with an inverted bucket, often called backhoes, is applied - picture 3. Hydraulic excavators can dig along a variable digging trajectory chart, and the dimensions of the digging reach depend on the manufacturing i.e. technical and technological excavator's performances.

Figure 2. Loading material into a truck with a hydraulic excavator with a folding bucket

Figure 3. Loading material with a hydraulic excavator with an inverted bucket into a truck - bottom digging

Figure 4 shows a classic combination of a hydraulic excavator with a bottom dump bucket in the start position for digging the bench and discharging rock material into the truck, as well as the digging trajectory chart. The unit proportions of the excavator, whose bucket volume is 16 m^3 and the position of the associated truck, show the performance of digging depth and height and digging reach (ft, m). The example shows the efficiency of digging 11.5 m hight of the bench[5].

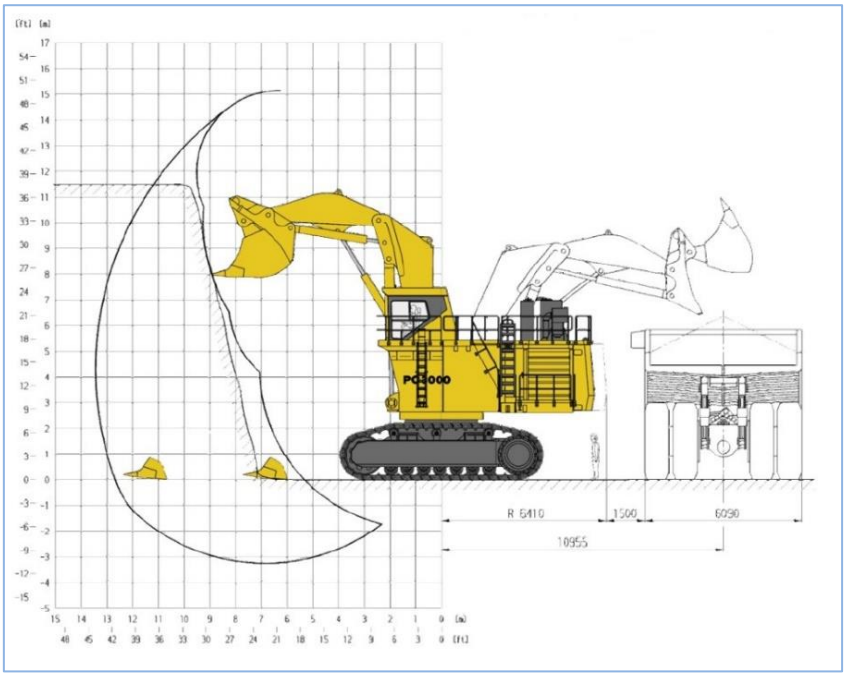

Figure 4. Hydraulic excavator performances for a bench height of 11.5 m and the associated truck capacity of 165 t

The bucket shovel digs exclusively at the ground level of the excavator, utilizing bottom dump buckets. The operating layout is very similar to digging with hydraulic bucket excavators (working in a block, loading into a truck), and they have an arc form digging trajectory chart. Although they use steel ropes to control the working organs, decades of experience in the operation of shovels, have shown that this type of excavator is extremely durable, reliable, with a low number of downtimes and have low maintenance costs. The bench hight digging depends on the technical and technological performance of the shovel, and the usual bench height is up to 16 m.

Figure 5. Loading of material with a rope shovel into a truck

[5] Catalogue Komatsu hydrulic excavator PC3000 capacity 16 cu.m.

Figure 6 shows the classic combination of a shovel in the digging position and discharging excavated materials into the truck, as well as the arched digging trajectory chart. The unit proportions of the shovel, whose bucket volume is 16 m^3 and the position of the associated truck, show the performance of digging depth (up to 1 m) and digging height (16.3 m), digging reach of 24.5 m and bench height of 12.2 m.

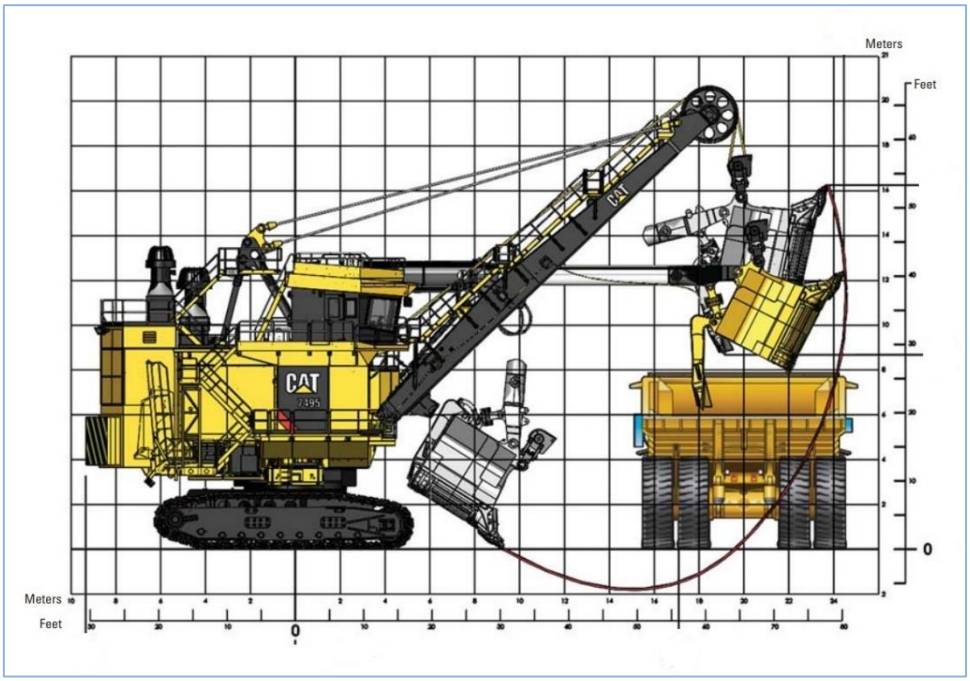

Figure 6. Performance of the shovel for a maximum bench height of 12.2 m and the associated truck

2.3 Bench parameters without blasting

The bench parameters without blasting are the hight, slope and length of the bench. Two groups of parameters influence the choice of bench height in a lithium ore open pit mine - basic and secondary.

a. Basic parameters
   - geomechanical characteristics of the rock massif where lithium ore is mined,
   - the presence of water in the massif and
   - (maximum) excavator's digging height.

b. Secondary parameters
   - the rock strata formation,
   - deposition of lithium ore deposits,
   - the direction of mining front advance,
   - advancement of the mining block excavation in relation to the deposit's strike and dip.

Taking into account the digging height of the bucket excavator, variable bench heights can be considered, depending on the technical-technological performance of the excavator. From the point of view of the available mining equipment and transport conditions, it is advisable to choose a higher bench height, since in this case the number of benches, the number of equipment shiftings and the time of shifting equipment along the benches, the length of transport is shortened (transportation cost takes up to 60% of the mining costs[6]), which in any case results in cost reduction, i.e. increasing the profitability of lithium ore exploitation. On the other hand, in working environments where selective mining is applied, i.e. where is nonstandard or scattered disposition of minerals in the deposit, which is usually the case with lithium ores, then a more acceptable option is lower bench heights. It is expected that the bench height in lithium

[6] https://www.linkedin.com/pulse/cost-calculations-mine-planning-shyamal-bag

ore open pit mine does not exceed 12 m and that the bench slope angle ranges from 70^0 - 80^0. The bench length, i.e. horizontal length of the working benches of the pit mine, depends on the length of the mining front operations, however, it is limited by the horizontal dimension of the pit contour and the positions of the ultimate pit slopes at the mine.

In an intention to work with higher bench heights, the potential risks that occur when digging with the full - maximum digging height of the excavator must be taken into account. The first risk is the collapsing of rock material positioned near the top of the bench, and the second risk is the suddenly reduced digging force when the excavator bucket exits the bench slope.

The optimal bench parameters at the lithium ore open pit mine are shown in Figure 7, which is not a rule because the bench parameters depend on several influential factors that were previously discussed. The example illustrates a bench height of 10 m, a bench slope angle of 70^0 to 80^0 and a block width of 10 m. The bench height, for example, is synchronised with the technical and technological parameters of the hydraulic excavator (for example RH 75 - 7.6 m^3 to 10 m^3 bucket volume) which digs and discharge the rock material, and the truck (for example FAUN 85.5 - capacity 77 t) that after loading, transports excavated material. The compatibility of the excavator-truck system refers to the capacities of the excavator and the load capacity of the truck, the physical sizes of the machines and the excavator's operating parameters, which is a matter of special calculation procedure. On average, for a complex with the specified performance, the excavator performs loading / discharge in 8 cycles, which takes about 5 minutes in total. The picture 7, cross-section A-A, shows the influence of the change in the bench slope angle (slope angle option 70^0 and 75^0) on the position of the associated excavator's digging trajectories charts that excavates a 10 m bench high at ground level.

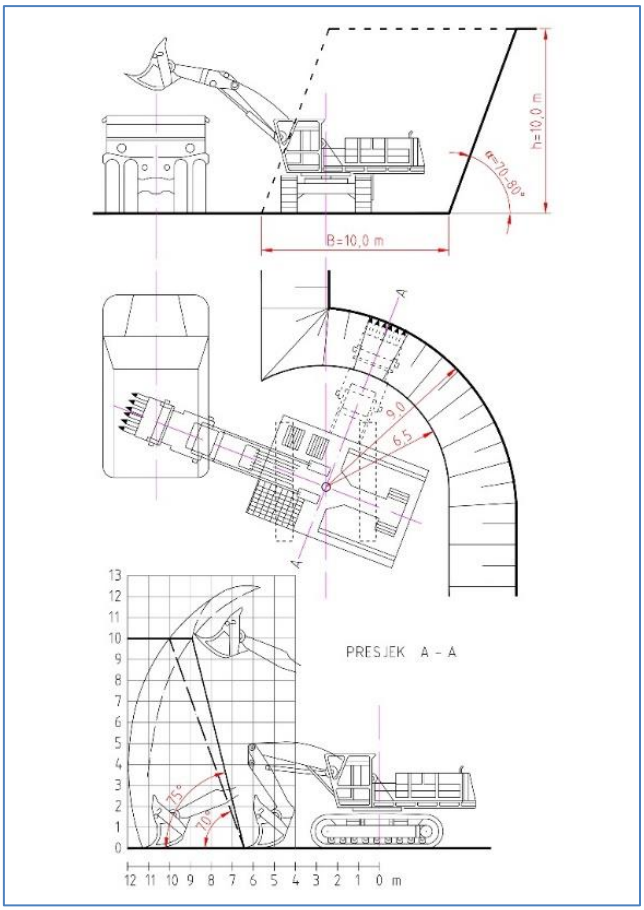

Figure 7. Bench parameters, mechanization position and digging trajectories chart for different bench slope angles

2.4 Bench parameters with blasting

Blasting by explosive on the benches can be done for the presplit blasting the material that will be subsequently excavate by mining machinery, or by production or secondary blasting, when the bench turns

from a solid monolithic status into an incoherent mass consisting of different granulations of pieces of the rock massif. The parameters of the bench that are blasted for presplitting differ slightly from the parameters of the bench that are excavated by mining machinery.

The bench parameters with production blasting of the rock massif are the bench height, the bench slope angle and the bench length, and after blasting, the width of the collapsed material at the face. Three groups of parameters influence the bench hight selection at a lithium ore open pit mine where drilling and blasting operations are needed.

a. Basic parameters
   - geomechanical properties of rock mass being blasted.

b. Secondary parameters
   - performance of the excavator for loading (digging) broken mass and discharge the material into the truck,
   - safety distances of blasted material pile from transport communication,
   - the rock strata formation,
   - deposition of lithium ore deposits,
   - the direction of mining front advance,
   - advancement of the mining block excavation in relation to the deposit's strike and dip.

c. Parameters of drilling and blasting works
   - characteristics of the surface blast patterns (spatial distance between boreholes),
   - blast hole depth and hole inclination and
   - type of explosives charges and method of filling the blast hole (with tamping and intermediate filling the hole with clay).

Calculation of drilling and mining works on the bench is a special engineering calculation procedure.

After the blasting process, the original bench height is reduced due to spreading - sinking of the broken material towards the free surface of the bench slope, and this directly increases the working area width, and thus the bench block. The minimum bench height should meet the condition that the excavators' bucket can be filled in one pass - filling from the bottom up, which primarily depends on the excavators' performances and the stability of ground floor where the excavator discharge rock mass. Blasted material is loaded with excavators (at the ground level) into trucks. During the lithium ore exploitation, carried out in hard rocks, where the drilling and blasting processes are unavoidable, the fundamental bench parameters consider the bench parameters before blasting rock mass.

CONCLUSIONS

Lithium ores open pit mining is based on the pit mine geometry, which is primarily defined by the bench height and the bench slope angle in the contour of the pit mine. Three groups of influential factors impact to the calculation of the bench height and bench slope angle. Those are geotechnical conditions of the working environment, the presence of groundwater and surface water and the performance of digging - loading and transport machinery. The usual combination is digging and loading rock material with shovels into trucks, whose technical and technological performances allow digging the optimal bench height of 10 m, the bench slope angle of 70^0 to 80^0 and the related block width of 10 m, within the condition that excavation is performed at the ground level of the excavators. The bench length is limited by the position of the mining front in-between one final pit slope of the final pit slope at the opposite end of the mine. Engineering calculations for specific working conditions and for the specific mining mechanization applied, results in the precise open pit mine geometry for lithium ores, i.e. precise values of bench height and slope angle, block width and bench length.

REFERENCES

1. Ausenco Services Pty Ltd, Technical report on the feasibility study for the Sonora lithium project in Mexico, South Brisbane, Australia, 2018.
2. Balasubramanian A., Rock blasting for mining, Technical Report, Centre for Advanced Studies in Earth Science, University of Mysore, Karnataka, India, April 2017.
3. Gandhi R.K., Estimating bench design parameters for open-cut excavation, Masters thesis 5639, School of Mines and Metallurgy of the University of Missouri, Missouri, SAD, 1964.
4. Knežiček T., Computer aided opencast mine planning for steeply dipping bedded deposits, Master thesis, Indian School of Mines, Dhanbad, India, 1989.
5. Knežiček T., Nurić S., Osnove površinske eksploatacije mineralnih sirovina, Tuzla, 2015.
6. Kose H, C.O. Aksoy, A. Gönen, M. Kun, and T. Malli, Economic evaluation of optimum bench height in quarries, The Journal of The South African Institute of Mining and Metallurgy, February, 2005.
7. Laurich R., Planning and Designing of Surface Mines, Surface Mining 2nd Edition, SME, Kennedy B.A. editor, Baltimore, 1990.
8. Nutakor D., Asbury N., Zavodni Z., Back analysis of Rio Tinto Borates and Lithium Mine north wall failure, conference Slope Stability 2022, Tucson, SAD, 2022.
9. Popović N., Naučne osnove projektovanja površisnkih kopova, NIŠRO Oslobođenje, Sarajevo, 1984.
10. Simonović M., Bageri I, Beograd 1987.
11. Web https://bacanoralithium.com/sonora_lithium_project/default.aspx - the World largest lithium open pit mine.
12. Web https://www.linkedin.com/pulse/cost-calculations-mine-planning-shyamal-bag - transport cost in the total mining cost.