Cut winnings methods of an open-pit mine development

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Prierez vývoja dobývacích metód povrchových baní

Surface mining is an extremely significant process of acquisition of a substantial amount of minerals serving the needs of human society. The open-pit mining process is characterized by horizontal removal of a huge amount of blasted rock. The deposit is often mined in several horizontal sections. The deposits may be mined via so-called shelf quarries, which are quarries created in the hill slope or via so-called pit quarries where the quarry is established in the terrain lacking the camber and the quarry is "deepened" in the depth direction by gradual mining. A combined way is also possible, when after the initial mining in the shelf quarry, mining continues to altitudes under the surrounding level.

***Key words:** open-pit, mining project, cut winning, transport*

Introduction

The development of an open-pit quarry represents a summary of winning operations and other works which implement the development and transport connection of working and delivery points on the terrain surface.

General conditions of development

After the implementation of the geometric analysis of an open-pit quarry and the selection of an optimum variant, the development of an economic mineral deposit begins. Basic criteria for the selection of a manner of development are as follows:

- minimum volume of development operations,
- minimum investment stripping,
- transport as short as possible,
- as short a period of quarry construction as possible.

The following factors shall be taken into consideration during the selection of a development place:

- terrain configuration,
- size of the open-pit quarry,
- type of economic mineral,
- geotechnical parameters of stripping and economic mineral,
- investment intensity of mining,
- final contour of the open-pit quarry (preliminary).

The terrain configuration is an important factor in terms of use, organization of operation as well as intensity of economic mineral mining, which is an important part of the technological process. The terrain configuration can be:

- hilly,
- sloped,
- flat.

The volume of open-pit mining determines if the development is carried out via:

- one,
- several development workings.

Depending on the position of the economic mineral, i.e. depending on the depth of the deposit, the development workings are built:

- at the beginning of quarry construction,
- during the mining process.

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(Recenzovaná a revidovaná verzia dodaná 15. 6. 2007)

Geotechnical parameters – properties of rock material and massif (strength, hardness, humidity, internal friction etc.) play an important role during the implementation of winning operations (terrain gradient, volume of natural material, quality of material etc.) [1, 9].

The investment intensity of mining is an important factor of the necessary capital for constructing an open-pit mine. It amount and value depends on the development point of open-pit mining.

The final contours of an open-pit mine influence the length of transport routes and the number of development points. There are further factors influencing the selection of the development working place including:

- external conditions,
- objects of economic mineral processing,
- dumpings (waste dumps),
- related industrial operations,
- connection to the railway, etc.

The issue of the object location is most often dealt with via a variational method while observing the following criteria:

- maximum use of areas of non-fertile land (during localization of dumping and objects on the surface),
- minimum transport distances,
- minimum works during construction of infrastructure.

The transport has a decisive influence during calculation of costs of mining intensity in the price structure per one m^3 of the economic mineral as well as during the selection of the development place [4].

Apart from the stated basic criteria the following factors also influence the development place selection [1, 2]:

- sanitary conditions, distance of residential quarters, processing objects (noise, dust etc.),
- border of dangerous zone in terms of seismicity (in case of blasting works),
- border of piece spreading (during blasting),
- wind mode (direction and speed of wind).

The development of technology enables us to increase the depth of open-pit mining on the basis of which the stope changing the quarry contour is replaced (the open-pit mining which penetrates into the depth and where the excavation limiting coefficient k_{hr} can be shifted by the technology development) [10].

The development of transport technology currently enables the technological overcoming and economic maintenance of irrational transport distances. It is necessary to observe this factor in the case of horizontal, slightly sloped deposits and during the stage building of workings [3].

Methods of cut winning

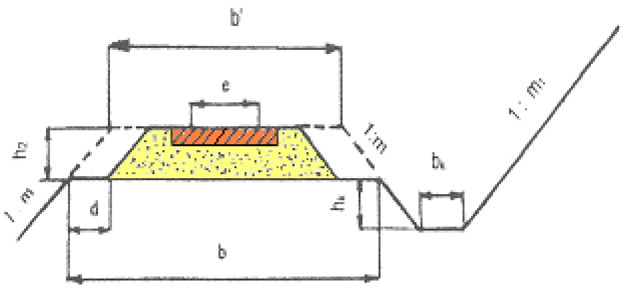
The appropriate technology shall be used depending on the use of a cut and its volume (the mass to be mined). The speed and dynamics of an open-pit mine construction depends on the speed of making development and preparatory cuts. The size of cuts depends on the used technology, geomechanical properties of minerals and their purpose [8].

The development cut width b (Fig. 1) in terms of transport conditions (for railway transport) is determined by the relationship:

$$b = b' + 2mh_2 + b_k + 2m_1 h_{K_1} \quad , \quad m \qquad (1)$$

b – cut width [m],
b' - subbase width (transport route) [m],
$1{:}m$ – subbase surface gradient
b_2 – subbase thickness [m],
b_k – channel width [m],
$1{:}m_1$ - cut inclination,
h_k – channel width [m],
e – platform width [m].

In a similar way the cut width for automotive transport is determined.



The second important condition for the determination of a cut width includes the use of mechanisms for the development, i.e. the appropriate technology.

Fig. 1. Determination of a cut width for railway transport [10].

Selection of technology for the cut implementation depends on:

- a section size,
- geological/geomechanical parameters,
- possibilities of mineral stowing (waste rock),
- implementation time.

Methods of cut winning are as follows:

- transportless method
- transport method
- cut winning with excavators with continuous working cycle
- special methods of cut winning.

Transportless method of cut winning

It is used in cases where the mined rock can be stowed along the cut. The cut shall be won with the following mechanisms:

- draglines,
- shovel excavators (less often).

The excavator position to the cut axis at work can be:

- *along the cut axis*, the excavator is located on one side of a cut (laterally) where it stows the mined mineral (Fig. 2),

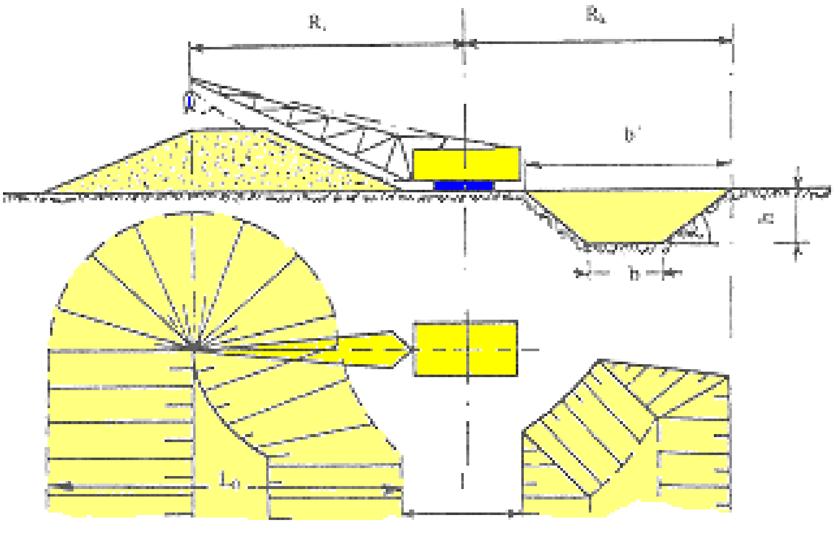


Fig. 2. Cut winning with a dragline including earth deposit on one side of the cut [1].

b-cut floor width, b-cut width at the top, h-cut depth, r1-diameter of excavator discharge, r2-diameter of excavator mesh, L-distance between the mining waste dump and a cut, α-cut slope gradient angle.

- *in the cut axis*, the excavator is located on a cut front and places the mineral on both sides. The excavator may change its position in a loop way depending on the side to which the mineral is stowed (Fig. 3).

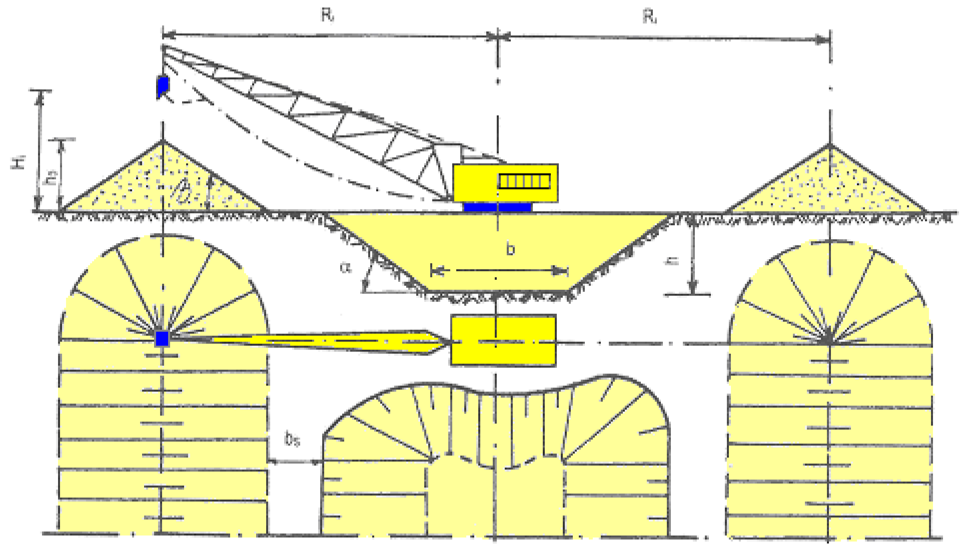


Fig. 3. Cut winning with a dragline located in the front and earth deposit on both sides of a cut [1].

H1-height of discharge, ho-height of waste dump, β- mining waste dump slope angle, α – cut slope gradient angle, bs –safety distance between the stowed material and a cut.

During cut winning with draglines (dragline excavators) the cut size is limited by the working excavator parameters. The cut depth h shall not exceed the maximum mining depth h_{kmax} and the height of the mining waste dump h_0 shall not exceed the maximum height of discharge h_{imax} (Fig. 2, Fig. 3):

$h \leq h_{kmax},$,

$h_o \leq h_{imax}.$.

In the case of double-side stowing the excavator discharge semi-diameter R_i (Figure 3) is determined by the relationship:

$$R_i > \frac{b}{2} + hctg\alpha + b_s + h_0 ctg\beta, \quad m \qquad ...(2)$$

b – cut bottom width [m],
h – cut depth [m],
α – cut slope gradient angle [°],
b_s – safety distance between the stowed material and a cut [m],
h_0 – height of the mining waste dump [m],
β – mining waste dump slope angle [°].

Depending on the relief, cut cross section, excavator parameters and physical-mechanical properties of a rock, the following widths L_0 are necessary for the mining waste dump:

for one-layer one-sided stowing (Fig. 2):

$$L_0 = \frac{k_r F}{H_i} + H_i ctg\beta + \frac{I_b}{2}, \quad m \qquad (3)$$

k_r – placer coefficient,
F – surface of a cut cross section [m],
H_1 – mining waste dump height (maximum discharge height) [m],
I_b – excavator range [m].

The coefficient of the repeated replacement K_1 in percentage for one-layer, one-sided stowing is determined by the relationship:

$$K_1 = \frac{0{,}5b' + \dfrac{0{,}5k_r F}{H_i} + 2Hctg\beta + 0{,}5I_b - \left(R_k - R_i\right)}{R_k + R_i - \sqrt{Hk_r - ctg\beta}} \;, \;[\%] \qquad (4)$$

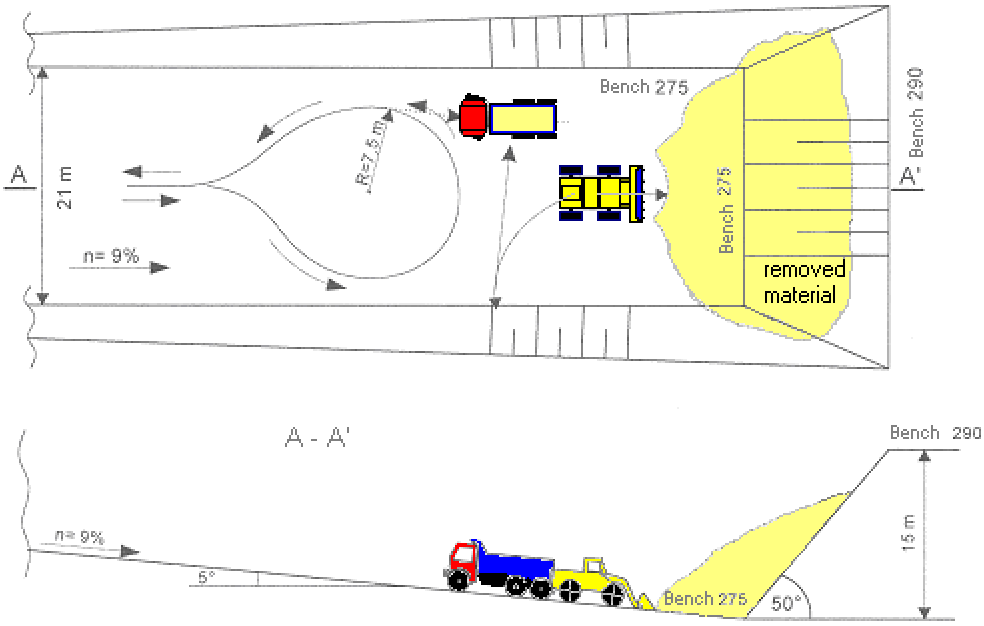
R_A - diameter of excavator mesh [m],
b' - cut upper width [m],
R_l – semi-diameter of excavator unloading (discharge) [m].

Cut winning including earth disposal

During the use of the method of cut winning, the price of one m^3 of the mined and stowed mineral is higher than that for the transportless method. Usually shovel excavators or loaders (Fig. 4) are used for winning and dump trucks are used for transport (Fig. 5) [10].

Fig. 4. Loaders on wheel and caterpillar chassis used in open-pit mining.

When using the stated method of cut winning the excavators/loaders are located in the front position. The cut shall be won in the full cross section; parts of cuts are prepared for creation of the bench. [6]



1-loader, 2-truck, → - strategy of an automobile and loader movement during loading.

Fig. 5. Front winning of the cut with a loader; open-pit quarry, Lisičnjak, Croatia [10].

The success of the cut implementation is verified via the structure of a diagram *L=f(T)* (Fig. 5) where the *BC* direction expresses the loading process in the part I_1, consequently the cycle is repeated by the length I_2 in such a way that during the loading to the length I_1 a phase of disconnection of part I_2 occurred *[5, 7]*.

The speed of a cut advance is:

$$v_1 = \frac{I_1}{T_1}\ , \qquad m/month \tag{5}$$

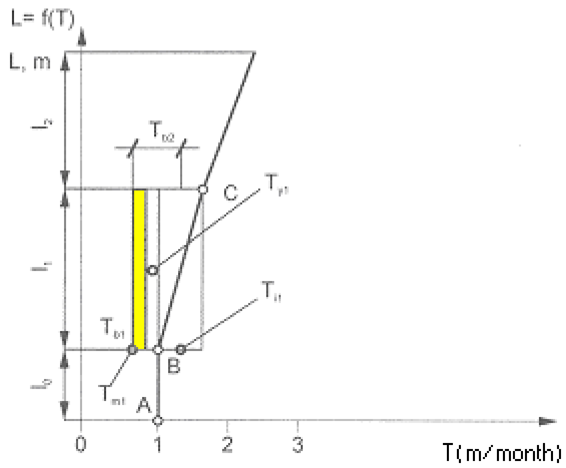


Fig. 6. Diagram L = f (T) (when applying blasting works).

T01 I0-time and length of a cut implemented without blasting works (entrance to the cut), Tb1-drilling time in block I, Ti1-loading time (with excavator), I1-length of block I, Tm1-time of drill filling for blasting and blasting in block I, Ty1-time necessary for cleaning (of a road) of block I, T1, T2-time of cut opening of blocks I and II, B-start of loading works, C-completion of loading works.

The time of the opening the cut in block I is determined by the relationship:

$$T_1 = T_{b1} + T_{m1} + T_{y1} + T_{i1},$$

$$v_2 = \frac{I_2}{T_2}\ , \quad m/month \tag{6}$$

Average speed of opening a cut:

$$v = \frac{L}{T_0 + T_1 + T_2}\ , \quad m/month \tag{7}$$

$$L = I_0 + I_1 + I_2 .$$

Cut winning with excavators with continuous operating cycle

When opening big open-pit mines where the volume of the development cut represents more than millions of m^3 of mineral to be mined, excavators which shall further serve for economic mineral mining shall be used. Such technology contributes to reducing the costs. The following combination can be used during cut winning:

- excavator – belt conveyer – stowing machine, (RPZ),
- excavator – stowing machine, (RZ), (Fig. 7).

In the case of direct connection (Fig. 7) the excavator *1* works in front on a cut and by means of a conveyer belt it is connected to the stowing machine *2*. On the side of the mining waste dump the dragline excavator *3* can operate as an auxiliary machine.

The width of the shaped mining waste dump L_0 (Fig. 6) created in this way shall be determined according to the relationship:

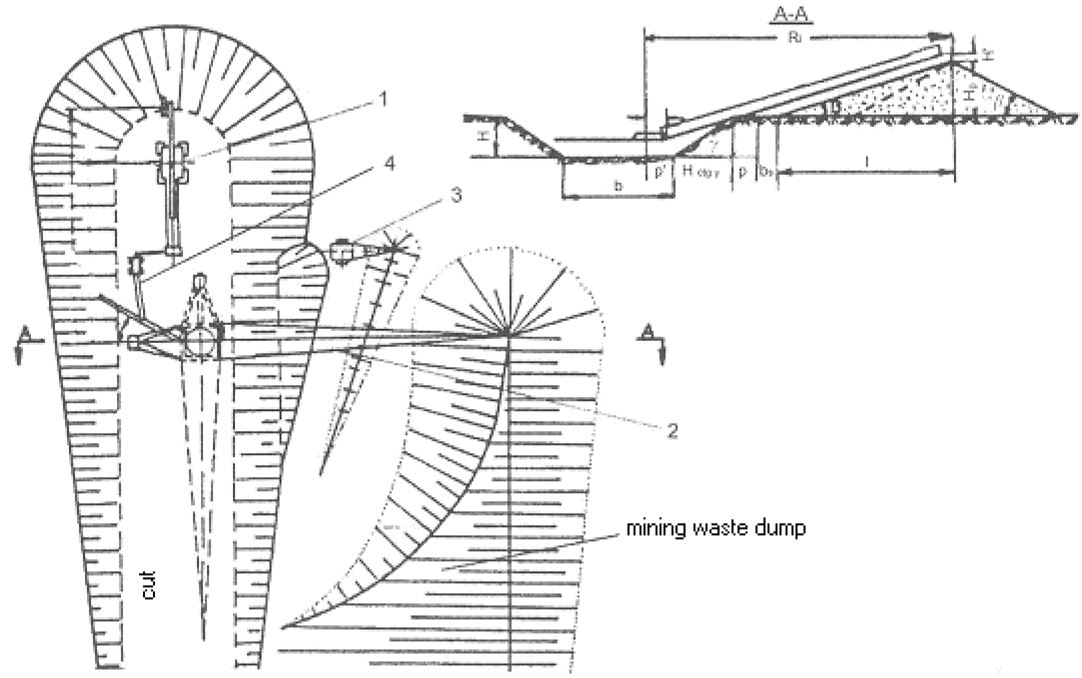
$$L_0 = R_1 - p' - Hctg\gamma - p - b_s \,, \quad m \tag{8}$$

R_1 – semi-diameter of a stowing machine discharge [m],
p´ - distance of a stowing machine axis from the lower edge of a cut slope end [m],
H – cut depth [m],
γ –cut slope angle [º],
p - slope transition width (for the belt arm) [m],
b_s –safety zone between the mining waste dump and the cut slope transition [m].

The mining waste dump height H_0 is determined by the relationship:

$$H_0 = H_i - H' - H_1 \,, \qquad m \tag{9}$$

H_I-height of a stowing machine discharge [m],
H'-height of the gap between a stowing machine belt and the mining waste dump top [m],
H- cut height (depth) [m].



1-excavator, 2-stowing machine, 3-excavator for works in the mining waste dump (auxiliary), 4- conveyer belt, r-distance from the stowing machine axis up to the point of stowing machine belt suspension.

Fig. 6. Cut winning by means of a combination wheel excavator – stowing machine[10].

Conclusion

The development of technology enables us to increase the depth of open-pit mining on the basis of which the stope changing the quarry contour is replaced (the open-pit mining which penetrates into the depth and where the excavation limiting coefficient k_{hr} can be shifted by the technology development).

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