

Justification of design parameters of compact load-haul dumper to mine narrow vein heavy pitching deposits

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ABSTRACT: Consideration of loading unit performance within the system “Rock mass - load-haul equipment - stowing mass” justification of its design parameters covers to mine narrow vein heavy pitching deposits. To intensify the machine performance it is proposed to use vibratory loader while entering ladle into rock mass, and while unloading. Under the same geometrical characteristics of ladle it will help to improve rate of load-haul machine work.

1 INTRODUCTION

From the viewpoint of efficient use of resources the paper uses systematic approach of justification of design parameters of compact load-haul dumper. Considering loading unit performance within “Rock mass-loading and hauling equipment- stowing mass” approach justification of parameters of recommended loading equipment is run by means of the three stages.

In the context of method (Korovyaka, 2003) stage one determines design dimensions of the loading equipment across the width of working excavation and throughout its height (minimum width of working excavation is $m_{min} = 1,2$ m, unevenness of wall of stope is $b_l = b_h = 0,2 \div 0,25$ m, shift of dynamic axis of working is $\alpha^\circ = 15$ deg., and face movement is $a_1 = 2,0$ m) (Figure 1).

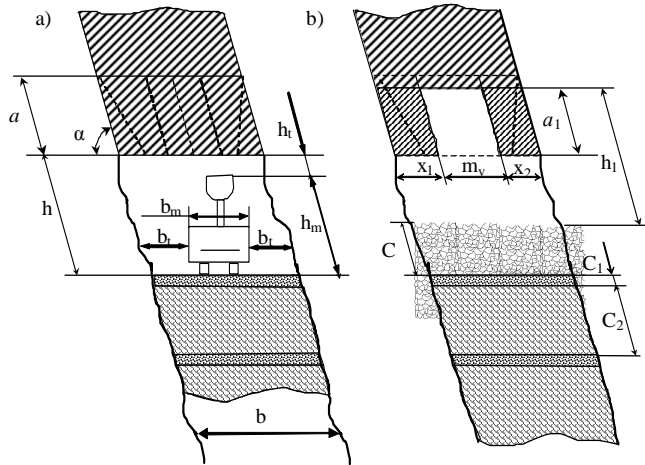


Figure 1. Design model of face space parameters control: b is width of stope, m; a is depth of holes, m; a_1 is face movement, m; h is distance from stowing layer surface up to the top drilled, m; h_1 is height of free working space over shot rock, m; α is vein's dip, deg.; m_v is thickness of vein, m; $x = x_1 + x_2$ is width of enclosing roof and floor out-of-seam dilution, m; C is height of shot rock, m; C_1 is a lift of rapid-hardening stowing, m; C_2 is a lift of dry stowing, m; b_t and h_t are manufacturing clearances of width and height according to Safety Rules, m; b_m is minimum constructive width of loading equipment, m; h_m is maximum of loading equipment ladle raise, m.

While ore hauling by means of load-haul dumper making maximum allowable thickness of stowing mass is important process parameter of goaf stowing. It depends on the fact that under raise bench working

procedures concerning drilling and charging as well as shot ore loading are performed from consolidating stowing. According to DBO certificate, standard height of face space should be permanent between top and filling mass surface. Under the height, manufacturing clearance h_t being minimum allowable on Safety Rules distance between top and vertical position of loader shovel is kept. Manufacturing clearance h_t is required for free ranging movement of equipment with vertical position of shovel within block (Figure 1,a). Manufacturing clearance b_t across the width of face space is the parameter which determines loading equipment adaptability while hauling ore within block.

Taking into account real hypsometry of face space walls and shift of dynamic axis of working obtained as a result of simulation, stage two determines adaptive capacity of loading equipment. That is, minimum length of the equipment is determined for minimum width defined during stage one.

Semitheoretical problem of justification of design parameters of compact load-haul dumper can be solved by means of simulation of its design adaptive capacity within narrow stope which stochastically changes its direction and spatial outline as a result of drilling and blasting, and requirement to follow ore body.

There was performed structural analysis of configuration of side wall and bottom wall of working excavation formed under controlled drilling. Then approximating surfaces of stope were built up, and they had m mining height, $A = 0,2 \div 0,25$ m amplitude of benches and basins, curvatures r_l of side wall and r_h of bottom wall reflecting shift of trend azimuth and vein's dip $\Delta\beta = 15^\circ$ within 5 m segment.

Solving the problem of determining load-haul dumper parameters for its operability assurance in stoping faces which can vary greatly per unit of working's length has been realized in terms of *Poisk b/l* program (Shirin & Korovyaka, 1998).

To describe algorithm and the program of the equipment parameters determination state description of the problem solved with a computer. It is required to find extreme length l of rectangle with fixed width b inscribed in zone D_i limited from left and right by vertical lines $X = x_0$ and $X = x_N$. From above and from below they are limited by certain curves $f_u(X)$ and $f_e(X)$ accordingly (Figure 2):

$$D = \{(X, Y), X \geq X_0; X \leq X_N; Y \leq f_u(X); Y \geq f_e(X)\}$$

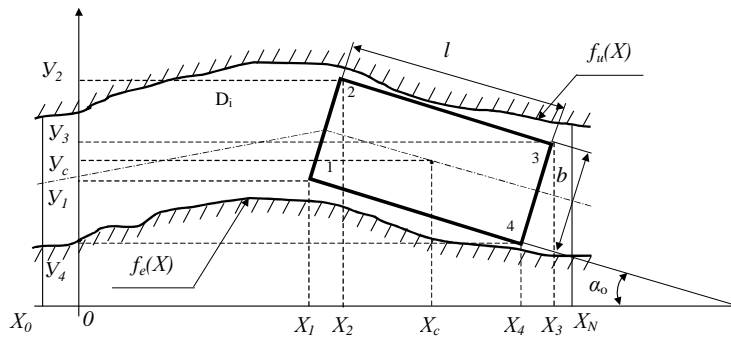


Figure 2. Adaptation of load-haul dumper to shifts of dynamical axis and hypsometry of stope walls: $[x_0, x_N]$ is area of loading equipment optimum length search; X_c, Y_c are coordinates of center of rectangle describing load-haul dumper; $(X_1, Y_1), (X_2, Y_2), (X_3, Y_3), (X_4, Y_4)$ are coordinates of rectangle's vertexes; $f_u(X)$ and $f_e(X)$ are certain curves limiting width of stope.

The minimum value is chosen among all l_X values obtained within $[X_0, X_N]$ area of search:

$$\ell = \min_{X \in [X_0, X_N]} \{ \ell_X \}$$

The value is taken as a length of rectangle (load-haul dumper under study).

Stage three defines constructive parameters of compact load-haul dumper working element under its minimum structural dimensions (length is $l = 3,0$ m, width is $b = 0,8$ m, height with raised ladle is $h = 1,8$ m).

2 PROBLEM DEFINITION

For compact batch overhead loaders working within narrow stope with variable dynamical axes loading equipment duty cycling is one of the key characteristics of rock mass loading process. Loading equipment (having reduced clearance) with downdip ladle moving from draw hole to rock mass pile at the expense of motional energy being proportional to equipment weight and its velocity squared as well as travel mechanism moving force introduces ladle at a depth of L' into a pile. At the expense of the lift after ladle has been introduced it turns vertically before leaving pile, and dips some rock. Then lifting drive is broken, ladle stops, and equipment moves to draw hole where lift is connected again. With it ladle rises up to maximum upward position, unloads at the expense of handle on buffer, falls, and loading equipment starts its new cycle.

Theoretically, duration of working cycle T_c of batch ladleman loading equipment as it is shown in (Bartashevski, Strashko, Shirin & Shumrikov, 2001) is additive quantity covering timing to perform a number of serial operations:

$$T_c = \sum_{i=1}^n t_i, \text{ where } i = 1, 2, 3, \dots \quad (1)$$

where t_0 is time to shift a handle (as a rule, 1 to 2 seconds); t_1 is time for equipment to move from a draw hole to a pile; t_2 is time to bring ladle into rock mass pile; t_3 is time for ladle to draw rock mass; t_4 is time for equipment to leave with loaded ladle; t_5 is time for ladle lift to be unloaded; t_6 is time for ladle to be unloaded; t_7 is time to lower ladle into origin return.

As cycle time is a quantity inversely proportional to output then its cutting is connected with increase in theoretical output which reflects loading equipment feasibility. Besides, as (Yevnevich, 1975) informs such parameters or factors effect cycle duration: power and mechanical characteristic of drives, reduction ratio of carrier and lift of ladle, equipment weight, shape and dimensions of ladle, physical and mechanical properties of rock mass, and distance from pile to draw hole.

3 ANALYSIS OF THE PROBLEM STATE

Stage one considers factors effecting initial charge of ladle under separate ladling from rock mass pile. Figure 3 shows kinematic chain of ladling rock mass which density is ρ_0 . The Figure demonstrates possible motion trajectories of front ladle edge within the pile form. As it is seen, types of the trajectories depends on ladling method, value R_0 , rotational center "O" position, and ratio of lift speed and pressure of ladle introduction into rock mass (Poluyanski, Savitski, Strashko & Voloshanyuk, 1981).

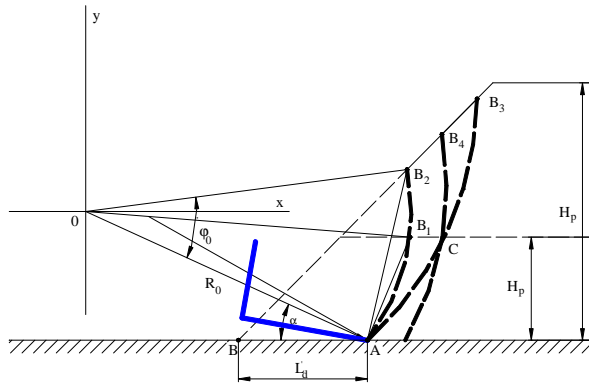


Figure 3. Specified Trajectories of Front Edge of Ladle Bottom Movement within the Pile Form.

Symbolize introduction depth as L'_d , height of a pile as H_p , and square determining initial loading a ladle as F' . Trajectory of ladle front edge under sequential operation of introduction and loading (when ladle winds) is AB_1 and AB_2 curves. With it (as Figure 4 shows) trajectory may cross form of pile either on horizontal face at B_1 point or on its aslope at B_2 point depending on height of a pile H_p . Theoretically, it can be shown in terms of the inequations:

$$\begin{aligned} H_p &\leq R_0(\sin \alpha + \sin(\varphi_0 - \alpha)) && \text{for the first variation, and} \\ H_p &> R_0(\sin \alpha + \sin(\varphi_0 - \alpha)) && \text{for the second variation.} \end{aligned} \quad (2)$$

If it is referred to combined ladling method when lift of ladle introduced into some depth keeps pace with continuous introduction then trajectory of ladle front edge will go with AB_3 and AB_4 curves.

Thus, front edge of ladle bottom under its vertical winding separates some volume of rock mass from pile. The volume of rock mass is proportional to involved square F' . When ladle leaves pile the volume of rock mass (separated from the pile), and values of the pile height H_p and introduction depth L'_d are different, the square of polygon $BCDEK$ is separated (Figure 4) and ladle is partially loaded. Theoretically, the figure square is close to square F' value. With it, vertex $D(D')$ lies on perpendicular erected to ladle bottom plane from point B (that is front edge).

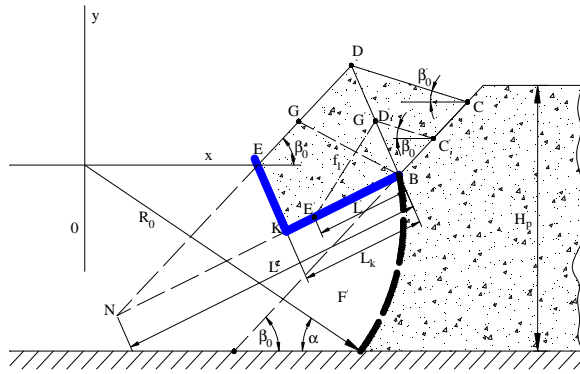


Figure 4. Location of Rock Mass within Ladle at the Moment of its Leaving the Pile.

Inside the ladle rock mass is located on the angle of natural levee β_0 with l' length which in turn may be both more and less than ladle bottom length l_k depending upon introduction depth L'_d .

Rock mass facing a pile with CD slope has slope angle to β'_0 level. Most of all, practical calculations takes the angle as that equal to friction slope, that is $\beta_0 = \beta'_0$.

With it, volume of rock mass taken from a pile in one working cycle is:

$$V_k = f_1 \cdot B_1, \quad (3)$$

where B_1 is ladle width, m; f_1 is square in vertical plane limited by $BGEK$ contour.

While defining square f_1 consider that height is $H_p > R_0(\sin \alpha + \sin(\varphi_0 - \alpha))$, and introduction depth L_d is equal to ladle bottom length that is $L'_d = l_k$. For the case, (Figure 5) square of $BGEK$ figure is:

$$f_1 = \frac{1}{2} [l_k(h + h_2) - h_1 \cdot l_0] \quad (4)$$

$$\text{But as } \begin{cases} h_2 = h - l_k \cdot \tan(\beta_0 - \tau) \\ h_1 = h \cdot \cos(\beta_0 - \tau) \end{cases}, \text{ then } l_0 = |DG| = |BC| \text{ will be equal to:} \quad (5)$$

$$l_0 = \frac{\cos(\beta_0 + \tau)}{\sin 2\beta_0}, \text{ where } \tau = \varphi_0 - \alpha_0 \quad (6)$$

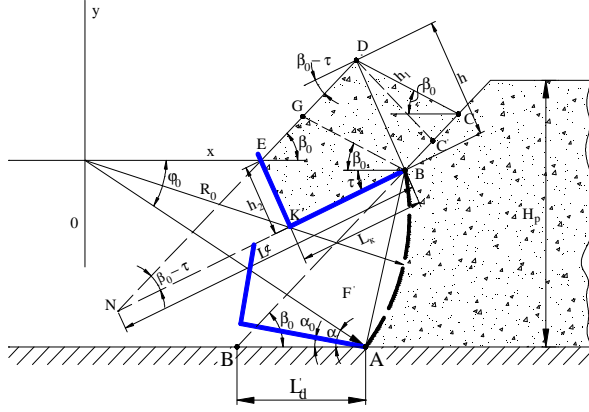


Figure 5. Design Diagram for Loading Ladle with Rock Mass.

Formula (4) will be:

$$f_1 = \frac{1}{2} \left[2 \cdot h \cdot l_k - \frac{h^2 \cdot \cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)}{\sin 2\beta_0} - l_k^2 \cdot \operatorname{tg}(\beta_0 - \tau) \right] \quad (7)$$

In the formula h is undetermined value. It characterizes location of rock mass at the moment of ladle leaving a pile. While determining it (to simplify the problem) specify approximate equation of squares F' and F'' (BCDEK figure). According to Figure 5:

$$F' = \frac{1}{2} \left[L_d' \frac{1}{\operatorname{ctg} \beta_0 - \operatorname{tg} \left(\alpha - \frac{\varphi_0}{2} \right)} + R_0^2 \cdot \left(\frac{\pi}{180^\circ} \varphi_0 - \sin \varphi_0 \right) \right] \quad (8)$$

Taking into account

$$R_0 = \frac{L_d' \cdot \sin \beta_0}{2 \sin \frac{\varphi_0}{2} \cdot \cos \left(\beta_0 + \alpha - \frac{\varphi_0}{2} \right)}, \quad (9)$$

Expression (7) will be:

$$F' = \frac{1}{2} L_d'^2 \left\{ \frac{1}{\operatorname{ctg} \beta_0 - \operatorname{tg} \left(\alpha - \frac{\varphi_0}{2} \right)} + \frac{\left(\frac{\pi}{180^\circ} \varphi_0 - \sin \varphi_0 \right) \sin^2 \beta_0}{\left[2 \sin \frac{\varphi_0}{2} \cdot \cos \left(\beta_0 + \alpha - \frac{\varphi_0}{2} \right) \right]^2} \right\} \quad (10)$$

In turn, from Figure 5 we get:

$$F'' = \frac{1}{2} [l_k(h + h_2) + h_1 \cdot |BC|] \quad (11)$$

Substituting into (9) values h_1 , h_2 and $|BC|$ from Formula (6) we get:

$$F'' = \frac{1}{2} \left[2 \cdot h \cdot l_k + \frac{h^2 \cdot \cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)}{\sin 2\beta_0} - l_k^2 \cdot \operatorname{tg}(\beta_0 - \tau) \right] \quad (12)$$

Equating $F' \approx F''$ if $l_k = L_d'$ determine depth h :

$$h = d_1 \cdot L'_d \quad (13)$$

where

$$d_1 = \sqrt{\frac{\sin 2\beta_0}{\cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)} \left[\frac{\frac{\sin 2\beta_0}{\cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)} + \frac{1}{\operatorname{ctg} \beta_0 - \operatorname{tg} \left(\alpha - \frac{\varphi_0}{2} \right)} + \frac{\left(\frac{\pi}{180^\circ} \varphi_0 - \sin \varphi_0 \right) \sin^2 \beta_0}{\left[2 \sin \frac{\varphi_0}{2} \cdot \cos \left(\beta_0 + \alpha - \frac{\varphi_0}{2} \right) \right]^2} - \operatorname{tg}(\beta_0 - \tau) \right] - \frac{\sin 2\beta_0}{\cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)}}$$

Finally, substituting value h into Formula (7) and result obtained into (3) find ladle capacity of recommended compact loading equipment:

$$V_\kappa = k_1 \cdot B_1 \cdot L_d^2, \quad (14)$$

where

$$k_1 = d_1 - 0,5 \cdot d_1 \frac{\cos(\beta_0 + \tau) \cdot \cos(\beta_0 - \tau)}{\sin 2\beta_0} - 0,5 \cdot \operatorname{tg}(\beta_0 - \tau)$$

It results from Formula (14) that under otherwise conditions maximum value of ladle volume is $f(k_1 B_1 L_d^2)$ function, and $V_{\kappa_{max}}$ if $\beta_0 = \frac{\pi}{2}$. On the other hand, value of ladle loading to the full extent depends on frequency of its introduction into rock mass (Semko, 1960).

To determine relationship between ladle loading volume and current time apply directly-proportional dependence of loading time on rock mass being loaded under limiting factors. As a rule, maximum loading volume (Yevnevich, 1975) is among them:

$$\frac{dV}{dt} = k \cdot V(b - V), \quad (15)$$

where $\frac{dV}{dt}$ is time of ladle loading, m^3/s ; k is ladle loading factor; V is current value of ladle loading under one-time introduction, m^3 ; b is maximum ladle loading.

Reduce differential expression (15) to nondimensional values: $V = \frac{V_{min}}{V_{max}}$; $b = 1$ if $t = t_i$.

Then symbolize (15) as:

$$\int \frac{dV}{V(b-V)} = \int k \cdot dt, \quad (16)$$

Separate integral in right member into the two addends, and integrate:

$$\frac{1}{b} \left[\int \frac{dV}{V} + \int \frac{dV}{b-V} \right] = \int k dt \quad (17)$$

Obtain:

$$\frac{1}{b} [\ln V - \ln(b-V)] = kt - C_1 \quad (18)$$

With it, constant of integration C_1 is determined with the help of initial conditions $C_1 = -\frac{1}{b} \ln a$, where a is starting volume of ladle loading.

(18) helps to get final output:

$$V_{(t)} = \frac{b}{1 + a \cdot e^{-bkt}} \quad (19)$$

(19) shows that current value of ladle loading depends on values “ a ” and “ k ”. Specify $\tilde{a} = k_1$, then rewrite (19) as:

$$V(t) = \frac{1}{1 + k_1 \cdot e^{-kt}} \quad (20)$$

Values k_1 and k depend on different factors – physical and mechanical properties of rock, its hardness, lumpiness etc. as well on method of ladle introduction into rock mass.

4 RESULTS

To increase efficiency of ladle equipment a number of papers recommend different ways of loading process intensification (Yevnevich, 1975; Poluyanski, Savitski, Strashko & Voloshanyuk, 1981). For example, Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine developed technique of ladle loading intensification with the use of vibration exciter as vibration loader. Hydraulic pulsators or pneumo pulsators with 10÷15 Hz rhythm and $A = 3 \div 5$ mm of ladle loading edge oscillation amplitude. With it, factors k_1 and k increase up to 0,6÷0,8.

Figure 6 shows dependence diagrams of ladle loading on its introduction into rock mass without applying vibration on ladle and with it. Graphical dependences are obtained with the help of *Mathcad* program.

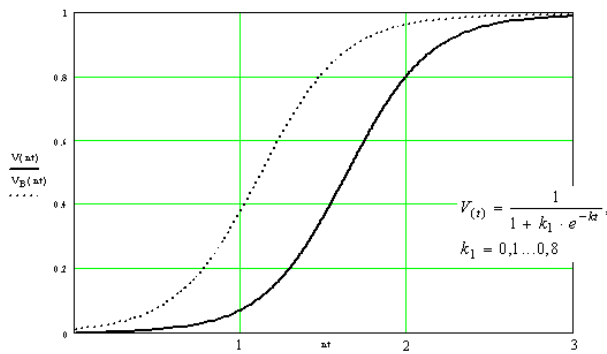


Figure 6. Dependence of Ladle Loading on its Introduction into Rock Mass Frequency: — Conventional Ladle; ---- Vibrating Ladle; $nt = \frac{\bar{t}_q}{t}$, where \bar{t}_q is average time of cutting cycle; and t is current time of single cutting.

From the dependences it follows that under conventional loading the same volume needs more cuttings to compare with vibrating ladle. Thus, application of vibrating exciter both during introduction into rock mass and during unloading will help to increase efficiency of load-haul-dumper even if geometrical characteristics of ladle stay to be identical.

Hence, according to design model (Figure 1) volume of rock mass to be loaded (if length of semiblock is 25 m, working face movement is 1,8 m, degree of fragmentation is $k_p = 1,5$, and mining power is 1,2 m) will be 81 m³. Then time to haul gangue to draw hole under continuous operation of compact load-haul-dumper with fixed ladle is about 10 hours, and with vibrating ladle it is about 7 hours.

While determining dimensions of ladle on rolling handle following ratios are taken:

$$l_K = 1,14\sqrt[3]{V_K}, B_K = l_K, h_b \approx 0,4 \cdot l_K, H \approx 1,2 \cdot l_K,$$

where l_K is a ladle bottom length; B_K is a ladle width; H a ladle height from the front; and h_b is a ladle bottom height.

There are identified following design factors for compact load-haul-dumper ladle: $V_K = 0,3$ m³, $l_K = B_K = 0,76$ m, $H = 0,91$ m, and $h_b = 0,3$ m.

Since cutting is performed by means of pressing loading equipment into rock mass pile then adhesion weight is determined as:

$$G_c = n \frac{P}{\Psi - z(W_m + W_k - W_d)}, H$$

where n is reserve coefficient equal to $1,1 \div 1,15$; P_{BH} is rated force of a ladle introduction into a pile, H; Ψ is a coefficient of wheels adhesion with stowing mass; z is the relation between working weight of equipment and its adhesion weight; W_m is running resistance of equipment; W_k is resistance of equipment on curves equal to $(0,25 \div 0,3) \cdot W_m$; $W_d = 0,7 \cdot v^2 / L_d$ is dynamic resistance; and v is stroke speed of equipment, m/s.

Usually, pressure of ladle into pile equal to rock mass reaction when lumpiness is no more than 400 mm is determined as:

$$P = 341 \cdot a \cdot L_d^{1,25} \cdot B_k \cdot k_h \cdot k_f \cdot \kappa H,$$

where a is a factor taking into account tightness and abrasive properties of rocks and mineral (at average, it is $0,17 \div 0,2$ for iron ore; $0,15$ for sandstone and granite, and $0,12$ for sandy shale); $k_h = (1,16 \div 1,57) \cdot (2 + \lg H_p)$ is a factor taking into account influence of pile's height; and k_f is a ladle form factor (roughly, it is taken as that equal to $1,2 \div 2,0$).

5 CONCLUSIONS

From the viewpoint of mining mechanization the area is rather promising while mining ore bodies which thickness is $> 1,5$ m. To cut qualitative losses of minerals while mining seams (to dilute them as a result of mixing with dead rocks) it is necessary to be geared to ore body selective mining and diluted rock walls. It depends on the fact that ore dilution and losses, and cripples economy greatly not only while mining but in the process of processing. Excessive mining dead rocks (connected with dilution) then separating in tails harms environment too as vast territories are required to place tailing pounds which negative influence is known.

The research are implemented in method of determining rational parameters of operation schedule to mine narrow vein heavy pitching deposits by means of compact load-haul dumpers, and in "Initial Standards" to design compact load-haul dumpers for mining narrow heavy pitching veins. The Standards are agreed with Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, approved and passed to the State Design Institute "Krivbassproject" to be applied.

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