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A METHOD FOR DEFINING THE BOUNDARIES OF AN OPEN PIT ACCORDING TO THE SURFACE

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ABSTRACT. One of the most important strategic tasks in designing and exploitation of opencast mines is to define of their boundaries according to the surface The paper describes a method for defining the mine profile according to the surface. The method envisages the ensuring of optimum boundaries and safe work in the mine, ı e creating a stable construction in the non-raining flank The volumetric problem when studying the stability of the slopes is solved. The optimum profile is surveyed in the zone between the profiles with stability coefficients t|=1 and rpTi^man™- For that purpose the cumulative curves of the function between resistance and dnve forces £Si=f(£Ti) are drawn for each profile The curves £Sı=f(£Tı) are compared with the location of the cumulative curves ZVi=flTPi), expressing the function between the waste and the minerals in a given profile. The dangerous sections can be reinforced if there is a need or if profit can be made In this case a coefficient of effectiveness of the expenses for reinforcement is recommended The method is illustrated through solving numerical examples for the conditions of the "Elatsite" and "Kremikovtsi" open pits

The main condition necessary to ensure optimum boundaries and safety is the creation of a stable construction of the non-mining flank The task of the designer or the specialist is to determine the inclination of the flank which ensures stability of the slope together with maximum extraction of the deposits and minimum overburden The effective work in die mine is closely related to solving this problem.

Unlike the angle of the working flank the angle of the non-mining one is a long-term one and should be determined more precisely Hence, the method used must reflect the influence of all basic factors on the stability and should minimise any possible errors

Lei us look at the condition of the flank when the mine is being closed after we have defined the boundaries of its bottom [I]

The calculation of the stability of the flanks is done by radial piofiles 1 to XVÏ m Fig I

We have to determine the resistance ($S_{,,}$) am' (he slıdırıy (T_n) forces for the most unfavumablc sliding suilüce (f) for (he site (i) Willi inmpaiaiivdv iniiuof.fnuu:; mining conditions

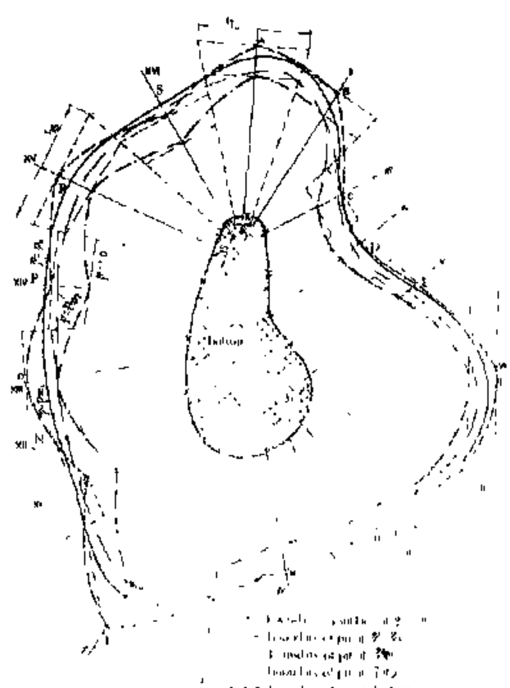
For a homogenous rock mass (at Fig 2a)

$$S_{ij} = P_i \cos\alpha_{ij} tg\,\varphi + cf_i + F_1 + F_2 \quad (1)$$

$$T_{ij} = P_i \sin\alpha_{ij} \quad (2)$$

where (P.) is the weight of the break-down pnsm in the site,

(ctjj) is the angle between the tangent to the sliding



1-iKuie 1 Radial Piofiles I lo XVI

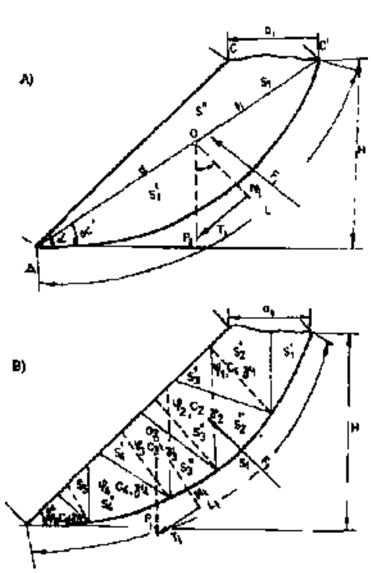


Figure 2. The Resistance and Sliding Forces for Homegeneous (a) and Non-Homogeneous Rock Mass(b)

slope at the centre of gravity and the horizon,
(fi) is the sliding surface in infers,
(c) and (<p) are the cohesion and the «cgle of internal friction of the rock in N/m and degrees respectively,
(Fi) and (F2) are the resistance forces to the side pressure in sections AB'B and HC'C of the site,

$$F_1 = cS_1 + \sigma'_2 S_1 tg\varphi;$$

$$\sigma'_2 = \frac{1}{2}\gamma H_1 tg^2(45^\circ - \frac{\varphi}{2}) - 2ctg(45^\circ - \frac{\varphi}{2}) \quad (3)$$

$$F_2 = cS_2 + \sigma''_2 S_2 \, tg\varphi,$$

$$\sigma''_2 = \frac{1}{2}\gamma H_2 tg^2(45^\circ - \frac{\varphi}{2}) - 2ctg(45^\circ - \frac{\varphi}{2}) \quad (4)$$

(H[) and (H3) are the heights of the site in the left and right part of the flank in meters, respectively.

For non-homogenous rock mass the resistance and sliding forces are determined according to the formulas (see Ftg 2b):

$$S_{\sigma i} = \sum_{\substack{j=1\\i=1}}^{\substack{j=m\\i=n}} P_{ij} \cos\alpha_{ij} tg\varphi_{ij} + \sum_{\substack{j=1\\i=1}}^{\substack{j=m\\i=n}} c_{ij}\gamma_{ij} + F_1 + F_2 \quad (5)$$

$$T_{\sigma i} = \sum_{\substack{j=1\\i=1}}^{\substack{j=m\\i=n}} P_{ij} \sin\alpha_{ij} \quad (6)$$

where: (Py) is the weight of the pnsm (j) for the given lithological variety from the site (i) of the flank (N),
(cty) is the angle between the tangent to the sliding-surface within the boundaries of the prism at point (Oj) and the horizon in degrees,
(fjj) is the sliding surface in the boundaries of one prism (j),
(cjj) and (tpij) are, respectively, the cohesion and the angle of internal friction of the rock in the boundaries of the prism (j),

$$F_1 = \sum_{j=1}^{n} c_j S_j + \sum_{j=1}^{n} \sigma_{2j} S_j tg\varphi_j \quad (7)$$

$$\sum_{j=1}^{n} c_j S_j = c_1 S_1 + c_2 S_2 + \ldots + c_n S_n \quad (8)$$

$$\sigma_{2j} = \sigma_{ij} tg^2\left(45^\circ - \frac{\varphi_j}{2}\right) - 2c_j tg\left(45^\circ - \frac{\varphi_j}{2}\right) \quad (9)$$

(Sj) - areas of the cross-sections of the respective lithological varieties along the vertical plane in sq meters,
(o'2j) - the horizontal tension perpendicular to the plane (Sj) in N/m^2,

$\sigma_{ij\,avg} = \frac{\sigma^r_{ij} + \sigma^g_{ij}}{2}$ - is the average main tension of

the lithological variety in N/m^2,
(YIJ) (S the specific gravity of the lithological variety in N/m\

$\sigma'_v = \sum_{1}^{n-1} \gamma_{j-1} h_{j-1}; \sigma''_v = \sum_{1}^{n} \gamma_j h_j$ are the tensions m the upper and lower part of the lithological variety in the boundary section İn N/m^2,
(hj) is the average thickness of the prism in meters.

The force of the lateral pressure (F_2) is expressed similarly. Then the resistance (Si) and sliding (T,) forces are determined (excluding the forces of the lateral pressure F| and F_2). Based on these data, we can draw the cumulative graph showing the functional relation between the resistance and the sliding forces $\Sigma S_i = f(\Sigma T_i)$ in Fig. 3. Taking the same values for the stability coefficient ($T|_H$) the contour of the opencast mine will be a broken line ABCDEF.. MN on Fig. 1. However the technological requirements for rail or automobile transport create the need for a curved contour of the mine.

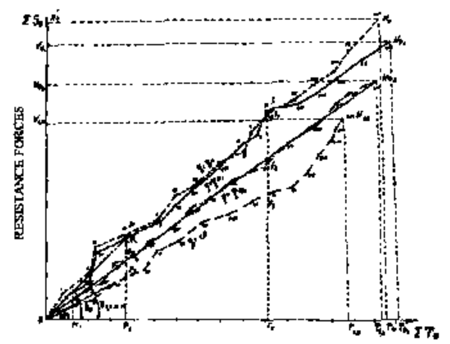


Figure 3 functional Relation Between the Resistance and the Sliding forces

Because of the probability of the initial data the right thing to do at the beginning is to determine the boundaries of the mine taking into account the possible mistakes when determining the rock strength, ensuring the safe operation of the mining and transport equipment, practical experience etc.

To determine the rational boundaries of the pit which meet the technological requirements for effective mining, the parameters for every site are determined for two values of the stability coefficient r\-1 and 1l=1l1, The zone between these two values is the area within which 1hc rational solution for the boundaries should be sought (Fig I) At eveiy site the aclua! stability coefficient is chosen according to the resultant error due to different factors.

For each contour of the mine cumulative curves IS.^IT,) are plotted. The stability coefficient n. is determined as the tangent of the angle of the straight line of the function characterising every site(Fig. 3).

For site I where $\eta_I = \eta_{\phi 2}$

$$\eta = tg\delta_1 = \frac{MM_1}{OM_1} \quad (10)$$

For sites I to IV where $\eta_I = \eta_{\phi 1}$

$$\eta_{I-IV} = tg\delta_2 = \frac{P_1 P_4}{OP_4} \quad (11)$$

For the whole mine - sites 1 to XVI where $\eta_i = \eta_{\phi 2}$

$$\eta_{avg} = tg\delta_{avg} = \frac{N_{\phi 2} T'_{\phi 2}}{OT'_{\phi 2}} \quad (12)$$

The average stability coefficient of the flank for the whole pit can be determined as a weighted average by the following formula:

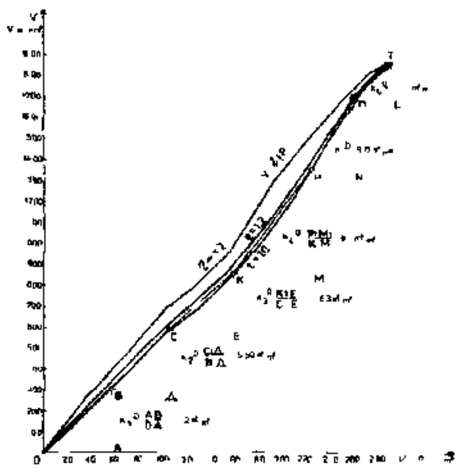
$$\eta_{wa} = \frac{\eta_1 P_1 + \eta_2 P_2 + \dots + \eta_i P_i}{100} \quad (13)$$

where: (n.i) is the stability coefficient of for each site, (P,) is the percentage of the area of the site compared to the whole area of the pit

$$P_i = \frac{S_i}{S_{total}}, \% \quad (14)$$

This formula allows to evaluate the stability of the whole pit, of several sites as well as the weight of the different sites in the total stability, i.e. according to their importance.

The family of cumulative curves £Sj = f(ET,) in Fig 3 is compared to the cumulative curve £V=f(XP) which expresses the relation between the overburden and the deposit in a certain contour. The combined use of the cumulative curves IS; = fiTTi) and £V=f(EP) gives the opportunity for a full analysis of



Hgure4

the factors for stability and uninterrupted operation mode

The following situations are possible

— uninterrupted operation mode and nommai stability coefficient,

— uninterrupted operation mode with stability coefficient greater or lower than the nominal

keeping the nominal stability but changes in the operation mode

When taking decisions where the actual boundanes of OIL pit will be the following factois should bt taken into account

— In what part of the mine is the site where the stability coefficient is lower than the nominal

what is the stability coefficient in the sites adjacent lo the above

tht place ol opening up and llu iyp< ol transport

the lifetime of the flank

11K valut, of txtratitd deposit

the necessity ol extrat lion

the laiei al pi ensure *I,* and I >

Hit, nsk which should be consulted to^ulıo with tht o; pet le.il icnnomic eft et 1

If it ıs netessaiy 01 pi ol liable the dnn^eious sites tan be suenglbericd b> intens of toncrclL pjks antlını

or any physical or chemical method The value of the additional resistance force for the reinforcement can be obtained from the graph $\Sigma S_i = f(\Sigma T_i)$ where it is represented as the residual between the ordinales of the resistance forces with stability coefficient n,,, and *r\<t,* {where r)* is the actual stability coefficient for the site in a given contour of the pit) In our example reinforcement is necessary for sites X, XIII and XV

f-or site X the necessary additional resistance force is

— for contour I

$$(\eta_{HX}-\eta_{\Phi 1x})T_{o1x}$$

— for contour II

$$S_{res\,x} = (\eta_{HX}-\eta_{\Phi 2x})T_{o2x}$$

Using S,,, we can calculate the piles or anchors necessary for reinforcement of the unstable site X

$$\eta_x = \frac{S_{res}\, l}{Q_{sh}} \qquad (15)$$

where (O*) is the resistance of the piles (anchors) to sheanng,

(l,) the length of the site to be reinforced

When using pre-strained anchors

$$\eta_x = \frac{4 S_{res}\, l}{\pi d^2 R_{sh} \cos\delta} \qquad (16)$$

where (d) is the diameter of the reinforcement m the pile (anchor)

(R_K) is the nominal lesistanet lo sheanng ol the material of the pile (anchor)

(ft) is *\hv <ingh* bel ween tht Jıdmj,' aırfau *mt* Ibe (lirtttion of the pile

Thi tkcıtasc m the si ıbılıty coiflicienl *(A\\)* compared to the nominal (n) in a j ivm „ik (I) of the pit ran be determined by Hit *tonmiU*

$$\Lambda\eta \quad \frac{S_r}{l} \quad \frac{S}{} \qquad /)$$

ff(Aï]|) is within llu limits of the po »sihir- en tu whin calculating the stability ol ihc slopt (taknliUrl atcoidinj' lo lot inula (I4) lemforccmenl ol llu llfiil ear be dont al the site

The method for reinforcement is chosen according to the expenses The coefficient of effectiveness if the expenses is described by the formula

$$k_{ef} = \frac{1}{\Delta\eta_i} E \rightarrow \min \qquad (148)$$

Using this coefficient the necessity of reinforcement can be evaluated and best solution can be found

The stability of ten radial profiles if the non-mining flank of "Elatzite" open pit with T|=1 08 and rp1 30 is calculated using a computet and tentative contours of the pit are drawn Based on the values calculated for IS, and IT, characterising three possible contours of the pit the cumulative curves XS, = f(ST,) are plotted Depending whether there is an increase or decrease of the mining mass relative to the contour of the operations project the areas $+AS_{,m}$ and $-AS_{,m}$ and the volumes $+AV_{im}$ and $-AV_{im}$ are calculated

According to the first variant additional 821 000 m^1 of overburden should be dug and 8 090 000 m^1 will be lost According to the second variant the additional overburden is 22 652 000m^3 but 910 000m of ore are gained According to the third vanant the additional overburden is 17 375 000 m' and the ore gain will be 5 039 000 m^1

Table I shows the economic effect for the three variants

No	Economic indicators	Loss or gain in thousands USD VARIANTS		
		I	II	III
1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	0	0
3	[illegible]	0	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]

I'akm/) into account the reasonable nsk even more icsfivcs can be sought for digging additional volumes of ore from the deposit The evaluation of vjtiiiuK I, H and 111 foi expenses for digging of additional ovcrbuiden and profits from extra ore compaied to the onginal project show that vanant III is the most effective economically Applying this vanam 5 000 000 tons of ore are gained The profits fmm this exti<i oie aie approximately 10 000 000 USD and the stability of the flanks of the pit is guaianteed The second vanant can be consideicd as applicable, loo, having in mmd the constant increase of the pnces of non-ferrous metals on the international markets

The theoretical conclusions of the volumetric interpretation of the possibilities for determining the boundaries of an open pit was illustrated by calculating numencal examples for the conditions of "Elatsite" open pit and determining the stability of the north flank of "Kremıkovtsı" open pit near the drainage shaft

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