# Method of Computing Open Pit Slopes Stability of Complicated-Structure Deposits

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## Abstract

*In substantiation of the parameters of stable open pit slopes of complicated-structure deposits it is necessary to take into account a number of natural and anthropogenic conditions of the open pit side masses, such as: lithological heterogenity, plicative and disjunctive tectonic broken state, rocks laminated structure, form of the open pit side, hydro-geological conditions of the deposit development, the mining-transport equipment loading effect, etc.*

*In the article there is suggested a solution of this problem consisting in the improving of numerical-analytical method of professor P.S. Shpakov, whose advantage is the accounting if stresses acting on the elementary ground based on integrated effect of all the acting factors. The essence of the solution con-sists in the following: with a unified algorithm of realization (numerical solu-tion, iteration method) every time there is built a new analytical formula of the limit equilibrium corresponding to the concrete minin-g-technical and mining-geological conditions permitting to establish the mechanism of the possible de-forming of open pit slopes.*

*Keywords:*

## Introduction

The variety of mining-geological and mining-technical conditions of developing deposits predetermined a lot of methods of computing open pit slopes stability (over 150), which are used for concrete mining-geological conditions.

An adequate geo-mechanical model of the complicated-structure side mass de-veloped on the basis of geo-mechanical monitoring is to include: geological and geo-mechanical estimation of the deposit; substantiation of the design strength properties of the mass; methodology of computing accounting for the slope geometry, the mass structural features, the open pit slope forming duration and service life of its separate sections.

One of the main problems in substantiating open pit slopes stability in compli-cated-structure deposits is the establishment of the slopes deformation mecha-nism, as there arise a lot of possible realizations of collapse, and it is important to select the most probable of them. One of the ways of solving the problem is the improving of the numerical-analytical method of prof. P.S. Shpakov, whose advantage is accounting for stresses acting on the elementary ground based on integrating all the acting factors. This is achieved by building an inte-gral formula of the limit equilibrium where, in accordance with the original da-ta, there are added the rules of accounting for the acting factors. Thus, with a unified algorithm of realization (numerical solution, iteration method) very time there is built a new analytical formula of the limit equilibrium correspond-ing to the concrete mining-geological conditions.

## Computing open pit slopes stability taking into account structural features of the side mass

### *Theoretical basis of the computation method*

Complicated-structure deposits are characterize by: lithological heterogeneity with different physical and strength properties; tectonic broken state, cracking, lamination of the side mass where structural-lithological contacts are often pre-set by the weakening surface on which there are formed slide surfaces.

Their location establishing is an important task when substantiating rational and safe parameters of open pits.

Slide surfaces can run both on the mass and on the structural-tectonic contact (Figure 1) with simultaneous satisfying of the ordinary and special equilibrium at the boundary of two media. The inlet (outlet) angle θ / of the slide surface at the boundary of two media (mass-contact) is determined with observing geo-mechanical conditions by formula (1) [1].

The limit slopes structural parameters can be determined by the function of $P_R$ profile of the open pit side (or its section)

$$P_R = f(H, \alpha, \rho_i, k_i, \gamma_i, \rho'_j, k'_j, h_k, b_k, \delta_k, \lambda_m, \beta_m, g) \qquad (2)$$

where:
H, α are the open pit side parameters; $\rho_i$, $k_i$, $\gamma_i$ , $\rho'_j$, $k'_j$ are mining rocks physical-mechanical properties for structural-lithological elements and their contacts, respectively; $h_k$, $b_k$, $\delta_k$ are the benches parameters; $\lambda_m$, $\beta_m$ are elements of structural-lithological elements bedding in the mass; g is the ground water level.

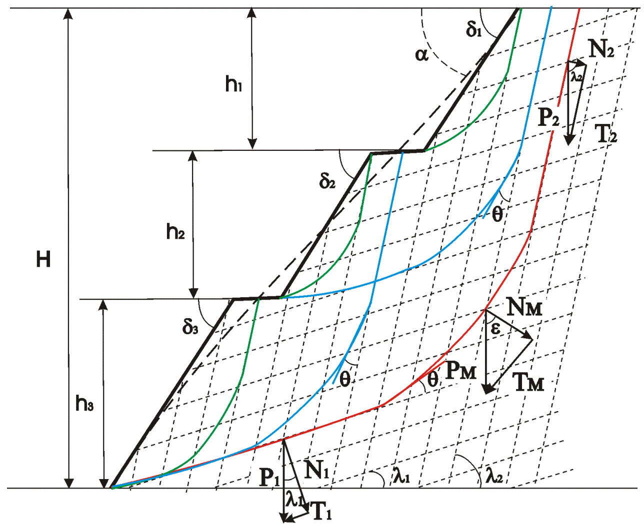


Fig. 1. Building slide surfaces in a cracked mass under the condition of shifting the landslip prism on cracks and mass

$$\theta' = 0,25\pi \pm 0,5\left(\rho - \rho'\right) - 0,5\arcsin\left\{\sin\rho' / \sin\rho\left[1 - \left(H - H'\right)\sigma^{-1}\right]\right\} \quad (1)$$

where σ is reduced stress, MPa; ρ is the angle of the mass inner friction, degree; ρ’ is the angle of the poor contact inner friction, degree.

The elements of the side structure can be preset both in obvious form $\lambda_m$, $\beta_m$, $\delta_k$, $h_k$, $b_k$, g, and through the junc-tion points coordinates describing the struc-ture. In the second case there may be taken into account structural features of any form (plicative, planetary, etc.).

Giving the boundary conditions in accordance with structural-lithological elements bedding, the integral equation of the limit equilibrium can be presented in the general form

$$n = \left( \sum_{i=1}^{m_1} \int_{L} \left(\sigma \cdot tg\rho_i + k_i\right) \cdot dl + \sum_{j=1}^{m_2} \int_{L_k} \left(\sigma \cdot tg\rho_j' + k_j'\right) \cdot dl \right) / \int_{(L_i + L_k)} \tau \cdot dl = 1, \quad (3)$$

where $m_1$ is a number of lithological differences crossed by the slide surface; σ is a normal stress acting on the elementary slide ground; $m_2$ is a number of con-tacts (weakening surfaces) on which there is formed the slide surface; $L_м$, $L_k$ are slide sections running on the mass and contact (weakening surface), respective-ly; τ is a tangent stress acting on the elementary ground of the slide sur-face.

Depending on the geometrical design model and tak-en to the analysis mecha-nism of slopes deforming, the equation of the limit equilibrium includes the el-ements of the side mass structural features, corresponding to the concrete con-ditions, and with their accounting there is carried out searching potential slide surfaces in the de-sign prism and selected the most dangerous one. As a re-sult of analyzing the open pit side sections by the factor of its stability there is per-formed its contour correcting which can become more concave or convex, with the aim of determining the mist rational profile of the open pit stable side. Such an approach permits to compute not only a single bench flat slope, but also a stepped slope of the benches group which increases substantiation and accuracy of engineering decisions to estimate open pit slopes stability and determining their limit parameters. The estimation of a stepped open pit slope consists in determining the main parameters of open pit side H, α, the of private $h_k$, $b_k$, $\delta_k$ parameters of benches [2].

***Design diagrams of open pit slopes stability***

The totality of mining-geometrical conditions of the side mass defines its struc-tural features and a new de-sign diagram. Each of these conditions can be deci-sive with substantiation of the open pit side rational profile.

Let’s consider the most often met in practice variants of forming the slide sur-face accounting for the presence in the mass of weakening surfaces, and make respective design diagrams of slope stability.

A design diagram of open pit slopes cut by the in-clined flat weakening surface as a simplest diagram tak-ing into account the mass structure was dealt with by a lot of scientists (G.L. Fissenko, R.P. Okatov, P.S. Shpa-kov, A.M. Mochalov, I.I. Yermakov and others). The de-cisions developed by them have a number of drawbacks. In them curvilinear slide surfaces are replaced by linear sections. The slide surface inlet angle into the weakening surface θ / is determined by the simplified formula. The computation of the real slope is performed not for the conditions of the limit state. As a result of the decision there are determined the values of the limit slope param-eters (H ,r).

The slide surface CDEE1A begins from the depth $H_{90}$ with a tearing off crack CD (Figure 2). Then there fol-lows a curvilinear section of the slide surface, ap-prox-imated by the round-cylindrical surface (DE), which on the contact enters the weakening surface at the angle θ /, determined by formula 1.

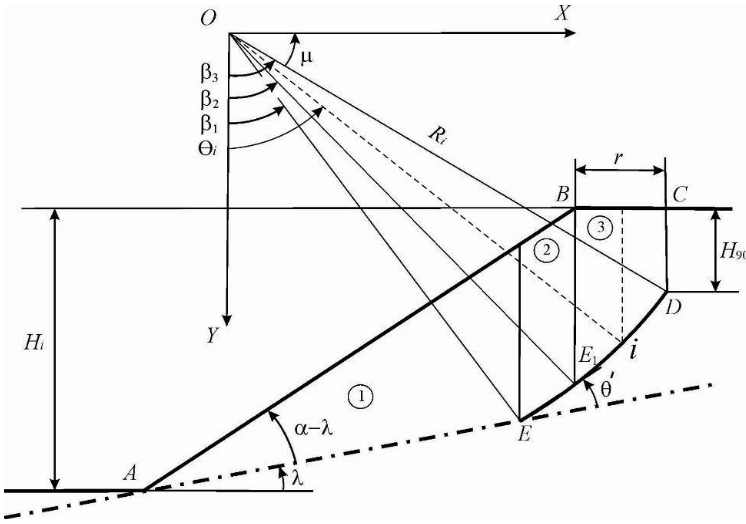


Fig. 2. Design diagram of slope stability with inclined weakening surface at $\beta_1 < \beta_2$

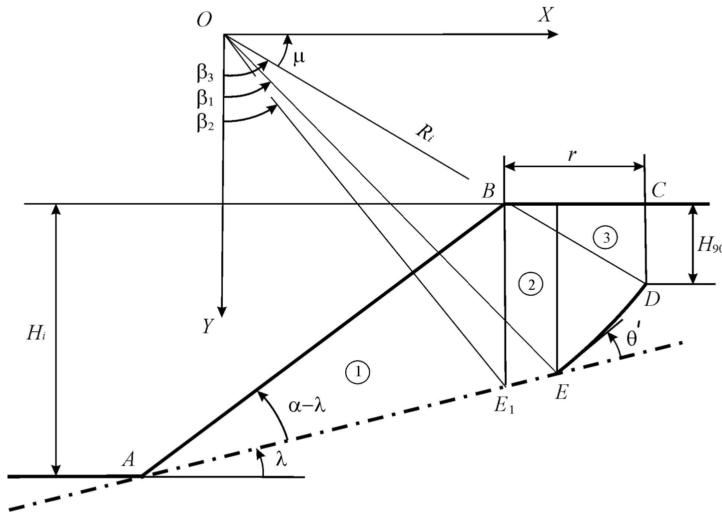


Fig. 3. Design diagram of slope stability with inclined weakening surface at $\beta_1 > \beta_2$

Then the considered slide surface continues in the weakening surface (section EA) with exit to the earth surface at the point A at the angle μ=(45°-ρ'/2) to the direction of the main stresses action.

Depending on the slide surface location there can exist two design diagrams [2]: diagram 1 – $\beta_1<\beta_2$ (Figure 2, formula (4)); diagram 2 – $\beta_1>\beta_2$ (Figure 3, formula (5)).

For diagram 1 – $\beta_1<\beta_2$

$$n=\frac{P_1 tg\rho'\cos\lambda+k'|E\,|+\gamma R\,tg\rho(\int_{\beta_1}^{\beta_2}H_2\cos^2\theta\,d\theta+\int_{\beta_2}^{\beta_3}H_3\cos^2\theta\,d\theta)+kR\int_{\beta_1}^{\beta_3}d\theta+H_{90}/3}{P_1\sin\lambda+0,5\gamma R(\int_{\beta_1}^{\beta_2}H_2\sin 2\theta\,d\theta+\int_{\beta_2}^{\beta_3}H_3\sin 2\theta\,d\theta)} \quad (4)$$

where k is the rock adhesion in the mass, MPa; k' is the weakening surface rocks adhesion, MPa; Hi is the elementary design block height, m; Pi is the de-sign element weight on the weakening surface, N.

For diagram 2 – $\beta_1>\beta_2$

$$n=\frac{(P_1+P_2)tg\rho'\cos\lambda+k'|E\,|+\gamma R\,tg\rho\int_{\beta_1}^{\beta_3}H_3\cos^2\theta\,d\theta+kR\int_{\beta_1}^{\beta_3}d\theta+H_{90}/3}{(P_1+P_2)\sin\lambda+0,5\gamma R\int_{\beta_1}^{\beta_3}H_3\sin 2\theta\,d\theta} \quad (5)$$

For sharply incident weakening surface there are also can be two design dia-grams: diagram 3 – $\beta_2 > \beta_3$ (Figure 4, formula (6)); diagram 4 – $\beta_2 < \beta_3$ (Figure 5, formula (7)).

For diagram 3 – $\beta_2 > \beta_3$

$$n=\frac{\gamma R\,tg\rho\int_{\beta_1}^{\beta_3}H_1\cos^2\theta\,d\theta+kR\int_{\beta_1}^{\beta_3}d\theta+(P_2+P_3)tg\rho'\cos\lambda+k'|E\,|}{0,5\gamma R\int_{\beta_1}^{\beta_3}H_1\sin 2\theta\,d\theta+(P_2+P_3)\sin\lambda} \quad (6)$$

For diagram 4 – $\beta_2 < \beta_3$

$$n=\frac{\gamma R\,tg\rho(\int_{\beta_1}^{\beta_2}H_1\cos^2\theta\,d\theta+\int_{\beta_2}^{\beta_3}H_2\cos^2\theta\,d\theta)+kR\int_{\beta_1}^{\beta_3}d\theta+P_3\,tg\rho'\cos\lambda+k'|E\,|}{0,5\gamma R(\int_{\beta_1}^{\beta_2}H_1\sin 2\theta\,d\theta+\int_{\beta_2}^{\beta_3}H_2\sin 2\theta\,d\theta)+P_3\sin\lambda} \quad (7)$$

For the inclined weakening surface there can be two design diagrams: diagram 5 – without the slope cutting (Figure 6, formula (8)); diagram 6 – with the slope cutting (Figure 7, Formulae (9, 10)).

Let's replace the integration by the angle by the integration by the slide sur-face length L. The formula will take the form

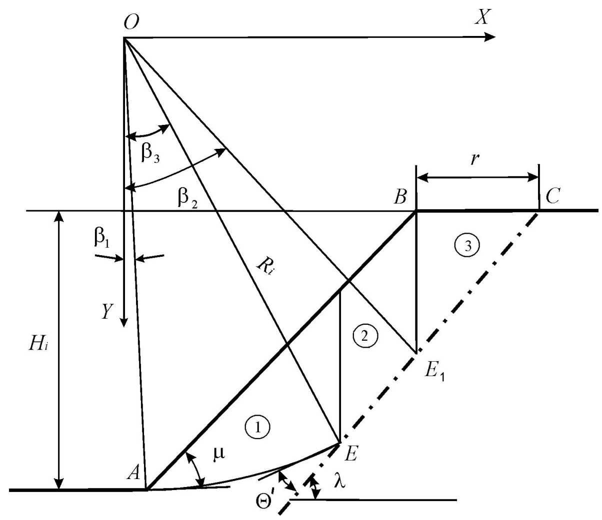


Fig. 4. Design diagram of slope stability with sharply incident weakening sur-face at $\beta_2 > \beta_3$

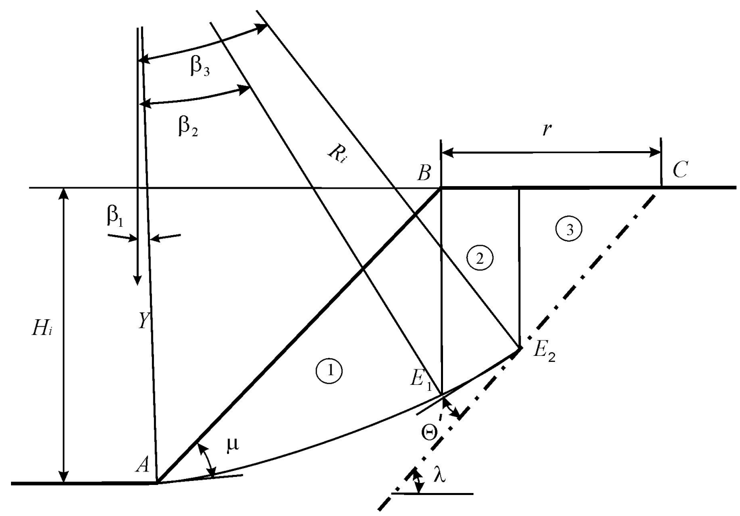


Fig. 5. Design diagram of slope stability with sharply incident weakening sur-face at $\beta_2 < \beta_3$

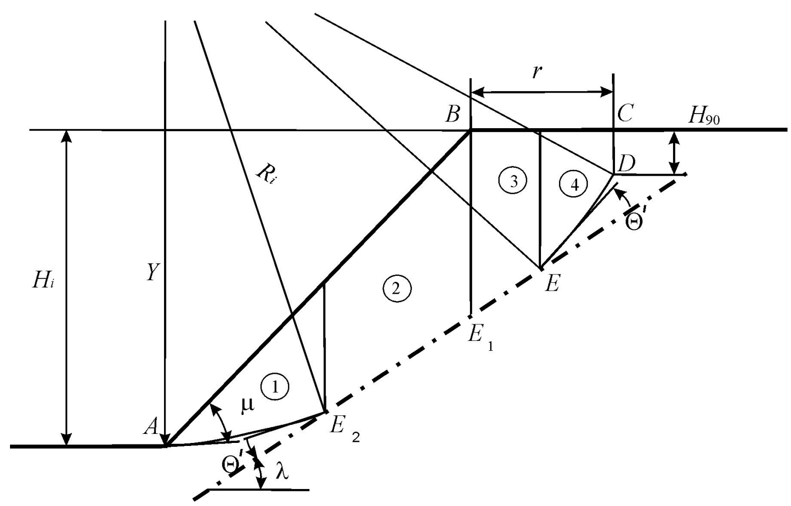


Fig. 6. Design diagram of slope stability with inclined weakening surface with-out the slope cutting

$$n = \frac{\gamma tg\rho \int_{L_1} H_1 \cos^2 \theta \, dl + k \int_{L_1} dl + (P_2 + P_3) tg\rho' \cos \lambda + k' \left| E_2 E \right| + \gamma tg\rho \int_{L_4} H_4 \cos^2 \theta \, dl + k \int_{L_4} dl + k \quad 90/3}{0,5\gamma \int_{L_1} H_1 \sin 2\theta \, dl + (P_2 + P_3) \sin \lambda + 0,5\gamma \int_{L_4} H_4 \sin 2\theta \, dl} \quad (8)$$

Diagram 6:

$$n = \frac{(P_1 + P_2) tg\rho' \cos \lambda + k' \left| \quad \right|}{(P_1 + P_2) \sin \lambda} \quad (9)$$

If the weakening surface is nor flat and is described by an array of junction points (points 1 to 7 in Figure 7), the angle of the elementary ground inclination is determined using the formulae of Lagrange interpolation.

In this case the integral equation of equilibrium can be presented in the following form

$$n = \frac{\gamma tg\rho' (\int_{L_1} H_1 \cos^2 \theta \, dl + \int_{L_2} H_2 \cos^2 \theta \, dl) + k' \int_{L_1 + L_2} dl}{0,5\gamma (\int_{L_1} H_1 \sin 2\theta \, dl + \int_{L_2} H_2 \sin 2\theta \, dl)} \quad (10)$$

The immediate solution of equilibrium equations (3) to (8), (10) relative to H and r in the elementary functions is impossible. Therefore these equations solution is performed by the numerical-analytical method taking into account that the slope is every time brought to the limit state by the proportional sequential changing of the mass strength characteristics up to the limit ones.

The experience of using this method of designing the slope stability in practice shows that there is a possibility to take into account the cracked and laminated structure of the rocks composing the open pit benches and sides slopes [3].

**Conclusions**

The versatility of the presented method of computing open pit slopes stability permits to take into account a number of natural and anthropogenic conditions of the open pit side masses., such as lithological heterogenity, plicative and disjunctive tectonic broken state, rocks laminated structure, form of the open pit side, hydro-geological conditions of the deposit development, the mining-transport equipment loading effect, engineering aids effect, strengthening the open pit slopes and sides, etc., which gives it priority in substantiation of the parameters of open pit slopes of complicated-structure deposits.

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