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CORRELATION MODEL OF THE FACTOR OF SAFETY OF THE WATERED PIT WALL

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The purpose of correlation analysis:

1) Perform a regression analysis and identify the regression equation of the functional (factor of safety) from arguments (strength characteristics of the pit slope materials, and hydrogeological conditions).

2) To assess the presence and closeness of the dependence between arguments.

3) To form a multifactorial correlation model of the flooded and watered pit wall.

The experience of work in terms of geomechanical and hydrogeological stability of the pits walls shows that when the groundwater supply area is close to them, the boundary of the water table formation is located at the pit slope [2]. As a result, the position of the intersection point of the sliding surfaces and the outflow of groundwater does not depend on the horizon of the outflow of groundwater from the pit slope.

However, when the supply area is located much further away, the water table becomes flat, and the higher the horizon of groundwater outflow, the larger the cross-sectional area of the side will be exposed to groundwater. Assuming that the groundwater supply area is infinitely far away, the line of the water table can be represented as a horizon. The hydrodynamic effect will be negligible, due to the pressure gradient $I \to 0$ tending to zero.

To determine the multifactorial correlation of the factor of safety (n) of the flooded and watered pit wall, analyzed of a homogeneous isotropic slope with a height of 200 m, with a slope angle of 30° and with a variable watering coefficient of 0.1-1.0:

$$k_{\text{в}} = \frac{H_{\text{в}}}{H}, \tag{1}$$

where $H_{\text{в}}$ = height of groundwater outflow (m); H – height of slope (m).

The criterion for the risk of deformations and instability of the pit wall is the factor of safety on the most stressed sliding surface [4], in total has the form:

$$n = \frac{1}{\Delta l}\int_0^l \left[\frac{2Cl \cdot \left(1 - k_{\text{в}} + k_{\text{в}} K_{\text{р}}\right) + \operatorname{tg}\varphi \cos\alpha' \,(\gamma h + \gamma_{\text{в}} h_{\text{в}})}{\sin\alpha' \,(\gamma h + \gamma_{\text{в}} h_{\text{в}})}\right] dl, \tag{2}$$

where Δl = difference of the function arguments on the interval (m); C, φ – cohesion (MPa) and friction angle (degree); l = coordinate along the sliding surface L, $l \in L$ (m); $k_{\text{в}}$ = watering coefficient of slope; $K_{\text{р}}$ = softening coefficient of slope material; α' = angle of base (degree); γ and $\gamma_{\text{в}}$ = unit weight (kN/m^3) of slope material and groundwater; h and $h_{\text{в}}$ = height elemental block and level of groundwater (m).

In general, the functional (2) can be written:

$$n = f\big(H, \alpha, \varphi, C, \gamma, k_{\text{в}}, K_{\text{р}}\big)\,, \tag{3}$$

where H and α = height (m) and angle of slope (degree); φ, C, γ = friction angle (degree), cohesion (MPa) and unit weight (kN/m^3) material of slope; $k_{\text{в}}$ = watering coefficient; $K_{\text{р}}$ = softening coefficient.

The arguments selected for analysis should have a causal dependence with the functional. It is not recommended to include in the model a group of arguments whose correlation coefficient exceeds 0.85 between each other.

For the board, with explicitly defined geometric parameters, the arguments H and α are constants. Unit weight of the material varies slightly (according to research, about 2%). In this regard, the effect of its change on the functional – factor of safety, can be neglected.

As arguments for evaluating the impact of hydrogeological factors on the functional (3), the following are accepted: the watering coefficient (coefficient of the hydrostatic conditions), the softening coefficient, the friction angle and cohesion. The variable values of the accepted arguments are written in Table 1. Their value corresponds to the largest, smallest and average values (for the conditions of coal open pit mines in Kuzbass). The watering coefficient has 10 possible values to identify a more smoothed correlation.

All values of factor features were taken arbitrarily and independently of each other, thus, there is no correlation between them at all, which allows an assessment of their joint influence when determining a multifactorial correlation model.

Table 1

Variable values of arguments for determining a correlation model

Watering coefficient (coefficient of the hydrostatic conditions)	Softening coefficient	Friction angle, degree	Cohesion, MPa·10^2
0.1÷1.0	0.9	35	50
	0.7	25	30
	0.5	15	20

The level of influence of factor arguments on the value of the functional (n), expressed as a percentage was determined (Table 2) in based on the data obtained during the stability analysis of the isotropic slope of the wall.

Table 2

The level of influence of factor arguments on the functional

Factor arguments	Influence on the pit wall	
	flooded	watered
Watering coefficient (coefficient of the hydrostatic conditions) $k_{в}$	4%	18%
Softening coefficient $K_{р}$	14%	9%
Friction angle φ, degree	59%	55%
Cohesion C, MPa·10^2	23%	18%
Overall impact of arguments	100%	100%

The analysis of the results of determining the level of influence of factor arguments on the value of the functional identified a close dependence between factor of safety and friction angle (φ) for both the flooded (59%) and watered (55%) pit slope.

The second most important in case of flooding is the material cohesion (C, 23%), and in case of watering the watering coefficient ($k_{в}$, 18%) and the material cohesion (C, 18%) are equivalent. These arguments are accepted for the formation of multifactorial correlation models of the flooded and watered pit slope, as the most influential on the functional.

A graphical interpretation (Figure) of the factor of safety functional based on the selected arguments is obtained and is generally written [1]:

$$z = a + bx + cy\,, \tag{4}$$

$$\begin{cases} aN + b\Sigma x + c\Sigma y = \Sigma z\,; \\ a\Sigma x + b\Sigma x^2 + c\Sigma xy = \Sigma xy\,; \\ a\Sigma y + b\Sigma xy + c\Sigma y^2 = \Sigma yz\,, \end{cases} \tag{5}$$

where a, b and c = linear regression coefficients determined by a system of normal equations; N = total number of variant arguments.

The multiple correlation indicator is determined from the expression [3]:

$$R = \sqrt{1 - \frac{\sigma_{ост}^2}{\sigma_{эмп}^2}}\,, \tag{6}$$

where $\sigma_{ост}$ = standard deviation of a set of difference theoretical and calculated values; $\sigma_{эмп}$ = standard deviation of a set of calculated values.

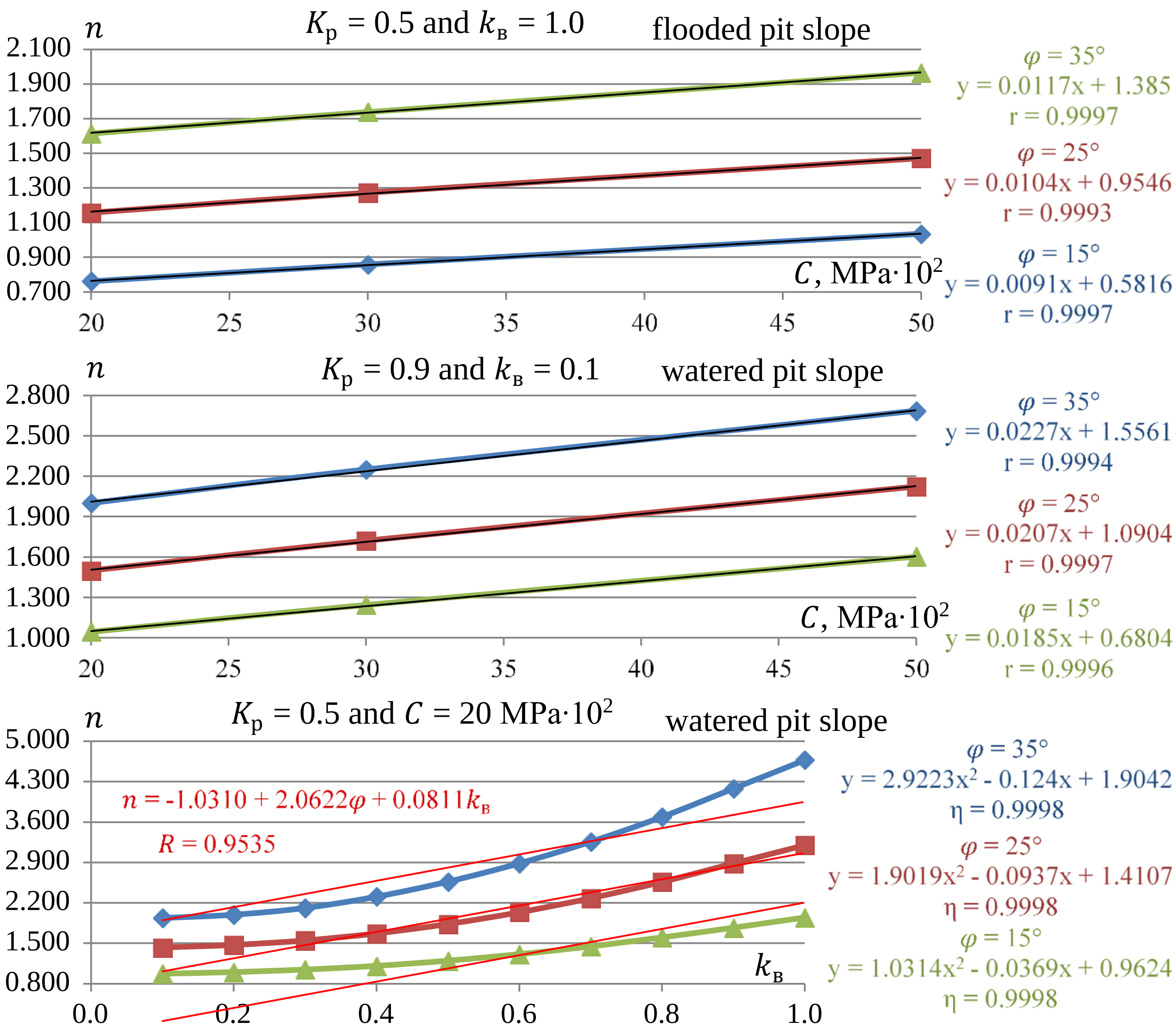

Figure – The correlation of the factor of safety (n) of the pit slope on arguments

A multivariate correlation model in mathematical form for a flooded and watered pit slope, and the results of the linear correlation analysis are written in Table 3.

Conclusion about multifactorial correlation of the factor of safety (n) of a homogeneous isotropic slope with a height of 200 m, with a slope angle of 30°:

1. The most important arguments in case of flooding pit wall is friction angle (φ, 59%) and material cohesion (C, 23%). We see <u>a linear</u> increase in the functional (n) with an increase in the values of these arguments.

The correlation of the functional and the arguments is expressed by a linear correlation indicator (r), the value of which is close to 1. The smallest value (0.9993) is obtained by softening coefficient $K_{\text{p}} = 0.5$, watering coefficient (coefficient of the hydrostatic conditions) $k_{\text{p}} = 1.0$ and slope material friction angle $\varphi = 25°$.

2. The most important arguments in case of watering pit wall is friction angle (φ, 55%), material cohesion (C, 18%) and watering coefficient ($k_{\text{в}}$, 18%).

Table 3

Linear correlation analysis between factor of safety (n)
and most important arguments

Hydrogeological condition		Arguments		Coefficients			Correlation indicator R	Maximum functional difference
		x	y	a	b	c		
Flooded pit slope	K_p = 0.5, $k_в$ = 1.0	φ	C	-0.1371	0.0104	0.0444	0.9986	0.03
Watered pit slope	K_p = 0.9, $k_в$ = 0.1	φ	C	-0.1597	0.0206	0.0507	0.9987	0.04
	K_p = 0.5, C = 20 MPa·10^2	φ	$k_в$	-1.0310	2.0622	0.0811	0.9535	0.81

We see a linear increase in the functional (n) with an increase in the first and second arguments. An increase in the values of the friction angle (φ) and a decrease in the watering coefficient (k_p) results in an increase in the factor of safety (n) in quadratic polynomial function.

Linear correlation indicator (r) is also close to 1. The smallest value (0.9994) is obtained by softening coefficient $K_p = 0.9$, watering coefficient $k_p = 0.1$ and slope material friction angle $\varphi = 35°$.

The level of parabolic correlation of the arguments and the functional is expressed by the correlation ratio (η), value of which is close to 1 (0,9535), however, the theoretical value of the functional differs significantly from the calculated one. The largest discrepancy in the value of the factor of safety is 0.81 by softening coefficient $K_p = 0.5$, cohesion of slope material $C = 20$ MPa·10^2 and slope material friction angle $\varphi = 35°$

3. The linear multifactorial correlation model allows you to quickly analyze the pit slope stability with specific material properties of slope and hydrogeological conditions. To choose the optimal parameters of the pit wall by varying the arguments and then conduct a time-consuming stability analysis.

4. **Watered pit wall** in non-linear correlation between functional and one of the arguments have a most dependable multifactorial correlation model in **quadratic polynomial function** with system have a much number of normal equations.

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