The influence of fracture model on rock slopes stability assessment

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Abstract

Landslides in rock masses ("rocky landslides") are the separate class of sliding processes. The major influence on such landslides have non-homogeneity (like various types and genesis of dividing surfaces (for example the fracturing)) and computation method, which is the basement for stability modelling.

The object under investigation is rock slope of the river Kuban right bank. It is near the Krasnogorsk lowest hydroelectric power station. The bank consists of sandstones and siltstones. There are fractures and dislocations with a break of continuity. However, the main feature is interbedding of rocks with different strength with sub-horizontal bedding of the layers.

Quantity slope stability assessment of the rock slope bases on the methods of limit equilibrium in the three-dimensional formulation of the problem using the criterion of linear anisotropic strength. There also was the consideration of the parameters influence on estimations results. These parameters are the part of the criterion of linear anisotropic strength.

As a result, the identification of fracture systems is not a trivial task (in case of rocks massive with a complex structure of weakening zones). There may be two ways:

1. Generalization (unification) of crack systems with increasing dispersion of their spatial orientation.

2. Dispersion of spatial orientation of the revealed systems of cracks minimization at the expense of their quantity increase.

1 INTRODUCTION

Landslides in rock masses ("rockslides") are the separate class of sliding processes. (Varnes 1978). The significant influence on such landslides has non-homogeneity (like various types and genesis of dividing surfaces (for example the fracturing)). Any quantity slope stability assessments are incorrect without understanding the mechanism, structure and role of weakened zones in slope stability. The major problem in rock landslides stability modelling is the objective consideration of the cracks parameters and other interfaces influence on the calculation data. On the one hand, natural rock masses have the irregular fracturing system. On the other hand, there always will be the specific measurement mistake in process of fracturing study. All of these leads to significant variability of measured crack parameters. As a result, the mistakes during estimations of rock slopes sliding hazard occurs (Fomenko & Zerkal 2017). At the same time, the concept of calculated values is used, that is we could change somehow the parameters of cracks to get the necessary margin factor, unlike the strength characteristics of soils. As a rule the mean values take part in estimates. At its best, it could be the mathematical expectation of the fracture parameters. This fact may be the reason of incorrect results. It occurs because of one unfavourably oriented crack leads to slope collapsing. The mean value of the cracks orientation and the most dangerous concepts are not equivalent.

2 ROCK LANDSLIDES SYSTEMATIZATION

European specialists were the first who started the investigations of rock landslides. They studied the sliding processes in Alpine region. They offer first types and classifications of slope deformations in rocks: A. Baltzer (1875), A. Heim (1882, 1932), A. Penck (1894), V. Pollack (1925) and others. (Zerkal & Fomenko 2016). I.V.Mushketov (1890), D.I. Mushketov (1914), I.A.Preobragenski (1920) organized first investigations of rocky landslides in in epicentre zones of intense earthquakes (Verenski (1887), Kebinski (1910), Usolski (1911)). K.I.Bogdanovich studied the landslides of Black Sea coast at Caucasus. In 1913, he offers the native classification of slope deformations. It takes into account the presence of stratification planes and soil mass fracturing, as well as the orientation of the stratification and fracturing relative to the slope.

Slope processes in rock masses are considered as the separate type of landslides (with individualization of some types) in some widely used sliding classifications (Sharpe 1938). Such processes also belong to independent class of slope deformations (Varnes 1978; Cruden & Varnes 1996) and the part of the classification scheme updated version D.J. Varnes (Hungr 2012). Development features of slope deformations in rock massifs are in an implicit form in most widely used sliding processes classifications in Russia. For example the landslides classification of F.P.Savarenski (1935) (Savarensky 1937) had the major influence on the landslides study in Russia. The consequent landslides in it are the offsets in the stratification system or cracks, on the one hand. On the other hand, it is the landslide of unconsolidated soils on the existing surface.

3 THE RESEARCH OBJECT DESCRIPTION

The object under investigation is rock slope of the river Kuban right bank. It is near the Krasnogorsk lowest water power plant (figure 1).

The coastal slope stability in rock soils massive depends on the presence of weakens zones (cracks, discontinuities, planes of bedding or stratification, interlayers of rocks with weak shear resistance), their orientation over each other and the plane of the slope bank.

Figure 1. General view of the research area.

The bank consist of sandstones and siltstones. There are fractures and dislocations with a break of continuity. However, the main feature is interbedding of rocks with different strength properties with sub-horizontal bedding of the layers (fig. 2).

Figure 2. Rocky slope of the Kuban river right bank near the research area.

The weakening surface in the massif (stratification cracks) falls towards the coastal slope. It is oriented along or diagonally to the stretch of the coastal slope in plan (fig. 2). Stratification orients in direction of coastal slope with low-angle of up to 10° and undercuts by the slope. Moreover, the rocks in the interlayer are with different strength, often weathered, with weak adhesion between elementary structural blocks (separateness) and with carbonaceous interlayers, on which sliding surfaces mainly forms. The situation complicates by the pumping of groundwater.

4 ROCK SLOPE QUANTITATIVE STABILITY ASSESSMENT

There are many methods for estimating slope stability. The choice of the method (Pendin & Fomenko 2015) and strength criteria's (Duncan & Wright 2005; Fomenko et al. 2019) depends on the sliding processes type and possible displacement mechanism of landslide mass.

In 1966, F.D. Patton (Patton 1966) was the first who shows the features influence of the interface roughness character, oriented at a certain angle of roughness *i*, and the importance of taking into account this influence in assessing the rock slopes stability. F.D. Patton shows that in conditions of low normal stresses the slope of the sliding surface is equal to the sum of the average value of the roughness angle i the internal friction angle ϕ obtained on the prepared smooth surface. He did it on the base of sliding surfaces features in the limestones. This situation could occur when there is no cut of wavy or angular inhomogeneities (Patton 1966). When normal stresses increase to certain values, the inhomogeneities of the surface cut off during shear. The value of the roughness angle i reduces to zero.

$$\tau = \sigma \times tg(\varphi + i), \text{ if } \sigma < \sigma_o \quad (1)$$

$$\tau = \sigma \times tg\varphi + c, \text{ if } \sigma > \sigma_o \quad (2)$$

where:

σ = effective normal stresses,

i = roughness angle

and

$$\sigma_o = c/(tg(\varphi + i) - tg\varphi) \quad (3)$$

The examples of rocky slope stability assessment by the limit equilibrium methods in the three-dimensional formulation (Gitirana et al. 2008; Fomenko & Zerkal 2011) using the criterion of linear anisotropic strength (Zerkal & Fomenko 2013; Bar N et al. 2018) are under the analysis in this work.

Criterion of linear anisotropic strength is the strength criterion (Snowden 2007; Snowden 2015). It is the generalization of the Mohr-Coulomb strength criteria for anisotropic rocks.

In the linear anisotropic strength model (Snowden 2007) it is considered that the minimum shear strength relates to the fracture. It is necessary to find the following parameters to define this criterion (fig. 3):

- Strength characteristics of soil (cohesion and friction angle c_1, φ_1) in the crack zone (determine the minimum shear strength).
- Strength characteristics of soil (cohesion и friction angle c_2, φ_2) in the massif (determine the maximum shear strength).
- The angle of anisotropy plane incidence α.
- Parametres A and B define the linear conversion from shear strength in the crack to shear strength in the massive depending on the position of the shear plane, which determines by the anisotropy angle (α).

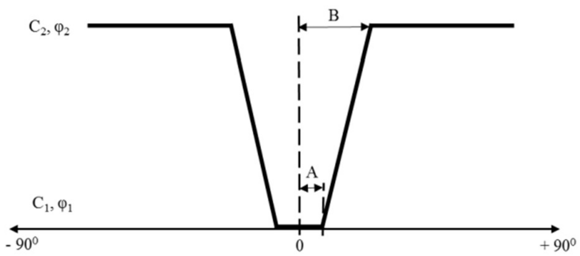

Figure 3. Scheme of parameters determining in the criterion of linear anisotropic strength (Snowden 2007).

The influence on the calculation results of parameters A and B that are the part of linear anisotropic strength criterion was estimated.

The 3D modelling of bank slope stability is based on the main measured fracture systems. There are 9 fracture systems at the research area.

The main estimation method was simple Janbu method (Janbu, 1954).

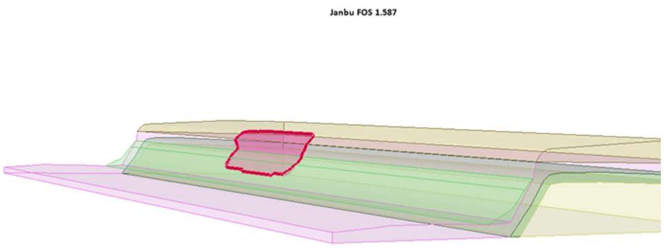

Figure 4. The estimation results by the first variant of calculation

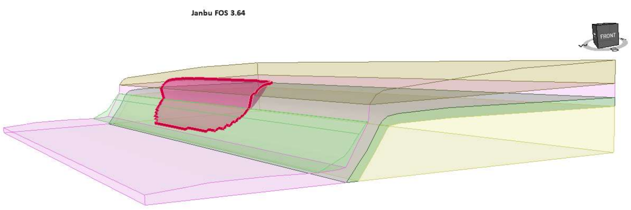

Figure 5. The estimation results by the second variant of calculation

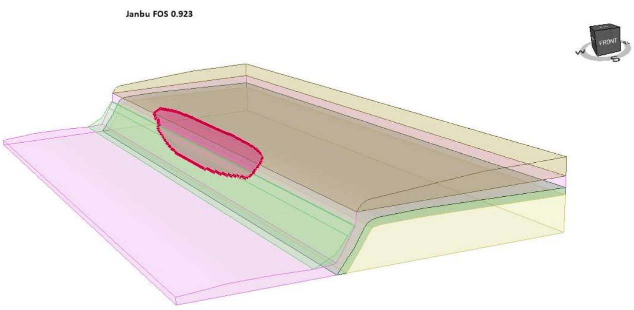

Figure 6. The estimation results by the third variant of calculation

5 THE ROCK SLOPE STABILITY MODELLING RESULTS

There were 3 variants of estimation in the process of modelling. They are in the table 1.

The first variant based on the actual determination of the parameters A and B included in the criterion of linear anisotropic strength. It bases on statistical processing of fractures.

The second variant models the situation when parameter A is the mathematical expectation of cracks orientation in the system. The parameter B characterizes weak disturbance of the rock mass.

The third variant models a strongly disturbed array with a distribution of crack systems close to chaotic.

The results of estimation are on the figures 5-7.

Table 1. Resistance parameters Hoek-Brown

Dip angle	Direction of true dip	Variant 1		Variant 2		Variant 3	
		A	B	A	B	A	B
71	90	3	8	1	3	10	20
1	330	1	6	1	3	10	20
71	75	1	5	1	3	10	20
83	53	3	9	1	3	10	20
75	222	9	12	1	3	10	20
81	10	10	20	1	3	10	20
85	140	2	8	1	3	10	20
65	293	6	10	1	3	10	20
66	263	7	10	1	3	10	20
71	90	3	8	1	3	10	20
71	90	3	8	1	3	10	20

6 CONCLUSION

The analysis of the results shows that the slope is stable (by the first (Fs=1,59) and second calculation variant (Fs= 3,64)). The slope is unstable by the third variant (Fs=0,92). It is obvious that parameter A is determined by the statistical spread of cracks in the system. Parameter B is determined by disturbance of the array because of fracturing. The last thing associates it with a parameter GSI from Hoek-Brown strength criteria (Hoek & Brown 1981; Hoek et al. 2002).

Numerical experiments of quantify stability show the importance of accounting the fracture variability and anisotropy of rocks strength properties that are composing the rocky slopes. The anisotropy of the rock properties underestimation may cause an incorrect assessment of the engineering and geological situation.

As a result, the identification of fracture systems is not a trivial task (in case of rocks massive with a complex structure of weakening zones). There may be two ways:

1. Generalization (unification) of crack systems with increasing dispersion of their spatial orientation.

2. Dispersion of spatial orientation the revealed systems of cracks minimization at the expense of their quantity increase.

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