Stability analysis of pit slopes in Zapadno-Ozerny quarry to ensure mine safety

N. F. Pykhteeva[1,*], *O. N.* Andreeva[2], *P. V.* Koltsov[2]

[1]Ural Federal University named after the first President of Russia B. N. Eltsin, Department of Structural and Soil Engineering, 620002 Ekaterinburg, Russia
[2]JSC Uralmekhanobr, Laboratory of pit wall stability and rock movement, 620063 Ekaterinbirg, Russia

Abstract. The article discusses the design parameters of open pit slopes and the approach to calculating the stability of open pit slopes. The main deformations of slopes of open pits are considered. An assessment of the influence of the stress-strain state of quarry slopes on their stability is made. On the example of an open pit at the Zapadno-Ozernoye field, the assessment of stability under the actual stress-strain state of the site was performed. Recommendations to determine the new boundaries of the open pit, in which the section of the South Eastern slope of the open pit will be stable are given.

1 Introduction

The most important tasks at a mining enterprise are stabilization of open pit walls, timely prevention of emerging pit slope deformations and correction of slope angles depending on the changing mining and geological situation, both in developing open pit mining and when setting open pit walls to the limit position at the stage of revision. The solution of these problems is aimed at increasing the safety and economic efficiency of mining, as well as ensuring the safety of the territories adjacent to the quarries and the objects located on them [1–3].

2 Background

Zapadno-Ozerny deposit is located in the Uchalinsky district of the Republic of Bashkortostan. It was discovered in 1980 by the North-Eastern geosurvey expedition of the Bashkir Production Geological Association.

Zapadno-Ozerny deposit is located on the northwestern flank of the Uzelginsky ore field and occupies a separate position somewhat apart from the semicircular system of other deposits owing to its confinement to an independent local volcanic structure, the signs of which are noted at different stratigraphic levels according to geological data. In the modern structure of the field, there are two zones of northwestern trending faults with a dip to the

* Corresponding author: n.f.pykhteeva@urfu.ru

north-east, namely western and eastern. They are expressed by zones of intense shear formation.

Field mining is carried out in an open-cut way. Main characteristics of mining method according to original design are presented in Table 1.

Table 1. Mining method characteristics.

Name	Unit of measurement	Value
Working bench height	m	12.0
Bench height	m	24.0-36.0
Bench face angle: - in soft grounds - in weathered rocks - in hard rocks	deg.	 40 65 75
Width of safety benches	m	10-12
Width of bench: - in soft grounds - in weathered rocks - in hard rocks / ore zone	m	 35.0 55.5 53.0 / 50.0
Width of haulage bench	m	20.5
Road slope	‰	0.20-0.08

Calculation of the stability of open pit walls can be performed in various ways [4-7]. For this object, the calculation of the stable open pit wall angle in the project was carried out on the VNIMI method in accordance with “Guidelines for determining the angles of inclination of the sides, slopes of benches and dumps of open-pit mines under construction and in operation”, VNIMI, 1972. The stability rating was performed based on the method of algebraic addition of forces along the most stressed surface. According to the results of calculations presented in the project, the safety margin coefficient of the northern, eastern, southern, and western sides of the open pit accounted for 1.3 corresponding to the standard value. However, it should be noted that the calculation was carried out for the entire depth of the pit wall at the end of the pit mining and some of the weakest areas, such as the upper open pit benches composed of clay rocks were not considered.

3 Problem statement

Field development should be accompanied by the complex of surveying and geological observations to monitor the state of slope fronts, open pit walls and dumps to ensure their stability, timely prevention of the deformation development as well as the correction of slope angles depending on the changing mining and geological situation and eventually to ensure safety and efficiency of open pit mining.

Under the Project designed by Uralmekhanobr Institute in 2010, the complex of instrumental observations to monitor the open pit wall stability in Zapadno-Ozerny deposit has been employed since 2011. The complex includes satellite observations at control points, ground laser scanning and visual inspection of the condition of slope fronts, safety berms and the adjacent territory.

The least stable areas in the quarry are upper levels, where smooth deformations of slope fronts, composed of loose clayey sediments and intensely weathered rocks have taken place for long periods of time. In these areas, deformation processes are recorded in the form of screes and failures due to scouring. These deformations increase in size over time and lead to the destruction of the open pit bench and the adjacent pit wall surface. One of these areas is the eastern side of the open pit (Fig.1).

The middle and lower groups of open pit benches are composed of fractured intensely weathered andesite-dacites. In addition, there are local deformations in the form of screes observed on these levels due to the weathering of rocks in the near-slope part. In October 2019, a rock mass fell out on the eastern side at elevations of 470 ÷ 420 m. The collapse was recorded on the open pit bench above which the transport ramp is located (Fig. 2).

Fig. 1. Upper quarry face deformation in August 2019.

Fig. 2. Upper bench deformation at elevations of 470-420 m in October 2019.

In April 2020, deformations were also recorded in the form of local collapse of the open pit bench at elevations 497 ÷ 485 m and deformations at elevation 478.4 m (transport ramp) in the form of subsidence with the following crack dimensions: the length is 8.0 m and the width is 0.1-0.15 m. At the beginning of June 2020, the mine surveying service of the enterprise recorded the collapse of a rock mass with a total volume of 120.758 m^3 with its displacement towards the mined-out area on the southeastern side of the open pit of Zapadno-

Ozerny deposit (Fig. 3). According to the certificate of the collapse, the dimensions of the deformation were as follows: the length along the front is 140 m and the development depth is 23 m.

Fig. 3. Southeastern bench deformation at elevations of 504-400 m.

4 Theoretical part

To determine the possibility of localizing deformations and further safe mining of ore reserves, Uralmekhanobr Institute performed a stability calculation for the deformation area.

The stability rating of the southeastern open pit wall was carried out using the software package Slope (the software package Scad Office Slope). The package includes a series of calculation methods and allows to perform multivariate calculations of slope stability. Calculations were made according to the following methods: Fellenius, Spencer, and Bishop methods.

Figure 4 shows the calculated sliding surfaces for stability rating of the actual state of the deformation area. The obtained data on the values of the safety margin coefficient were summarized in Table 2.

The calculation results showed a weak stability of the slopes resulting in the deformation development and the instability of the enterprise performance. Further open pit mining is possible only when correcting the southeastern open pit limits, thus ensuring its long-term stability.

One of the main reasons for the deformation occurrence in the open pit of Zapadno-Ozerny deposit is the overestimated design angles of the benches, which do not correspond to the actual physical and mechanical characteristics of the rocks composing these open pit benches. The staff of Uralmekhanobr Institute rebuilt the recommended (new) open pit limits to ensure long-term stability of the open pit wall.

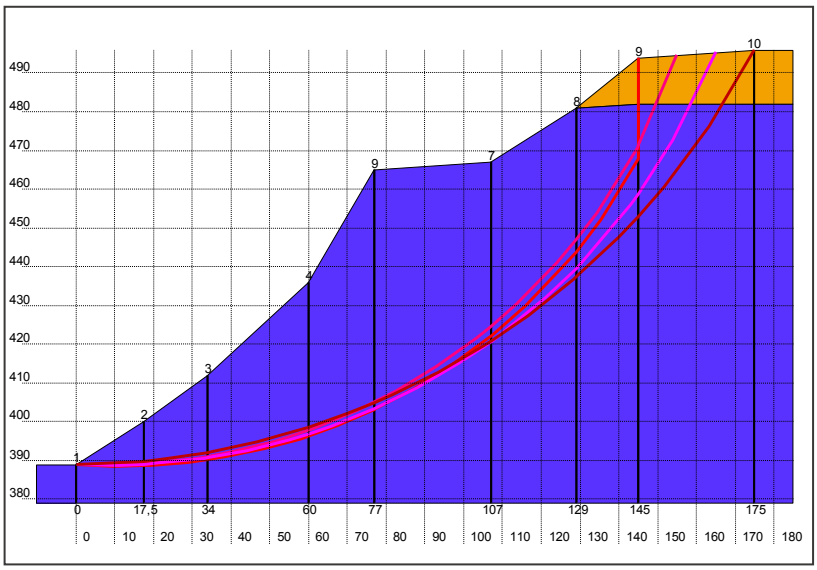

Fig. 4. Calculated strip pits. Stability rating of the actual state of the deformation area.

Table 2. Stability rating of the actual state on 09 June 2020.

Bench height, m	Method	Resulting stability coefficient	Minimum stability coefficient
465÷388 77	Fellenius	0.99	0.99
	Spencer	1.04	
	Bishop	1.06	
495÷467 28	Fellenius	2.1	2.1
	Spencer	2.19	
	Bishop	2.2	
495÷388 107	Fellenius	1.0	1.0
	Spencer	1.04	
	Bishop	1.05	

5 Practical outcome

The stability rating was carried out along the new open pit limits in the software package Slope. The design sliding surfaces are shown in Figure 5. The stability rating of the recommended open pit limits is presented in Table 3.

Based on the calculations performed, Uchaly Mining and Metallurgical Combine was recommended to reduce the slope angle of the upper part of the eastern open pit wall at elevations 508 ÷ 479 m to 24° in the area under consideration and reduce the slope angle at elevations 477 ÷ 438 m to 40°. With these parameters, the pit wall will be in a steady state [8] that will ensure the safe development of the field.

Currently, the enterprise is working on the excavation of the upper levels to give the slope the recommended parameters (Fig. 6).

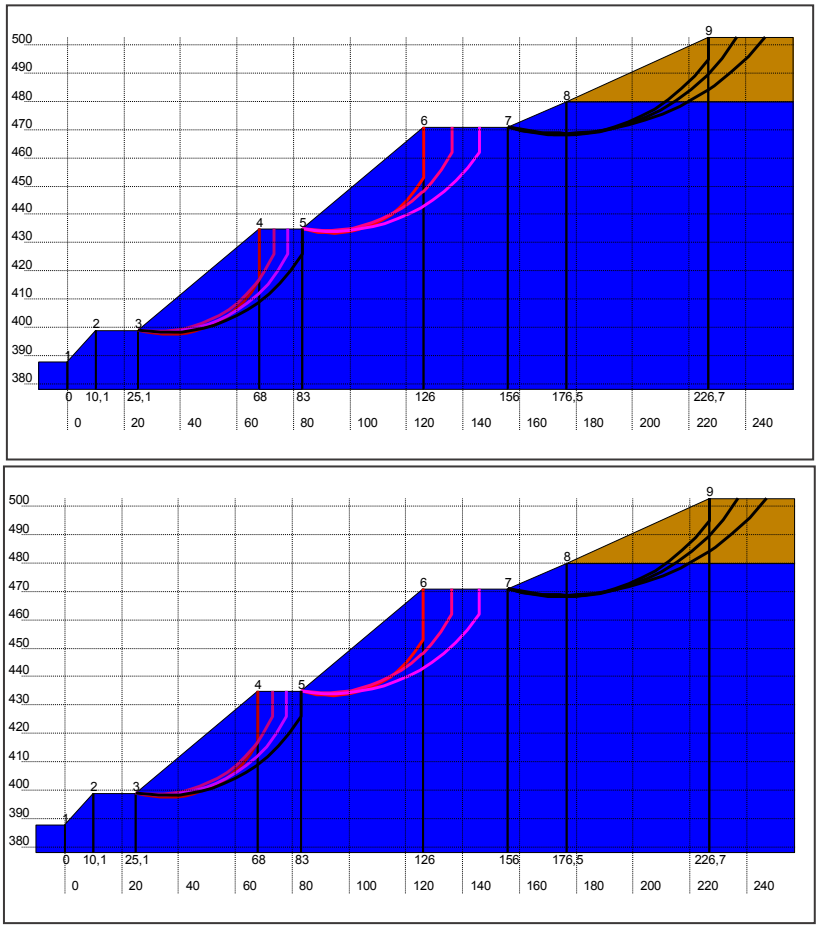

Fig. 5. Calculated strip pits. Stability rating of recommended open pit limits.

Table 3. Stability rating of recommended (designed pit limits).

Level/bench height, m		Method	Resulting stability coefficient	Minimum stability coefficient
503÷471 32	bench	Fellenius	2.37	2.37
		Spencer	2.47	
		Bishop	2.48	
471÷435 36	bench	Fellenius	1.54	1.54
		Spencer	1.61	
		Bishop	1.62	
435÷399 36	bench	Fellenius	1.54	1.54
		Spencer	1.61	
		Bishop	1.62	
471÷399 72	Part of open pit wall	Fellenius	1.25	1.25
		Spencer	1,3	
		Bishop	1.3	
503÷388 115	Entire open pit wall	Fellenius	1.24	1.24
		Spencer	1.29	
		Bishop	1.29	

a) as at June 2020

b) as at August 2020

Fig. 6. Excavation area of upper horizons of eastern open pit walls.

6 Conclusion

Both overstated open pit bench angles and poor geological knowledge of the rock mass caused the development of various deformations in the southeastern open pit walls of Zapadno-Ozerny deposit. Further open pit mining can be continued only if the issued recommendations are fulfilled. The latter are based on the mining operations under the new recommended open pit limits of the southeastern open pit wall giving the slopes the recommended angles corresponding to the properties of the rocks.

References

1. V. M. Lizunkin, A. V. Volokhov, M. V. Lizunkin, Mining information and analytical bulletin (scientific and technical journal) **12**, 153-165 (2016)
2. S. P. Reshetnyak, M. V. Melikhov, Open pit mining in the XXI century, 349-355 (2011)
3. S. G. Ozhigin, F. K. Nizametdinov, P. S. Shpakov et al., Proceedings of the University **4**(**81**), 54-58 (2020)

A. N. Akishev, Iu. I. Lel', I. V. Bokii et al., News of higher educational institutions. Mining magazine **8**, 5-15 (2018)

4. Q. Xu, H. Du, M. Cai, J. of Eng Sc. and Tech. Review **15**, 127-136 (2022)
5. X. Yang, Z. Hao, G. Ma, G. Li, Shock and Vibration **2021**, 6713581 (2021)
6. P. Olah, P. Gorog. LNCE **305**, 293–302 (2023)
7. Rules for ensuring the stability of slopes in coal mines: approved by Gosgortekhnadzor RF 03/16/98 1998 (VNIMI, Saint Petersburg)