Implementation of slope drainage system for optimal slope design at Anfisa open pit, Khabarovsk Territory, Russian Federation

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Abstract

Open pits' slope angles determine company profit and work safety. Steep slope and benches angles increase company's profit as well as increase risks of landslides occurrence. Thus, slopes design should be optimal – profitable and safe. Groundwater negatively influence slope stability. Implementation of slope depressurization program greatly influence slope stabilization and reduce negative risks of pit wall deformation.

The object of the study is Anfisa open pit at gold mineral deposit "Albazino", situated in Khabarovsk Territory, Russian Federation. Complicated geology conditions along with low hydraulic permeability of rocks are the reasons of high groundwater level in the South and South-East walls of Anfisa open pit which substantially influences open pits slope stability.

The main goal of the investigations is optimization and construction of depressurization system at South and South – East walls of Anfisa open pit to achieve slopes stabilization.

Introduction

Open pits' walls angles along with other mining aspects determine company profitability and safety. Steep walls increase company's profit as well as increase risks of landslides occurrence. Thus, slopes design should be optimal – profitable and safe. High pore-water pressure negatively influence slope stability. Therefore, implementation of slope depressurization programs can greatly influence slope stabilization and reduce risks of pit wall failure.

The payback of a slope depressurization program in terms of an increased walls angle and/or improved slope performance is dependent on many factors, including the geomechanical properties of the rock massif and the height of the wall. Every $10 million invested in slope depressurization activities can save $50-100 million realised in mining costs (Geoff Beale, 2013).

The object of the study is Anfisa open pit at gold mineral deposit "Albazino", situated in Khabarovsk Territory, Russian Federation (Figure 1). Reserves (JORC) of the deposit are estimated at 2.3 Moz GE, resources (JORC) are 1.6 Moz GE. At the deposit there are two open pits and one underground mine in operation. In addition, two open pits and two underground mines will start soon. The largest of the quarries is named Anfisa. Complex geological conditions along with low hydraulic permeability of rocks are the reasons of high groundwater level in the South and South-East walls of Anfisa open pit which substantially influences open pits wall slope stability.

The main goal of the investigations presented in the article is optimization and implementation of a depressurization program at the South and South-East slopes of Anfisa open pit. Initial configuration of the open pit was unstable without depressurization system implementation. Instability confirmed by rock mass movement at South and South-East walls. Preliminary cost estimate of slope flattening accepted by the mine as the main scenario assessed

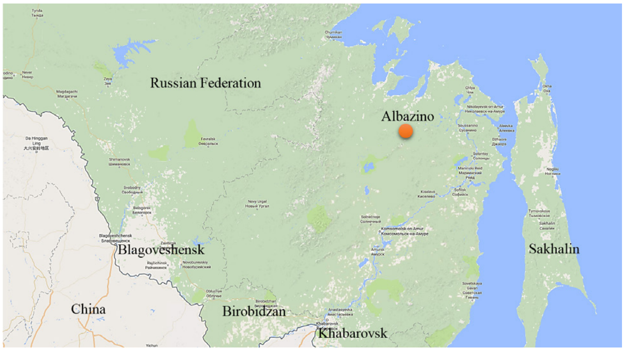

Figure 1 Location of the "Albazino" gold mineral deposit

around 50 million USD. Considering high costs of pit wall flattering development few alternative scenarios were assessed. All scenarios considered development of depressurization system at the pit walls where instabilities took place.

The following tasks were solved to assess the efficiency of the proposed depressurization systems:

Interpretation of geotechnical core logging documentation to determine hydraulic characteristics of rocks. This innovatory approach is based on relationship of the Q – classification system and hydraulic properties of rocks used.

Development of 3d numerical model of groundwater flow.

Slope stability assessment considering effect of different options of depressurization systems.

Detailed description of the tasks is presented further.

Interpretation of geotechnical core logging documentation

Geotechnical core logging documentation was conducted in accordance with the standard of International Society of Rock Mechanics (ISRM). Documentation result contains rock characteristics according to Rock mass classification – Q-system (Barton et al. 1974).

Based on core logging documentation hydraulic conductivity for every drill run interval was calculated using the following formula:

$$K \approx 0.002/(Q_{H20} D5/3), \text{ m/s} \quad (1)$$

Where D is a depth of top of drill run interval relatively to ground surface, in m, Q_{H2O} – permeability rock quality (Barton, N. 2006, Barton, N. 2007),

$$Q_{H20} = \frac{RQD}{Jn} \times \frac{Ja}{Jr} \times \frac{Jw}{SRF}, \quad (2)$$

dimensionless value

Where RQD - Rock Quality Designation,
Jn - Joint set number,
Jr - Joint roughness number,
Ja - Joint alteration number,
Jw - Joint water reduction factor,
SRF - Stress Reduction Factor (Using the Q-system, 2015).

$$Qc = 10^{-7} K(m/s) = 0{,}00864 \text{ (m/day)} \quad (3)$$

Where Qc - Gives a description of the rock mass stability in jointed rock masses. High Qc-values indicates good stability and low values means poor stability

$$Q_c = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}, \quad (4)$$

dimensionless value

Where $\frac{RQD}{Jn}$ Degree of jointing (or block size)

$\frac{Jr}{Ja}$ - Joint friction (inter-block shear strength)

$\frac{Jw}{SRF}$ - Active stress.

Hydraulic conductivities for every interval with geotechnical core logging documentation were calculated using

Table 1 Comparison of conductivity coefficients by geotechnical core logging interpretation and packer tests.

Interval, m		Arithmetic mean value of the hydraulic conductivity, m/d (geotechnical core logging interpretation)	Hydraulic conductivity, m/d (packer tests)
From	To		
7.4	100	0.0425	0.038
100	202.7	0.0183	0.01
202.7	280	0.0097	0.005

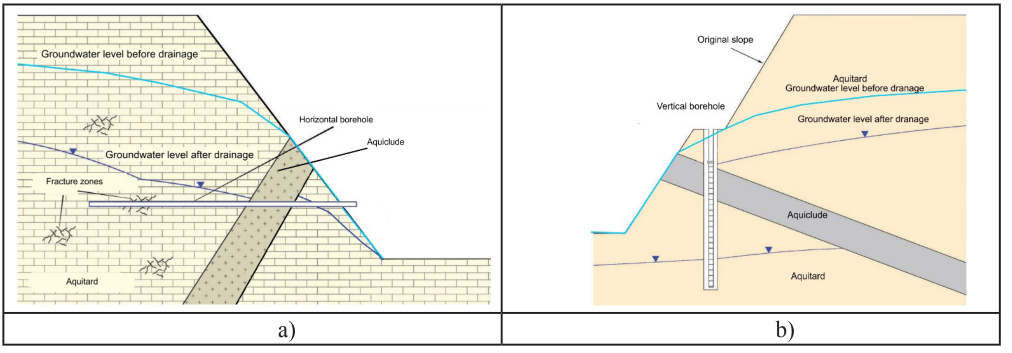

***Figure 2** Principal schematization of Horizontal (a) and vertical (b) boreholes use for drainage (Beale, G. and Read J., 2013)*

both approaches. Calculated parameters varied substantially. The reason is that used approaches do not take into account specific conditions of current deposit. That is why calculated parameters require calibration to the real hydrogeological conditions of the deposit. The next step was calibration.

Calibration of hydraulic properties

Hydrogeological investigation report contains information on packer pumping tests. In terms of calibration, results of core interpretations for both approaches and pumping tests results were compared. Best results of calculated parameters are presented for the second approach by equation (4).

The comparison of results is showed in table 1. Calculated hydraulic conductivity is used for hydrogeology schematization and creation of numerical model.

Numerical model of the groundwater flow

Considering results of hydraulic conductivity calculations schematization of hydrogeological conditions were conducted. Table 2 presentes results of hydrogeology schematization and hydraulic conductivity accepted in the numerical model. There are two main types of hydrogeological units presented in South and South-East walls of Anfisa open pit:

- Aquitards, presented by Residual soil, Siliceous - carbon shale, Microdiorite, Sandstone with silt stones layers, Silt stone with sandstones layers, Granodiorite an Siltstone. Average hydraulic conductivity of the aquitard assessed during calibration is 0.5 m/day for the Residual soil and 0.016 m/day for the others rock types (Figure 2).
- Aquiclude (confining bed), presented by Granite-porphyry, Spilite and Rocks confined to tectonic fault. Average hydraulic conductivity of the aquiclude assessed during calibration is 0.0019 m/day for all rock types (Figure 2).

Hydrogeological model of the South and South-East slope was developed in Visual Modflow Classic v.4.6.0.168. Steady-state groundwater flow was modelled. Model calibration was carried out by comparison of actual and modeled seepage intervals levels

Table 2 Schematization of hydrogeology conditions

Rock / Color of rocks on cross-sections	Hydrogeology schematization	Accept hydraulic conductivity coefficient in the hydrogeology model, m/day
Residual soil	Aquitard	0.5
Silt stone with sandstones layers	Aquitard	0.016
Granodiorite	Aquitard	0.016
Siltstone	Aquitard	0.016
Siliceous - carbon shale	Aquitard	0.016
Microdiorite	Aquitard	0.016
Sandstone with silt stones layers	Aquitard	0.016
Granite-porphyry	Aquiclude (confining bed)	0.0019
Spilite	Aquiclude (confining bed)	0.0019
Rocks confined to tectonic fault	Aquiclude (confining bed)	0.0019

on the quarry's slope. Boundary conditions were changed during calibration to reach the best convergence between the monitoring data and calculated seepage levels parameters.

The following scenarios were considered and simulated on the groundwater model:

- Base case: no depressurization,
- Depressurization scenarios using:
  - horizontal depressurization wells,
  - vertical depressurization wells, and
  - drainage drift with raising boreholes.

10 horizontal wells on berm with elevation +360 m. simulated. Number of horizontal wells limited by pit design, space limitations for installation works, water removal form the pit benches and the short length of pit walls where groundwater discharges.

The groundwater model allowed estimating inflow into drainage systems for each scenario. The results were then used for slope stability calculation.

Slope stability

Calculations of slope stability executed in program Rocscience Slide. The method of calculation based on search weak landslide surface with the lowest factor of safety (FOS). Most critical sliding surfaces presented on figure 3. Mechanical properties used in calculations determined at laboratory and during fields tests. Mechanical properties characterized every rock type.

Results of slope stability estimation of South and South-East walls as well as schematic geological cross sections are presented in figures below (Figure 3).

Discussion

Table 3 presents parameters of the 4 different scenarios (base case without depressurization and 3 options of drainage systems). It includes basic characteristics (slope safety factor and groundwater inflow) and preliminary cost estimate for each scenario. Table 4 shows pros and cons of different drainage systems scenarios.

Increasing of well quantity does not effect on safety factor because groundwater flow in rock massif associated with highly fracturing zones. In that case, for the dewatering purpose most effective way is to drill horizontal wells exactly through these zones. It may be solved by accurate identification of those zones using information from pit wall mapping and exploration drilling.

Three-dimensional model of drainage drift with rising boreholes is presented in figure 4.

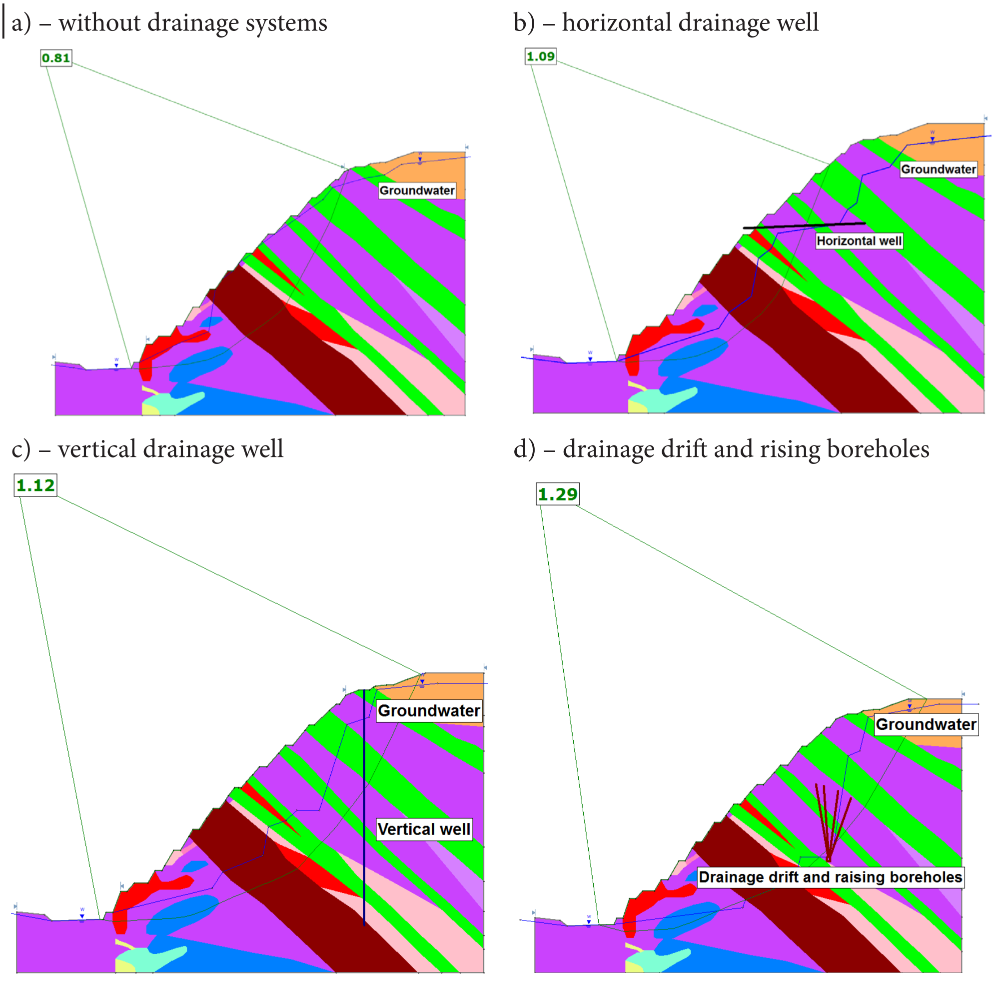

Figure 3 *Safety factors of South and South-East walls using different drainage systems*
a) Slope *without drainage system. Slope is unstable.*
b) Slope *is stable, but safety factor less than regulation value.*
c) Slope *is stable, but safety factor less than regulation value.*
d) Slope *is stable and safety factor above than regulation value.*

Table 3 *Comparative table of the drainage systems scenarios*

Type of drainage system	Safety factor	Short characteristics of drainage system	Discharge of groundwater	Costs
Horizontal wells	1.09	Number of wells: 10; Drilling meters drilled:1,600 m.	16 m^3/h	$ 240 thousand
Vertical wells	1.12	Number of wells: 5; Drilling meters drilled: 1,600 m	27 m^3/h	$ 400 thousand
Drainage drift and rising boreholes	1.29	Drift's length: 572 m; Number of wells cluster: 6; Number of boreholes: 24; Drilling meters: 2,400 m.	46 m^3/h	$ 1.2 million
No drainage systems	1.2	Additional stripping to flatten pit wall.	50 m^3/h groundwater discharge	$ 50 million (the cost of stripping to flatten pit wall: drilling and blasting, haulage)

Table 4 Pros and cons of drainage systems scenarios

Type of drainage system	Advantages	Disadvantages
Horizontal wells	Lower cost. Accessibility on berms. Fast implementation (2-3 months).	1. Limited effectiveness. Safety factor less than regulation value. 2. To avoid water freezing in pipes, drainage system should be equipped with warmth-keeping facilities (heating cable and other).
Vertical wells	Lower cost. Fast implementation (2-3 months).	1. Limited effectiveness. Safety factor less than regulation value, but higher performance than horizontal wells. 2. Difficult access to wells location. 3. Wells drill can be implemented after geophysical investigations for high fractured rocks' zones identification. 4. To avoid water freezing in pipes, drainage system should be equipped with warmth-keeping facilities (heating cable and other).
Drainage drift with rising boreholes	Most effective drainage method. Safety factor above than regulation value.	1. Higher cost of mining workings. 2. Longer implementation period (about 2 years).

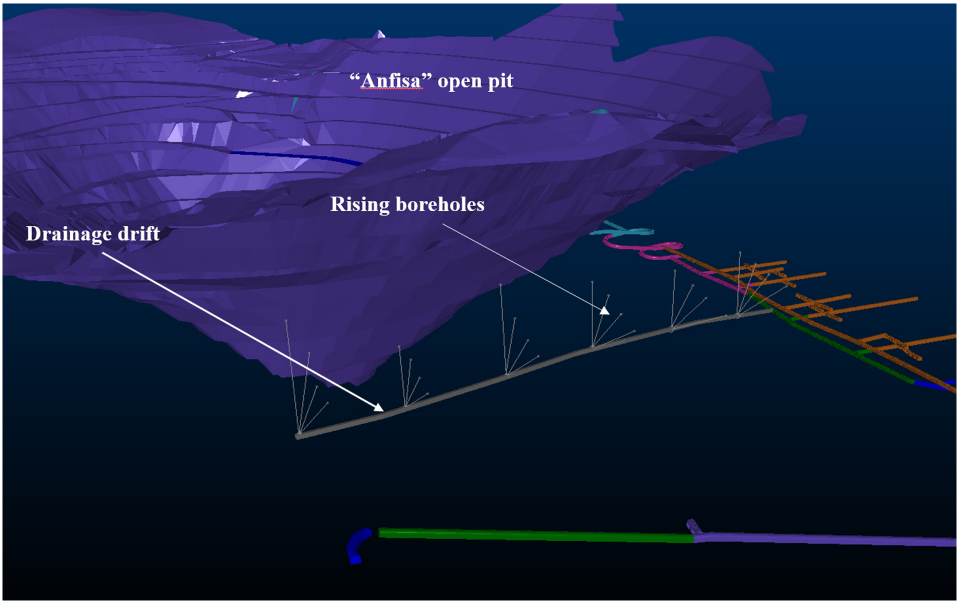

Figure 4 3d model of the drainage drift with rising boreholes

Conclusion

Result of this work is based on innovative method of hydraulic conductivity determination using geotechnical core logging. Based on risks and effectiveness analyses drainage drift with rising boreholes is recommended. The second option is stripping to pit wall flatten and construction of vertical dewatering wells. Nevertheless, disadvantages of this option are higher cost of additional stripping; drainage system should be equipped with warmth-keeping facilities and difficulties with wells service.

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