Improving slope stability at Kışladağ Gold Mine

S. Ergun, E. Gungor & B. Ozdemir
Eldorado Gold Corporation / Tuprag, Usak, Turkey

S. Esen
Drill and Blast Consultant, Sydney, Australia

ABSTRACT: This paper presents part of the slope stability improvement program carried out at Kışladağ Gold Mine in Turkey. A slope stability project was initiated at the site recently to review the minor slope failures as well as the geotechnical and final wall design aspects in detail. Two minor slope failures occurred in December 2014 at the north-east section of the pit in spite of the high quality slope stability implementations at Kışladağ Mine. The work presented in this paper showed that changes to the blasting and geotechnical parameters are required at the north-east section of the pit. Geotechnical design changes were 10 m bench heights with 70 ° slope face angle at that specific area. Having implemented several geotechnical and blast design changes, the followings were observed in the pit: reduced crest loss, reduced number of minor slope failures and more visible half barrels in friable rock types.

1 INTRODUCTION

Kışladağ Mine is the largest gold mine in Turkey. It is operated by Tüprag Metal Madencilik which is a subsidiary of Eldorado Gold Corporation. The mine site is located in southwest of Uşak, west-central Turkey between major cities Ankara and Izmir (Fig. 1).

Figure 1. Location of Kışladağ Mine in Turkey.

To date, detailed geotechnical data collection and evaluation studies as well as stability assessments have been carried out at the Kışladağ Gold Mine.

The onsite geotechnical studies involved the following studies and methods:

a) data collection and evaluation (geotechnical drilling of boreholes, scan line and window mapping surveys, geotechnical logging from oriented cores, rock mass classification, geotechnical characterization of the slope forming materials, pit dewatering and slope depressurization studies etc.);
b) slope movement monitoring (manual surveying of prisms, slope monitoring radars (Reutech Mining 2016), visual inspections and wireline extensometers);
c) slope performance evaluations (monthly berm and bench inspections, preparation of rock failure reports and open pit hazard map); and
d) slope stability analyses (the use of different methods to assess the stability of the benches, berms and overall slopes under different conditions).

This paper summarizes the recent geotechnical works and assessments which were combined with the final wall blasting project carried out on-site.

2 ROCK MASS CONDITIONS AND SLOPE DESIGN

2.1 *Rock mass conditions*

Table 1 lists the main lithologies present at the mine with the depth of oxidation and alteration types. The ore is classified into sulfides and oxides. Uniaxial compressive strength (UCS) was measured using point load, indirect (scriber) and direct via laboratory UCS testing. Direct UCS test results have mean values ranging from 30 MPa to 78 MPa. In general, sulfides are stronger than oxides.

Table 1. Summary of lithology, depth of oxidation and alteration types.

Lithology		Depth of Oxidation	Alteration
Rock	Description		
PYCL	Pyroclastic	Oxide (OX)	Potassic-Biotite (P-B)
INT-1	Intrusive - 1	Sulfide (SUL)	Tourmaline-Sericite (T-S)
INT-2	Intrusive - 2		Argillic (A)
INT-2A	Intrusive - 2A		Advanced Argillic (AA)
INT-3	Intrusive - 3		Combined Clay (CC)
INT-3 DYKE SCHIST	Intrusive - 3 Dyke Schist		Intrusive 3 (INT3) Schist

A 3D model was constructed using LeapFrog® software (Aranz Geo 2015) based on data from rapid recognition of downhole geotechnical conditions, called the Geotechnical Blockiness Index (GBI) (Walker & De Bruyn 2006). The GBI classes were modified for the entire site's specific conditions and the final classes in the GBI model were: Friable zone, Blocky and Semi Massive.

a) Friable zone (FR): FR zone has a range of block size between 1 and 5 cm. This material local deformed and altered. FR zone causes stability problems on benches and ramps at specific locations.

b) Blocky (BL): BL has a range of block size between 5 and 30 cm. This type of material causes stability problems like wedge, planar and toppling failures with relatively high volume.

c) Semi Massive (SM): SM material has a range of block size between 30 and 60 cm and has a very low number of joints/cracks and also intensity of alteration is very low. They may cause very low operational risks.

Rock mass strengths were determined using the material strengths (as determined in the laboratory from different strength tests and during geotechnical core logging with using scriber) as well as the rock mass characterization parameters (determined during core logging using the Laubscher RMR^{90} Classification System) (Laubscher 1990).

It was expected that the RMR would improve for the most recent drill holes from 2012 because these holes were drilled further from the central zone of intrusives (INT1, INT2, INT3) with potentially less change in the rock mass condition due to the geological disturbances and alteration. This was found to be true.

A total of 97 windows (defined areas on the pit wall) have been recorded via geotechnical mapping since the start of the geotechnical slope management program in a 100 month period. 17 window maps out of 97 were carried out using CAE Sirovision ™ remote mapping tool (CAE Mining 2014). This represents an appropriate level of data which were used in the geotechnical investigations.

This data was also used to define the continuity of structures (persistence scaling mainly of joints) for the Swedge (Rocscience 2007) analyses of the bench scale failure volumes that have been used in the assessment of the Spill Berm Width.

2.2 *Slope design parameters*

The aim of the slope design is to provide optimum slope geometry parameters and limitations for implementation by the mine planning team based on the geotechnical condition of the in-situ materials and their likely response to the mining process.

The analysis procedure consists of two independent processes: an empirical assessment and a structural assessment. Both processes provide an estimate of the likely slope geometry per pit sector, according to the following controls:

a) Lithology and alteration
b) Oxide or sulfide zone
c) Minor structural controls
d) Major structural controls
e) Geotechnically defined GBI

The results produced by the empirical and structural analyses are used to provide indicative slope geometries. These geometries are then used in the numerical analyses. The material properties required to populate the models are derived from the geotechnical database and from the results of the laboratory testing.

The rock mass characterization is used to perform an empirical analysis. The results of the analysis provide an initial set of design parameters, which are used to create Indicative Overall Slope Angles (IOSA) and Indicative Bench Stack Angles (IBSA) (Fig. 2) for each geotechnical domain. The rock mass characterization data and laboratory test results are used to determine the of rock mass strengths for input into the numerical models.

The logged in-situ RMR are adjusted for the mining environment conditions in order to convert RMR into MRMR. For the purposes of the empirical analysis of rock mass properties, the data was subdivided firstly into the 5 spatial domains. Next, the data in each of the 5 domains was subdivided by weathering domain: oxide and sulfide. Finally, the data in each weathering domain was sub-divided by lithology, alteration and GBI.

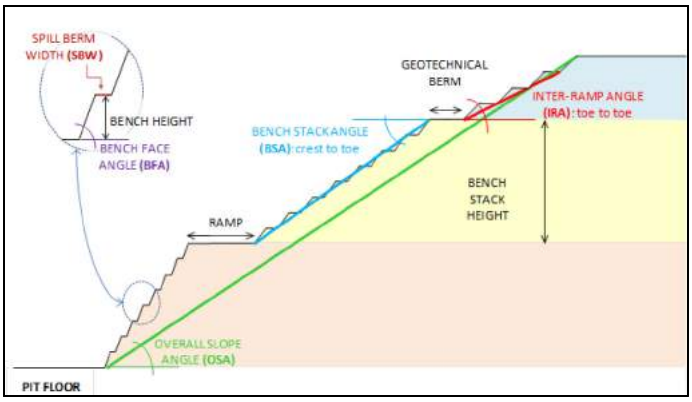

Figure 2. The slope profile terminology.

3 ANALYSIS OF THE MINOR SLOPE FAILURES AT NORTH-EAST SECTOR

3.1 *Occurrence*

Two minor slope failures occurred at north-east section of the pit in December 2014 (Fig. 3). In-situ volumes were 96 and 130 m^3.

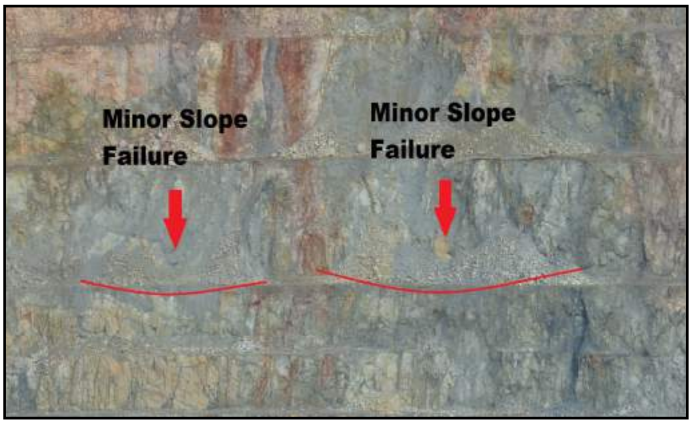

Figure 3. Minor slope failures at north-east section of the pit.

Following these minor failures, a root-cause analysis was performed to identify the causes of these failures. Geotechnical and blast designs were also investigated as part of this work.

3.2 *Analysis of the geotechnical parameters and modifications in design*

Rock mass at NE sector starting from 940 m RL to 900 m RL was found to be a weak rock mass according to the face mapping conducted at the area. Mapping was carried out by using Sirovision software (CAE Mining 2014). The results showed that three were major joint sets leading to unstable slope (Fig. 4). Rock type for the area was PYCL with clay alteration. Analyses using Dips software (Rocscience 2016) showed that the geometry of these three different joint sets were day-lighting from the bench face and there was a high potential to get planar and wedge type of fall of grounds. If the site continues to operate with the original slope design parameters, which is 20 m high benches with 65 degree bench face angle, it is likely that we could see some bench-scale or multi-bench scale fall of ground according to achieved factor of safety value lower than 1.0 in Swedge (Rocscience 2007) and RocPlane (Rocscience 2016).

As shown in Figure 5, the design was updated with 10 m high benches and a 70 degree slope angle. Catch bench berm widths are 7 m.

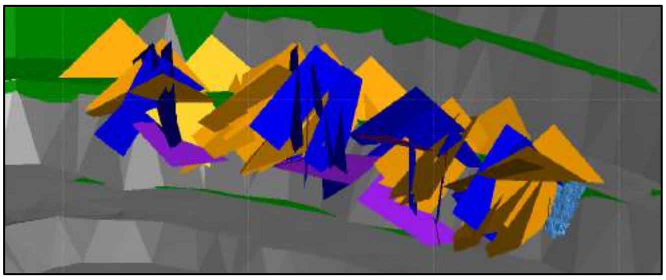

Figure 4. Three major joint sets (purple; blue and orange colored planes) as analyzed using Sirovision™ (CAE Mining 2014).

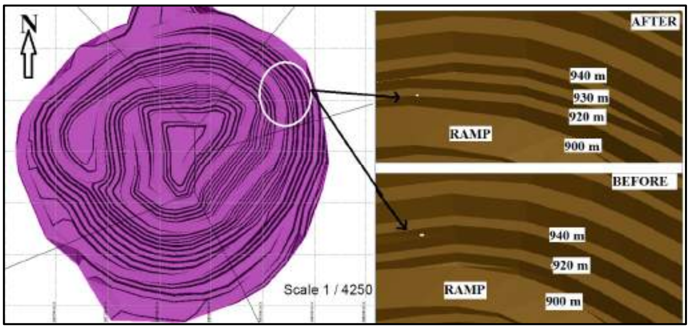

Figure 5. Geotechnical design changes at north-east section of the pit.

3.3 *Analysis of the final wall blast design and suggestions*

Failures occurred approximately one week after final wall blast 940-239 was fired. Therefore, the design of 940-239 as well as the final wall and production designs above the design crest line were analyzed.

The production shot above the design crest line had the last row positioned 1.3 m away from the design crest. All production and final wall designs had the subdrill of 0.8 m. This situation caused rock stress (compression, tensile, shear) failure and crack extension (Fig. 6). Compression and tensile failure is usually caused by subdrill into the catch bench due to excessive stresses. Once the rock is damaged, repetitive blasting can reduce the shear strength of the slope to the point of failure. Block heaving occurs when the explosive pressure adjacent to the slope is poorly relieved away from the wall.

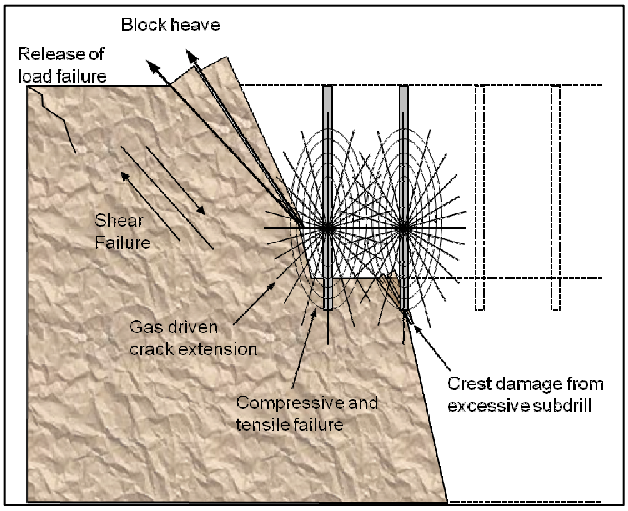

Figure 6. Blast induced wall damage mechanisms (ISEE 1998).

In order to prevent the above damage types, hole positions of the final wall and production shots need to checked against the crest line. All final wall blast rows above the catch bench should not have any subdrill; and therefore, they should have zero subdrill or 0.5-1 m standoff in such specific areas. If the last row of the production shot falls within 5 m of the design crest, it should not have subdrill. It is also suggested reducing the maximum instantaneous charge by changing the delay time. The use of 67 ms along the control row and 25 ms along the echelon result in single hole firing and better relief. The previous final wall shots were fired other way around (i.e. 25 ms control row).

3.4 *Implementation of the new design and outcomes*

Causes for the minor slope failures were found to be two-fold:

a) Geotechnical:
  i. rain events which caused further reduction in the shear strength of the joints.
  ii. structurally controlled weak rock mass.

b) Blasting:
  i. Subdrill: avoid subdrill into the catch bench as explained above.
  ii. Change of primer location: They were located at the bottom of the holes. However, they should be located at the grade level to minimize the damage to the catch bench.
  iii. Cumulative damage (repetitive blasting). Once the damage is caused by the blasts above the design crest, the blasts following this can drive the cracks further and reduce the shear strength of the joints further.
  iv. Initiation timing: Use 67 ms along the control row to allow for the single hole firing and better relief to the rock mass.

Following these failures, geotechnical and blasting recommendations were implemented. 10 m high benches with 70° face slope angles were designed. In addition, above blasting recommendations were implemented. Having implemented above changes, the site did not experience the minor failures again and the crest loss was less indicating more stable slopes with these changes. Figure 7 is an example of the face condition after the changes have been applied.

Figure 7. A view from the north-east area of the pit after the design changes.

A significant reduction in the crest loss was achieved in this specific area by implementing the geotechnical and blasting recommendations as discussed above. Final crest line can be clearly seen after scaling is completed.

There were some areas where major and moderate levels of crest loss were minimized and/or eliminated. There were no cracks penetrating into the wall behind the final crest. Majority of the walls contained visible presplit holes (half-barrels) between 10 m and 20 m high, depending on the bench height used.

Once the final crest was achieved, the crest line was scanned using the Sirovision™ system (CAE Mining 2014). Following these analyses, catch berm width reconciliation was completed. The achieved average catch berm value for this test area was 7 m which was the design length of the planned berm.

4 FINAL WALL BLASTING AT SITE

4.1 *Current design*

Presplits are fired well in advance at the site before firing the production blasts. Blasthole diameter is 95 mm and spacing is 1 m. Hole angles are 70 and 65 degrees at blocky and friable zones, respectively. 10 gram detonating cord is used for surface and downline. 32 mm emulsion charges are placed on the cord in a string loading configuration (one on and one off). Uncharged collar is 2 m. Typical powder factor is 0.36 kg/m^2.

Production blasts are drilled using 165 mm hole diameter. Various drill patterns are used in waste, ore and ROM. Subdrill is 0.8 m. ANFO is used as a main bulk explosive product (Duzgun et al 2015).

Final wall blasts consist of usually 3 rows and shots are free-faced. Hole diameter is 152 mm. ANFO is used with 4 m stemming. 0.8 m subdrill is used in top and bottom 10m benches. Historically, the site was using 25 ms along the control row and 67ms along the echolons. Typical pattern is 4.2 m x 4.8 m with powder factor of 0.22 kg/t.

4.2 *Final wall blast designs*

4.2.1 *Final wall blast designs*

Following changes were considered for the alternative final wall designs with the crest loss >1.5 m:

a) Low density ANFO (0.55 g/cm^3) in the last row of the top final wall blast designs;
b) 0.5 m standoff from the catch bench;
c) 67 ms control row delay with 25 ms delay along the echelons.

4.2.2 *Presplit designs*

Inclined presplit holes using 95 mm hole diameter gave us good results at single and double bench profiles as shown in Figure 8. However, the number of collapsed holes has been reached up to %60 of the presplit holes in friable zones and %20 in blocky zones. Therefore, it was decided to try 140 mm presplit holes with different powder factors for different rock zones:

a) Friable zone: 1.6 m spacing at 0.22 kg/m^2 powder factor;
b) Blocky and semi massive zones: 1.3 m spacing at 0.28 kg/m^2 powder factor.

Figure 8. A view from very good single and double bench profiles with good floor conditions at Kışladağ Mine.

4.3 *Analysis of crest loss*

In order to quantify the crest loss spatially in the pit using lithology and GBI data, heat maps (Fig. 9) were created to track the crest loss data and improvements made with the changes (geotechnical and blasting). Crest loss values were determined in different categories: 0 m - 1.5 m (minor), 1.5 m – 3 m (medium) and >3 m (major). It is planned to minimize the crest loss with medium and major levels using alternative blast designs.

Current final wall blast designs were reviewed. Alternative designs were suggested for zones with crest loss more than 1.5 m. The site is currently updating the heat map every bench to track the improvement made.

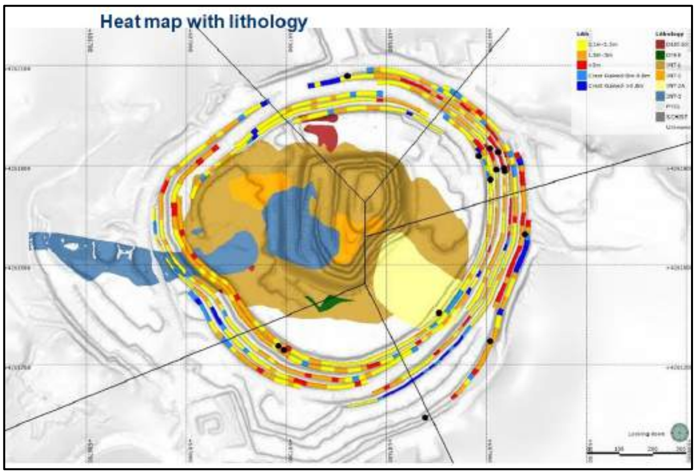

Figure 9. Heat map of crest loss with lithology data.

4.4 *Implementation of the new design and outcomes*

140 mm presplit holes trial was found to be successful with a reduction in the number of collapsed holes and similar or improved half barrels (Fig. 10). This should improve the vibration filtering into the wall and thus should improve wall stability.

As discussed in Section 4.3.1, alternative final wall blast designs would be considered for the areas with more than 1.5 m crest loss. Alternative blast designs have been implemented since November 2015.

Figure 10. A view from the trial 140 mm presplits at friable zones.

A heat map is used to compare the achieved crest lines and design crest lines spatially.

Figure 11 shows a big black box which was located around the test area, medium size black box which was located around the area before blasting and geotechnical implementations and a small size black box which was located around the area after implementations so that a visual comparison can be made with the berms.

As shown in Figure 11, the area is significantly better after implementations (mostly yellow) in comparison to the area in black box. Yellow zones indicate the target crest loss of <1.5 m. Figure 11 indicates that the zones with >1.5 m crest loss do not repeat in lower benches after the implementations.

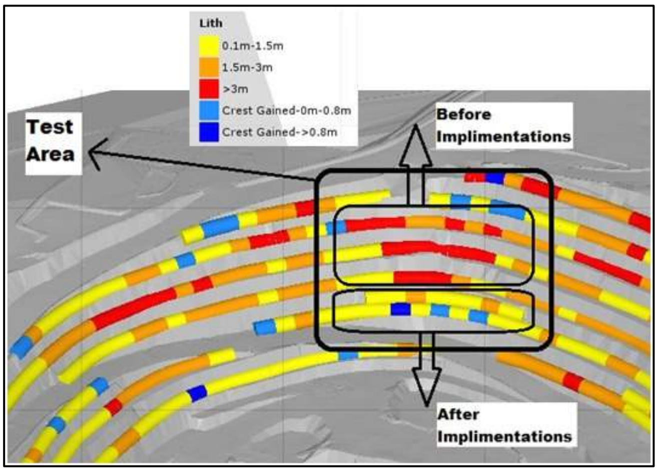

Figure 11. Heat map of the test area.

5 CONCLUSIONS

The root-cause analysis carried out for the two minor slope failures showed that the causes for these minor slope failures were two-fold:

a) Geotechnical: rain events (as a contributing factor), structurally controlled weak rock mass.
b) Blasting: the use of subdrill for the catch bench, incorrect primer location, cumulative damage (repetitive blasting) and unfavorable blast tie-up and delays.

Following these two minor slope failures, geotechnical and blasting recommendations were implemented. 10 m high benches with 70 degrees slope angles were designed. In addition, blasting recommendations were implemented. Having implemented both geotechnical and blasting recommendations, Kışladağ Mine did not experience the minor failures again in the area. A significant reduction in crest loss was achieved.

In addition, heat map of the crest loss was created for the entire pit. Alternative presplit and final wall blast designs have been implemented for the areas with crest loss greater than 1.5 m. The use of larger diameter presplit holes resulted in less incidents of hole-wall collapse and thus more zones with visible presplit areas. A heat map is currently being updated for every bench to track the improvements made and/or modify the designs if needed. The combined geotechnical and blasting design modifications should help improve the slope stability further.

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