A Stability Analysis of the Cantilevered Blocks in the Underground Gold Mine of Akka (Anti-Atlas of Morocco)

Taha Ezzarrouk¹, Toufik Remmal¹ and Rachid El Hamdouni²

¹. Department of Geology, Faculty of sciences of Ain Choc, University of Hassan II-Casablanca, Casablanca 5366, Morocco
². Department of Civil Engineering, University of Granada, Granada 18071, Spain

Abstract: A cantilevered block is instable rock which results from a combination of several discontinuities, in interaction with an underground mining excavation giving a mass rocky under-gangway without natural support. Since the starting of the gold mine of Akka in 1998, 4 deaths and 26 grave accidents happened that are associated to the falling of the cantilevered blocks. However, this study analyzes the causes of apparition of this instability in the underground gold mine of Akka which is in the buttonhole of Tagragra (Anti-Atlas, Morocco) taking into account the geological and geotechnical aspects. The more utilized geotechnical approaches were used to evaluate the quality of rocky mass including RQD, RMR and Q System method besides laboratory tests and geomechanical stations. After development of some classical formulas and using of simulation software and analytical methods, a way of support by bolting is proposed to stabilize the risk of blocks collapse inherent to the mining operations. Also we discuss here other technical solutions and theirs application limits in these cases. Finally, we confirmed the reliability of our conclusions and the type of the support proposed during 2012 and 2013 because we did not register any accident associated to cantilevered block falling.

Key words: Stability, block cantilevered, support.

1. Introduction

A cantilevered block is a structural element embedded in one end and free at the other. This is the result of a combination of several discontinuities, interacting with the excavation, without giving a natural support block. In the mining jargon, it is a mass rock suspended without abutment. Since the starting of the gold mine of Akka in the Anti-Atlas of Morocco (Fig. 1) in 1998, 4 deaths and 26 grave accidents happened that are associated to the falling of blocks. To overcome this problem, a method of retaining bolting is proposed, taking into account the geometry of the fracture, and the geomechanical properties of the blocks. An analog simulation is discussed to evaluate the safety factor inherent to this approach.

2. Materials

2.1 Geological Background of Mine Site

The Precambrian buttonhole of Tagragra Akka is located in the western Anti-Atlas at about 280 km south-east of Agadir. The central portion of the buttonhole that houses the mining district contains several mineralized structures of EW direction and spaced by 30 m to 50 m with a dip to the north. These structures move dolerite dykes and gabbro to the right side oriented NE with a decametric extension to hectometric. The mineralized thickness varies between 0.5 m and 5 m, with tight areas in places (Fig. 1). Some satellites of low thickness and limited extension structures are associated to the main EW structures.

2.2 Cantilevered Blocks

The gold mine of Akka show abundantly cantilevered blocks which is consecutively behind the major risk to
minors falling blocks. The detailed structural study of the gold deposit showed three main families of discontinuities that have shaped geometry of cantilevered blocks (Fig. 2).

It is the F1-F3 or F2-F3 combination with the excavation during the cull of ore [1], which form the hanging and unstable blocks (Fig. 3). In the case where the thickness of the vein coincides with the width of the underground gallery, which is of the order of 1.6 m required for movement of extraction machines (scoop), the risk of cantilevered blocks is no longer possible.

Despite the good rheological competence of sandstone rocky matrix, there are the density and the orientation of fractures that weaken the rock mass and induce the creation of cantilevered blocks.

2.2.1 Simulation by Unwedge Logiciel

For a spatial scene of the structure, we performed a 3D (three-dimensional) view by Unwedge Software (Fig. 4) simulation, which also allows to calculate the safety factor of cantilevered blocks and in this case it is in the order of $F = 0.778$ and when the weight is $W = 0.093 \text{ MN}$. The views following various angles are taken to geometrically model such instability in the non-shot sterile area.

The analysis of the effect of the orientation of the excavation realized by a 3D graph by the same software Unwedge (Fig. 5), shows that certain directions promote stable operation including directions of 0° and 200°, regardless of the dip of the excavation.

2.2.2 Geomechanical Proprietes of Blocs

Geomechanical properties of sandstone which constitute the bulk of the material cantilevered blocks of the mine are reflected in the tables (Tables 2-5) below [2].
Table 1 The three main families of fractures which cause the apparition of cantilevered blocks.

<table>
<thead>
<tr>
<th>Sandstone letic facies</th>
<th>Direction</th>
<th>DIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Famille 1 (F1)</td>
<td>N80</td>
<td>85SE</td>
</tr>
<tr>
<td>Famille 2 (F2)</td>
<td>N100</td>
<td>88NNE</td>
</tr>
<tr>
<td>Famille 3 (F3)</td>
<td>N60</td>
<td>10SSE</td>
</tr>
</tbody>
</table>

![Cantilevered Blocks](Image)

**Fig. 3** Mining of the mineralised structure.

![3D views of a cantilevered block](Image)

**Fig. 4** 3D views of a cantilevered block.

In conclusion, the results are allowed to characterize the quality of the mass rock from good to moderate.

2.3 Simulation by the Method of Finite Element

To understand the reaction amongst all geological compositions taking into account the geotechnical aspects [3], we used the finite element method which originally was a numerical technique for finding approximate solutions to boundary value problems for differential equations.

![Effect of orientation on the stability of the excavation for a safety factor of 1.5.](Image)

**Fig. 5** Effect of orientation on the stability of the excavation for a safety factor of 1.5.

We used a numerical simulation by finite element method proposed by Phase 2 software, which could identify the major tensile stresses around the excavation and therefore deduce the magnitude of the instability associated with cantilevered blocks (Fig. 6). The latter in this case exceed 2 m for a safety factor of 1.57.

2.4 Mode of Support

Among the tested methods of support to deal with the risk of falling blocks, we tested the anchor bolts. To estimate the number as well as the length of anchor bolts required to support the cantilevered block, we developed the analytical calculations proposed by Stillborg [4] and Hadjigeorgiou [5] and the results were as following.

\[ N = \frac{Wf}{T} \]

(1)

where: \( N \): number of anchor bolts;
\( W \): weight of cantilevered bloc;
\( T \): sum of the bolts in tension;
\( f \): safety factor.

\[ s \leq 3e \]

(2)

\[ p \geq L + 1 \]

(3)

\[ 2 \leq f \leq 5 \]

(4)

where: \( s \): spacing between bolts;

Table 2 Mechanical tests of laboratory.

<table>
<thead>
<tr>
<th>( R_c ) MPa</th>
<th>( E ) GPa</th>
<th>( v )</th>
<th>( K_s ) MPa</th>
<th>( R_t ) MPa</th>
<th>( R_{tri} ) MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>54</td>
<td>0.28</td>
<td>5.3</td>
<td>4</td>
<td>141</td>
</tr>
</tbody>
</table>
Table 3  In situ characterization via RocLab software.

<table>
<thead>
<tr>
<th>Hoek-brown classification</th>
<th>Hoek-brown criterion</th>
<th>Mohr-Coulomb fit</th>
<th>Rock mass parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI: 63</td>
<td>mb: 6.669</td>
<td>Cohesion: 12.905</td>
<td>Tensile strength: 0.406 MPa</td>
</tr>
<tr>
<td>Mi: 25</td>
<td>σ: 0.0164</td>
<td>Friction angle: 43.34°</td>
<td>Uniaxial compressive strength: 20.926 MPa</td>
</tr>
<tr>
<td>Disturbance factor: 0</td>
<td>α: 0.502</td>
<td></td>
<td>Global strength: 58.433 MPa</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Modulus of deformation: 21234.89 MPa</td>
</tr>
</tbody>
</table>

Table 4  Empirical classification “RMR” (rock mass rating) [6].

<table>
<thead>
<tr>
<th>Rc = 101 MPa</th>
<th>RQD = 75</th>
<th>Spacing of the joints 0.5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Joint conditions (smooth, planar)</td>
<td>Filtrations (no water influx)</td>
<td>Adjustment factor (low orientation)</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>-5</td>
</tr>
</tbody>
</table>

RMR corrected = 62 (Rock with moderate quality)

Table 5  “Q system” method. [7] & [8]

<table>
<thead>
<tr>
<th>RQD = 75</th>
<th>Jn = 9</th>
<th>Jr = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ja = 1</td>
<td>Three families</td>
<td>Joints plans lisses</td>
</tr>
<tr>
<td>Joints slightly altered</td>
<td>Jw = 1</td>
<td>Low water inflows</td>
</tr>
<tr>
<td>Q = 3.33</td>
<td>Moderate mass rock quality</td>
<td></td>
</tr>
</tbody>
</table>

2.4.2 Slippery Cantilevered Block

\[
N = \frac{W \cdot (f \cdot \sin \beta - \cos \beta \cdot t g \phi) - CA}{B \cdot (\cos \alpha \cdot t g \alpha + f \cdot \sin \alpha)}
\]  

Fig. 6  Simulation of unstable areas by Phase 2 software.

- $e$: spacing between joints;
- $L$: length of bolts;
- $p$: reach of excavation.

\[
(5)
\]
where: $B$: bearing capacity of the bolt (t);
$A$: area of the sliding surface;
$\alpha$: angle between the bolts and the normal to the sliding surface;
$\beta$: inclination of the sliding surface;
$C$: cohesion along the sliding surface;
$\varphi$: angle of friction of the sliding surface;
$R$: slip resistance.

With:

\[ R = CA + W \cos \beta \tan \varphi \]  \hspace{1cm} (6)
\[ f = 2 \] \hspace{1cm} (7)

2.4.3 Calculation of Length Bolt Anchors

\[ L - h \geq \frac{W}{A} \text{ then } L \geq \frac{W}{A} + h \] \hspace{1cm} (8)
\[ W = f(s,c,h,\gamma) \] \hspace{1cm} (9)
\[ B = 1.5W \] \hspace{1cm} (10)

$h$: Cantilevered block height;
$\gamma$: specific weight of the rock (t / m³);
$s$: spacing bolts perpendicular to the axis of the excavation (m);
$c$: spacing between bolts along the axis of the excavation (m);
$A$: anchoring capability (ton / m);
$B$: bolt capacity (metric tons);
$W$: weight of cantilevered block supported by a single bolt (metric tons).

2.4.4 Digital Application

(1) Case of a cantilevered block suspended
Block dimensions: $1 \times 1.5 \times 1$ m³, with a density of 2.7;
$N = 2$ boulons split set ach 1 m laterally;
$N = 1$ boulon swellex each 1 m laterally;
Also: $e = 0.5$, then bolts spacing = 1.5 m.

Fig. 7  Cantilevered block supported by bolts of the Swellex type.

(2) Case of a cantilevered slipping bloc:
$N = 3$ split set bolts each 1 m laterally;
$N = 2$ swellex bolts each 1 m laterally.
(3) Length of bolts:
$L \geq 2$ m;
Reach of the excavation: $P = 3$ m.

3. Conclusions

Bolt of the Swellex type seems the most effective since it does not unshod because of the vibrations induced by the firing explosives, against the bolt shell, in addition to its high capacity of anchoring compared to the first two (Fig. 7). This bolt will also affect the containment seal as it will append the blocks to each other.

Bolting is done before the initiation of slaughter, that is, before the land destabilization by explosives. Note that the holes can be only inclined if the drilling is done using a conventional hammer, given the difficulty of parking this heavy tool vertically. Other solutions can be recommended to address these instabilities in similar conditions, including connectable Swellex, and lashings.

References


[5] F. Charrette, J. Hadjigeorgiou, Practical guide to mining support, in: Ed Mining Association of Quebec, Canada. 2009, p.120.

