Influence of pit wall stability on underground planning and design when transitioning from open pit to sublevel caving

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Introduction

• Beyond economic pit limit, opportunity to transition to underground
• Challenges exist
• Availability of resources/reserves, project economics, geotechnical environment and safety
• Study focuses on the geotechnical environment specifically:
  o Stability/instability of the pit wall
  o Positioning of excavations and infrastructure
  o Role of numerical modelling in assessing stability
Stability and Transition Challenge

• Stability has to be satisfied and at the same time open pit to underground transition has to occur

• Inadequate consideration of geotechnical parameters can cause:
  o Uncontrolled backbreak
  o Failure of pit walls
  o Loss of lives and equipment
  o Excessive dilution
  o Loss of the mine
Case Study Mine

- Located in Africa
- Diamond mine – consists of two kimberlite pipes, P1 and P2
- Spaced at 800m apart
- Several other blow pipes in the vicinity
- Initially mined by open pit until they reached their economic limit at 300m
- Kimberlite pipes intruded the granitic gneiss host rock
Case Study Mine – Geology

- Kimberlites are intruded into the Archean-aged Leonean granitic gneisses of the West African craton
- Gneissic fabric is not obvious everywhere, but appears to define areas of higher strain
- From sight observations and geotechnical investigations, the kimberlite dyke zones are the most prominent structures
- Dykes are not continuous, but pinch and swell, bifurcate and form eastward stepping echelon arrays
- Vary from thin stringers (<30cm), separated by the country rock, to 1.5m wide
Why Investigating Transition?

- Factors that affect mine stability:
  - Structural Geology
    - Faults
    - Bedding
    - Joints
    - Foliation
    - Dykes
  - Groundwater
  - Rock mass classification
  - Geometry
  - Alteration
  - Stress conditions
  - Weathering
  - Blasting
Underground Infrastructure

• Considered for the project:
  o Ramp development
  o Connecting drive for the two underground workings
  o Ventilation shafts
  o Underground workshop
  o Drilling water reticulation
  o Dewatering system
  o Electrical system
  o Secondary escape route
  o Level drives
Infrastructure Considerations

- Infrastructure to be placed in stable ground conditions
- Assess stability risk posed by stress concentrations around pit walls
- Haul roads to be open during initial stages
- Stable position for primary access breakaway
- Mining sequence that does not cause excessive slope failures
Numerical Modelling

- FLAC3D
- Model for predicting the effect of stress changes around the pit wall and underground
- Input parameters include geomechanical properties, initial conditions, boundary conditions, groundwater and mining sequence
- Top down sub level caving through 40m slices
  - 4 slices for Pipe A
  - 5 slices for Pipe B
- Hoek-brown failure criterion used
- Informed siting of infrastructure
## Rock Property Parameters

<table>
<thead>
<tr>
<th>Rock Unit</th>
<th>Breccia</th>
<th>Granite</th>
<th>Kimberlite Dyke</th>
<th>Leached Granite</th>
<th>Translational Dykes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2570</td>
<td>2680</td>
<td>2920</td>
<td>2260</td>
<td>2650</td>
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<tr>
<td>UCS (MPa)</td>
<td>64</td>
<td>124</td>
<td>120</td>
<td>24</td>
<td>55</td>
</tr>
<tr>
<td>Young Modulus (GPa)</td>
<td>55</td>
<td>65</td>
<td>82</td>
<td>15</td>
<td>32</td>
</tr>
<tr>
<td>Base Friction Angle (°)</td>
<td>28</td>
<td>36</td>
<td>30</td>
<td>35</td>
<td>20</td>
</tr>
</tbody>
</table>

![Graphs](GRT_Unit.png)  ![Graphs](KIM_PIPE_Unit.png)

![Graphs](LGRT_Unit.png)  ![Graphs](TRANS_Unit.png)
<table>
<thead>
<tr>
<th>Rock type</th>
<th>UCS</th>
<th>RMR</th>
<th>GSI</th>
<th>mI</th>
<th>c</th>
<th>Φ</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breccia</td>
<td>72</td>
<td>45</td>
<td>40</td>
<td>6</td>
<td>262</td>
<td>34</td>
<td>1.9</td>
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<tr>
<td>Granite</td>
<td>133</td>
<td>63</td>
<td>57</td>
<td>16</td>
<td>1004</td>
<td>55</td>
<td>9.5</td>
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<tr>
<td>Kimberlite dyke</td>
<td>120</td>
<td>61</td>
<td>56</td>
<td>6</td>
<td>977</td>
<td>44</td>
<td>4.9</td>
</tr>
<tr>
<td>Kimberlite pipe</td>
<td>65</td>
<td>61</td>
<td>56</td>
<td>6</td>
<td>694</td>
<td>40</td>
<td>3</td>
</tr>
<tr>
<td>Leached granite</td>
<td>25</td>
<td>48</td>
<td>43</td>
<td>6</td>
<td>184</td>
<td>27</td>
<td>0.5</td>
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</tbody>
</table>
### Joint Set Characteristics for the Mine

<table>
<thead>
<tr>
<th>Set</th>
<th>Dip</th>
<th>Strike</th>
<th>Spacing</th>
<th>Length</th>
<th>Macro planarity</th>
<th>Micro Roughness</th>
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</thead>
<tbody>
<tr>
<td>P1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J1</td>
<td>Shallow</td>
<td>a) SW b) SE</td>
<td>2 m - 10 m</td>
<td>&gt;5 m</td>
<td>Wavy</td>
<td>Rough undulating</td>
</tr>
<tr>
<td>F2/J2</td>
<td>Sub vertical</td>
<td>N-NNE</td>
<td>0.5m</td>
<td>&gt;5 m</td>
<td>Straight</td>
<td>Rough undulating</td>
</tr>
<tr>
<td>J3</td>
<td>Sub vertical</td>
<td>ENE</td>
<td>&lt;0.5 m - 2 m</td>
<td>&gt;5 m</td>
<td>Straight stepped at intersections</td>
<td>Smooth undulating, sometimes slickensided</td>
</tr>
<tr>
<td>J4</td>
<td>Sub vertical</td>
<td>NW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J1</td>
<td>Shallow</td>
<td>a) SW b) SE</td>
<td>&gt;10 m</td>
<td>&gt;5 m</td>
<td>Straight</td>
<td>Rough undulating</td>
</tr>
<tr>
<td>J3</td>
<td>Sub vertical</td>
<td>ENE</td>
<td>&lt;0.5 m - 2 m</td>
<td>&gt;5 m</td>
<td>Straight stepped at intersections</td>
<td>Smooth undulating, sometimes slickensided</td>
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<tr>
<td>Dykes</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SJ1</td>
<td>Moderate sub vertical</td>
<td>60~80° anti-clockwise from J3</td>
<td></td>
<td></td>
<td>straight, slightly curved</td>
<td>Smooth planar</td>
</tr>
<tr>
<td>SJ2</td>
<td>Shallow moderate</td>
<td>N</td>
<td></td>
<td></td>
<td>Wavy</td>
<td>Smooth planar</td>
</tr>
<tr>
<td>J3</td>
<td>Sub vertical</td>
<td>ENE</td>
<td>&lt;0.5 m - 2 m</td>
<td>&gt;5 m</td>
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</tbody>
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Mechanisms of Slope Failure

Note: The convention adopted in this analysis is that the flatter plane is always referred to as Plane A.
Results and Analysis

• Factor of Safety iso-shells
• From the modelling, areas of interest were
  • Pit slope behaviour
  • Interaction of pit and underground mining
  • Zone of geotechnical stability and instability

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Factor of Safety Shells

Factor of safety of 2: P1

FoS 2.5 on P2

FoS 2 on P2

P2 Safety Factor 3.0
Workshops and vent shaft need to move
FoS Shells for Pits P1 and P2

- FoS of 2 chosen to ensure critical excavations are outside failure zone
- Signs of pit instability and slope movement were projected when mining second stope
- Faults and dykes adversely affected pit wall stability
Conclusions and Recommendations

• FLAC 3D FoS iso-shell used for design outside expected zone of influence
• Conservative FoS of 2 was chosen to cater for the unknown rock mass behaviour
• New conditions discovered during the project should be recorded and added to the numerical model
• Strong cross-functional approach from both the geotechnical and the mine planning departments
• Effective monitoring system is required in place around the pit wall, to continuously assess and evaluate displacement and deformation as mining progresses