THE GROUND CONTROL PLAN FOR THE MINAS-RIO SYSTEM

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ABSTRACT

The Ground Control Plan (GCP) for Minas-Rio System is a process to address risks related to Fall of Ground (F.o.G.) events along the complex, including Open Pits, Waste Dumps, Slurry Pipeline and Industrial Assets. As per preconized by the Anglo American (AA) Group Technical Standard AA TS 401 001, the content includes processes maps, roles and responsibilities, risk management, design processes, operational water management, procedures, hazard identification and mitigations, monitoring system, data collection, functional trainings, emergency plans, learn from incidents and risk reduction plans. Besides, the document's content is in line with Brazilian National Mining Agency (ANM) resolutions as well as best practices from regulatory guidelines worldwide.

Keywords: Geotechnical Risk Management; Ground Control Plan; Governance; Geotechnical Hazards.

INTRODUCTION

The Ground Control Plan (GCP) for geotechnical structures comprises a management program to address potential damages related to Fall of Ground (F.o.G.) events in a mining complex. Across the globe, the GCP is being recognized as an essential framework to proportionate a clear overview about these sorts of events, being a regulatory requisite in some countries. In Australia, for example, the GCP in an obligation according to the Western Australia Department of Mines, Industry Regulation and Safety (2019) [1].

The ultimate objective is to reduce, as far as reasonably practicable or even eliminate, the risks associated with failure mechanisms of ground movement in surface and underground environments. Concepts of processes mapping, data engineering, governance best practices and continued improvement are intrinsically related to the GCP process, to be reviewed and audited annually.

In this paper, the Minas-Rio System's GCP is exampled, comprising the mining complex, slurry pipeline facilities and port is exposed to Fall of Ground (F.o.G.) events along the whole production chain. So that, the Ground Control Plan (GCP) is aimed to collect information about processes related to those sorts of events in the Open Pit, Waste Dumps, Slurry Pipeline and Industrial Assets.

METHODOLOGY

Operational Risk Management (ORM)

The Operational Risk Management (ORM) is a methodology to address risks in operational environment, standardized for every Anglo American BU worldwide. The guidelines and assumptions can be found in the standard AA RD 02_24 (Anglo American, 2013) [2]. In general terms, the ORM has its concepts based on ISO 31.000 (ABNT, 2018) [3], using a similar framework for risk management process, however, ORM stablish 4 layers for the management as shown in Figure 1. Other key aspect of ORM methodology is the risk prioritization matrix and priority unwanted events (PUE), focused on potential damage 4 and 5, as regards to harm to people, occupational safety, environment impacts, social impacts, regulatory impacts, material losses and reputational impacts.

Other important tool regarding ORM methodology is Bow Tie risk analysis, based on top event to be assessed, related causes and consequences, as well as controls (preventive or mitigatory) to avoid the event to occur or reduce the impacts (Figure 2). Once defined main causes and consequences, the classification of effectiveness and quality of controls are important tools as well to reduce the risk level in fact.

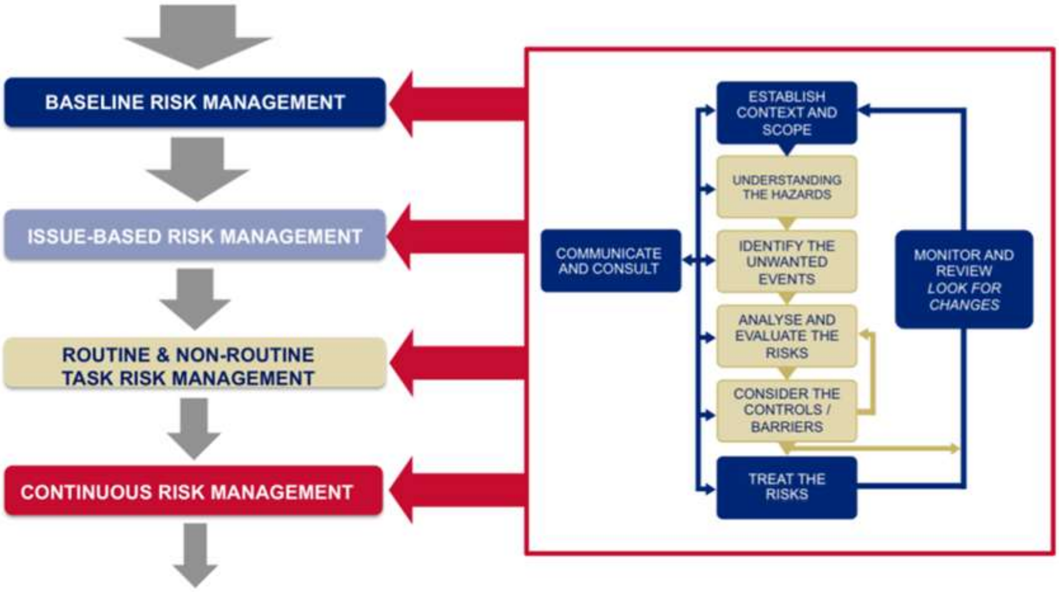

Figure 1: ORM management in 4 layers and requirements flowchart (Anglo American, 2013) [2].

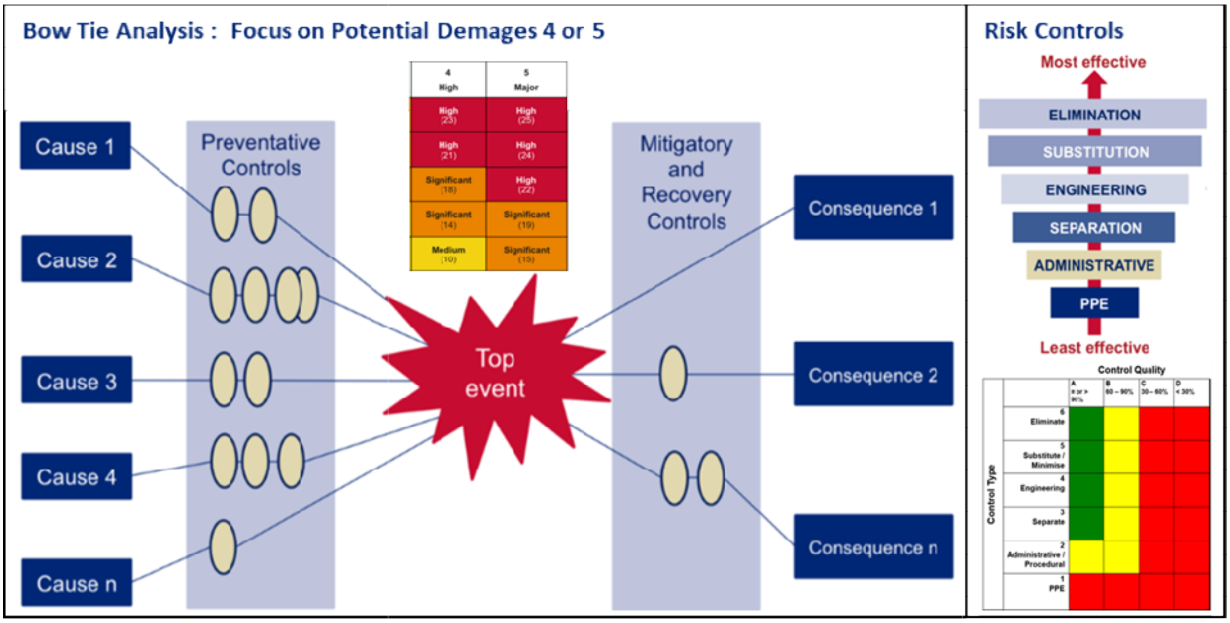

Figure 2: Bow Tie Risk Analysis tool (modified from Anglo American, 2013) [2].

Other consecrated tools in risk management in general are used as complementary analysis in GCP:

- **Failure Mode Effect Analysis (FMEA):** Used to identify main failure mechanisms and effects;
- **Event Tree Analysis (ETA):** Sequence of events (nodes) and related probability to occur that converge for a major undesired event. Events are separated by failure mechanisms and probabilities for each node are defined with FTA or specialists board analysis;
- **Fault Tree Analysis (FTA):** Combination of events, independent or not, that converge for a failure to occur;

- **Risk Breakdown Structure (RBS):** Collapsed structure of risk into themes and main causes;
- **Risk Baselines:** Gather all assessed risk information by process, subprocess, structure, segment or geographic location, including location, metrics, likelihood, consequences and other significative aspects of the risk assessment;
- **Risk KPI's Mapping:** Relates KPI's across the organizations since global
- corporate indicators up to operational KPI's.

Failure Mechanism Assessment

Sinnott & Towler (2012)[4] presented guidelines for to rank severity index (Si), ocurrance index (Oi) and detection index (Di) as potential likelihoods for FMEA analysis. All these aspects must be considered and multiplied in order to achieve resultant Risk Probability Number Index (RPNi). Besides, the potential effects or consequences, as well as the potential causes and controls are usually detailed in FMEA per failure mechanism. In order to fulfill the FMEA, usually an interview or brainstorming with experts are carried out. The Table 1 shows Si, Oi and Di criteria.

Table 1: Severity index (Si), ocurrance index (Oi) and detection index (Di) as potential likelihoods for FMEA analysis (modified from Sinnott & Towler, 2012)[4].

Rank of severity	Description
1–2	Failure is of such minor nature that the operator will probably not detect the failure
3–5	Failure will result in slight deterioration of part or system performance
6–7	Failure will result in operator dissatisfaction and/or deterioration of part or system performance
8–9	Failure will result in high degree of operator dissatisfaction and cause non-functionality of system
10	Failure will result in major operator dissatisfaction or major damage
Rank of occurrence	**Description**
1	An unlikely probability of occurrence: probability of occurrence < 0.001
2–3	A remote probability of occurrence: 0.001 < probability of occurrence < 0.01
4–6	An occasional probability of occurrence: 0.01 < probability of occurrence < 0.10
7–9	An occasional probability of occurrence: 0.10 < probability of occurrence < 0.20
10	A high probability of occurrence: 0.20 < probability of occurrence
Rank of detection	**Description**
1–2	Very high probability that the defect will be detected
3–4	High probability that the defect will be detected
5–7	Moderate probability that the defect will be detected
8–9	Low probability that the defect will be detected
10	Very low (or zero) probability that the defect will be detected

Complementary to FMEA analysis, other important tool is the Event Tree Analysis (ETA) and Fault Tree Analysis (FTA). The method comprises a construction Sequence of events (nodes) and related probability to occur that converge for a major undesired event. Assis et al. (2020) [5] exampled an event tree for estimating the failure probability due to piping of a dam, as shown in Figure 3. As per done in FMEA analysis, an interview or brainstorming with experts are carried out to define the nodes and probabilities for the ETA and/or FTA.

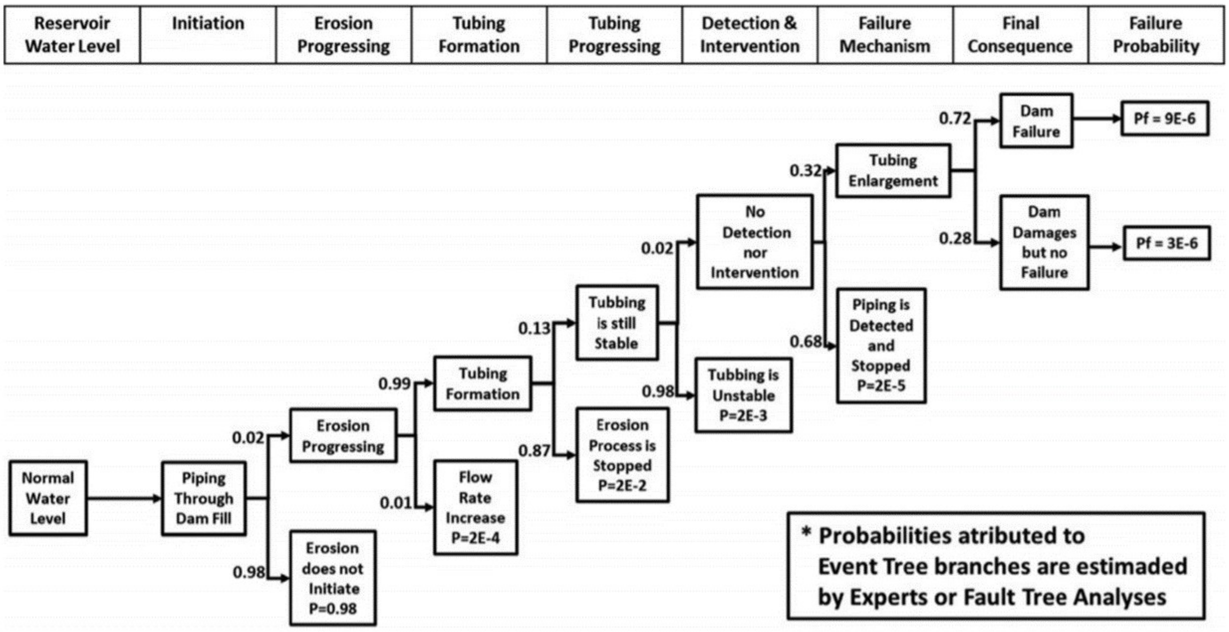

Figure 3: Example of an event tree for estimating the failure probability due to piping of a dam (Assis et al., 2020)[5].

Risk Controls

In a GCP, geotechnical instruments and inspections plays a very important role in the monitoring strategy. In order to define actions based the outcomes from monitoring and inspections, the Trigger Action response Plan (TARP) is fundamental. The triggers and actions can be related to preventive actions, such as monitoring intensification, or mitigatory, as an evacuation. Ross (2017)[6] summarized the general response levels of a TARP as shown in Figure 4.

Response Level	Manefay Timing	Response
0 (Blue)	Stable conditions	Routine operations
1 (Green)	Weeks to several months	Routine operations and prepare for failure
2 (Yellow)	Days to weeks	Modify operations, restrict access, and continue preparations
3 (Orange)	Hours to days	Evacuate failure areas and close access
4 (Red)	Unexpected acceleration or failure	Emergency evacuation and response

Figure 4: General response levels of a TARP (Ross, 2017)[6].

A succeeded risk management strategy must efficiently address an emergency response plan, even if the preventive controls are fully in place. The United States Federal Emergency Management Agency consolidated the concepts of Emergency Response Unified Command in its National Incident Management System (FEMA, 2017)[7], as shown in Figure 5.

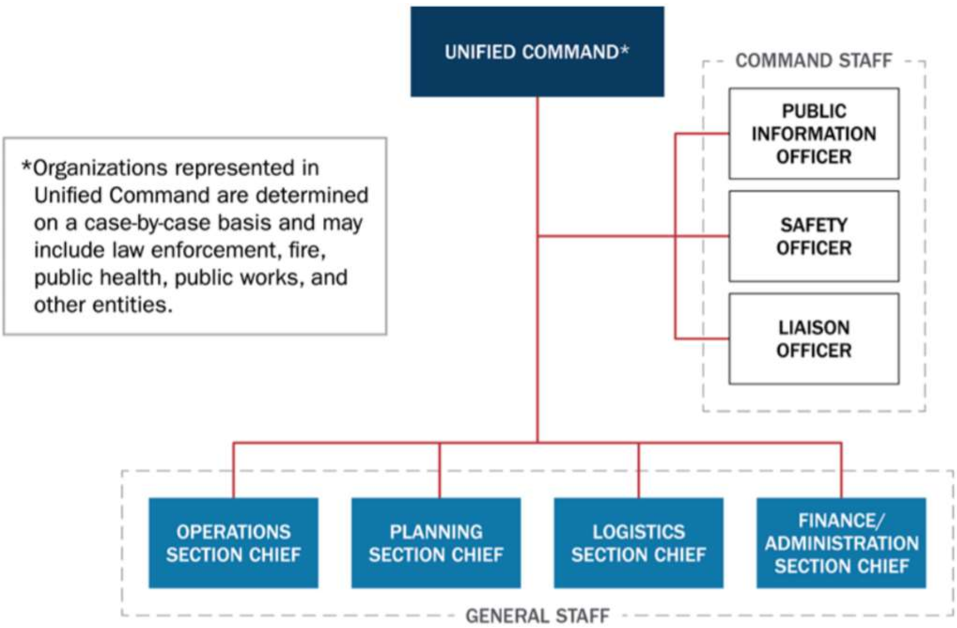

Figure 5: Unified Command for Emergency Response (FEMA, 2017)[7].

Risk Review Process and Audits

Finally, the Risk Review Process and Audits are essential for a healthy and refreshed risk management system. The risk baseline must be reviewed in a routine basis in order to update the risk level of an structure due to changes in the environment, as well as changes in the structures, such as new damages or improvements. Based on these updates a new strategy to reduce or maintain the risk level related to the structure must be carried out. Besides, an audit program is as essential topic in order to measure the compliance level, according to the rules of the normative ISO 19011 (ABNT, 2018)[8].

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Location

The GCP in Minas-Rio System covers structures since the Serra do Sapo Open Pit, where the iron ore is exclusively mined currently, up to the Port (Ferroport), passing through the Slurry Pipeline and Industrial Assets, where Fall of Ground (F.o.G.) events represents Priority Unwanted Events (PUE). The Figure 6 shows, schematically, the coverage of Geotechnical Risk Management in IOB, showing the structures, tools and staff involved in the process.

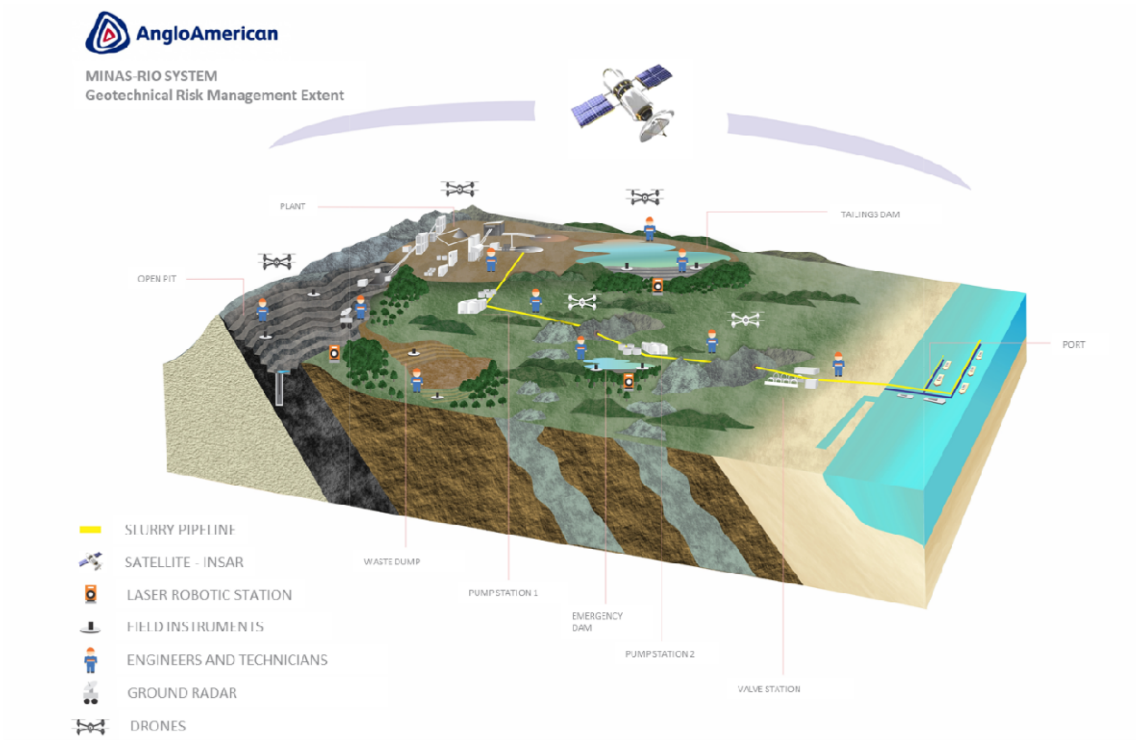


Figure 6: Schematic image of geotechnical risk management coverage in Iron Ore Brazil (IOB).

Structures

Open Pit: According to IOB CP Report for Mineral Resources (Anglo American, 2019) [9] "The Minas-Rio System comprises world class iron deposits, whose mineralization is hosted in a Proterozoic metasedimentary sequence in the Southern Espinhaço Ridge". In other segment of the same document it is said that "the iron formations from Serra do Sapo Deposit were submitted to strong weathering process, resulting on a supergene enrichment of iron grade, mainly on the top the sequence, generating the friable group of lithologies. In addition, hydrothermal processes can also occur locally, increasing eventually the iron enrichment".

The geological domain is typically siliciclastic metasedimentary, belonging to the Espinhaço Supergroup, in its southern portion, more specifically within the context of the Serra da Serpentina Group, where clastic and chemical metasedimentary rocks are understood. Knauer & Grossi-Sad (1997) [10] subdivide this group into three distinct lithostratigraphic units: the base formed by quartzites and schist quartz, followed by a unit composed of banded iron formations and, at the top, a unit with fine phyllites and quartzites. The Figure 7 the tectonic stages followed by the consequences in terms of failure mechanisms and geotechnical sectorization in the open pit.

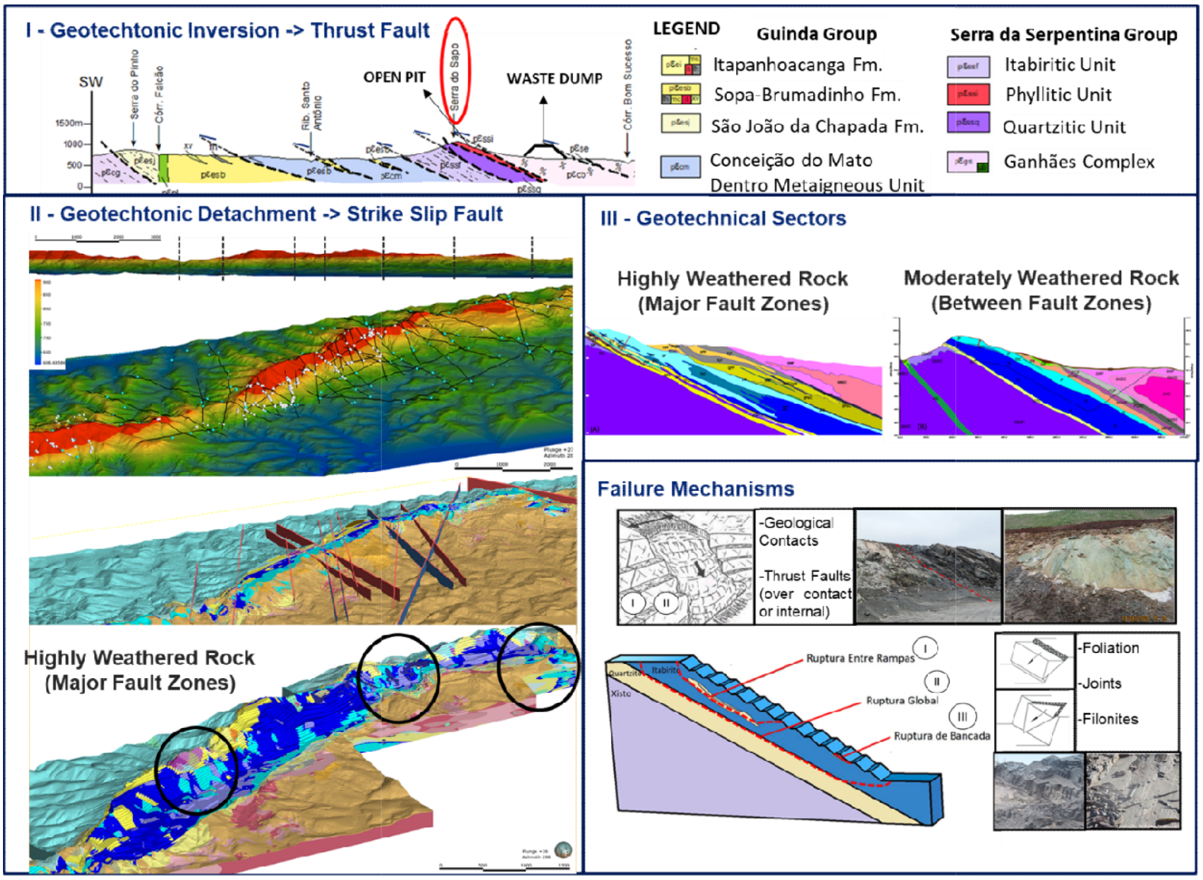


Figure 7: Tectonic Stages and consequences in terms of failure mechanisms and geotechnical sectorization in the open pit (modified from Knauer & Grossi-Sad, 1997) [10].

Waste Dumps: The North Waste Dump (PDE Norte) is located in the Basal Complex comprised of gneissified and migmatized granitoids, in addition to banded gneisses. In its eastern portion, contact is tectonic (due to a push failure) with the Itabiritic unit of the Serra da Serpentina Group and with quartzites from the Itapanhoacanga Formation. In its western portion, contact occurs with the proterozoic rocks of the Granitic Suite Borrachudos. Inserted in the Basal Complex, there are also tectonic wedges from other stratigraphic units, belonging especially to the Serro Group, Serra da Serpentina Group, Zagaia Unit and rocks of the Espinhaço Supergroup itself (Knauer & Grossi-Sad, 1997) [10].

Industrial Assets: The Industrial Assets comprise areas along the production chain with geotechnical structures such as slopes and retaining walls in industrial areas (e.g.: accesses, crushers, mills, conveyor belts, pump stations and administrative facilities). Main failure mechanisms depends on where the facilities are located in terms of geological geotechnical domains, to be known: Jacem, Itapanhoacanga, Serra do Sapo or Meloso Formations, as well as Guanhães Complex. As well as in Surry Pipeline, the focus are structures with potential damages 4 and 5 according to AA risk matrix, known as Priority Unwanted Events (PUE).

Slurry Pipeline: The Minas-Rio Slurry Pipeline starts at the Southern Espinhaço Ridge, in Minas Gerais State, passing through metasedimentary sequences and delivering the ore pulp at the Rio de Janeiro State coast, in the sedimentary sequences of the Barreiras Formation. The whole length comprises 528 km, with different geological-geomechanical context, and, consequently different predominant failure mechanisms. The Figure 8 shows the macro division made, according to different aspects in terms of lithology, pedology and geomorphology aspects, mainly.

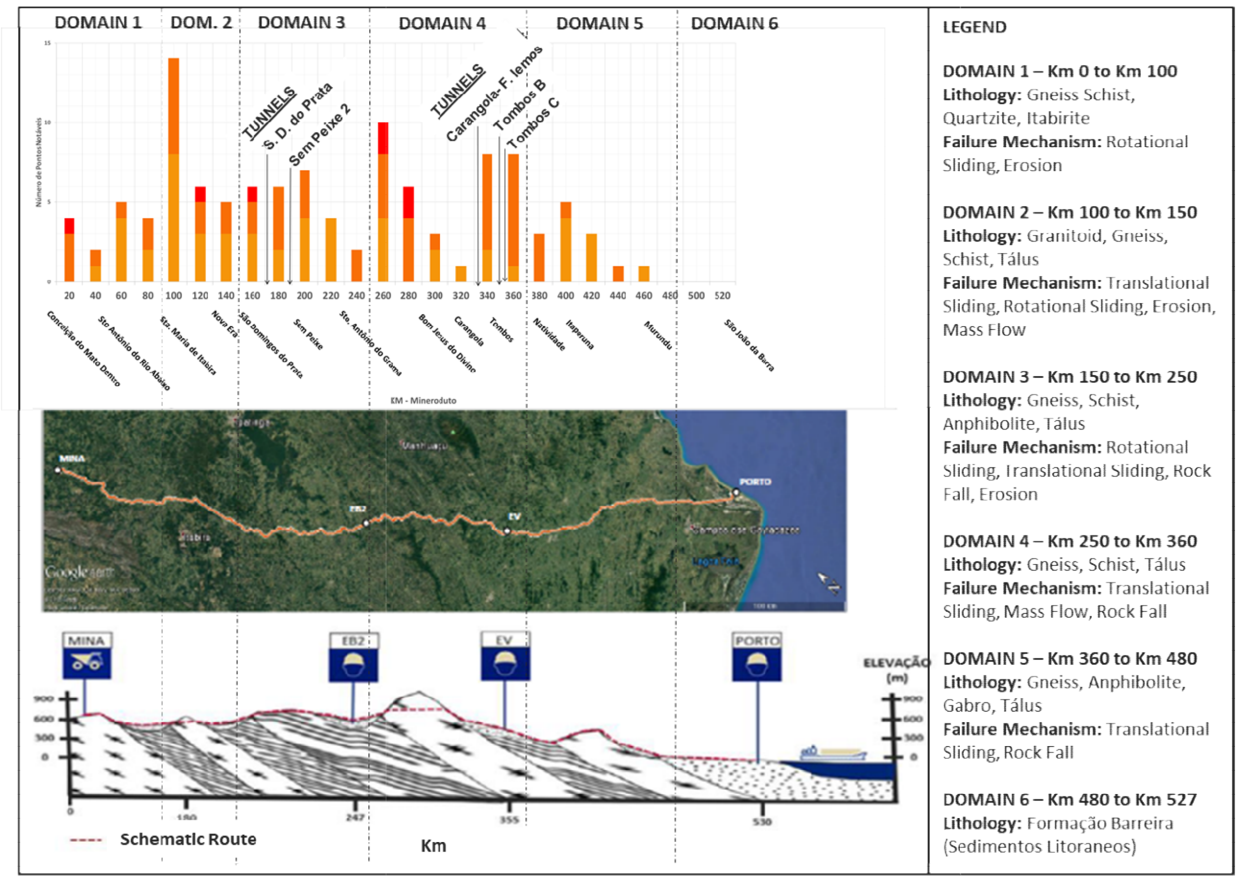


Figure 8: Domain divisions along Minas-Rio Slurry Pipeline in terms of predominant Failure Mechanisms.

Failure Mechanisms Analysis

For the failure mechanisms analysis in each structure, FMEA, ETA and FTA, based on experts ratings, were used. The Figure 9 is an example of a failure mechanism assessment, part of the Open Pit FMEA.

Process	Failure Mechanism	Effect /Consequence	Si	Cause	Oi	Control Measures	Di	RPNi
Open Pit Slopes	Shear	Global Failure with exposed people, equipments and/or monetary losses	10	Stress acting beyond the Rock Mass Strength Limit Presence of persistent features (discontinuity or lithotype) with lower strength than the rock mass strength Induced dynamic charge (Blast) Natural dynamic load (earthquakes) Water thrust (high water level) Excess pore pressure (localized water pressure) Erosion (affecting the complementary geometry)	7	Efficient design (reliable geological-geotechnical and hydrogeological investigations, parameterization and stability analysis by competent professionals) Construction adhering to Design Displacements Monitoring Hydrogeological Monitoring (INA's and PZ's) Efficient surface drainage system Efficient depressurization system (wells or drains) Proper Drill & Blast Plan / Execution Field Inspections to Effective Actions (confirmation of design conditions, anomalies and preventive and corrective actions).	4	280

Figure 9: FMEA for Open Pit shear failure mechanism.

In summary, the failure mechanisms are listed below:

- Open Pit
  - Shear;
  - Progressive Failures or driven by Stress x Strain;
  - Rock Fall;
  - Erosion.

- Waste Dump
  - Shear;
  - Progressive Failures or driven by Stress x Strain;
  - Erosion.

- Pipeline and Industrial Assets
  - Shear;
  - Rock Fall;
  - Erosion.
  - Tunnels: Collapse of Supported excavations;
  - Tunnels: Collapse of Non-Supported excavations;

Moving Forward in failure mechanism analysis, ETA and FTA were carried out in order to assess the impact of each event in chain as well as the combination of events over the increase of probability for an event to occur.

Preventive and Mitigatory Controls / Bow Tie Assessment

The aim of Bow Tie analysis is to identify main causes and consequences, always looking for preventive or mitigatory controls for a top event. The top events are always related to F.o.G.: slidings, rock fall, retaining structures collapses and erosions (specifically which leads to geotechnical instabilities). In this way, failure mechanism analysis clarifies main causes and extension of consequences, besides the controls and respective effectiveness and quality. The Main causes, consequences and critical controls are listed below:

1.0 Ineffective Design
- 1.1 Design according to AATS0014 guidelines
- 1.2. Peer Review process
- 1.3 Reliability and Design Reconciliation Process

2.0 Poor Execution and Maintenance
- 2.1 Appropriate Drill and Blast Design
- 2.2. Appropriate Adherence to Design

3.0 Lack of Water Management
- 3.1 Surface Water Infrastructure Management
- 3.2 Ground Water Infrastructure Management
- 3.3 Ground Water Level Control
- 3.4 Operational Water Management

4.0 Interaction with Cavities / other excavations
- 4.1 Appropriate excavations interaction assessment

5.0 Seismic Effect
- 5.1. Appropriate seismic assumptions assessment

6.0 Damages Mitigation
- 6.1 Appropriate Unstable zones blocking
- 6.2 Deformation Monitoring and Alarm
- 6.3 Inspections and Safe Declaration
- 6.4 Emergency Response Plan

Geotechnical Design Process (GDP)

The Geotechnical Design Report (GDR) is the technical document to support Geotechnical Term of Reference (T.o.R.). According to the standard TS 401 (Anglo American, 2016)[11], the main goal is to provide "slope and underground stability and rockfall risks to a level in which there is confidence in the ability to prevent unwanted incidents this forms the basis of As Low as Reasonably Practical (ALARP)". In order to achieve the desired effect, GDR must cover the items below:

- Data Acquisition (Data Confidence and Data Collection Program);
- Geotechnical Design & Analysis Assumptions;
- Geological-geotechnical (intact and rock mass) characteristics;
- Geological, geohydrological and geotechnical modelling;
- Update and validate rock mass properties;
- Deterministic, kinematic or probabilistic analysis;
- Risk versus Reward Design.

The GDP for Minas-Rio structures follows the Anglo American global standards, besides other Brazilian Standards:

- Geotechnical Standard for Underground Excavations and Slope Stability (Anglo American, 2016)[11];
- Mineral Residue Facilities and Water Management Structures Standard (Anglo American, 2016[2])[12];
- Structural Integrity Standard (Anglo American, 2019)[13];
- Slope Stability Brazilian Standard (ABNT, 2009)[14];
- Waste Dump Design Brazilian Standard (ABNT, 2017)[15].

Generally, Anglo American global standards are based on the Large Open Pit (LOP) guidelines such as the Guidelines for Open Pit Slope Design (Read & Stacey, 2009)[16], Guidelines for Open Pit Slope Design in Weak Rocks (Martin & Stacey, 2018)[17], Guidelines for Evaluating Water in Pit Slope Stability (Beale & Read, 2013)[18] and Guideline for Mine Waste Dump and Stockpile Design (Hawley and Cunning, 2017)[19].

Once consolidated and reviewed internally, the GDR must be Peer Reviewed by other business unit specialists and/or independent Consultant, observing the minimum criteria for reviewer choice such as relevant level of skill and experience, both operationally and in design work, to enable a valuable review process.

Minimum criteria for Factor of Safety (F.o.S.) acceptance, as well as service life time and scales criteria for designed slopes is shown in Table 2.

Table 2: Guideline for Minimum Acceptance Criteria for PoF (Anglo American, 2016)[11].

Slope Scale	Consequences of Failure	Acceptance Criteria		
		FoS Min. (Static)	FoS Min. (Dynamic)	Maximum P[FoS<1.0]
Bench	Low - high	1.1	N/A	25 – 50%
Stack/ Inter-ramp	Low	1.15 – 1.2	1.0	25%
	Medium	1.2	1.1	20%
	High	1.2 – 1.3	1.1	10%
Overall	Low	1.2 – 1.3	1.0	15 – 20%
	Medium	1.3	1.05	5 – 10%
	High	1.3 – 1.5	1.1	≤5%

The Open Pit Geotechnical Design Report (GDR) is aimed to be reviewed and peer reviewed annually or whenever it is necessary, considering abrupt Mine Plan changes (specially anticipating areas to be mined, driven by Change Management process). Another important task on GDP is related to approving process of Mine Plans, including Long Term Mine Plans (L.o.M. / Reserve Open Pits and reviews) as well as Short Term Mine Plans (Annual Mine Plan and reviews). Formal signed off (by Geotechnical Competent Person) of Mine Plans, including reviews, are essential to make sure that the design was, properly, adressed in the mine plans. Figure 10 shows the Mine Plans geotechnical approving flow.

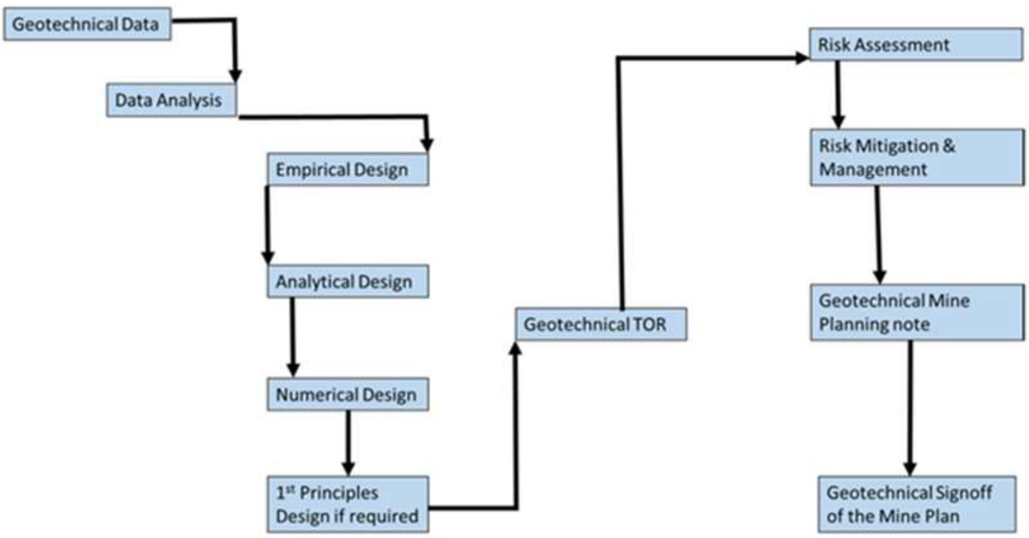


Figure 10: Geotechnical Process that Integrates with Mine Planning and Mining Operations (Anglo American, 2016)[11].

The Slurry Pipeline and Industrial Assets slopes minimum design criteria according to Brazilian standard for Slope Stability (ABNT, 2009)[14]. However, due to the permanent characteristic of those structures, and the fact that it includes other particular structures such as tunnels and retaining walls, other standards are references as the Structural Integrity Standard (Anglo American, 2019)[13] among others. Besides design criteria, other important issue covered in the Structural Integrity Standard is related to structural specialist inspections and conditions guidelines (Table 3). Although anomalies evidence (concrete and frame deterioration) are covered in Geotechnical Inspections, concrete retaining structures must be inspected by specialists according to the guidelines.

Table 3: Condition of the structures guidelines (Anglo American, 2019)[13]

Category	Description	% Original Strength	Typical Remedial Action
0	Excellent condition Safe use of the plant structures is assured	100	None required
1	No reduction in strength Safe use of the plant structures is assured	100	None required
2	Slight reduction in strength Safe use of the plant structures is assured	95 – 100	Minor work
3	Some reduction in strength Repair to receive attention in maintenance scheduling	75 – 95	Minor work
4	Major reduction in strength Safe use of the plant is compromised Urgent attention should be given to repair	50 – 75	Repair required
5	Little useful residual strength Safe use of the plant is impossible Urgent attention should be given to repair	< 50	Urgent repair required

Anomalies identification and mitigation plans

An important task in operational routine of Geotech Staff is the inspections for anomalies and new hazards identifications in the structures as well as actions plan to mitigate nonconformities identified. Complementary, the execution control of actions with operations services areas is equally an important task. The Figure 11 shows the process since the inspections plan, passing through the inspections effectively and culminating in mitigation plans management.

Furthermore, it is important to release that inspections items, as well as criticality levels are directly linked with critical controls / risk KPI's. In general terms, the correlation is made as follows:

- Group Anomaly: from Bow Tie Critical controls;
  - Surface Drainage;
  - Internal Drainage;
  - Geotechnical Instabilities (failure evidences);
  - Retaining Structures Pathologies;

- Anomalies: from Failure Mechanisms analysis
  - Surface Drainage: non existing / insufficient device, broken device, obstructed device, insufficient berm grade and others;
  - Internal Drainage: non existing / insufficient device, obstructed device, piping and others;
  - Geotechnical Instabilities (failure evidences): cracks, stuffing, subsidence, rock fall, erosion and others;
  - Retaining Structures Pathologies: concrete cracks, opened joints, rust and others.

- Criticality: from Failure Mechanisms analysis, according to evolution of the anomaly
  - Criticality 1: initial stage, without failure conditions, but can enhance to criticality 2;
  - Criticality 2: advanced stage, with anticipating failure, that will enhance to imminent failure;
  - Criticality 3: very advanced stage, with imminent failure.

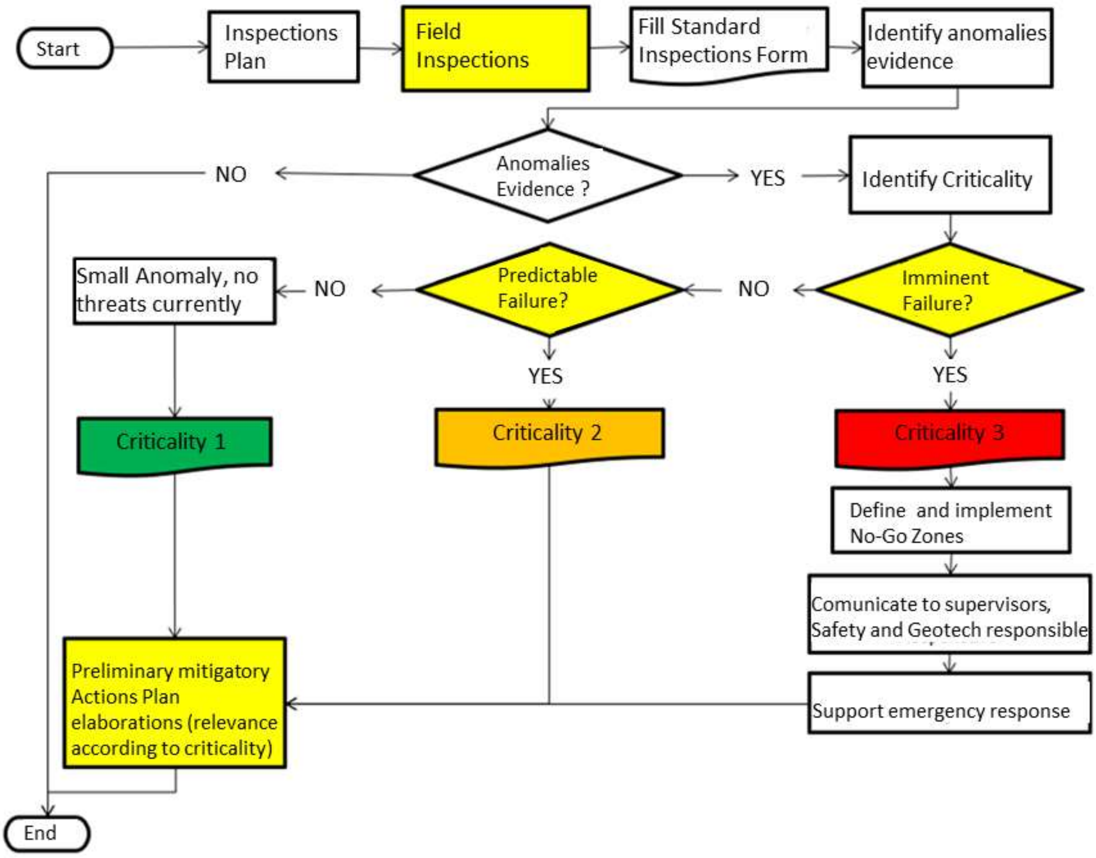


Figure 11: Inspection process and first response in case of anomalies identification.

Instrumentations and monitoring strategy

The purpose of a set of instruments / monitoring tools must be very clear in term of desired indicator to be monitored, as well as coverage area, precision, reading frequency, flexibility, cost/benefit and alarm capacity. The selection of each sort of instrument must be guided by main controls related to the risk assessment and critical readings must be defined and related to TARP's (Trigger Action Response Plans). It is important to turn evident that a set of instruments is aimed to work in chain, observed the capabilities of each sort of monitoring tool. Below, in Figure 12, the chain of instruments to detect hazards in Open Pit, Waste Dump, Slurry Pipeline and Industrial Assets for Minas-Rio.

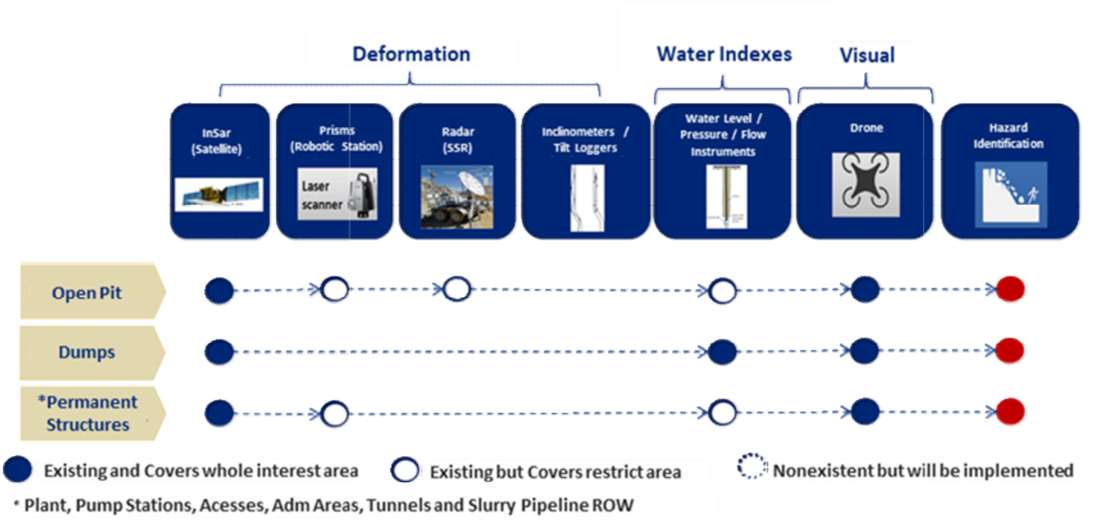


Figure 12: Set of monitoring tools working in chain up to the hazard identification in Open Pit, Waste Dump, Slurry Pipeline and Industrial Assets in Minas-Rio System.

The usage of Trigger Action Response Plan became standard in Anglo American, besides in other companies from Mineral Sector and other sectors, as a good practice in terms of effective response based on triggers, either related to instruments readings and inspections or other sort of quantified or semi quantified risk indicators.

- Design Adherence: As a preventive control, the adherence check between planned (regarding geotechnical assumptions) and executed must trigger corrections and intensification of monitoring / inspections in Open Pit and Waste Dump (can be correlated to technological controls in civil specialized works). With that purpose, the Geometric Adherence TARP is aimed to trigger actions focused on corrections prior to the undesired event to occur;
- Weather Conditions: The rains are recognized as one of the main agents that trigger large mass movements (landslides, rock falls, debris flows among others) especially in tropical regions, where extreme events are common during rainy periods. In an attempt to establish empirical correlations between the magnitude of rainfall and the occurrence of mass movement processes, several studies have been carried out in Brazil, some of which are used as a reference by Anglo American to define triggers for extra routine inspections in Minas-Rio System Geotechnical Structures.
- Inspections: According to the risk communication flow and first response, actions are weighted per criticality. The Inspections TARP is complementary, covering actions for related Operational, Safety, Planning and other areas
- Deformations: As mitigatory controls, the deformations monitoring systems, including Insar, Ground Radars and Topographical surveys (focused on deformations, including laser scanners) must have the capability to generate alarms to evacuate areas or trigger other actions such as make available online monitoring or/and extra inspections.
- Piezometers and Water Level Meters: The dual character of water level and pore pressures monitoring (preventive and mitigatory) through water level meters and piezometers network, brings the necessity for a TARP to either trigger preventive (pre failure) actions and mitigative (post failure) actions. As the triggers must be related to levels detected (piezometric and water level), it is necessary to transform those levels in Factor of Safety degradation, regarding an instrument and/or group of instruments. In this way, Risk Level Letters for each instrument must go along with Instruments TARP. The Figure 13 brings an schematic deformation monitoring strategy in Open

Pit and an analysis simulating critical water and piezometric levels for degradation of Factor of Safety in North Waste Dump.

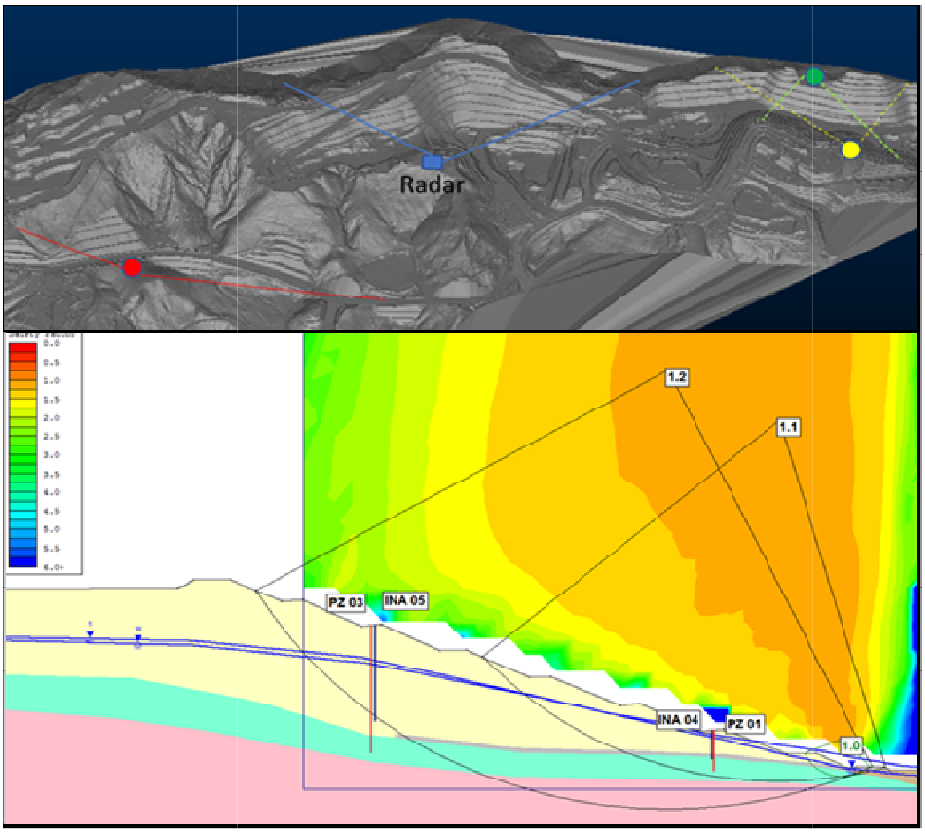


Figure 13: Above, an schematic deformation monitoring strategy for Open Pit Stability. Below, an analysis simulating critical water and piezometric levels for degradation of Factor of Safety in North Waste Dump.

Emergency Response Plan

An appropriate risk management process covers, besides preventive controls, mitigatory controls (damages mitigation), including unstable zones blocking strategy, deformation monitoring and alarm, inspections and safe declaration and an Emergency Response Plan. So that, Geotechnical Staff has a crucial role in F.o.G. events, either for enabling the emergency communication to safety staff as well as in the first responses such as setting the limits for blocking zones and provisory barriers / retaining structures in order to mitigate the damages. For that purpose the Unified Command for Emergency Response was consolidated in the internal standard for emergency response plans (Anglo American, 2020)[14].

Learning from Incidents

Learnt lessons from occurred incidents is an essential practice for a continuous improvement culture. Thus, keep the historical registers of incidents occurred both in the Business Unit as well as in other operations inside Anglo American or other companies. For that purpose, a compilation of events intrinsically correlated with Minas-Rio System structures is gathered, including the possible failure mechanisms; event details such as locality, date, consequences and description; local factors; human and organizational factors; learnt lessons and improvement actions.

Risk Review Process and Audits

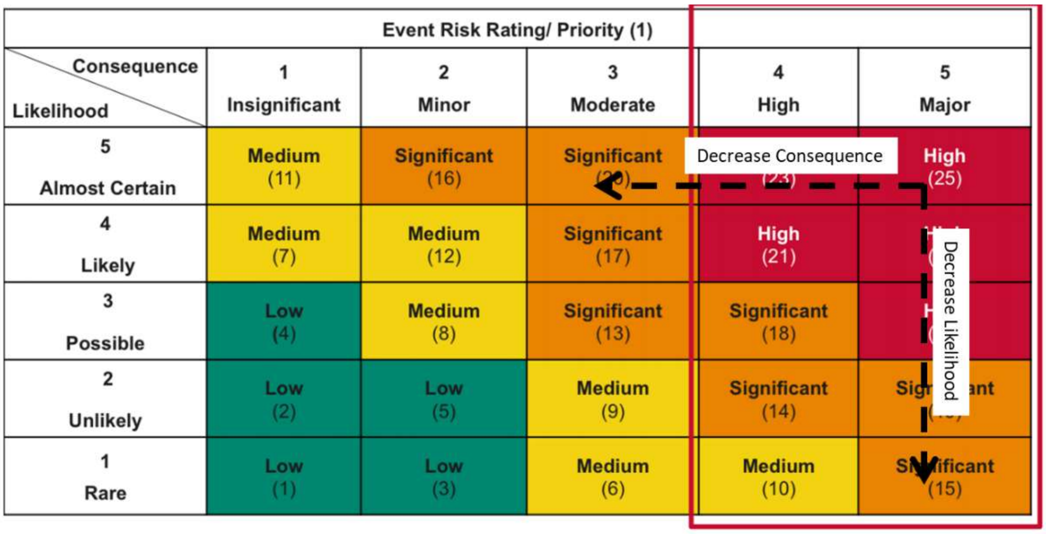
For a well succeeded Risk Management, it is imperative to reassess risk levels routinely in Risk Baselines (once a year, at least) based on new risk scenarios and actions completed from Actions Plans from design data confidence plan, anomalies controls and instrumentations plan, as well as Audits actions plan. In order to make the risk reduction plans effective, it is important to predict the resources necessary to make the plan feasible, according to risk assessments. The Figure 14 shows the possible risk reduction strategy, through decreasing the consequence and/or decreasing the likelihood, focused on Priority Unwanted Events (PUE).

The Geotechnical Risk Management Audit Program for the Minas-Rio System involves management processes to address the risks related to Fall of Ground (F.o.G.) events throughout the complex. The extent of coverage for this program includes Open Pit, Waste Dumps, Pipeline and Industrial Assets, in the IOB. The rules are based on the normative ISO 19011 (ABNT, 2018)[8].

The reference standards are related to the Anglo American Group in addition to Brazilian standards and resolutions of the National Mining Agency (ANM). Among the aspects covered in the audits are the risk management processes, functions and responsibilities, design processes, operational water management, procedures, hazard identification and mitigation, monitoring system, data collection, functional training, emergency plans, learning from incidents, risk reduction plans and human and organizational factors. In summary, the audit program can be seen in Table 4.

Table 4: Classes of audits in GRM.

Audit 1ª party	**Audit 2ª party**	**Audit 3ª party**
INTERNAL AUDIT AA TS 401 001, AA TS 602, AA TS 108 e F.o.G. Risk Process	INTERNAL AUDIT - GRB (GEOTECH REVIEW BOARD)	EXTERNAL AUDITS (regulators and others)



Event Risk Rating/ Priority (1)					
Consequence / Likelihood	1 Insignificant	2 Minor	3 Moderate	4 High	5 Major
5 Almost Certain	Medium (11)	Significant (16)	Significant [illegible]	[illegible]	High (25)
4 Likely	Medium (7)	Medium (12)	Significant (17)	High (21)	[illegible]
3 Possible	Low (4)	Medium (8)	Significant (13)	Significant (18)	[illegible]
2 Unlikely	Low (2)	Low (5)	Medium (9)	Significant (14)	[illegible]
1 Rare	Low (1)	Low (3)	Medium (6)	Medium (10)	Significant (15)

Figure 14: ORM risk matrix with Priority Unwanted Events (PUE) highlighted and possible risk reduction strategy, through decreasing the consequence and/or decreasing the likelihood (modified from Anglo American, 2013)[2].

CONCLUSION

The Ground Control Plan (GCP) is a key process for the mining companies to understand and manage risks related to Fall of Ground (F.o.G.) events along the production chain, including open pits, waste dumps and industrial / transport assets, among others. An important task when building the GCP is to identify the priority structures, through potential damage assessment, regarding life losses, environmental aspects, material losses, as well as reputational and legal consequences. As important issue too is to identify the potential failure mechanisms and the role out events related to this, together with the likelihood of occurrence in the current date of the analysis. Then, it is possible to assess the real risk level related to the geotechnical structure and define the appropriate controls to address these risks in the routine. Besides, define process for develop geotechnical designs and review the designs, as well as review the mine plans is a key preventive control. Define roles and responsibilities clearly and stablish effective procedures make the difference regarding human potential errors. Finally, a well-defined strategy in terms of monitoring, emergency plans, risk reduction plans and audits are essential for both, mitigatory and preventive controls, completing the geotechnical risk management.

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