The impact of EXtreme weather events on MINing operations

TEXMIN

European Commission

Research Fund for Coal & Steel

IMPACT IDENTIFICATION RELATED WITH CHANGES IN PRECIPITATION AND MONITORING METHODOLOGY IN TAILING DAMS

Final Conference Katowice

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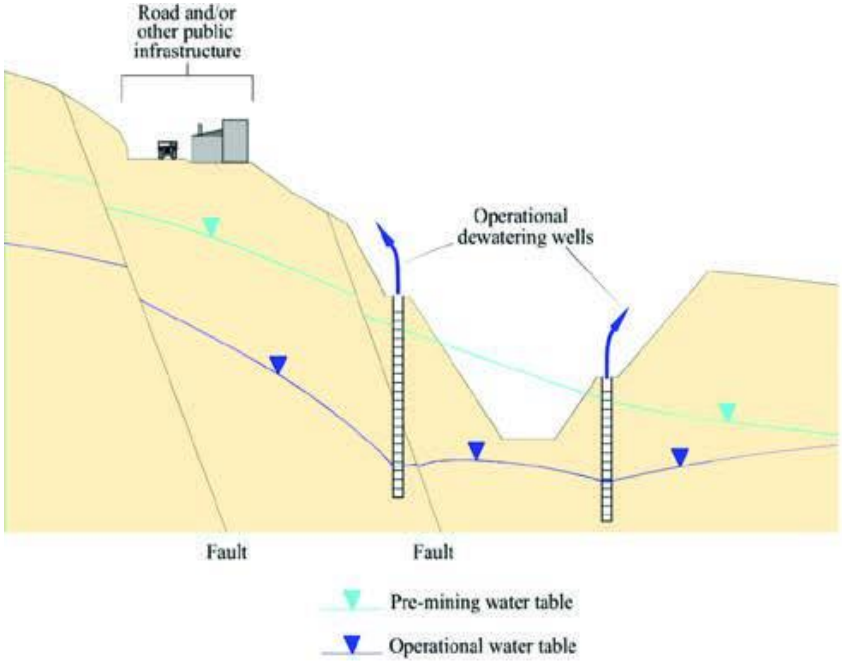
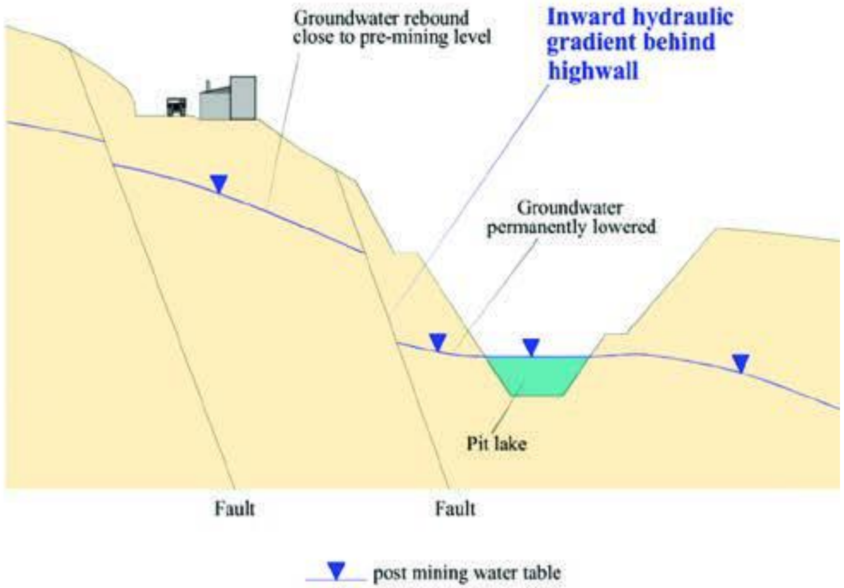
Impacts associated with stability of surface & structures

- Increased precipitation implies greater stability issues compared to prolonged dry periods.
- Where the foundation is composed of saturated, fine-grained soils with low hydraulic conductivity.
- Negative pore pressures can result from **drainage**.

Mine closure considerations on water rebound

- To maintain stable post-closure conditions, it may be necessary to implement a system that provides permanent depressurization.



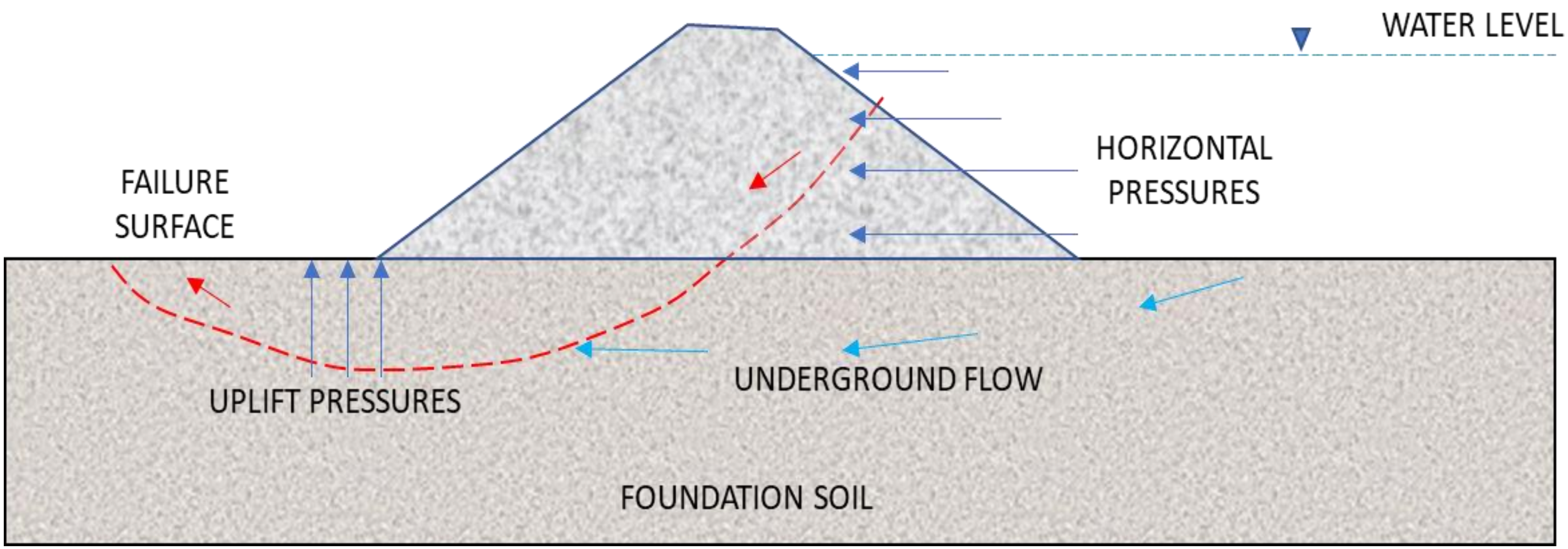


Analysis of impacts related with extreme precipitation events

- Control and management of groundwater and Surface water.
- The management of precipitation events, runoff and surface water throughout the mine site, including stormwater management.
- The need to discharge excess water from the site and the associated engineering environmental implications.
- The creation of stable and sustainable groundwater and surface water conditions for long-term post-closure.

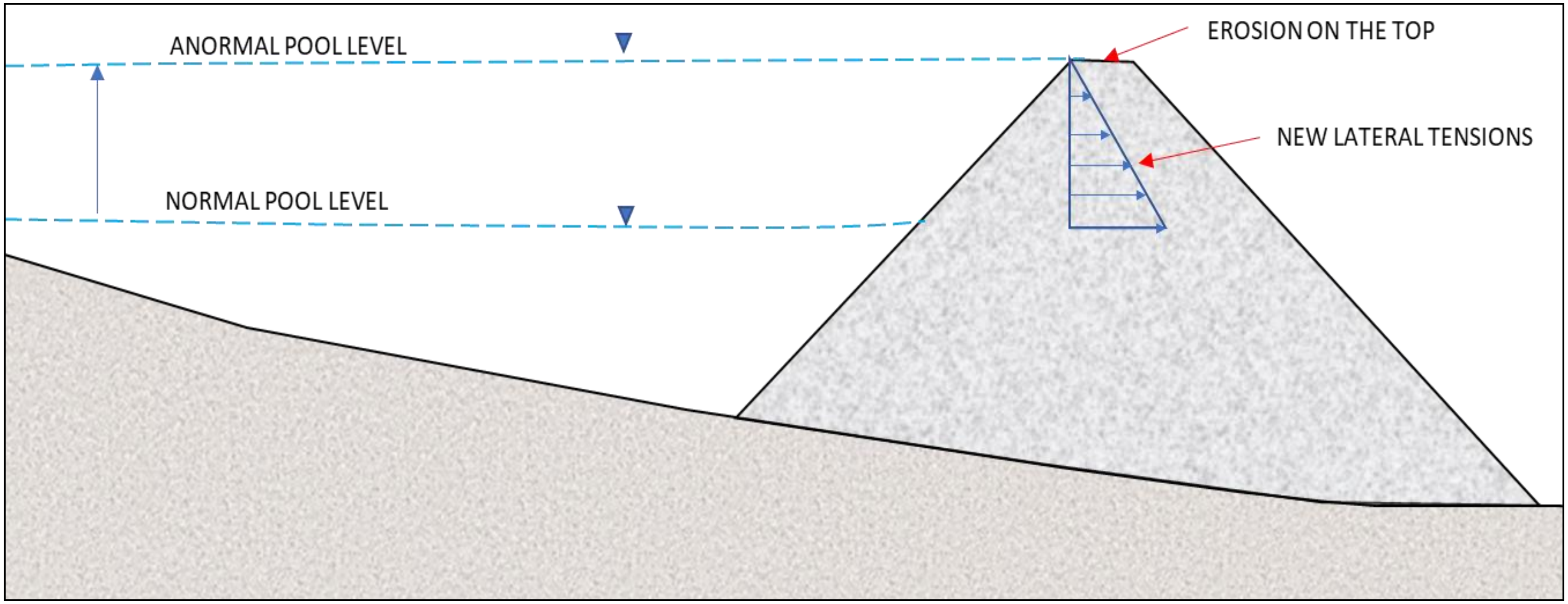
Tailing dams risk analysis

- Foundation failures



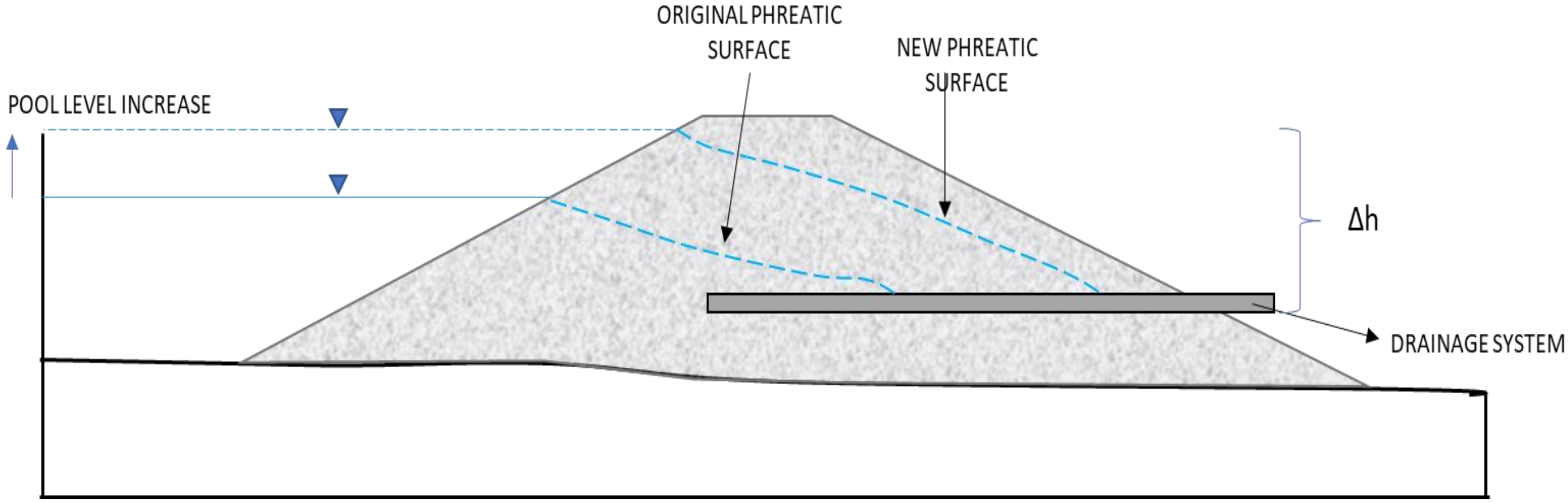
Tailing dams risk analysis

- Overtopping phenomenon (erosion of the crown)



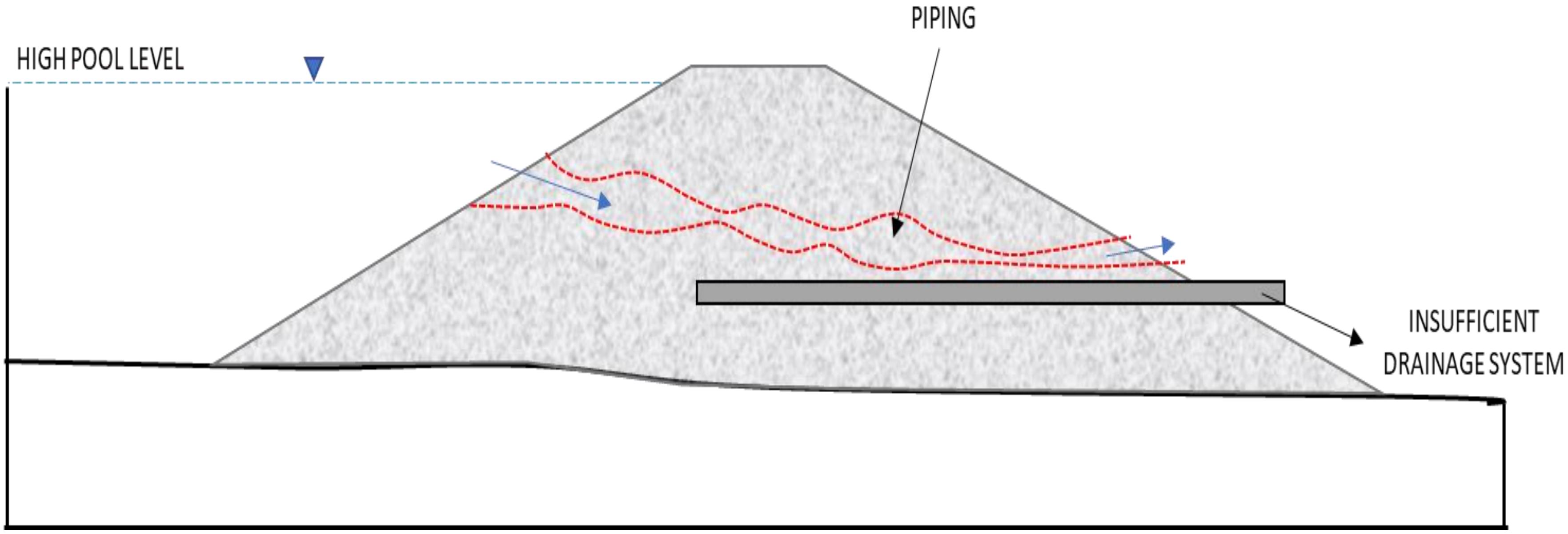
Tailing dams risk analysis

- Pool level and GW level increase



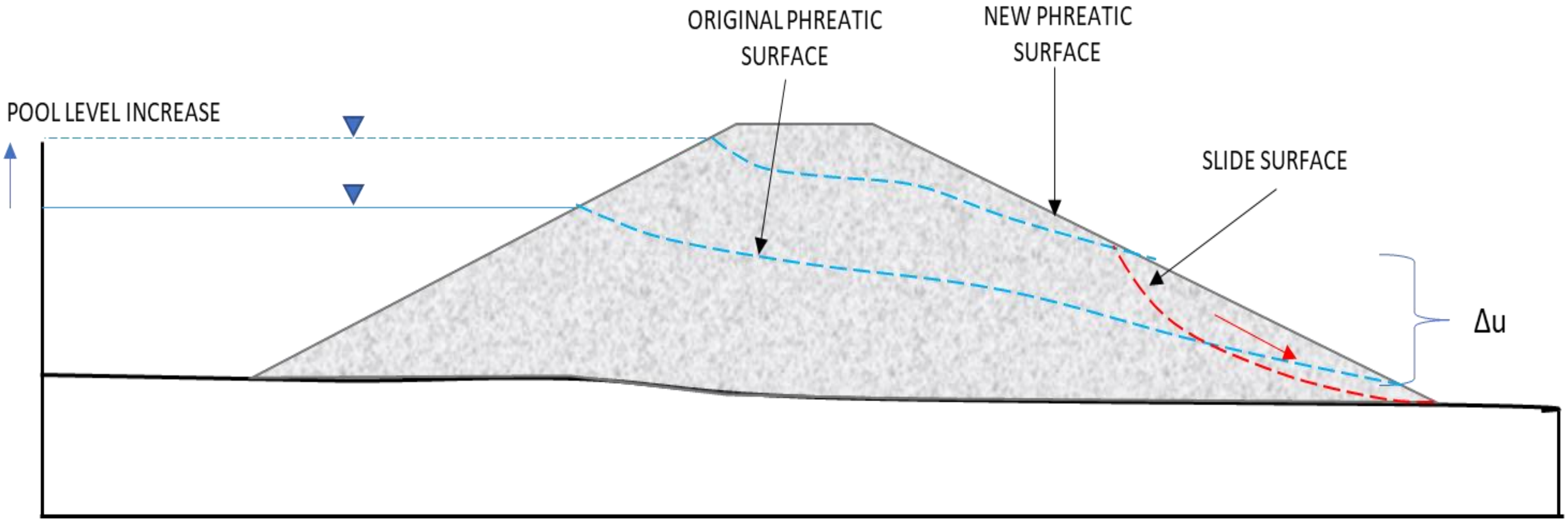
Tailing dams risk analysis

- Piping phenomenon



Tailing dams risk analysis

- Failure at the toe of the external slope



Methods to prevent drastic rise of groundwater levels

- Groundwater management
  - Ongoing construction or extension of rock drains is required as the footprint area of the dam increases.
  - Ongoing extension of the underdrainage system is required as the footprint area increases.
  - There is a need to construct management facilities to collect and control seepage in the downgradient toe areas.

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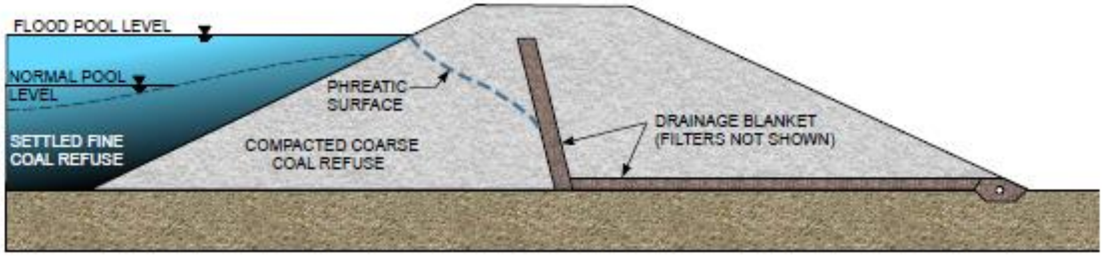
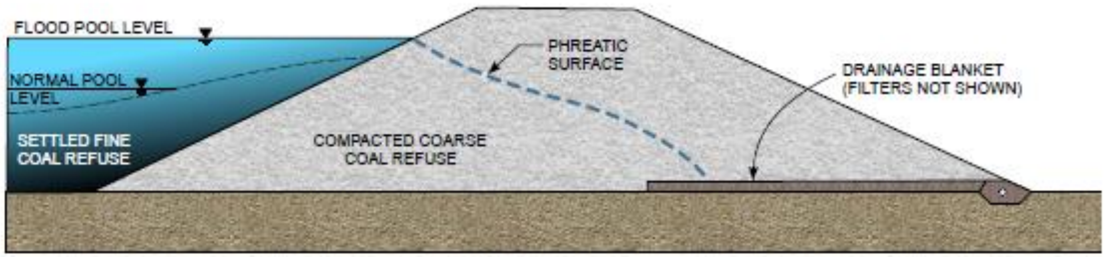
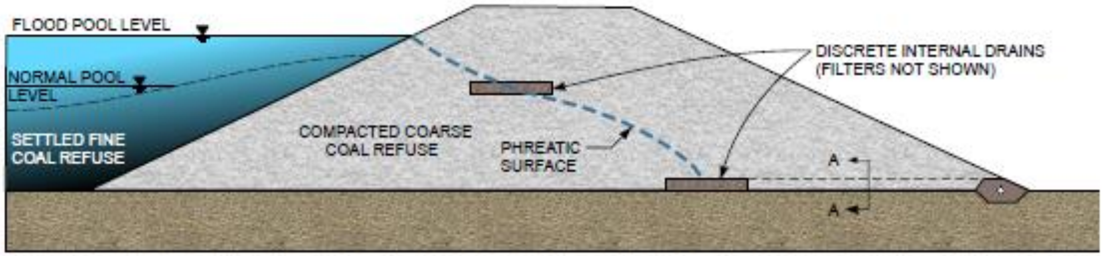


6.1a VERTICAL OR STEEPLY SLOPING CHIMNEY DRAIN



6.1b HORIZONTAL BLANKET DRAIN



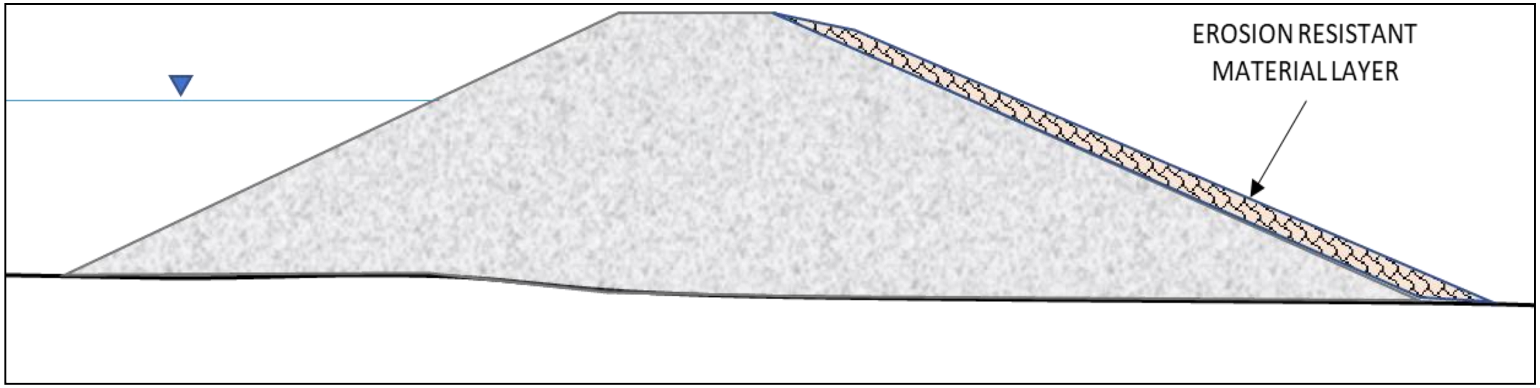
6.1c DISCRETE INTERNAL DRAIN

Methods to prevent drastic rise of groundwater levels

- Surface water management
- Diversion of any streams that may affect the area or may create recharge to alluvial materials.
- Diversion of runoff from the upgradient catchment areas.
- Diversion of runoff along drainage channels (toe drains) constructed.
- Installation of interception trenches or slurry walls to prevent shallow sub-surface seepage into the pit from sources of water near to the influence area (e.g. rivers or dams).
- Surface water collection channels routed along the side of access ramps.
- Minimization of flat areas and hollows to reduce the potential for ponding water to accumulate in topographic low points on the dump surface.
- Prevention of uncontrolled runoff down external faces by placement of crest berms.
- Avoidance of steep channel profiles that may increase the potential for erosion, or the incorporation of drop structures into the channel design.
- Incorporation of sediment traps within the drainage design, as needed.

Protection of the dam from erosion and mechanical failures

- Mesh or matting draped over vulnerable areas.
- Crest berms on individual catch benches to prevent run-on to the weaker zones.
- Lined drains feeding into downpipes.
- Rip-rap protection of the bench toes.



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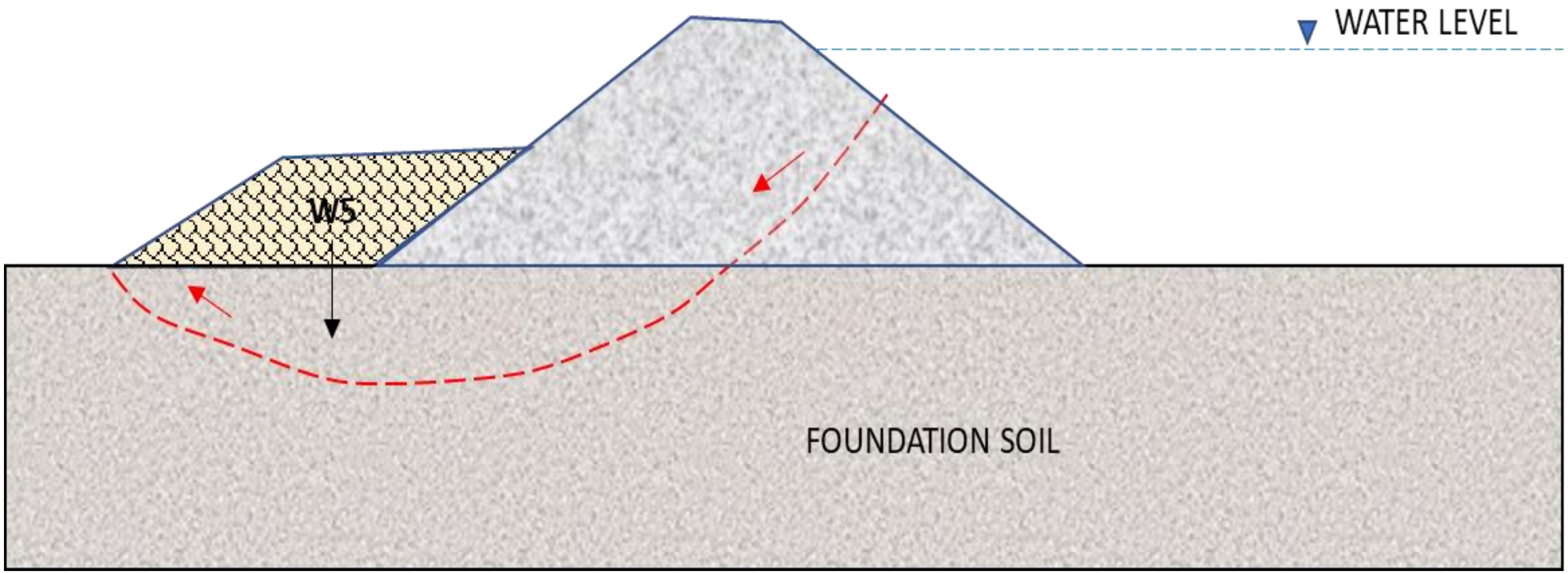
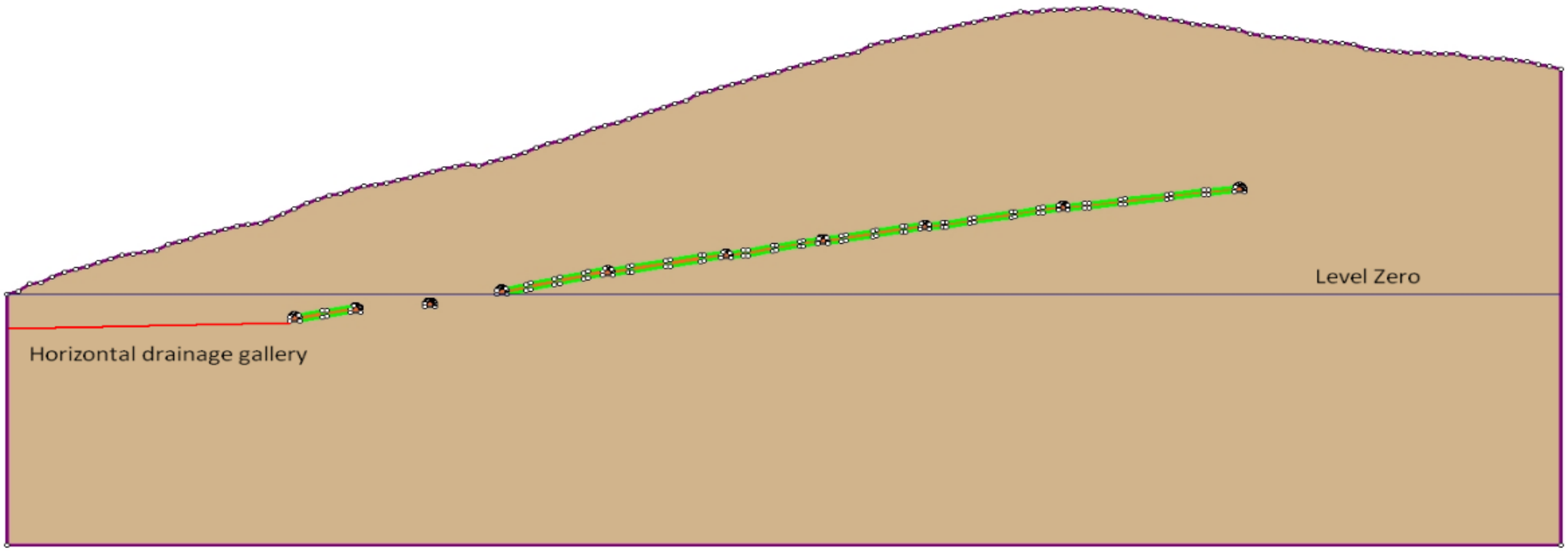


Sinkhole formation risk prevention

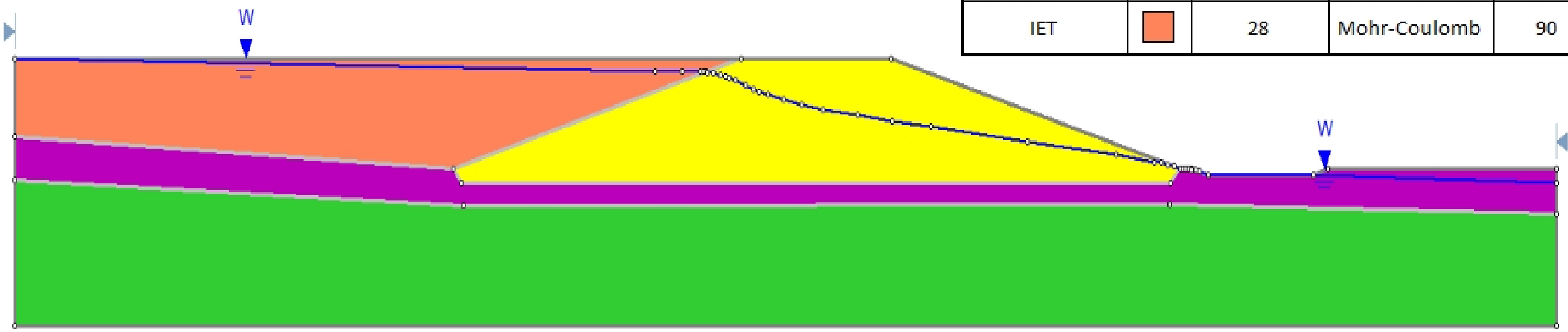
- Piezometric level control system
- Reduce infiltration
- Soil injections
- Drainage system



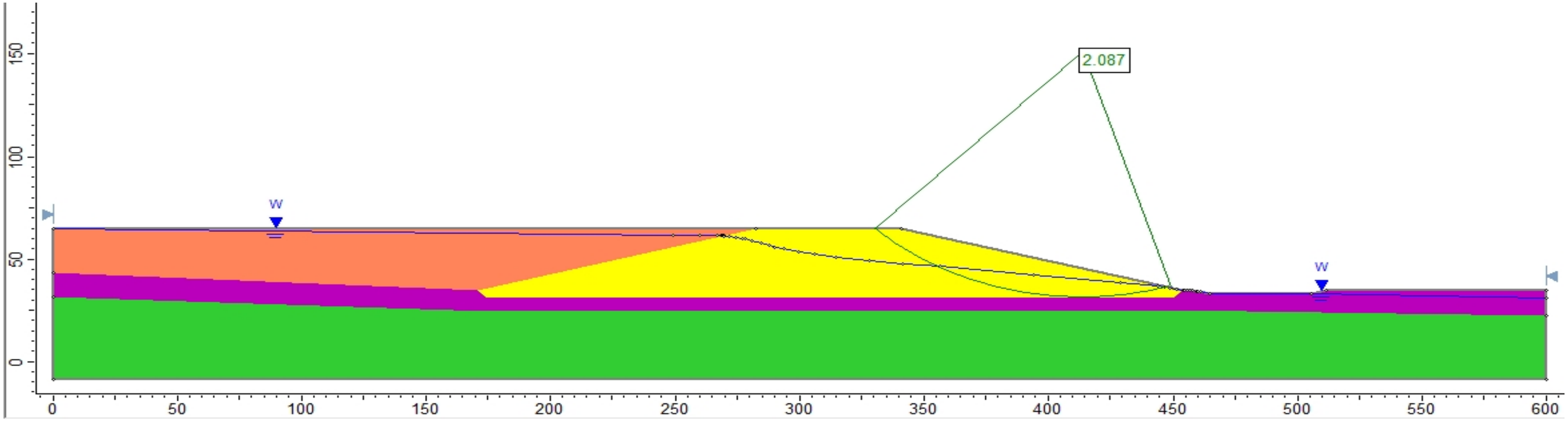
Verification of corrective measures using numerical modeling

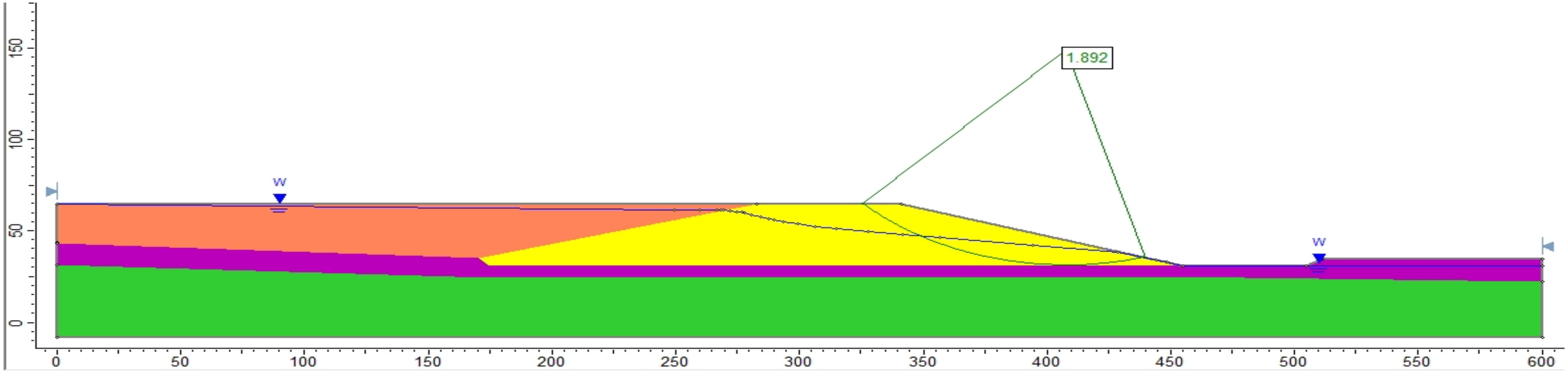
- Using models developed in WP3
- Appliying theorical knowledge aquired
- Focus on pore pressure variation

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
Met-2		19.7	Mohr-Coulomb	150	21
Met-1		18.9	Mohr-Coulomb	110	22
Margas 95% PM		18.9	Mohr-Coulomb	50	18
IET		28	Mohr-Coulomb	90	35



Toe failure (slope toe stabilizer removed)





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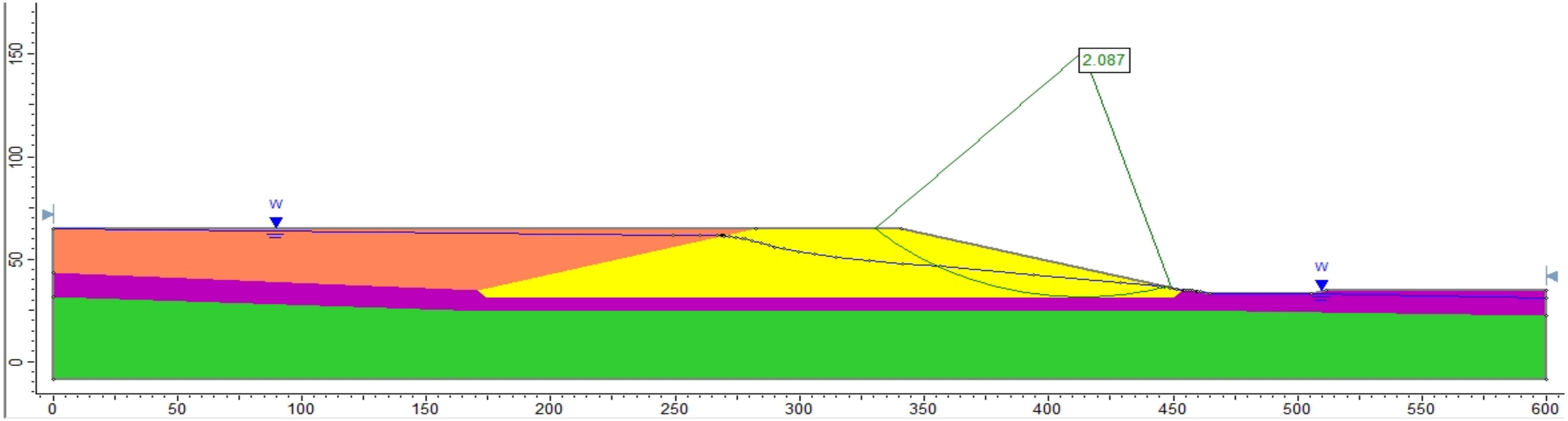
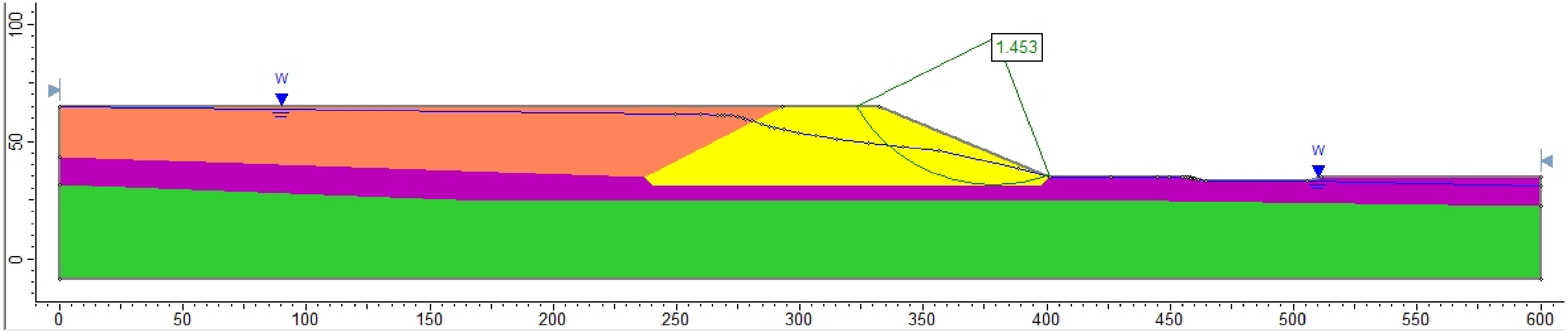
Modified geometry





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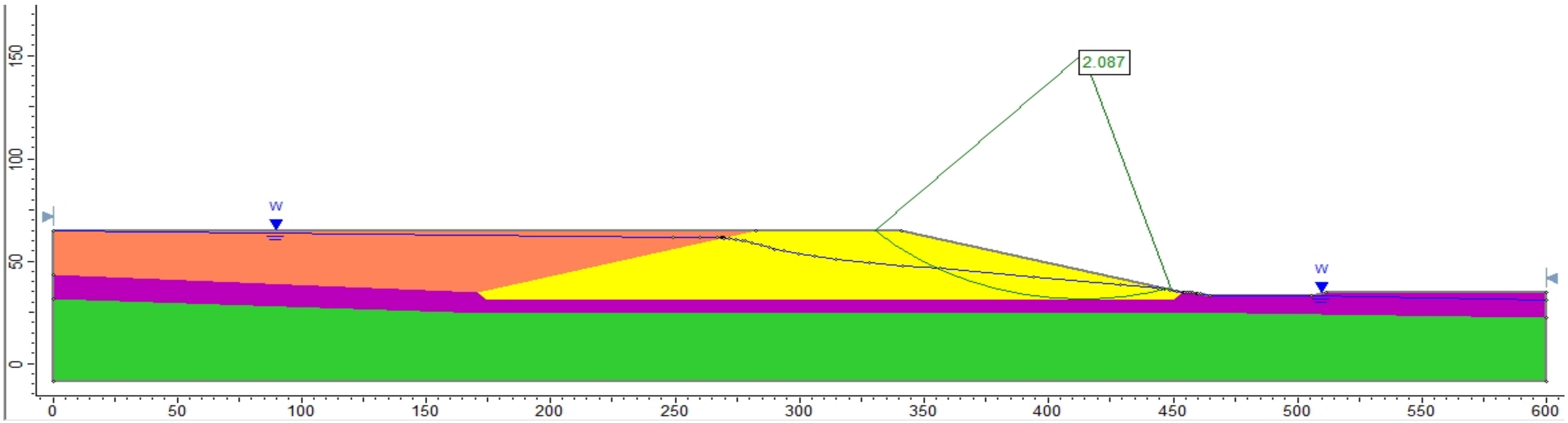
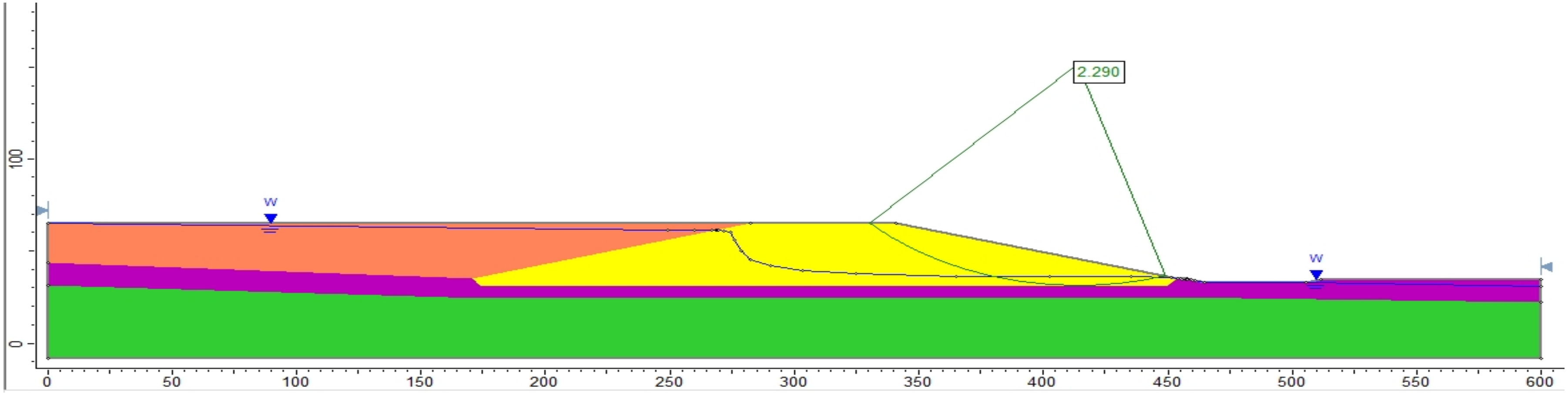
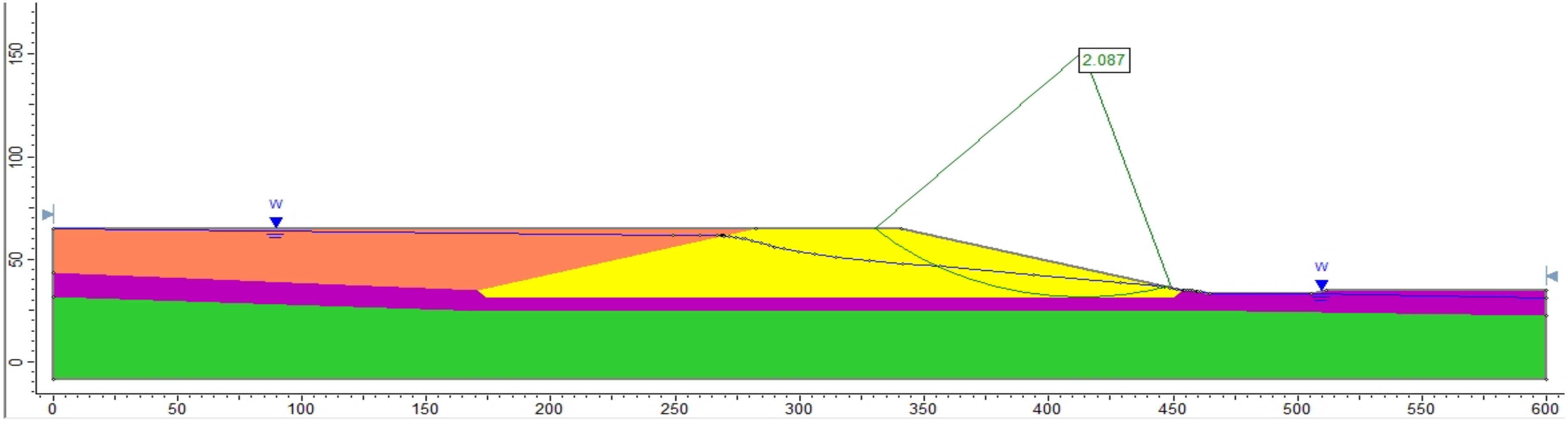
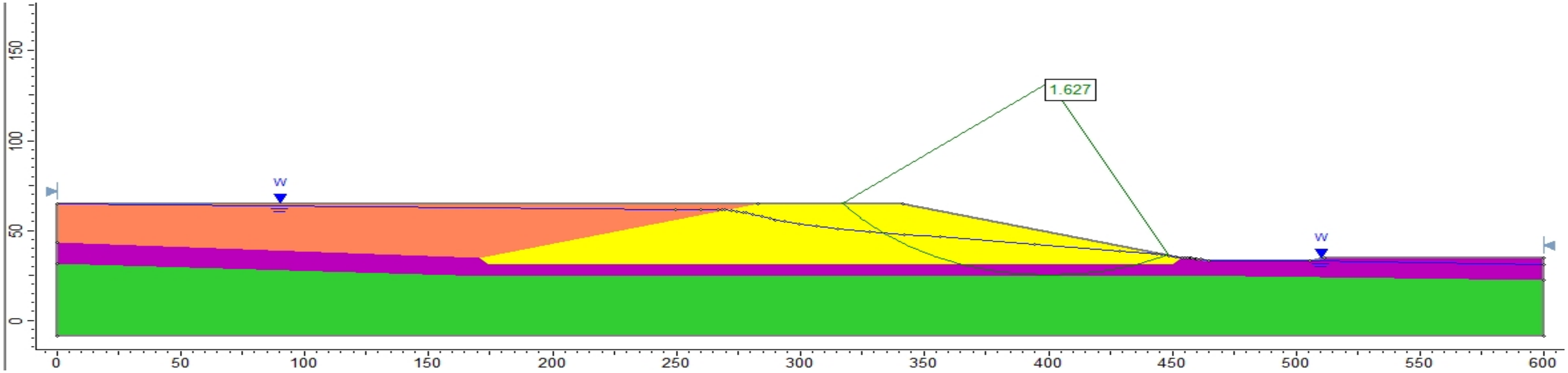
Horizontal drainage system



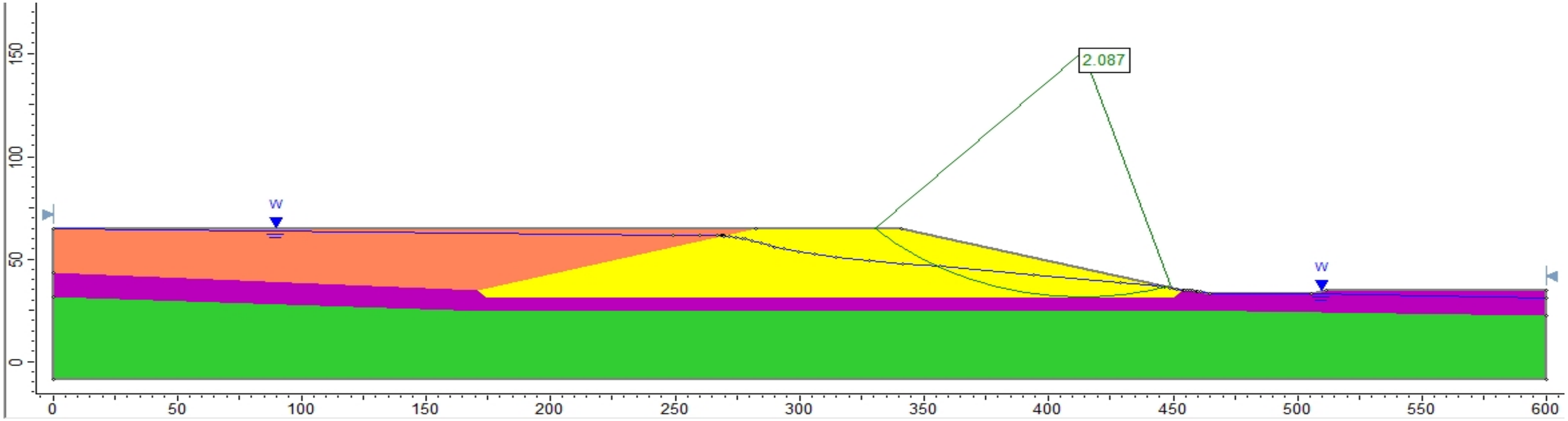


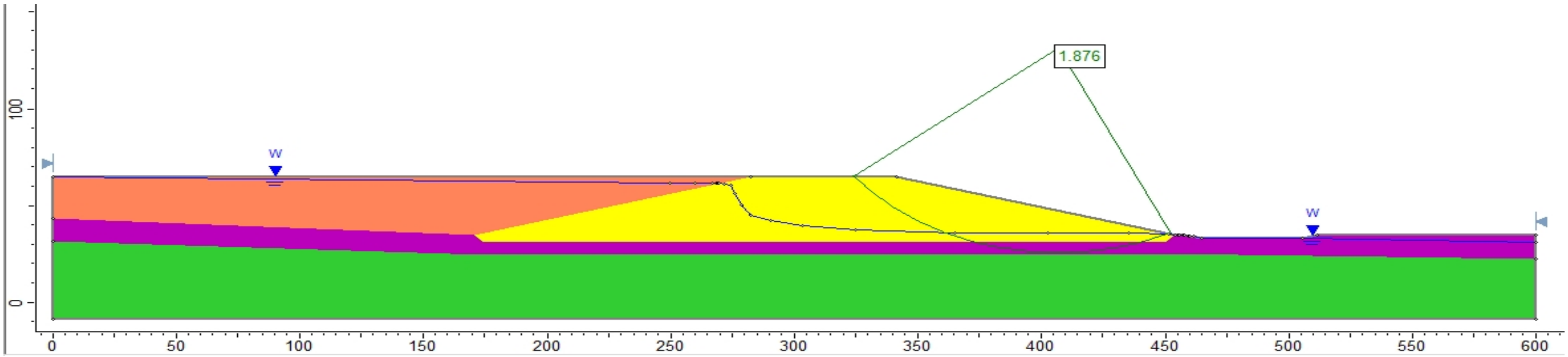
Excess pore pressure (B-bar increase)





Excess pore pressure (B-bar increase) with active drainage





Hillsides allocated over old underground mining galleries

- The most suitable **drainage system** would be a horizontal drainage system located in the lower gallery

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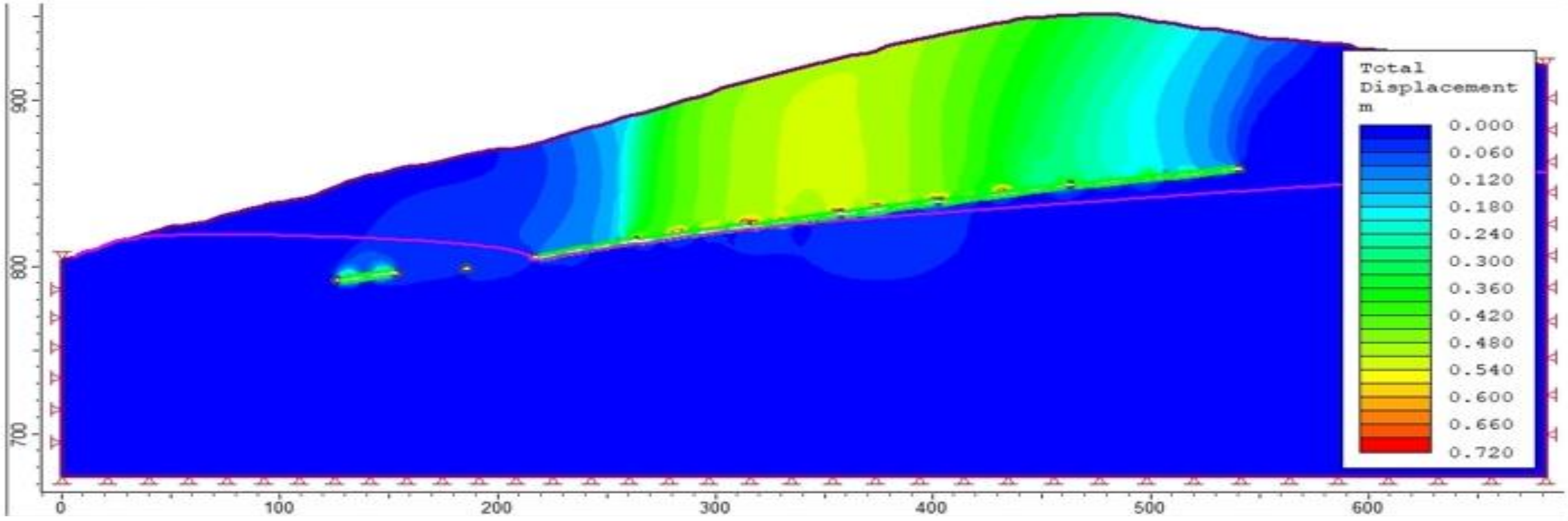

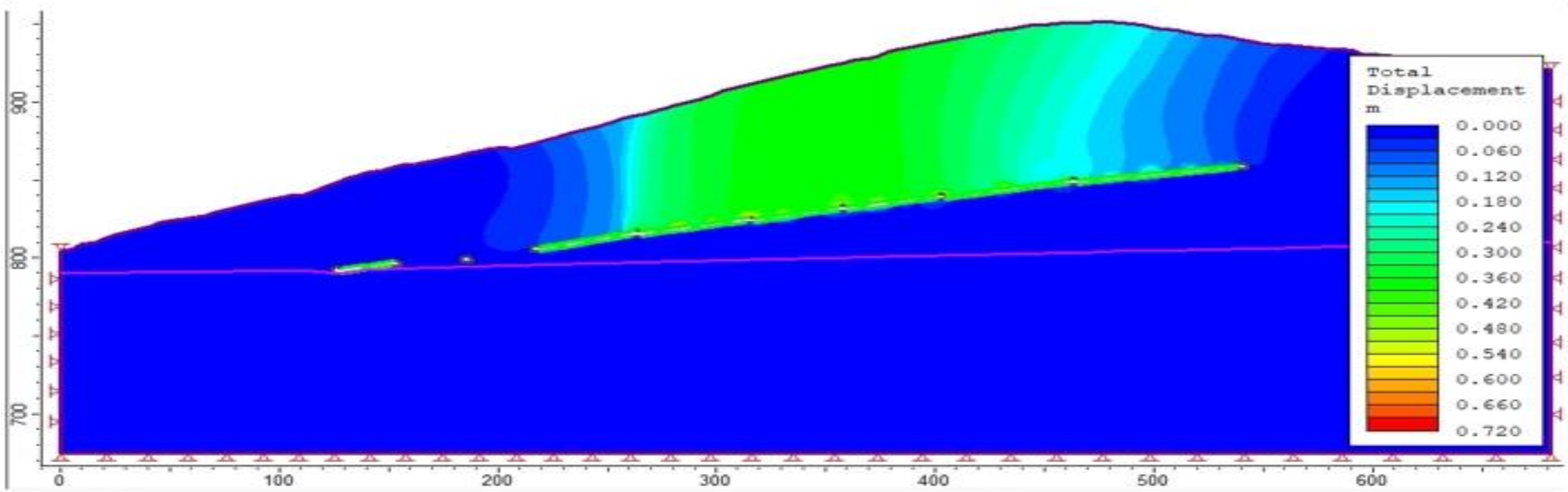

RISK AND IMPACT MITIGATION & MONITORING

Most sensitive impacts evaluated in models

- Frequency of **heavy rain events** (and duration)**.**
- **Drought periods** duration.
- Change in the **material properties.**
- **Geometry** of the structures. Monitoring.

RISK AND IMPACT MITIGATION & MONITORING

Phenomenon	Trigger
Seismic movements	• Over 3.5 Richter scale or noticeable by humans
Storms	• Accumulated precipitation into de basin over 218 mm/day
Overtopping	• Rising tailing level over exploitation level
Slides	• Slope cracks occurrence and earth movement symptoms
Dam movements	• Parameter anomalies • Over consolidation on top and cracks • Visual displacements
Abnormal behavior of the drainage system	Significant and observable modification of the flows collected in the seepage pool (downstream channel).
Dam erosion	• Signs of erosion in the channel in the vicinity of the dam.

Methodology

- 1. Monitoring and instrumentation.
- 2. Predictive models and level warnings.
- 3. Protocols for technical actions for emergency levels.
- 4. Verification of results and corrective reinforcement measures

Monitoring and instrumentation

- Environmental Monitoring Plan.
- Seismicity
- Surface deformations (by topographic control, radar, and extensometers) and at depth by biaxial and dynamic inclinometers.
- Pore pressure with open piezometers equipped with vibrating wire sensors.
- Total pressure by means of pressure cells.

RISK AND IMPACT MITIGATION & MONITORING

Predictive models and level warnings

- **Risk level 1**: Everything is normal and under control.
- **Risk level 2**: A non-conformance exists but the normal operating resources can manage the situation, commonly addressed with TARPS.
- **Risk level 3**: A non-conformance exists and appears manageable, but requires external resources to be engaged to manage the situation.
- **Risk level 4**: A non-conformance exists which may not be readily manageable and may pose immediate risk to the integrity of the TSF and community. Response activities are initiated. Emergency notification to employees and the community may be initiated.
- **Risk level 5**: Situation is out of control. Full emergency evacuation to be initiated.

Predictive models and level warnings

Horizontal displacements

Risk level 1	Risk level 2	Risk level 3	Risk level 4	Risk level 5
7-13	13-18	18-25	25-30	>30

Risk level 1	Risk level 2	Risk level 3	Risk level 4	Risk level 5
>2	2-1.5	1.5-1.3	1.3-1.1	<1.1

Pore pressure

Risk level 1	Risk level 2	Risk level 3	Risk level 4	Risk level 5
≤ 0.80	0.80 – 0.85	0.85- 0.90	0.90- 0.98	> 0.98

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Predictive models and level warnings

- **Deformations**. The strain rate has been considered more reliable than the deformation itself, since its prediction is simpler and provides us with more information about the state of stability of the slope structure and the proximity of failure. The deformation is mainly caused by the rise of the groundwater table.
- **Pore pressure**. Skempton's B-bar defined as the ratio of the increase in pore pressure in the ground to the increase in natural stress measured by total pressure cells or estimated from the ground height in the dumping area.

	EMERGENCY LEVELS SET FOR SKEMPTON'S B-BAR VALUE				
	Risk level 1	Risk level 2	Risk level 3	Risk level 4	Risk level 5
Bbar	≤ 0,80	> 0,80 – < 0,85	> 0,85 – < 0,90	> 0,90 – < 0,98	>0.98
Deformation	0-1 mm/day	>1mm/day	>2.5mm/day	>5mm/day	>1cm/day

PROTOCOLS FOR TECHNICAL ACTIONS FOR EMERGENCY LEVELS

Risk level 1

- Everything is normal and under control. No risk.

PROTOCOLS FOR TECHNICAL ACTIONS FOR EMERGENCY LEVELS

Risk level 2

- Increased frequency of measurements
- Visual inspections
- Verification with the mining department
- Aditional instrumentation
- Assessment of the situation according to the predictive model
- Review of the calculation processes

PROTOCOLS FOR TECHNICAL ACTIONS FOR EMERGENCY LEVELS

Risk level 3

- Frequency of readings every 2-3 days.
- Visual inspection every 2-3 days.
- Verification with the mining authorities.
- Installation of supplementary instrumentation if required.

PROTOCOLS FOR TECHNICAL ACTIONS FOR EMERGENCY LEVELS

Risk level 4

- Frequency of daily readings.
- Daily visual inspection.
- Verification with the mining authorities.
- Feedback of the numerical models used for the assessment of the stability of the structure and of the predictive model of the deformations and pore pressures.
- Assessment of the situation from the magnitude of the pore pressure and/or the rate of deformation evolution according to the predictive models.

PROTOCOLS FOR TECHNICAL ACTIONS FOR EMERGENCY LEVELS

Risk level 5

- Stoppage of activity in the area where the anomaly has been detected.
- Implementation of corrective or reinforcement measures.

VERIFICATION OF RESULTS AND CORRECTIVE REINFORCEMENT MEASURES

- Measures based on slope geometry modification
- Measures based on pore pressure reduction
- Measures based on increasing of the soil properties

ISSUING REGULAR REPORTS

in addition, the new readings of:

- Inclinometers
- Piezometers
- Pressure cells
- Topographical landmarks

- Particular attention shall be paid if the recorded data exceeds emergency levels and, in the event that an instability is detected, the necessary measures shall be taken to deal with it.

AUSCULTING AND POST-CLOSURE CONTROL SYSTEM

Post-closure control:

- Monitoring and control of piezometers and total pressure cells.
- Monitoring and control of inclinometers and topographic landmarks.
- The resolution of the sensors and the periodicity of the measurements are defined, defining a monitoring protocol.

Auscultation, surveillance and emergency plan:

- Pore pressure: its reading shall be stabilised with maximum values of the Skempton coefficient B-bar = 0.5.
- Total pressure cells: their reading shall be stabilised, with velocities of less than 1kPa/year.
- Horizontal displacements: their reading shall be stabilised, with velocities of less than 0.1mm/day.
- Settlements: their reading shall tend to stabilisation with a velocity of less than 3cm/year.

POST-CLOSURE MAINTENANCE AND MONITORING

- The guard channels will be maintained following extreme rainfall events or every 5 years
- For the remaining facilities of the project, an annual visit is considered, focused on reviewing the condition of its slopes.
- An additional visit will be considered after the occurrence of extraordinary events in the area.
- Groundwater quality monitoring will be carried out downstream of the facilities in the wells designed for this purpose.

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