GeoStabilization International®

Mine GeoHazard Rules of Thumb

Revision 4

Introduction

GeoStabilization International® is a geotechnical contracting firm servicing the United States, Canada, and Australasia. GeoStabilization repairs a full spectrum of mining geotechnical hazards and specializes in emergency landslide repair, slope stabilization, and rockfall mitigation using design/build and design/build/warranty contracting. GeoStabilization also builds retaining walls and bridges.

GeoStabilization's team includes some of the most experienced and innovative geologists, mining and geotechnical engineers, equipment operators, and rockfall remediation technicians in the mining industry. With over 100+ years of in-house mining experience, we are well versed in mining challenges.

- More than 40 geotechnical engineers on staff that focus exclusively on GeoHazard mitigation (slope repairs, waste dump stabilization, & rockfall mitigation).
- More than 80 drill rigs/launchers operated by more than 50 experienced crews.
- Our equipment is purpose-built to allow for exceptional production in difficult access areas, including remote sites. This translates into rapid, low-cost mitigation with minimal environmental impact and permitting time, allowing for continuous access and production with minimal disruption to your operations.
- GeoStabilization can respond within 24 hours to Geohazard events to safeguard your personnel and infrastructure.

Our Mining Services

Protecting Mine Infrastructure

- SuperMicropile™ foundations
- Access road and waste dump stabilization
- Exploration slope stabilization
- Abutments, buttresses, and box culvert
- Retaining headwalls for mineral processing facilities
- Reclamation and tailings dam reinforcements
- Portals and limited access tunnels

Safeguarding Mine Operations

- Emergency rock and soil slope stabilization
- Highwall and catch bench maintenance programs
- Highwall drilling and reinforcement
- Rapid response on-call services for rockfall mitigation and slope protection
- Highwall scaling and barrier fence installation
- Slope / Highwall Radar Monitoring

Engineering Solutions for GeoHazard Mitigation

- Highwall, spoil bank, slope stability failure assessment
- Zone dewatering and drainage diversions
- GeoHazard detection and highwall management planning
- Waste material geotechnical engineering
- Reclamation, rehabilitation, and waste dump stabilization
- Slope stability for earth fills and tailing dams

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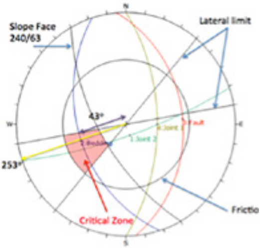


Planning for Total Mine Life

Regulations require that geotechnical issues be considered during the whole life of a mining operation; from its beginnings through the operation of the mine to the final closure and abandonment of the mine. The goal of open pit designs is to facilitate work in a manner to prevent hazardous and unexpected failures of the rock mass during the operating life of the open pit or quarry. For the development and mining of currently producing, or undeveloped mining blocks, a mine plan would include the production of plans, cross-sections and longitudinal projections of the mining block(s) as appropriate, plus a written description of the proposed mining work to be done and the mining issues that need to be addressed.

It is recognized that during the geotechnical design stage there is usually limited detail of the overall rock mass characteristics available and that it is common to make a number of assumptions to arrive at a balanced mine design. It is also recognized that ongoing geological mapping and failure assessments should be conducted periodically as mining progresses.

Geological Structure and Rock Mass Strength

Rock mass failures occur when driving forces acting on a given body of material exceed the resisting forces within that body of material. In a newly excavated slope, the force resisting failure can be attributed to the shear strength of the rock mass and/or geological structure. The driving force (that precipitates failure) is primarily dependent on the unit weight of the rock mass, the geometry of the wall/slope, and the potential modes of failure (which define the geometry and size of the block of potentially unstable material).

Mine operators must periodically evaluate the rock mass and its characteristics, mainly orientations of discontinuities and associated shear strengths, with respect to pit walls. In doing this a mine can evaluate potential failure modes within the rock mass and assess the size and potential stability of large and small block failures.

Factors affecting highwall stability include highwall geometry (height, slope, benches) and rock mass characteristics (type of rock, condition of discontinuities such as joints, bedding planes, faults, shear zone, etc.). Highwall failures generally occur along discontinuities in the rock mass. This is in a large part due to their orientation (the way in which discontinuities intersect each other) relative to the highwall face. Knowledge of the discontinuities allows for the anticipation of hazards and the proper design of highwall profiles or mining sequences to mitigate them.

Hydrogeology

As open pit wall failures are often associated with rain or heavy water events, it may be necessary to develop an understanding of the mechanisms of infiltration of surface water into the rock mass. The hydrogeological environment of an open pit needs to be understood to an appropriate level to ensure adequate provisions are made for the removal of rainfall and groundwater inflow as the mine continues to expand. Some of the more significant effects water can have on the general integrity of pit walls include:

- Increase in pore pressure within the rock mass (which reduces shear strength)
- Softening of infill or rock material (particularly clays)
- Slaking of soft rock due to wetting and drying cycles
- Freeze/thaw cycles (when water freezes it can induce significant expansion pressures on joints and cracks)
- Erosion of weaker bands of rock by water seepage or run-off
- Reduced blasting efficiency, and corrosion of ground support and reinforcement systems

In order to understand the hydrogeological conditions at a mine site, it is necessary to undertake adequate investigation of the range of geological conditions and characteristics of water flow throughout the site. Dewatering/depressurization programs can be better designed so that the required levels of depressurization can be achieved.

Rock Support and Reinforcement

The use of reinforcement must adequately match the design of rock support and reinforcement to the ground conditions. It is essential that each rock reinforcement element is correctly designed, installed, and the design is based on a thorough understanding of the following points:

1. Geological structure in and around the pit walls
2. Rock mass strength
3. Groundwater regime (particularly in terms of corrosion potential)
4. Behavior of the rock support or reinforcement system under load
5. Rock stress levels and the changes in rock stress during the life of the excavation
6. The potential for seismic events

The timing of the installation of ground support and reinforcement should be considered as an integral part of the design to limit the potential for raveling of the rock mass.

Wall / Slope Design

Before mining commences, it is necessary to establish an appropriate excavation design geometry from which to base the overall mine plan. It is acknowledged that the "final" pre-mining design may be modified with time: as additional data becomes available during the operational life of the mine.

Highwalls / slopes are designed to balance the anticipated failure risk. It is also recognized that the final design of open pit walls represents a balance between safety and the economic viability of the operations. It is generally not feasible to design the pit walls for "permanent" stability. The following steps should be followed with any mine design:

1. Define the geological domains and mining sectors
2. Conduct a bench design analysis to determine the maximum inter-ramp slope
3. Conduct inter-ramp design analysis using economic criteria for the selection of inter-ramp angles
4. Evaluate the resulting slope for potential instability and modify design if required

Slope stability for mine operations must consider global failures, localized failures, and small mitigation and control (i.e. Rockfalls). There are a number of ground control design methods that can be used, which rely on having a good understanding of the prevailing ground conditions before undertaking the design. The design methods that can be used include:

- Empirical or experience-based methods developed from extensive local information
- Limit equilibrium methods - using geotechnical parameters derived from either laboratory testing or back analysis of existing failures
- Kinematic analysis (stereographic and block analysis methods)
- Numerical modeling
- Physical modeling

Design criteria for each of these methods can differ; however, each design criterion is dependent on the level of acceptable risk of any particular failure.

Blasting Considerations

Inappropriate drilling and blasting practices can result in substantial damage to the rock mass within the operating and final pit walls. Poor blast results will leave walls jagged with loose or overhang situations. There is a need to have optimized drilling and blasting practices that have been determined using well founded and recognized blast design procedures that are appropriate to the ground conditions at the mine site.

The factors that control the level of wall damage caused by drilling and blasting include:

- Rock mass properties such as orientation, persistence and spacing of geological structure, and the presence of groundwater
- The degree of “confinement” and amount of burden shifted by the proposed blast
- Inadequate removal of rock debris from earlier blasts from the toe of batter slopes
- The degree of rock fragmentation required
- Selection of the appropriate hole diameter
- Control of individual hole collar position, hole bearing, inclination and length
- The type and amount of stemming used
- Placement of holes in a suitable pattern to achieve the required excavation geometry
- The use of specific perimeter holes such as stab holes or smooth blasting techniques (e.g. pre-splitting, post-splitting, or cushion blasting)
- Selection of appropriate initiation system(s) and initiation sequence of the blast or blasts
- Specific types or combinations of explosives [Explosives must be selected according to the given ground mass conditions (e.g. groundwater can affect the result of a blast). Explosives must also be selected to achieve required energy levels, maintain compatibility with the initiation systems, and the explosives’ expected product life in blast holes]
- Control of explosive energy levels in the near-wall holes and preferably using decoupled explosive charges, with a cartridge diameter less than the blast hole to minimize blast damage at the excavation perimeter

- The required mining bench height and the depth of subgrade drilling (subdrill)
- Availability of well-maintained drilling, explosives handling, and charging equipment of appropriate capacity

The perimeter/final wall blast hole and explosives system will need to take into account all these relevant issues to arrive at the optimal final pit walls. ***The extra cost of pre-splitting can be offset by reduced man-and-equipment hours spent with a scaling maintenance program.***

Monitoring

Early detection of wall failure allows mine operators to plan and implement appropriate actions with sufficient notice such that the effect of the failure on mine safety and productivity is minimal. Slope failures do not occur spontaneously, there is scientific reasoning for each failure, and failures do not occur without warning if the failed area is being well monitored. Once unusual pit wall movements such as cracking have been observed, it does not necessarily follow that the wall will collapse.

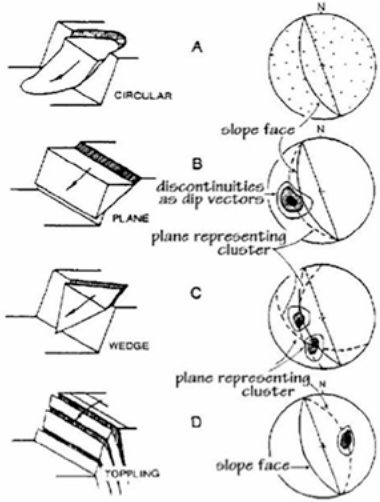
Each site must have its own monitoring strategy, matched to local ground conditions. Pit slope monitoring programs should start off simple, and become more refined or complex as conditions demand. To begin with, monitoring can be kept to visual inspection only; provided safe foot access can be maintained to all benches. Where safe foot access cannot be maintained or guaranteed, monitoring equipment that can be operated remotely should be installed on the respective slope faces or crests. Visual monitoring alone is acceptable until the pit wall expresses one or more signs of potential instability. There is a growing trend for radar monitoring systems at mine sites to identify specific areas of instability along highwalls, waste dumps and tailings dams. They can be incorporated to understand those factors that are influencing slope movement throughout the year, including weather events and mining activities (i.e. drilling, blasting or haulage). Monitoring can also be used to evaluate the effectiveness of a newly constructed buttress, dewatering key zones, or the impact of a drainage diversion against its overall effectiveness on reducing slope movement.

Visual signs that allude to incipient failure of pit walls include:

- Formation and widening of tensile cracks
- Displacements along rock defects in the batter face
- Bulging of the slope face or toe
- Raveling of rock within the slope
- Increased water seepage
- Bending of reinforcement or rock support elements
- Rock noise and ejection.

Records of visual observations made during regular inspections of pit walls play a very important part in implying a history of ground behavior for assessment of pit wall conditions.

Types of Failures



Rockfall Hazards are caused or induced by:

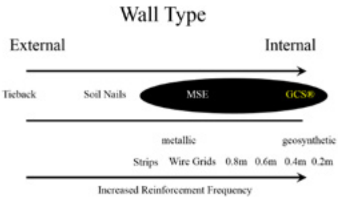
1. Planes of weakness such as joints, faults, mud seams, and changes in face orientation against the geological structure
2. Equipment or mining activity working on a bench above
3. Water issues (e.g. precipitation and ground water)
4. Freeze thaw cycle and erosion
5. Poor or insufficient drainage control
6. Tree and Vegetation along the highwall (e.g. Root jacking)
7. Excessive blast damage

Mine GCS® Retaining Walls

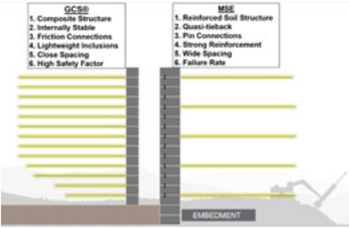
GeoSynthetically Confined Soil® (GCS®) Retaining Walls, commonly known as GeoSynthetically Reinforced Soil (GRS) walls, consist of densely spaced layers of granular fill and geosynthetic reinforcement. The combination of granular backfill and tightly spaced reinforcement creates a geo-monolith; a significantly superior product in comparison of the sum of the individual components.

GCS® retaining walls provide the added load bearing strengths commonly seen in a mining environment for the added factor of safety for your long-term infrastructure and operational applications. GeoStabilization has built over 1,400 GCS® retaining walls in a variety of applications from rockfall barrier protection systems to remote single span bridge abutments in some cases with a negative batter to allow for a wider top road overall width.

Technology Evolution



Benefits of GCS®



Applications

- Materials Handling and Processing
- Portal / Tunnel Entrances
- Headwalls and Crusher Stations
- Bridge Abutments and Culverts
- Rockfall Barriers
- Widening Haul Roads and Ramps
- Shortening Haul Distances
- Engineered Catchment Benches
- Mine Drainage and Diversion
- Earth Retention Systems

Mine Grouting Applications

Grouting is used in mining applications to control subsidence, provide for groundwater protection, backfill abandoned mine subsurfaces, stabilize soil/foundations, etc. GeoStabilization's rapid response teams design the solution, complete the grouting plan, perform the grouting, and provide all post-installation testing and evaluation as required.

Types of Mine Grouting

Compaction / Low Mobility Grouting
Chemical Grouting
Cement Grouting
Jet Grouting
Fracture Grouting
PUR – Polyurethane Injection

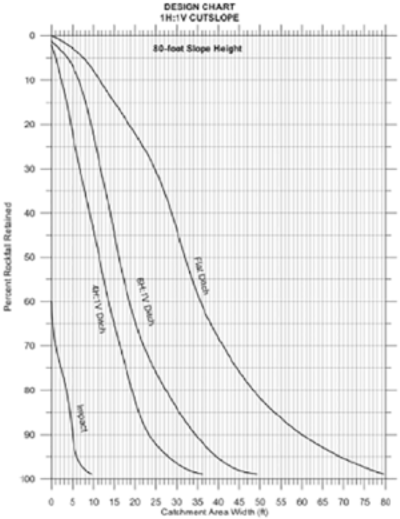
Applications

- Decant Line Abandonment
- Prevent Subsidence (Tailings)
- Groundwater Control
- Soil Stabilization
- Plugging Old Mine Workings / Sinkholes
- Bolt & Anchor Grouting
- Exploration Core Grout Plugs
- Infrastructure, Bridge and Foundations Grouting

Rockfall Mitigation Techniques

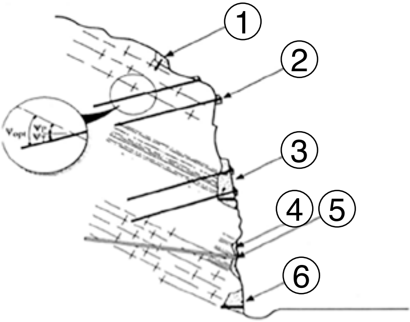
- Adequate catchment area and berms/catch bench maintenance
- Rockfall barriers and retaining walls
- Mesh/drape fences
- Highwall scaling (hand/mechanical)
- Protective blasting techniques
- Highwall drilling and reinforcement
- Zone dewatering and drainage diversions
- Highwall buttress
- Tree and vegetation removal along slopes
- Polyurethane Resin Grouting (PUR) – Rock Gluing
- Shotcrete or gunite
- Air bags for scaling

Catchment Area Design Chart

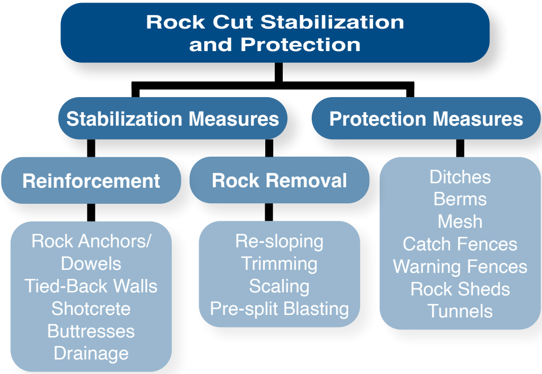


Methods of Stabilization and Protection

Methods of Reinforcements



1. Reinforced concrete dowel to prevent loosening of slab at crest
2. Tensioned rock anchors to secure sliding failure along crest
3. Tieback wall to prevent sliding failure on fault zone
4. Shotcrete to prevent raveling of zone of fractured rock
5. Drain hole to reduce water pressure within slope
6. Concrete buttress to support rock above cavity



Rules of Thumb for Rockfall Mitigation:

Step 1: Compare project site's catchment area to appropriate "Catchment Area Design Guide" chart on page 10.
Note the impact and appropriate ditch shape widths for 90% rockfall retained.

Step 2: If project site's catchment area is greater than a 90% ditch width, then the catchment area is adequate.

Step 3: If project site's catchment area is greater than first impact distance but less than a 90% ditch width, then the site is a candidate for a rockfall barrier.

Step 4: If project site's catchment area is less than a 90% impact and ditch width, then a slope treatment should be considered.

Rockfall Barriers

Barriers are structures located commonly within the catchment area to prevent or limit rockfall from rolling past the catchment area.

They include:

- Berms: soil or rock build up commonly placed at angles such as 30-45° limbs to prevent or limit rockfall from rolling past the catchment area. Berms are effective in many cases. Limitations with berms include space and ability to control rolling rock.
- Rigid Barriers: Berms can be included in the rigid barrier category, but are more commonly attributed to barriers such as k-rails, Jersey Barriers and GCS® walls. These are more costly than berms, but are more flexible in design and commonly require less area for construction.

- Flexible Barriers: also called rockfall fences. Increased cost in comparison to other barriers, but excellent for limited space applications as well as sites with bounce heights greater than berms and k-rails can contain.

Slope Treatment

Slope treatments are systems placed on the surface of the slope to either control rock as they fall down the face or contain rock on the slope surface.

Slope treatments include:

- Draped Mesh, Cable Nets, and Ring Nets: a mesh of high tensile steel draped over the slope and pinned only along the slope crest. A rockfall is controlled as they fall between the mesh and the slope. Rocks fall in a safe controlled manner and eventually come to rest at the base of the slope. Periodic cleanup of the catchment area is required with this system. There are two types of draped systems:
    - Draped mesh: high tensile steel that comes commonly in 2-4 mm diameter wire. Adequate for controlling rockfalls up to 2-3 feet in diameter.
    - Cable Nets: thicker diameter wire ropes that are adequate for rockfalls greater than 3 feet in diameter (commonly up to 5-6 feet in diameter maximum).
    - Ring Nets also allow for larger rockfall containment and work well with abrasive or jagged rocks that would otherwise cut through a lighter duty mesh fabric.
    - These systems can be combined to prevent small rocks from passing through the larger nets.
- Pinned Mesh: mesh or cable nets pinned to the slope at some designed interval to contain rocks on the slope. Used in locations when rockfalls should

not be controlled, but contained on the slope. More expensive than draped systems due to the anchors.

- Shotcrete: shotcrete or gunite application to the slope. This eliminates the potential for rocks falling from the slope. Generally used in only critical areas.

Rockfall Fence Design Guidelines

There are several variations in mesh designs providing different load capacities. Their application includes areas of highly weathered rock near high traffic areas such as access ramps and portals. This provides an adequate measure to reduce the risk to mine personnel and infrastructure by controlling rocks as they fall from a highwall. Flexible rockfall barriers, also called rockfall fences, contain falling rocks from moving into protected areas.

There are two predominant types of rockfall barriers on the market, standard flexible barriers and hybrid barriers. More robust fabrics, such as high-tensile mesh nets, have more recently been introduced to improve the capacity of these rockfall protection systems.

Design guidelines are based on existing performance of critical system components, back-analyzed system failures, evaluating typical loading conditions, and using developed analytical models to refine the engineering design of these systems. The guidelines were developed to support the design of these systems for a variety of loading conditions. Specifically, systems design guidance are evaluated based on site suitability, characterizing external loads, fabric selection, anchor requirements, and system detailing.



Recommended design approach for wire mesh/cable net systems. These guidelines attempt to highlight dominant concerns or limitations, and designers must then exercise their best judgment:

1. Evaluation of site suitability (block and event size, slope conditions)
2. Characterization of potential external loads (interface friction, debris loads, impact loads and snow loads)
3. Fabric selection (primarily based on the expected block/event size that the system will retain). Other fabric properties besides strength, such as puncture resistance and flexibility/rigidity are relevant
4. Anchorage requirements, anchor capacity, and spacing, should provide the primary support for mesh systems

Recommended fabric usage as a function of block size:

Fabric	Block Size
double-twisted hexagonal mesh	≤ 2 ft (0.6 m)
cable net	≤ 4 – 5 ft (1.2 – 1.5 m)

5. System details and specifications, slope coverage, anchors locations, support ropes, fabric seaming and fastening
6. Consideration of aesthetic concerns, areas of considerable scenic or recreational value consideration
   - Design efforts to mitigate these aesthetic concerns may focus on:
     - Reducing/limiting the coverage area
     - Achieving greater mesh contact with the slope
     - Colorizing system components or promoting vegetation to visually merge the system with the slope
     - Considering other slope stabilization alternatives

Construction and maintenance should consider how a system will be installed and inspected. An installation should require minimal maintenance over the design life of the system; while the dominant maintenance concern should be averting damaging debris loads.

A flow chart summarizes the overall design approach:

Rockfall Impact Energy Chart

Rockfall Energy: Imperial *(table continues on the next page)*

Height of Fall (feet)	Approx. Weight (lbs)	Equivalent Cube Size (inches)	Max. Speed (mph)
50	20	6	38
100	20	6	54
150	20	6	67
200	20	6	77
50	1,200	24	38
100	1,200	24	54
150	1,200	24	67
200	1,200	24	77
50	4,300	36	38
100	4,300	36	54
150	4,300	36	67
200	4,300	36	77
50	33,775	72	38
100	33,775	72	54
150	33,775	72	67
200	33,775	72	77

(table continued from previous page)

Kinetic Energy (ft-lbs)	Approx. Force of Impact [1] (lbs)	Kinetic Energy KJ
1,000	3,000	1.3
1,950	5,955	2.6
2,995	9,130	4.1
3,972	12,100	5.4
59,000	180,000	80
118,000	360,000	160
181,300	552,800	246
240,500	733,100	326
211,200	643,900	287
422,500	1,288,000	573
647,900	1,974,000	878
859,200	2,618,800	1,165
1,662,700	5,068,000	2,254
3,325,000	10,136,000	4,509
5,099,000	15,542,000	6,913
6,762,000	20,610,000	9,168

[1] Assuming that the rock penetrates the ground surface 3" upon impact.

Monitoring Techniques

Displacement monitoring techniques are most commonly used in open-pit mining to assess the condition of pit slopes.

The specific nature of monitoring programs required for a given open pit will be dependent on the site-specific conditions of the mine. There are different modes of deformation and failure that can exist within a slope. These failure mechanisms need to be understood in order to assist in a proper design of any monitoring system to be implemented. Most highwall monitoring systems measure the relative displacements to monitor slope behavior and maintain a safe operation.

In general, monitoring of the surface of a slide is likely to be less costly to set up and maintain than that of sub-surface measurements that require drilling holes to install the instruments. However, surface measurements can only be used where the surface movement accurately represents the overall movement of the slope. Other factors to consider in the selection of a monitoring system include the time available to set up the instruments, the rate of movement, and the safe access to the site.

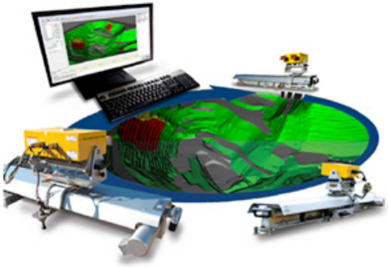
Surface Monitoring Methods:

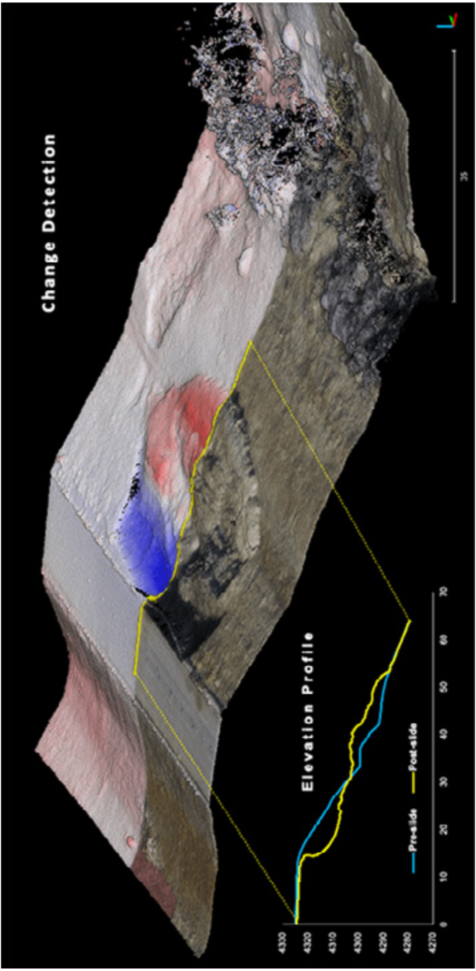
1. Crack Monitors
2. Surveying
3. Photographic Image Analysis
4. Total Station
5. Global Positioning System (GPS)
6. Acoustic Emission Technique
7. Laser Image Scanning System
8. Slope Stability Radar System

Sub-surface measurement is often used to obtain a more complete picture of the slope behavior. The main purpose of these measurements are to locate the slide surface or sub surfaces, and monitor the "rate of movement." In some cases, the holes are used for monitoring both movement and pore water pressures.

Sub-Surface Monitoring Methods:

1. Borehole Probes
2. Time–Domain Reflectometry (TDR)
3. Inclinometers
4. Extensometers
5. Measurement of Water Level and Pressure
6. Piezometer




Change Detection
Elevation Profile
Pre-slide
Post-slide
4330
4320
4310
4300
4290
4280
4270
0
10
20
30
40
50
60
70

Highwall and Slope Investigation Protocols

Highwall Safety, MSHA recommends the following best practices*:

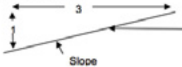
- Examine and monitor highwall often.
    - Miners must inspect their working place before starting work and be aware of any changes in conditions. Any unsafe condition must be reported and corrected. Cracks, cavities, and other unstable areas should be identified, marked, and avoided.
- Follow ground control plan.
    - The first step toward achieving safety goals is to begin with a sound engineering design that helps ensure the stability of the highwall. Once a safe plan for mining and controlling the wall has been developed and communicated, the supervisor should follow basic safety guidelines for any mining site and specific guidelines related to safe work on a highwall. The engineering design, whether simply a gradual slope or a series of benches of particular widths and angles, should consider carefully the nature of the ground and the type of material mined.
- Train miners to recognize hazardous highwall conditions.
    - Everyone at a site should participate in routine highwall safety instruction, including sharing tips for working at the top as well as on the bottom of a highwall. Look, listen, and evaluate pit and highwall conditions daily, especially after each rain, freeze, or thaw.
    - Train personnel to recognize adverse conditions and environmental factors that decrease highwall stability, and understand safe job procedures to eliminate all hazards before beginning work.

- Scale down or support the hazardous highwall areas.
  - Unknown structural weaknesses - the planes of weakness are hidden in rock, and miners should use continuous care when mining along the wall and scaling.
  - Correct hazardous conditions by working from a safe location.
  - Remove loose or overhanging material from the face.
- Keep drill and other mobile equipment operators away from highwall face or highwall hazards by positioning them in safe locations.
  - Heavy equipment can cause rock falls if driven on unstable ground at the crest of a highwall or along a bench.
  - Ensure that work or travel areas and equipment are a safe distance from the toe of the highwall.
- Employ mining methods that will maintain wall, bank, and slope stability in places where persons work or travel.
  - Miners should avoid working between mobile equipment and the highwall; where escape routes may be blocked if a rockslide begins.
  - Establish and discuss safe work procedures for working near highwalls.

*Information contained in this article was provided through the Safety & Health Committee of the National Stone, Sand & Gravel Association

Slope Conversion Tables

Slope Conversion Tables



Slope Ratio: 3:1 or 3 to 1
Percent Slope: 33%
Degree Slope: 18.4°
Inches per Foot: 4

Horizontal to Vertical Slope Ratio (__ to 1)	1/4	1/2	3/4	1	1-1/4	1-1/2	1-3/4	2	2-1/2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Percent Slope	400	200	133	100	80	67	57	50	44	33	25	20	16.7	14.3	12.5	11.1	10.0	9.1	8.3	7.7	7.1	6.7	6.3	5.9	5.6
Degrees Slope	76.0	63.4	53.1	45.0	38.7	33.7	29.7	26.6	24.0	18.4	14.0	11.31	9.5	8.1	7.1	6.3	5.7	5.2	4.8	4.4	4.1	3.8	3.6	3.4	3.2
Inches per Foot	48	24	16	12	9.6	8	6.9	6	5.3	4	3	2.4	2.0	1.7	1.5	1.3	1.2	1.1	1.0	0.92	0.86	0.80	0.75	0.71	0.67

Percent Slope	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Horizontal/Vertical	100	50	33.3	25	20	16.7	14.3	12.5	11.1	10	9.1	8.3	7.7	7.1	6.7	6.3	5.9	5.6	5.3	5.0	4.8	4.5	4.3	4.2	4.0
Degrees Slope	0.6	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.1	5.7	6.3	6.8	7.4	8.0	8.5	9.1	9.6	10.2	10.8	11.3	11.9	12.4	13.0	13.5	14.0
Inches per Foot	0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0

Degrees Slope	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Percent Slope	1.7	3.5	5.2	7.0	8.7	10.5	12.3	14.1	15.8	17.6	19.4	21	23	25	27	29	31	32	34	36	38	40	42	45	47
Horizontal/Vertical	57	29	19	14	11	9.5	8.1	7.1	6.3	5.7	5.1	4.7	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.6	2.5	2.4	2.2	2.1
Inches per Foot	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.0	3.2	3.4	3.7	3.9	4.1	4.4	4.6	4.8	5.1	5.3	5.6

Inches per Foot	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4	1-3/8	1-1/2	1-5/8	1-3/4	1-7/8	2	2-1/8	2-1/4	2-3/8	2-1/2	2-5/8	2-3/4	2-7/8	3	3-1/8
Percent Slope	1.0	2.1	3.1	4.2	5.2	6.3	7.3	8.3	9.4	10.4	11.5	12.5	13.5	14.6	15.6	16.7	17.7	18.8	19.8	20.8	21.9	22.9	23.96	25	26.04
Degrees Slope	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	5.9	6.5	7.1	7.7	8.3	8.9	9.5	10.0	10.6	11.2	11.8	12.3	12.9	13.5	14.0	14.6
Horizontal/Vertical	96	48	32	24	19	16	14	12	10.7	9.6	8.7	8.0	7.4	6.9	6.4	6.0	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0	3.8

Specific Gravity

Specific Gravity	
Andesite	2.5 - 2.8
Basalt	2.8 - 3.0
Coal	1.1 - 1.4
Diabase	2.6 - 3.0
Diorite	2.8 - 3.0
Dolomite	2.8 - 2.9
Gabbro	2.7 - 3.3
Gneiss	2.6 - 2.9
Granite	2.6 - 2.7
Gypsum	2.3 - 2.8
Limestone	2.3 - 2.7
Marble	2.4 - 2.7
Mica schist	2.5 - 2.9
Peridotite	3.1 - 3.4
Quartzite	2.6 - 2.8
Rhyolite	2.4 - 2.6
Rock Salt	2.5 - 2.6
Sandstone	2.2 - 2.8
Shale	2.4 - 2.8
Slate	2.7 - 2.8

grams per cubic centimeter (g/cm^3)

Unit Conversions

If you need to convert to other units of specific gravity, then multiply a specific gravity value listed to the left with one below:

$g/cm^3 \times 1685.6 = lb / yd^3$

$g/cm^3 \times 62.428 = lb / ft^3$

$g/cm^3 \times 0.84278 = t / yd^3$

Mining Facts

- Every American uses an average of 40,000 pounds of new minerals each year.
- Mining has touched less than one-quarter of one percent of all the land in the U.S.
- About 320,000 people work directly in mining throughout the United States and employment in industries that support mining, including manufacturing which accounts for another 3 million jobs.
- Processed materials of mineral origins account for 5 percent of U.S. gross domestic product.
- Minerals account for U.S. exports of as much as $6 billion per year.
- A television requires 35 different minerals; 40 minerals are used to make telephones, and 15 minerals are needed to make a car.
- The United States is the world's second-largest producer of copper and gold.
- The United States has the world's largest reserve of coal.
- Wyoming is the nation's top coal-producing state.
- Investment in technology, training and equipment has made the U.S. mining industry the safest in the world.
- The average American now consumes 37 million lbs. of minerals, metals and fuel, over the course of a lifetime. That includes 2,000 lbs. of copper, 6,000 lbs. of aluminum, 1,000 lbs. of lead, 1,000 lbs. of zinc and 1.8 oz. of gold per person.
- Gold was first legalized as money as early as 1091 BC in China as an alternative to silk. Gold is still the only universally accepted medium of exchange.
- Coal was used widely in England in the 1600's because of wood shortages. Brewers had decided to try to dry their malts with coal generated heat but the fumes were absorbed by the brew,

ruining the taste. The brewers found, however, that the undesirable gases could be eliminated if the coal was first heated in an air tight oven. Thus the discovery of the coke making process that has since been an essential part in the making of iron and steel.

- The greatest gold rush in U.S. History began when gold was discovered at Sutter's mill in California by a man named James Marshall on January 24th, 1848.
- Because of the California gold rush there were enough people there by 1850 for California to be admitted into the Union as a state.
- The Pikes Peak gold rush in 1859 opened up Colorado and launched the city of Denver.
- Of the 50 states in the union, ALL of them mine something.

GeoHazard Terminology

Abutment. The areas of unmined rock at the edges of mining excavations that may carry elevated loads resulting from redistributions of stress.

Batter slope. The sections of rock mass between catch benches within pit walls - usually excavated to a specific inclination/angle from the horizontal.

Bedding planes. Planes of weakness in the rock that usually occur at the interface of parallel beds or laminae of material within the rock mass.

Buttress. A body of material either left unmined or placed against a section of the pit wall to prevent continued movement or propagation of wall failure.

Cable bolts. One or more steel reinforcing strands placed in a hole drilled in rock, with cement or other grout pumped into the hole over the full length of the cable. A steel faceplate, in contact with the excavation perimeter, would usually be attached to the cable by a barrel and wedge anchor. The cable(s) may be tensioned or untensioned. The steel rope may be plain strand or modified in a way to achieve the appropriate load transfer from the grout and the steel strand to the rock mass.

Catch berm. The width of lateral ground (bench) separating successive batter slopes. The purpose of the catch berm is to both reduce the overall angle of the pit walls, and to catch any loose material or local scale rock mass failures, thus reducing the risk of injury to the workforce at the base of the pit.

Catch fence. A fence constructed either vertically or at an angle to the vertical at the required off-set distance from the toe of a slope. The purpose of the catch fence is to catch any loose material falling from overlying blocky ground, thus reducing the risk to the workforce at the base of the pit walls.

Controlled drilling and blasting. The art of minimizing rock damage during blasting. It requires the accurate drilling, placement, and initiation of appropriate explosive charges in the perimeter holes to achieve efficient rock breakage with least damage to the remaining rock around an excavation.

Dip. The angle a plane or stratum is inclined from the horizontal.

Discontinuity. A plane of weakness in the rock mass (of comparatively low tensile strength) that separates blocks of rock from the general rock mass.

Dowel. An untensioned rock bolt, anchored by full column or point anchor grouting, generally with a face plate in contact with the rock surface.

Elastic. The early stage of rock movement (strain) resulting from an applied stress which does not give permanent deformation of the rock - where the rock mass returns to its original shape or state when the applied stress is removed.

Fault. A naturally occurring plane or zone of weakness in the rock along which there has been movement. The amount of movement can vary widely.

Fill. Waste sand or rock, uncemented or cemented in any way, used either for support, to fill slope voids underground, or to provide a working platform or floor.

Foliation. Alignment of minerals into parallel layers; can form planes of weakness/discontinuities in rocks.

Friction rock stabilizers. Steel reinforcing elements, typically C shaped, that are forced into holes in the rock and rely on friction between the side of the hole and the element to generate a force to limit rock movement. The anchorage capacity of the device depends on the anchorage length and the frictional resistance achievable against the wall of the hole.

Geology. The scientific study of the earth, the rock of which it is composed, and the changes which it has undergone or is undergoing.

Geological structure. A general term that describes the arrangement of rock formations. Also refers to the folds, joints, faults, foliation, schistosity, bedding planes, and other planes of weakness in rock.

Geotechnical engineering. The application of engineering geology, structural geology, hydrogeology, soil mechanics, rock mechanics, and mining seismology to the practical solution of ground control challenges.

Ground control. The ability to predict and influence the behavior of rock in a mining environment, having due regard for the safety of the workforce, and the required serviceability and design life of the mine.

Hazard. A set of circumstances which may cause harmful consequences. The likelihood of its doing so is the risk associated with it.

Induced stress. The stress that is due to the presence of an excavation. The level of induced stress developed depends on the level of the in-situ stress and the shape and size of the excavation.

In-situ stress. The stress or pressure that exists within the rock mass before any mining has altered the stress field.

Instability. Condition resulting from failure of the intact rock material or geological structure in the rock mass.

Joint. A naturally occurring plane of weakness or break in the rock (generally aligned sub-vertical or transverse to bedding), along which there has been no visible movement parallel to the plane.

Kinematic analysis. Considers the ability or freedom of objects to move under the forces of gravity alone, without reference to the forces involved.

Loose (rock). Rock that visually has potential to become detached and fall. In critical areas, loose rocks must be scaled to make the workplace safe.

Mining induced seismicity. The occurrence of seismic events in close proximity to mining operations. During and following blast times there is a significant increase in the amount of seismic activity in a mine. Mining induced seismicity is commonly associated with volumes of highly stressed rock, sudden movement on faults or intact failure of the rock mass.

Ore. A mineral deposit that can be mined at a profit under current economic conditions: taking into consideration all costs associated with mine design and operation.

Ore reserve. A volume of known ore zones that a mine has identified as being suitable for mining at some time in the future.

Pillar. An area of ground (usually ore) left within an underground mine to support the overlying rock mass or hanging wall.

Plane of weakness. A naturally occurring crack or break in the rock mass along which movement can occur.

Plastic. The deformation of rock under applied stress once the elastic limit is exceeded. Plastic deformation results in a permanent change in the shape of the rock mass.

Raveling. The gradual failure of the rock mass by rock blocks falling/sliding from pit walls - usually under the action of gravity, blast vibrations, or deterioration of rock mass strength. A gradual failure process that may go unnoticed. The term unraveling is also used to mean the same thing.

Reinforcement. The use of tensioned rock bolts and cable bolts, placed inside the rock, to apply large stabilizing forces to the rock surface or across a joint tending to open. The aim of reinforcement is to develop the inherent strength of the rock and make it self-supporting. Reinforcement is primarily applied internally to the rock mass.

Release of load. Excavation of rock during mining removes or releases the load that the rock was carrying. This allows the rock remaining to expand slightly due to the elastic properties of the rock.

Risk. An expression of the probability - the likelihood - that a hazard will cause an undesired result.

Rock bolt. A tensioned bar or hollow cylinder, usually steel, that is inserted into the rock mass, usually via a drill hole, and anchored by an expansion shell anchor at one end and a steel face plate and a nut at the other end. The steel face plate is in contact with the rock surface.

Rock mass. The sum total of the rock as it exists in place, taking into account the intact rock material, groundwater, as well as joints, faults and other natural planes of weakness that can divide the rock into interlocking blocks of varying sizes and shapes.

Rock mass strength. Refers to the overall physical and mechanical properties of a large volume of rock which is controlled by the intact rock material properties, groundwater, and any joints or other planes of weakness present. One of the least understood aspects of geotechnical engineering.

Rock mechanics. The scientific study of the mechanical behavior of rock and rock masses under the influence of stress.

Rock noise. Sounds emitted by the rock during failure. These sounds may be described as cracking, popping, tearing, and banging.

Seismic event. Earthquakes or vibrations caused by sudden failure of rock. Not all seismic events produce damage to the mine.

Seismicity. The geographic and historical distribution of earthquakes.

Seismology. The scientific study of earthquakes by the analysis of vibrations transmitted through rock and soil materials. The study includes the dynamic analysis of forces, energy, stress, duration, location, orientation, periodicity, and other characteristics.

Shear. A mode of failure where two pieces of rock tend to slide past each other. The interface of the two surfaces of failed rock may represent a plane of weakness, or a line of fracture through intact rock.

Shotcrete. Pneumatically applied cement, water, sand and fine aggregate mix that is sprayed at high velocity on the rock surface and is thus compacted dynamically. Tends to inhibit blocks raveling from the exposed faces of an excavation.

Slope. Any continuous face of rock mass within the overall pit wall (without stepping/benches).

Smooth blasting. The use of specialized drill and blast strategies (e.g. low strength explosives, modified production blasting, cushion blasting, pre- and post-splitting) to reduce blast damage and improve wall stability.

Strain. The change in length per unit length of a body resulting from an applied force. Within the elastic limit strain is proportional to stress.

Strength. The largest stress that an object can carry without yielding. Common usage is the stress at failure.

Stress. The internal resistance of an object to an applied load. When an external load is applied to an object, a force inside the object resists the external load. The terms stress and pressure refer to the same thing. Stress is calculated by dividing the force acting by the original area over which it acts. Stress has both magnitude and orientation.

Stress field. A descriptive term to indicate the pattern of the rock stress (magnitude and orientation) in a particular area.

Stress shadow. An area of low stress level due to the flow of stress around a nearby excavation, e.g. a large slope may result in joints opening up causing rock falls.

Strike. The bearing of a horizontal line in a plane or a joint.

Subdrill. The length of blast hole which extends beyond the next bench floor level. Subdrill is included in the blast design to provide adequate broken rock subgrade for developing working benches.

Support. The use of steel or timber sets, concrete lining, steel liners, etc. that are placed in contact with the rock surface to limit rock movement. The rock mass must move on to the support before large stabilizing forces are generated. Support is applied externally to the rock mass (although untensioned cables can be classified as ground support).

Tectonic forces. Forces acting in the earth's rust over very large areas to produce high horizontal stresses which can cause earthquakes. Tectonic forces are associated with the rock deforming processes in the Earth's crust.

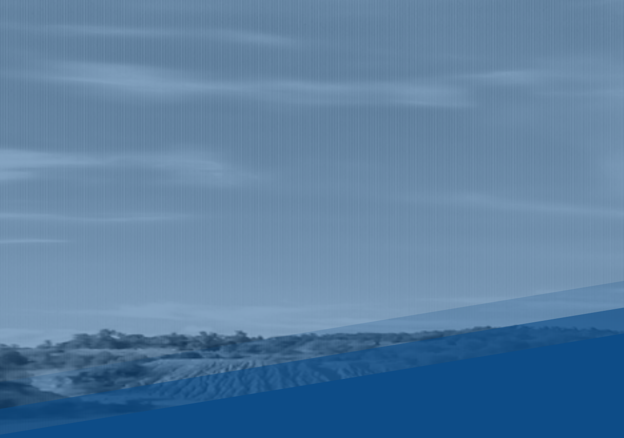
Tensile. The act of stretching of material. Tensile forces can cause joints to open and may release blocks causing rock falls.

Wall. A wall can pertain to a section of, or the complete profile of the perimeter of an open pit excavation.

Wedge. A block of rock bounded by joints on three or more sides that can fall or slide out under the action of gravity, unless supported.

Windrow. A continuous mound of loose material, of appropriate height, placed at the toe or crest of a slope as a barricade to falling objects or to prevent personnel/ mine equipment from falling inadvertently down pit walls.

Disclaimer: The information in this booklet is provided for general information only and does not constitute professional advice or a final design review. GeoStabilization has used reasonable endeavors to ensure the accuracy of the material contained within was correct. It is recommended any final remediation or design strategy be further evaluated on a case by case basis with an appropriate expert using sound technical judgment.



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