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Ground Control at Surface Mines:

Highwall Hazards and Slope Stability

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Objectives

To provide an understanding of:

- **How ground control hazards are created,**
- **How to recognize them, and**
- **how to prevent or correct these hazards**

Ground control (GC) hazards are created when workers are exposed to highwalls, pit walls, banks, or slopes with the potential for failure.

Exposure can be from above… (falling material)

…or below (loss of support).

Eliminating GC Hazards

1. **Establish mining methods that maintain stability** - through a comprehensive site investigation and thoughtful planning and design.
2. **Recognize hazardous conditions** - through regular examinations with consideration of changes in geology/ground conditions, seepage, pit wall geometry, rock mass composition, and potential failure modes.
3. **Remediate the condition** – through the application of corrective measures (such as scaling, bolting, buttressing, etc.) intended to prevent failure, or
4. **Prevent exposure** – through relocating work areas, barriers, protective measures, or monitoring.

What is a Highwall?

- **The unexcavated face of exposed overburden and coal in a surface mine.**
  - Dictionary.com

- **A steeply angled face of naturally occurring <u>rock</u> created by the excavation of adjacent rock and soil. – Working Definition**

- **Also know as a Rock Slope**

Highwall failures

- A highwall failure is generally the unintended loss of material from a highwall.

- Two general types of highwall failures:
  - Rock Mass Failures – involve a relatively large amount of material on a large portion of a highwall (can be material or structure controlled);
  - Rock Falls – involve a discrete number of individual rocks on a small portion of a highwall.

Rock Mass Failures – Involve a relatively large amount of material on a large portion of a highwall

Highwall Stability

- Highwalls are composed of rock masses that consist of blocks of intact rock that are separated by structural discontinuities.
- Unless the rock is very weak, highwalls fail along structural discontinuities (i.e., joints, cracks, sloping bedding planes and other discontinuities).
- The orientation and location of these fracture planes determine the failure type, extent of the sliding rock, and the path that it will take.

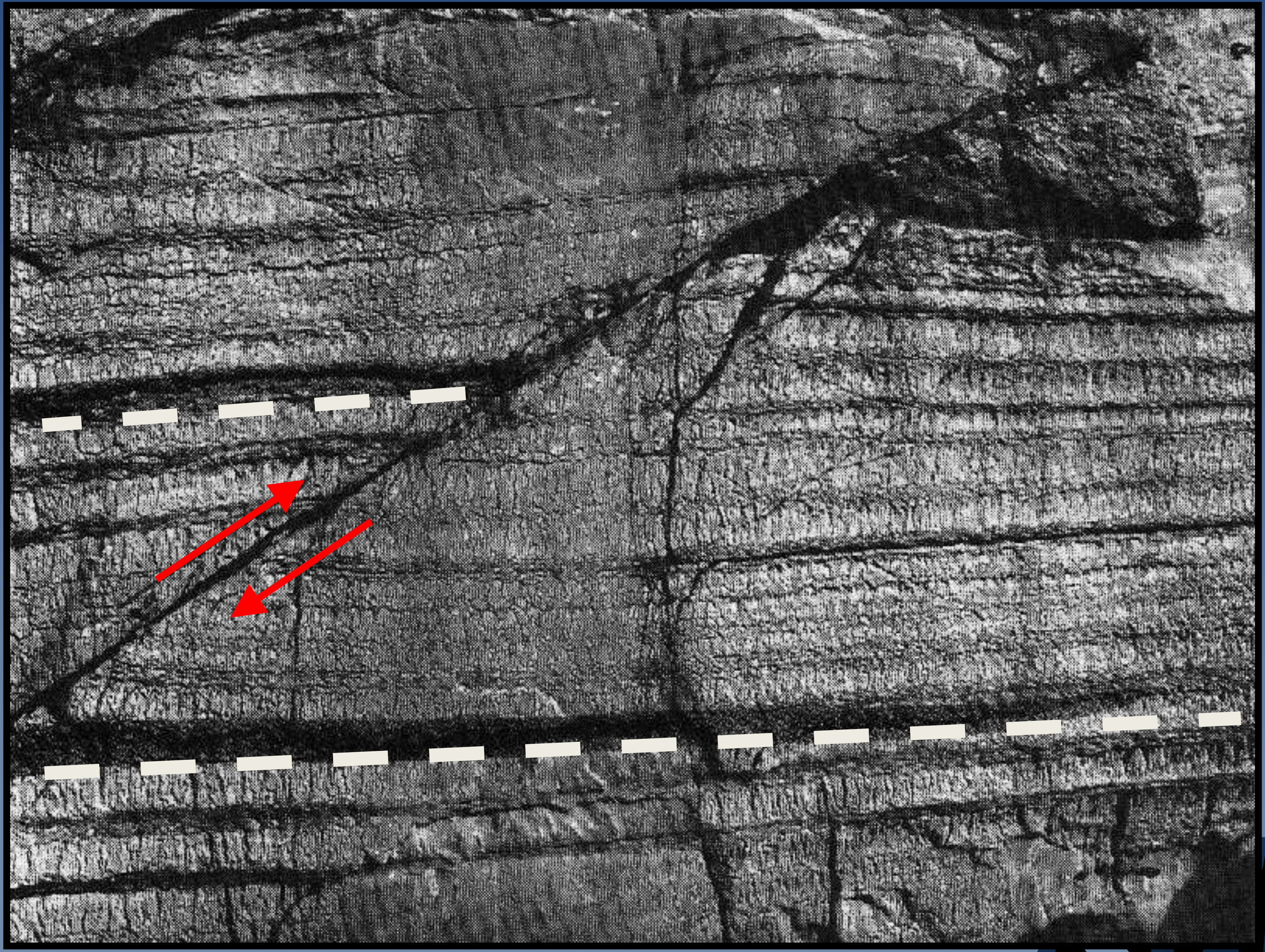
Common Types of Discontinuities

- **Bedding** – a depositional surface found in sedimentary rocks.
- **Joint** – a discontinuity along which no observable displacement has occurred.
- **Fault** – a discontinuity along which displacement has occurred.
- **Fracture** – a generic term applied to a variety of discontinuities.

Bedding

Joints

Fault



Fractured Highwall

Properties of Discontinuities

- Orientation
- Spacing
- Persistence
- Number of Sets
- Roughness
- Infilling
- Aperture (opening)
- Seepage

Rock Mass Failure Modes

- Planar
- Wedge
- Toppling
- Circular

Dip Into Highwall
Dip Into Pit

Planar Failure

Intersecting Discontinuities

Wedge Failure

Joints forming Columns

Toppling Failure

Toppling Failure

Circular Failure – Before and After

Examination of Ground Conditions

- This is a critical step in protection.
- Highwalls should be examined from all possible angles with particular attention to the toe and crest areas.
- Look for unfavorable Joints and Bedding.
- Common signs of potential stability problems include:
  - Cracks along the highwall crest
  - Bulging at the highwall toe or in the pit
  - Fallen rock or talus piles at the highwall toe
  - Vertical cracks through the highwall face
  - Active Raveling (immediate danger)

Slope Mass Rating (SMR)

- Adaptation of Rock Mass Rating (RMR) for slopes

- The basic RMR is computed using five parameters:
  1. strength of intact rock
  2. rock quality designation (RQD)
  3. spacing of discontinuities
  4. condition of discontinuities
  5. groundwater condition (seepage)

- Reductions for adverse joint orientations
  - parallelism between joints and slope face
  - joint dip angle for planar mode of failure
  - relationship between the dip of slope face and joints
  - excavation method

Points to Remember

- Discontinuities can occur at virtually any orientation and spacing.
- The orientation in which discontinuities intersect each other and the highwall face contribute to the failure type and potential.
- Knowledge of discontinuity properties in the mine environment is necessary for evaluation of highwall stability.

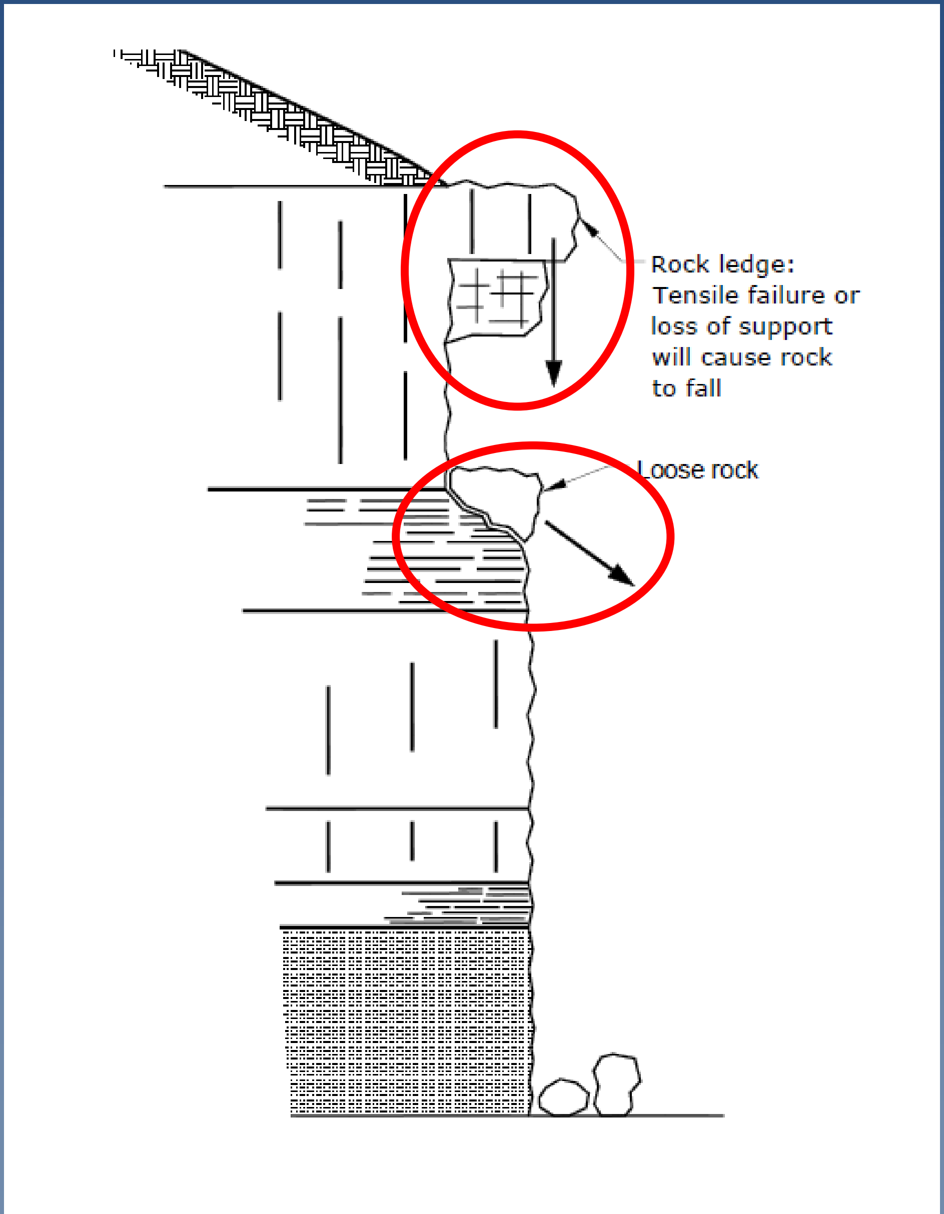
Seepage

Seepage

- Seepage is often a contributing factor to highwall failures.
- Effects of seepage:
  - reduces shear strength of soil/rock,
  - creates driving force in joints,
  - erodes supporting material,
  - adds weight to the potential sliding mass, and
  - formation of ice dislodges loose rock and increases pore pressure

Rock Falls

Rock Falls

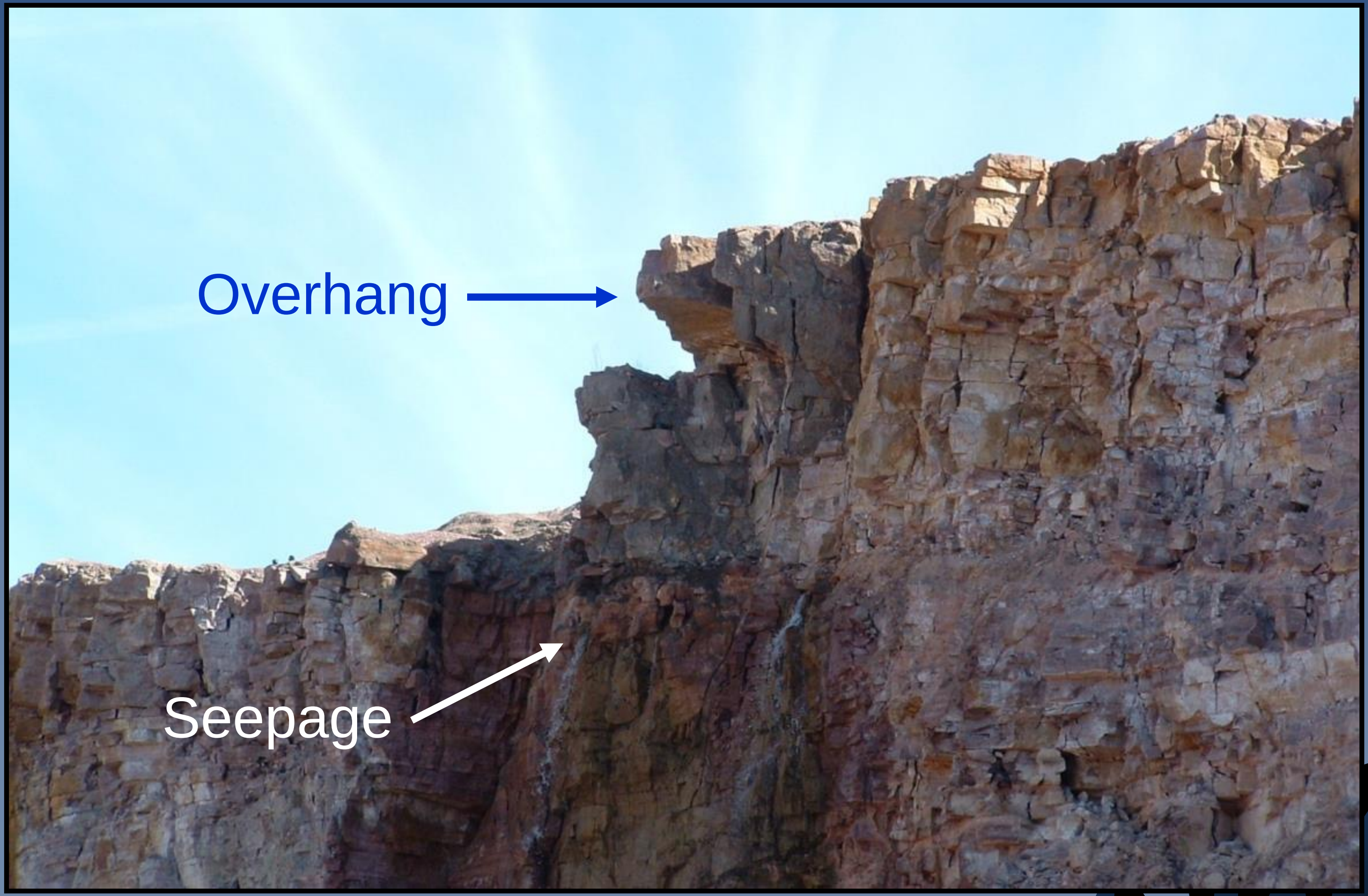


Intact blocks of rock on a fractured highwall are susceptible to falling when they are unconfined.

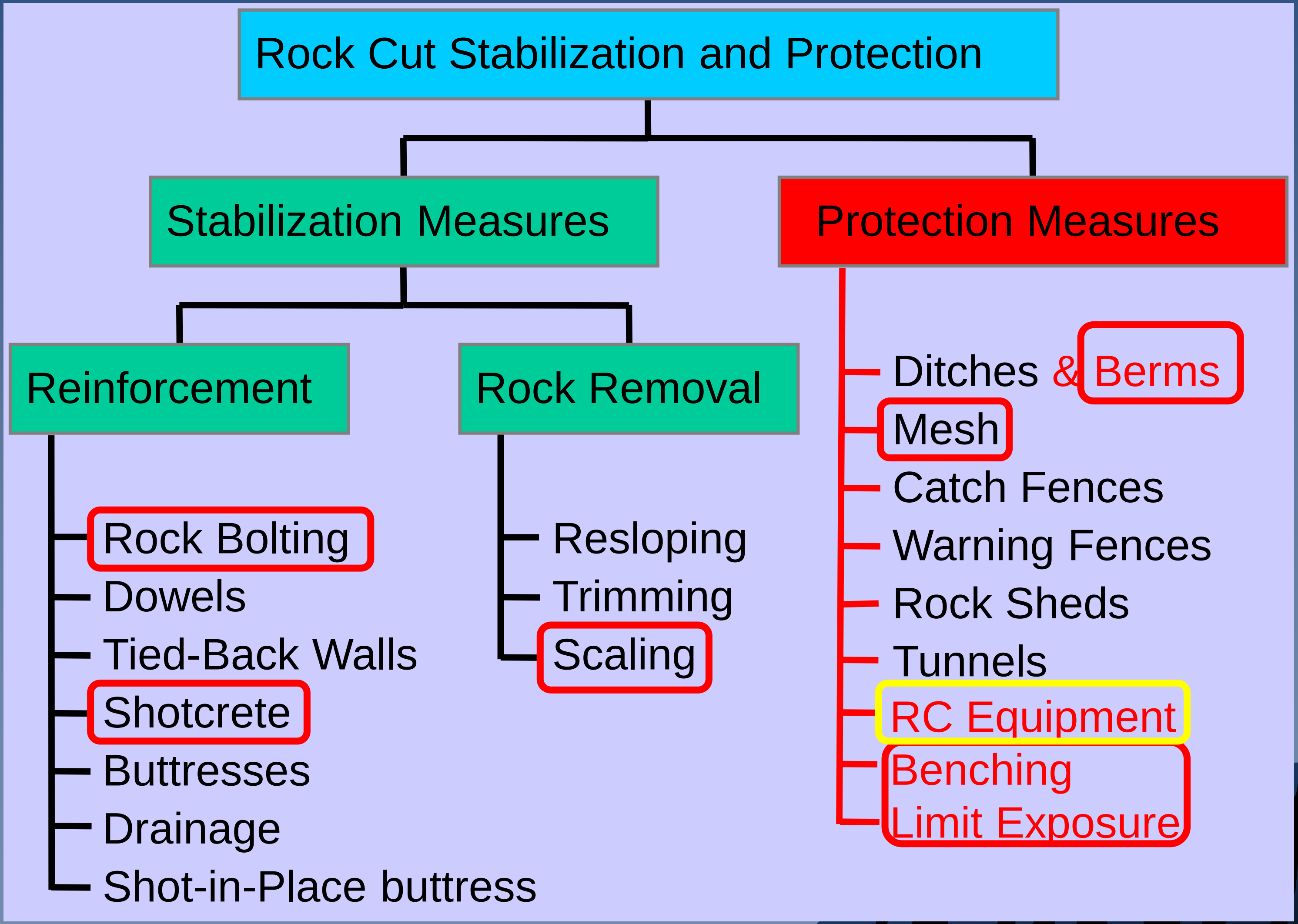
Trees near the edge of a highwall are also a fall of material hazard.

Loose Rock

Overhangs



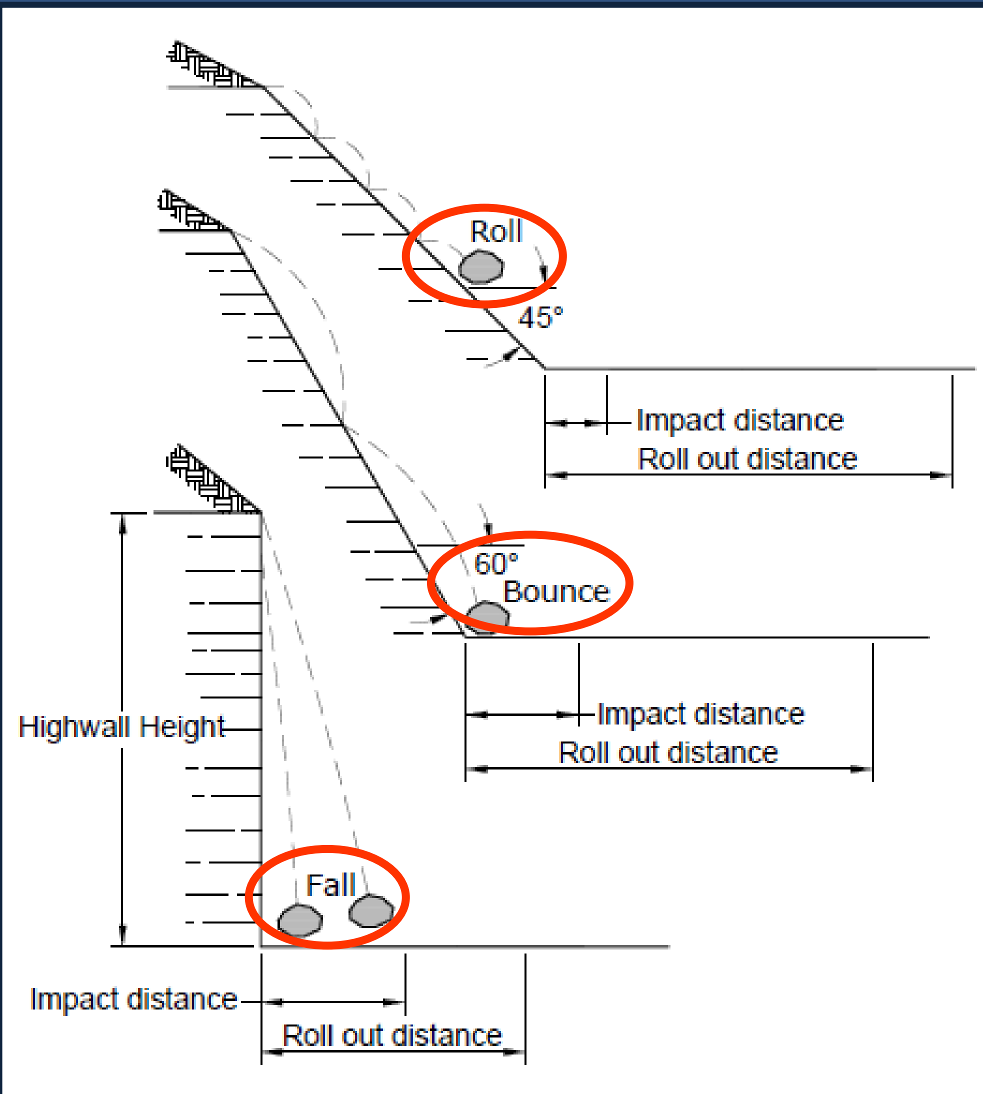
Corrective Measures Intended to Prevent Failure (Stabilization) and Prevent Exposure (Protection) – TRB, 1996



Rock Fall Analysis – for Design of Ditches and Berms

- **Geometry and height** of the highwall will affect how a rock falls, where it impacts, and where it comes to rest.
- Block size (weight) and drop height will determine the damage potential of a falling rock when it strikes.

Effects of Highwall Geometry on Rock Fall Trajectory, and Impact and Roll out Distance



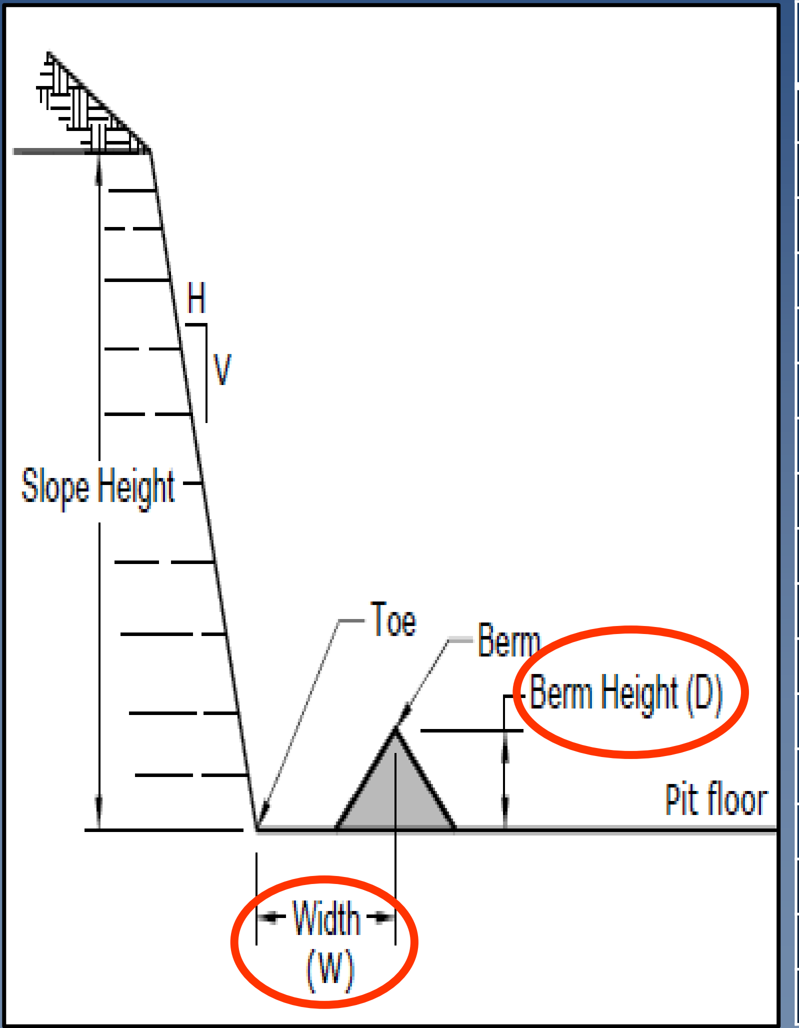
Impact Distances (feet) for 99% of rocks					
Highwall Height (ft)	Vertical 90°	0.25H:1V 76°	0.5H:1V 63°	0.75H:1V 53°	1H:1V 45°
40	14	9	6	5	0
50	15	13	11	10	4
60	16	16	15	14	8
70	18	19	17	15	9
80	21	22	19	16	10

Rollout Distances (feet) for 99% of rocks					
Highwall Height (ft)	Vertical 90°	0.25H:1V 76°	0.5H:1V 63°	0.75H:1V 53°	1H:1V 45°
40	30	32	48	44	60
50	30	51	56	54	63
60	30	69	66	65	67
70	30	74	67	66	73
80	30	79	68	68	79

USDOT (1998)

Design of Rock Fall Catchment Areas

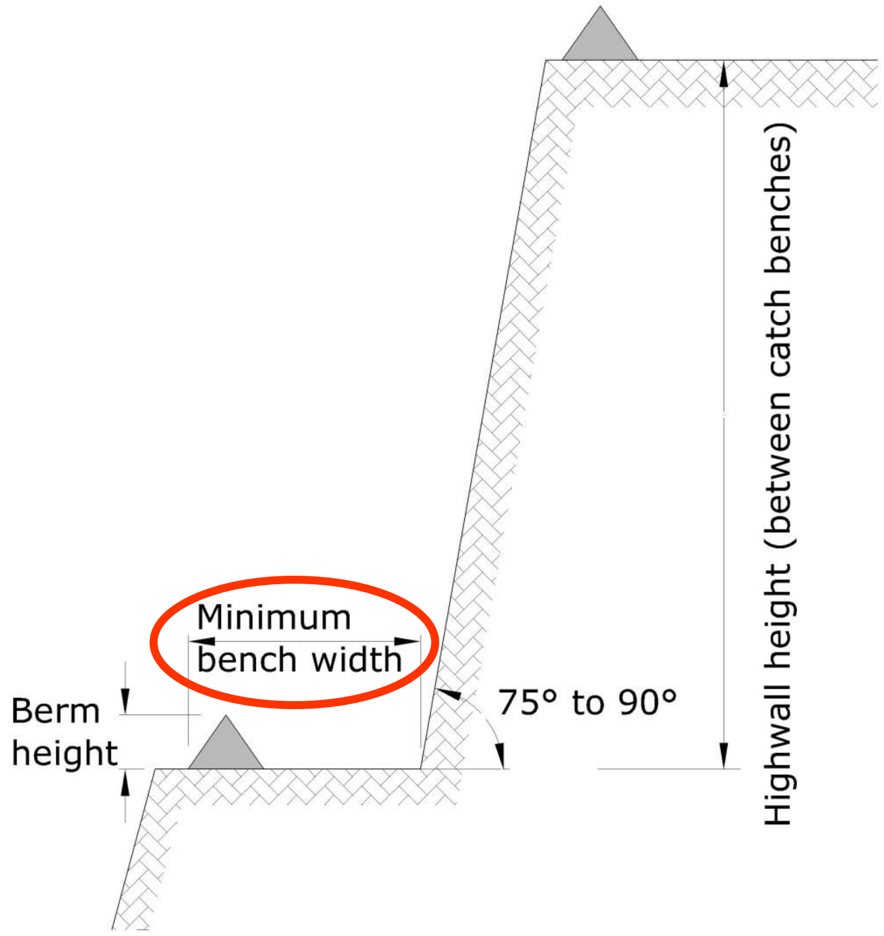
Catchment Width (W) Berm Height (D)



Highwall Slope	Height (ft)	W (ft)	D (ft)
Near Vertical, 90°	15-30	10	3
Near Vertical	30-60	15	4
Near Vertical	over 60	20	4
0.25H to 0.3H:1V	15-30	10	3
0.25H to 0.3H:1V	30-60	15	4
0.25H to 0.3H:1V	60-100	20	6
0.25H to 0.3H:1V	over 100	25	6
0.5H:1V	15-30	10	4
0.5H:1V	30-60	15	6
0.5H:1V	60-100	20	6
0.5H:1V	over 100	25	8
0.75H:1V	0-30	10	3
0.75H:1V	30-60	15	4
0.75H:1V	over 60	15	6
1H:1V	0-30	10	3
1H:1V	30-60	10	5
1H:1V	over 60	15	6

Ritchie (1963)

Catch Bench Design



- Minimum bench width = 15 feet + (0.2 x highwall height)
- Berm height = 3 feet + (0.04 x highwall height)

(adapted from Call, 1986)

Catch Bench w/Berm
– they do exist

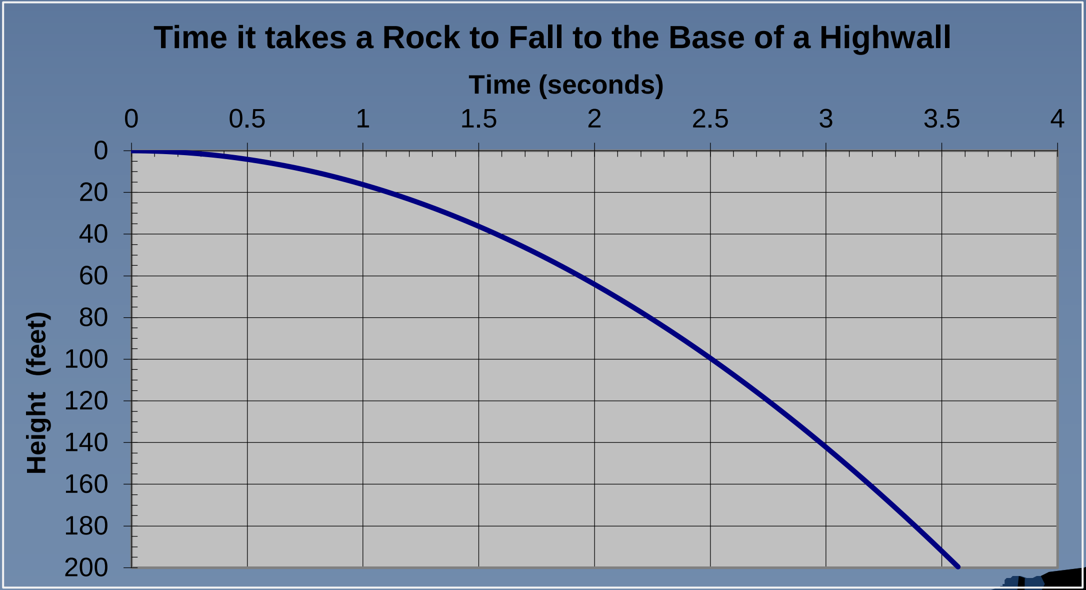
Relatively Small Rocks can pose an Impact Risk to Personnel On-Foot

- **1999 (TN) – Driller at base of 230 ft. highwall**
- **Rock measured 4” x 4” x 3” & weighed under 3 pounds**

Rock Fall: Impact Energy

Height of Rock Fall (feet)	Size of Rock[1] (inches)	Approx. Weight (lbs)	Kinetic Energy (ft-lbs)	Approx. Force of Impact[2] (lbs)	Speed (mph)	Time to Impact (secs)
50	4	6	300	1,200	38	1.8
50	6	20	1,000	4,000	38	1.8
50	12	160	8,000	32,000	38	1.8
100	12	160	16,000	64,000	54	2.5

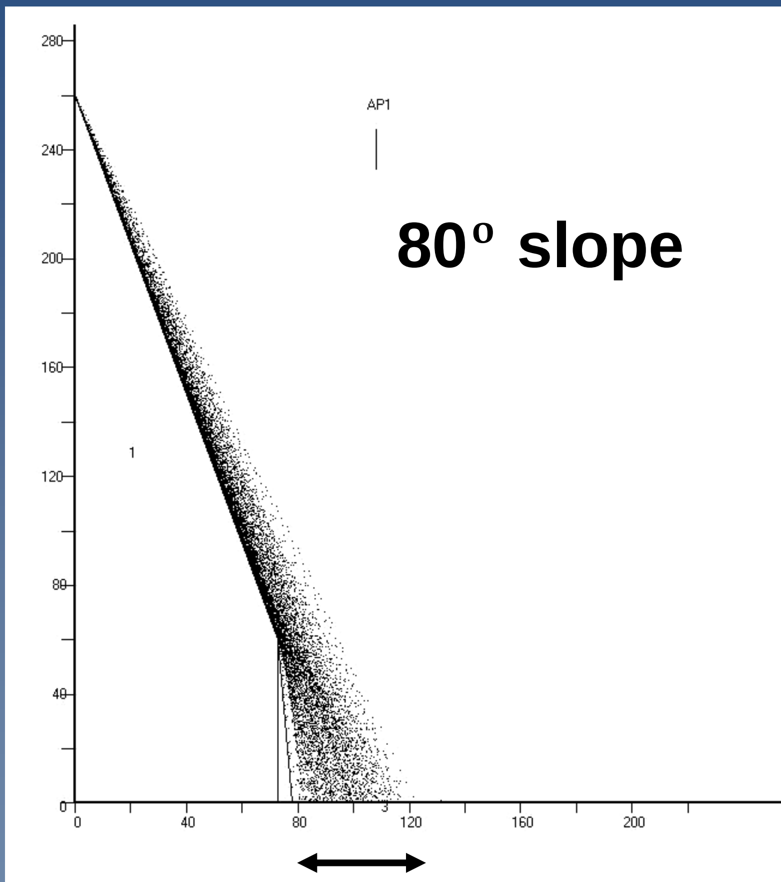
Hardhats are tested at 40 ft-lbs and FOPS are tested at 8,500 ft-lbs.



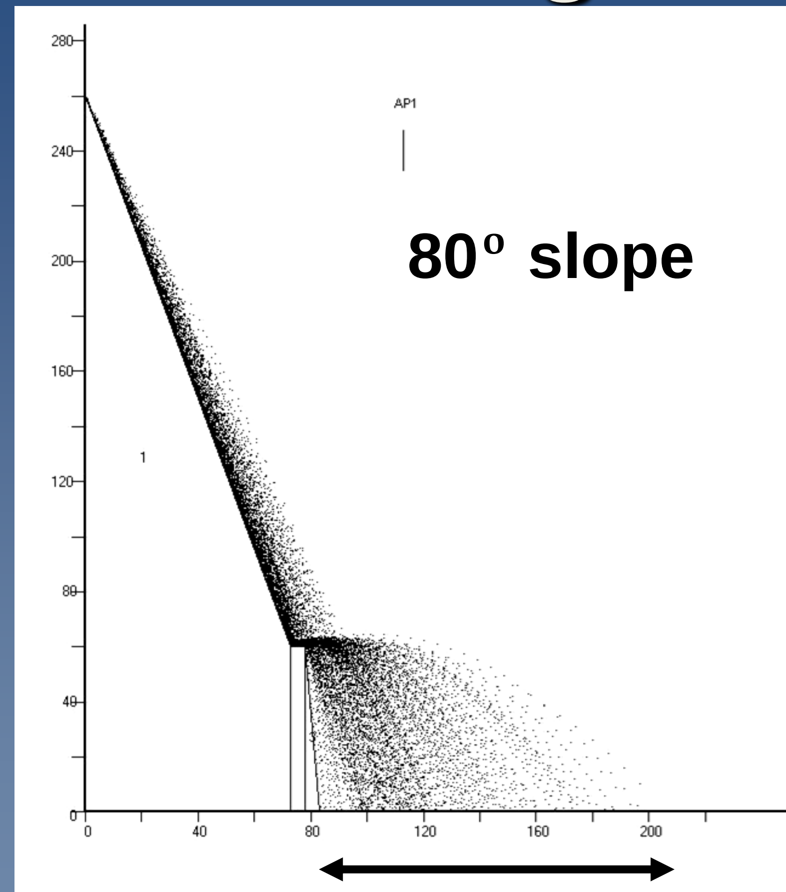
Computer Modeling

- Computer models such as the Colorado Rockfall Simulation Program (CRSP) can be used to design rockfall protection measures.
- Input/assumptions – cross-section, surface roughness, normal and tangential coefficients, rock size and shape.
- Program Advantages/Capabilities:
  – model field conditions such as
  – complex geometry & multi-bench,
  – run many simulations, and
  – analyze various mitigation scenarios.

Highwalls without and with a Ledge

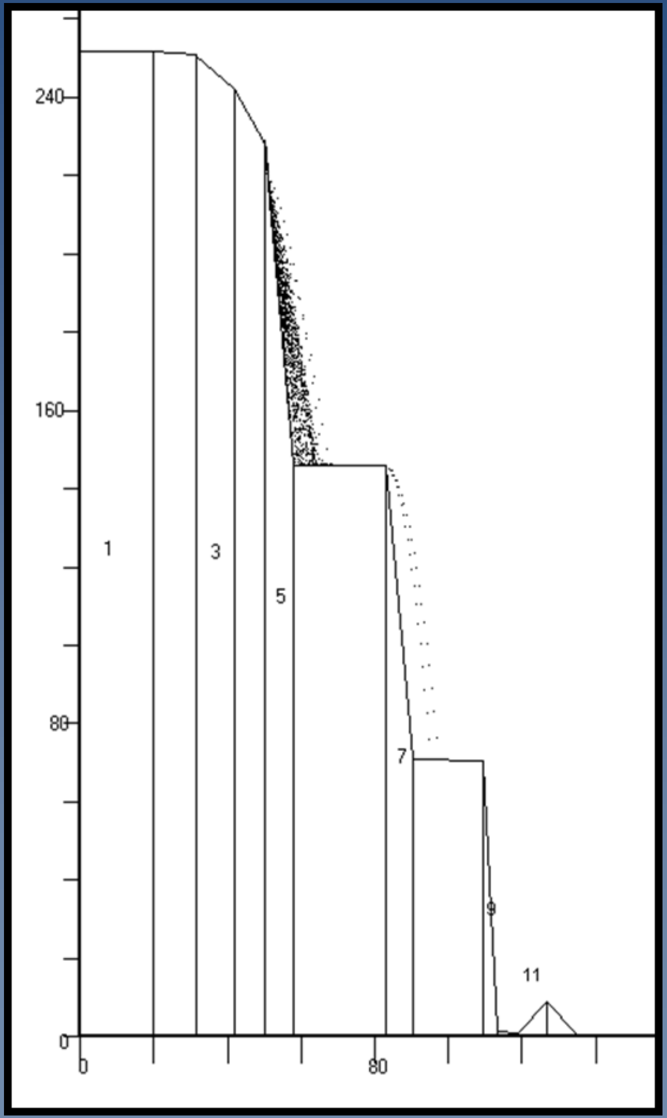


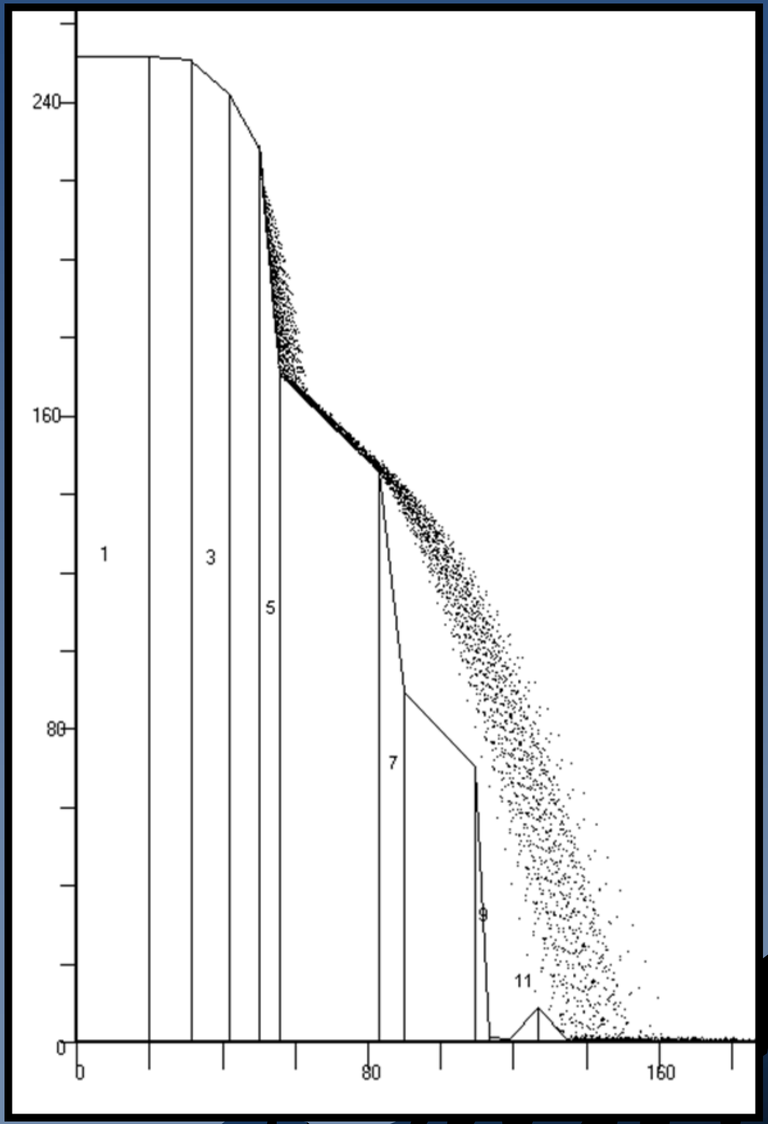
~45-foot impact zone



~130-foot impact zone

Modeling Empty/Full Benches





Unconsolidated Overburden (i.e., Soil):

- In geologic terms, unconsolidated overburden or an unconsolidated deposit is composed of sediments or deposits that are not classified as a rock unit (i.e., consolidated unit).

- Soil consist of silts, clays, sand, gravel, and organics.

Recommended Soil Slopes

Soil Type Classification:

Type A Soils - *cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (tsf) (144 kPa) or greater. Examples of Type A cohesive soils are often: clay, silty clay, sandy clay, clay loam and, in some cases, silty clay loam and sandy clay loam.*

Type B Soils - *cohesive soils with an unconfined compressive strength greater than 0.5 tsf (48 kPa) but less than 1.5 tsf (144 kPa). Examples of other Type B soils are: angular gravel; silt; silt loam; previously disturbed soils unless otherwise classified as Type C.*

Type C Soils - *granular soils & cohesive soils with an unconfined compressive strength of 0.5 tsf (48 kPa) or less. Type C soils include granular soils such as gravel, sand and loamy sand.*

Maximum Slope for Trench Excavations OSHA (1999)		
Soil type	Horizontal: Vertical (ratio)	Slope angle (degrees)
Type A	¾:1	53°
Type B	1:1	45°
Type C	1½:1	34°
For a maximum overburden of 20 feet; otherwise, perform a stability analysis.		
Type A – Short Term Slope	½:1	63°
For short-term, a maximum overburden of 12 feet; otherwise, perform a stability analysis		

Non-Cohesive Soil
(Sand and Gravel)

- Non-cohesive soils do not "stick together."
- Moist samples cannot be rolled into a string.
- Dry samples will easily break apart.
- Molded samples will not remain intact when submerged.

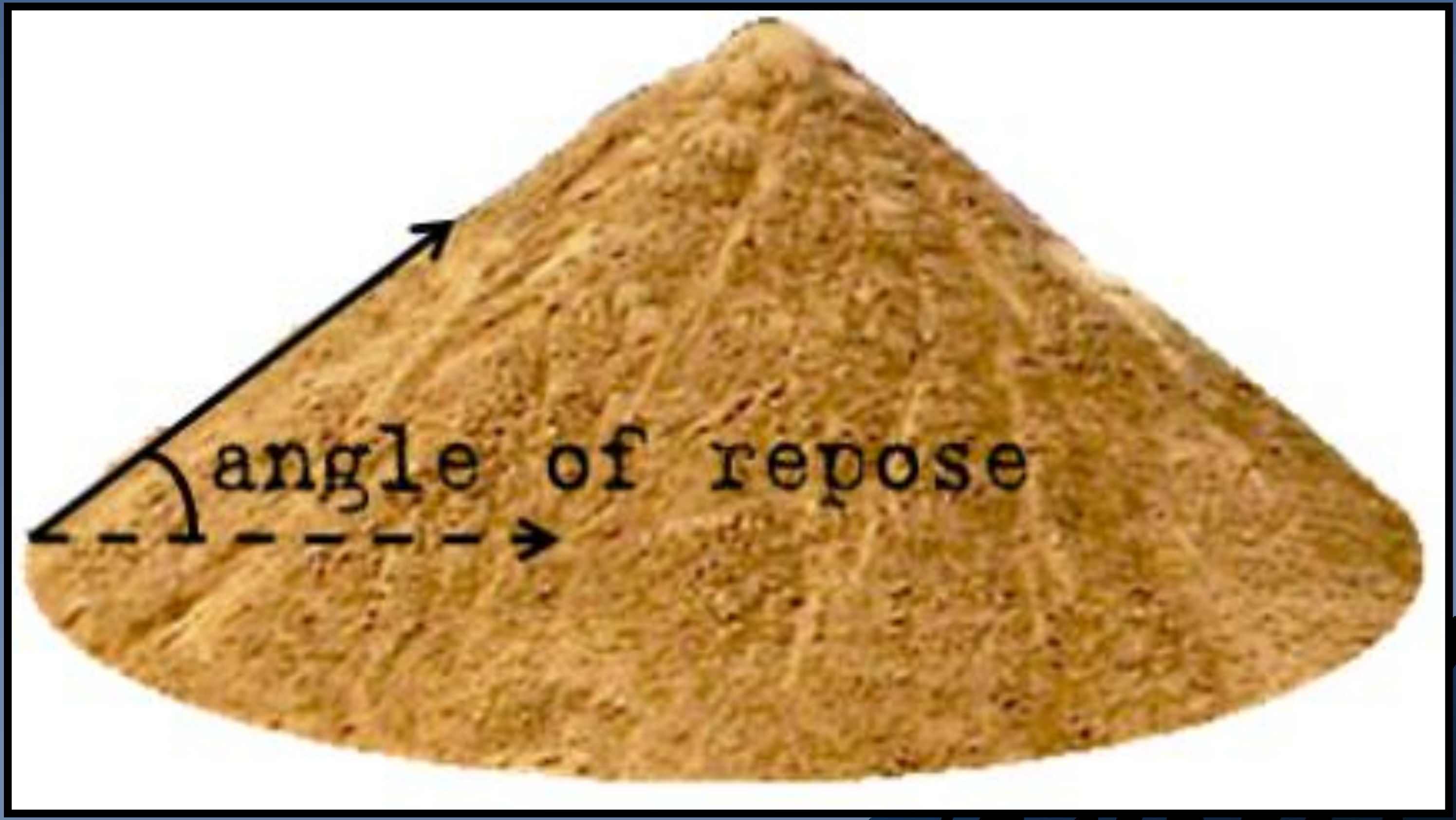
Non-Cohesive Soil Sample

Non-Cohesive Soil Strength

- Cohesion (c) for sands and gravels = 0
- Frictional resistance is represented by the friction angle (ϕ).
- For practical purposes, the friction angle in dry, loosely placed, sands and gravels is the "angle of repose."

Angle of Repose

The angle that a dry sand or gravel will form with respect to the horizontal when dumped into place.



A non-cohesive soil can stand steeper than its angle of repose due to "apparent cohesion"

However, Apparent Cohesion is Unreliable

- Apparent cohesion is highly dependent on moisture content.
- Stability is highly dependent on height.
- When the soil dries out or becomes saturated, it will collapse and go back to it’s angle of repose.
- It is unpredictable, unsustainable, and should not be relied upon for long-term stability.

Examples of Slope Failures

in Relation to Common Sand and Gravel Mining Methods

Fatal Sand and Gravel Accident

Massachusetts – June 2015

Fatal Sand and Gravel Accident
Massachusetts – June 2015

- The victim was operating a front-end loader at the toe of a 128-foot-high sand bank
- The sand bank was over-steepened (slope up to 58 degrees vs. 33 degree angle of repose)
- The victim was fatally injured when about 1,700 cubic yards of sandy soil fell from the highwall and engulfed the loader.
- The narrow mine space contributed to the hazard and consequences.

Fatal Sand and Gravel Accident

Massachusetts – June 2015

Fatal Sand and Gravel Accident
North Dakota – August 2015

Fatal Sand and Gravel Accident
North Dakota – August 2015

- The victim was operating a front-end loader at the toe of a 39-foot-high stockpile and was fatally injured when about 400 cubic yards of sand and gravel slid from the stockpile
- The victim was outside the loader near the access ladder between the stockpile and the loader
- The stockpile was over-steepened with slopes between 42 and 52 degrees, the angle of repose was 32 to 36 degrees
- The locations of the miner and the equipment contributed to the hazard and consequences.

Fatal Sand and Gravel Accident
North Dakota – August 2015

Common Accident Factors

- Slopes were primarily composed of non-cohesive soil (i.e., sand and gravel).
- Excavated at slope angles steeper than the material's angle of repose.
- Stability was unpredictable and unsustainable.
- Failures occurred very rapidly.
- Compounded exposure to the hazard (location and area).

Remediating the Hazard

- **Measures to Prevent Failure:**
  - Avoid creating a steep slope/bank.
  - Avoid cutting the out toe of the slope/bank.
  - Limit the slope/bank height.

- **Measures to Prevent Exposure:**
  - Mine material from the top down.
  - Move equipment away from the slope, bank, or stockpile before exiting.
  - Do not travel between equipment and the slope/bank/stockpile.

References

- Call (1986): “Cost-Benefit design of open pit slopes.” In: 1st Open Pit Symposium, Antofagasta, Chile, pp 1-18.
- FHWA (1989): “Rock Slopes: Design, Excavation, Stabilization,” Publication No. FHWA-TS-89-045, Federal Highway Administration, Turner-Fairbanks Highway Research Center, McLean, VA.
- OSHA (1999): Occupational Safety & Health Administration, “Excavations: Hazard Recognition in Trenching and Shoring.” In: OSHA Technical Manual (OTM), Chapter 2, Section V.
- Ritchie (1963): Ritchie, A.M., 1963, “An Evaluation of Rockfall and Its Control,” Highway Research Record No. 17, pg. 13–28.
- Romana (2003): Romana, M., Serón, J.B., Montalar, E., “SMR Geomechanics classification: Application, experience and validation,” ISRM 2003–Technology roadmap for rock mechanics, South African Institute of Mining and Metallurgy.

References

- TRB (1996): "Landslides Investigation and Mitigation," Special Report 247, Transportation Research Board, Washington, D.C.
- USDOT (1998): "Rock Slopes," FHWA HI-99-007, National Highway Institute, Federal Highway Administration, USDOT, Washington, D.C.
- Mine Safety and Health Administration (MSHA) Report of Investigation, MAI-2015-09, https://arlweb.msha.gov/fatals/metal/2015/final-reports/final-m15-09.asp
- Mine Safety and Health Administration (MSHA) Report of Investigation, MAI-2015-13, https://arlweb.msha.gov/fatals/metal/2015/final-reports/final-m15-13.asp
- https://www.msha.gov/news-media/announcements/2017/08/04/plant-trench

For Additional Assistance

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