# Ground Control at Surface Mines

## Highwall Hazards and Remediation

Mine Waste and Geotechnical Engineering Division

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PC400LC
3 30 '99


O&K

# Outline

- How highwall hazards are created
- How to recognize highwall hazards
- How to remediate highwall hazards

# Highwall hazards are created when workers are exposed to highwalls with the potential for failure.

# Eliminating Highwall Hazards

- **Recognizing the hazard** - through a better understanding of highwall geometry, highwall composition, and highwall failure modes.
- **Remediating the hazard** – through the application of protective measures intended to either prevent exposure or prevent failure.

# Recognizing the Hazard

# Highwall Composition (Intact Rock vs. Rock Mass)

- Highwalls are composed of rock masses that consist of intact blocks of rock separated by structural (geological) discontinuities.
- The properties of a rock mass are not the same as the properties of the intact rock blocks.
- The properties of a rock mass include the properties of the intact rock and the properties of the discontinuities.

# Intact Rock

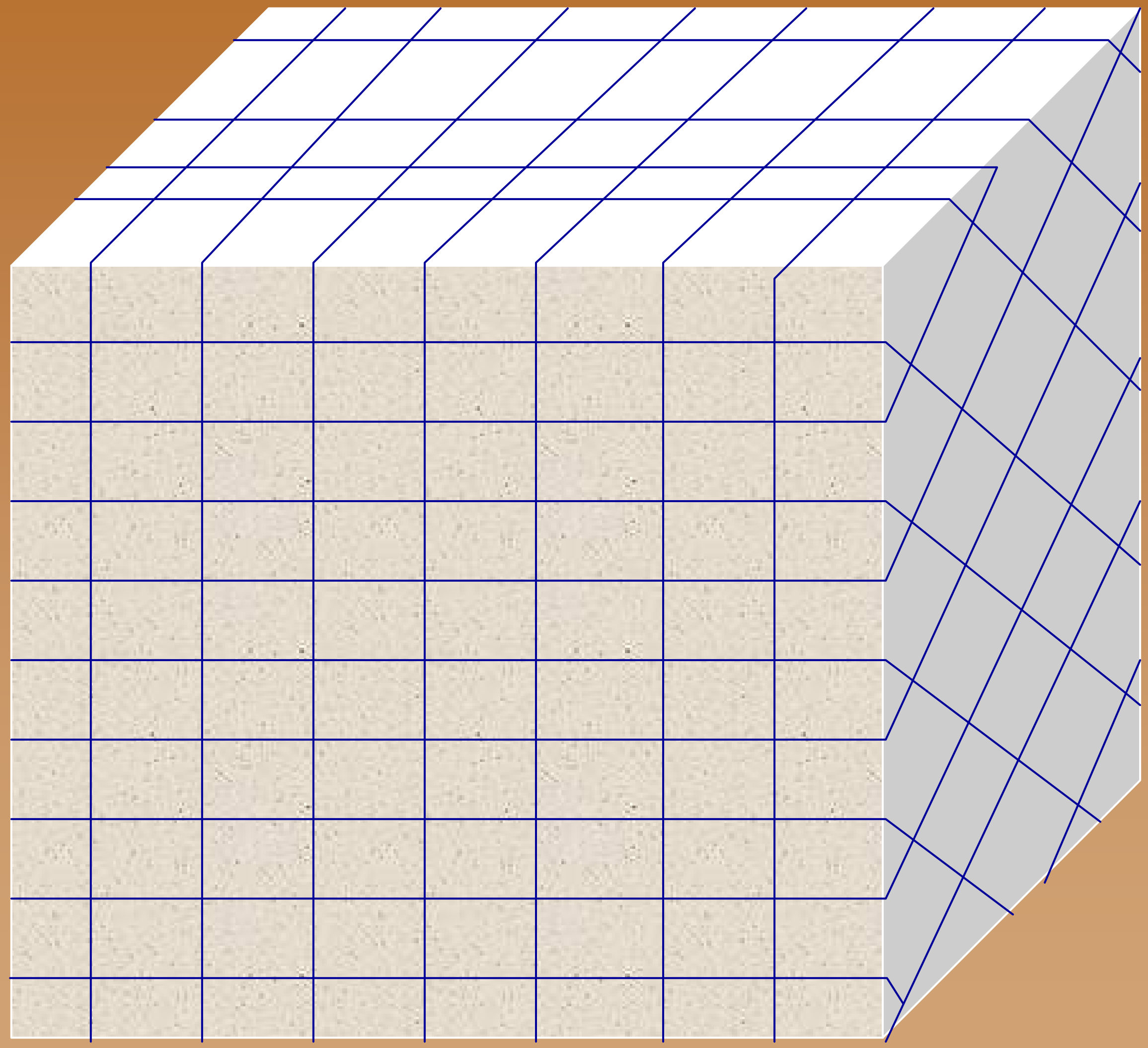
- Blocks of rock that are free of discontinuities.

# Discontinuities

- A discontinuity is any disconnect or break in the continuity of the rock material.

- It is a structural weakness along which movement and possibly failure can occur.

# Effect of Discontinuities on Rock Mass



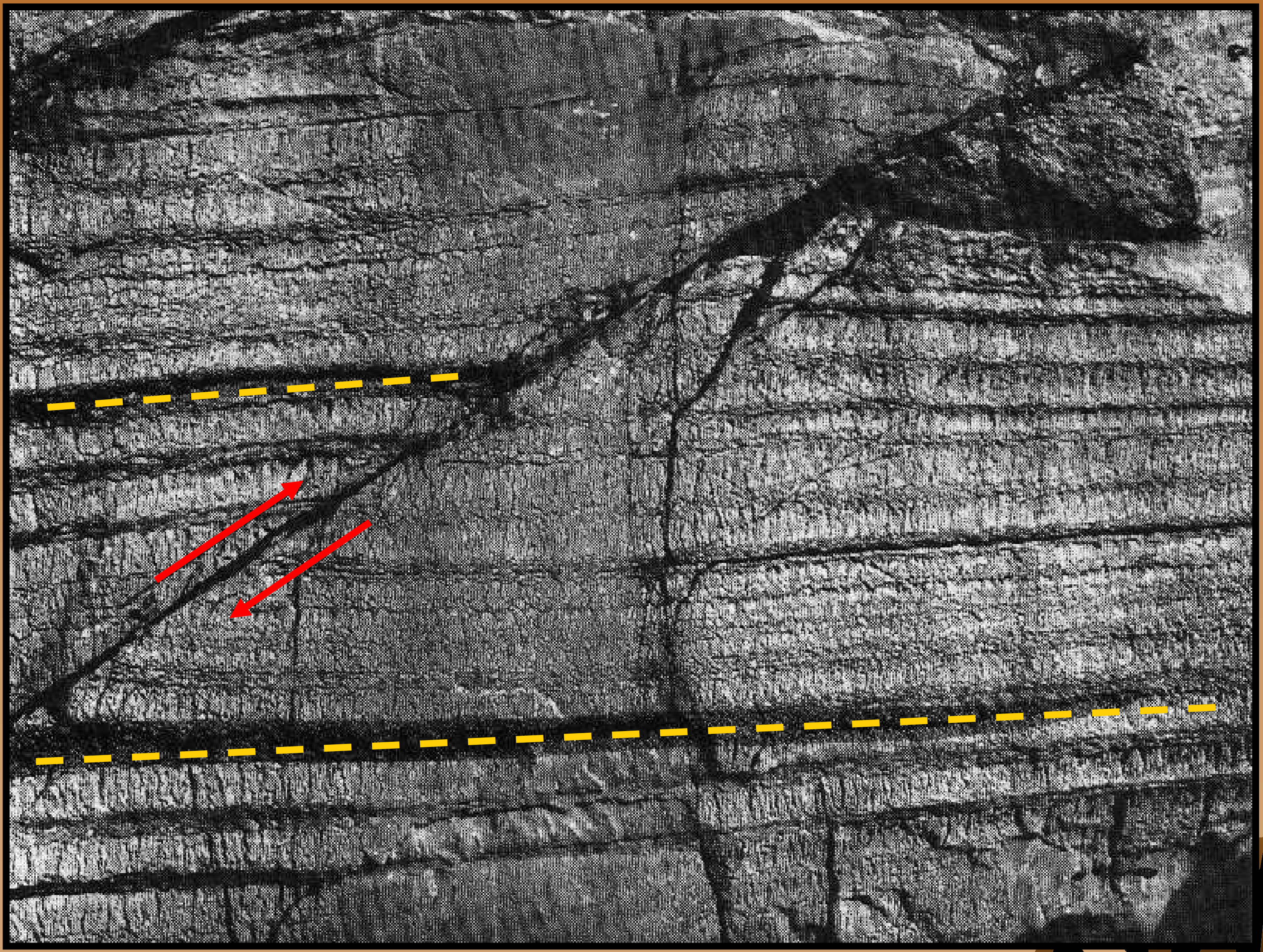
# Common Types of Discontinuities

- **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

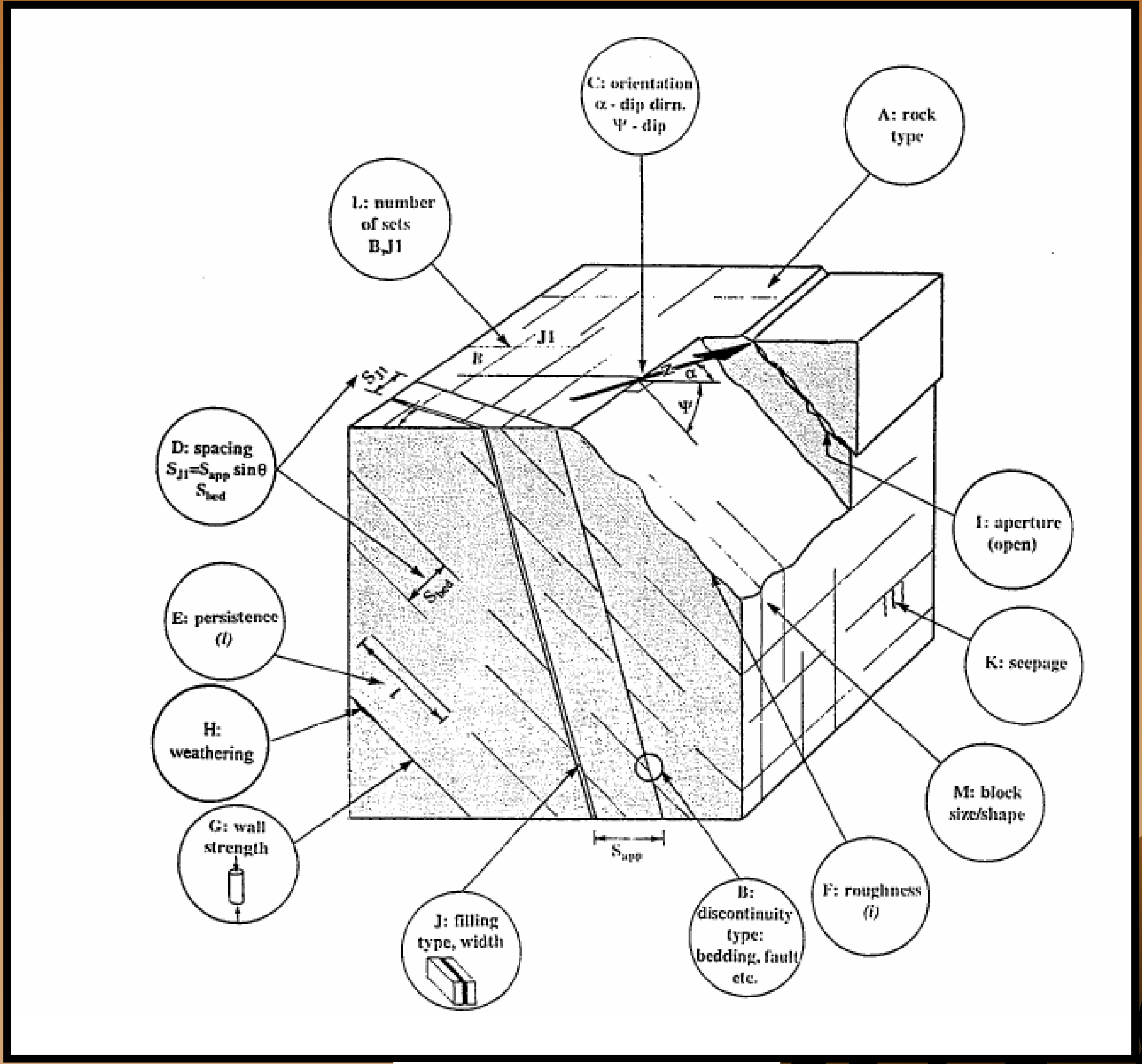
# Thrust Fault



# Fractures

# Properties of Discontinuities

- Orientation
- Spacing
- Persistence
- Roughness
- Aperture
- Infilling
- Seepage
- Number of Sets

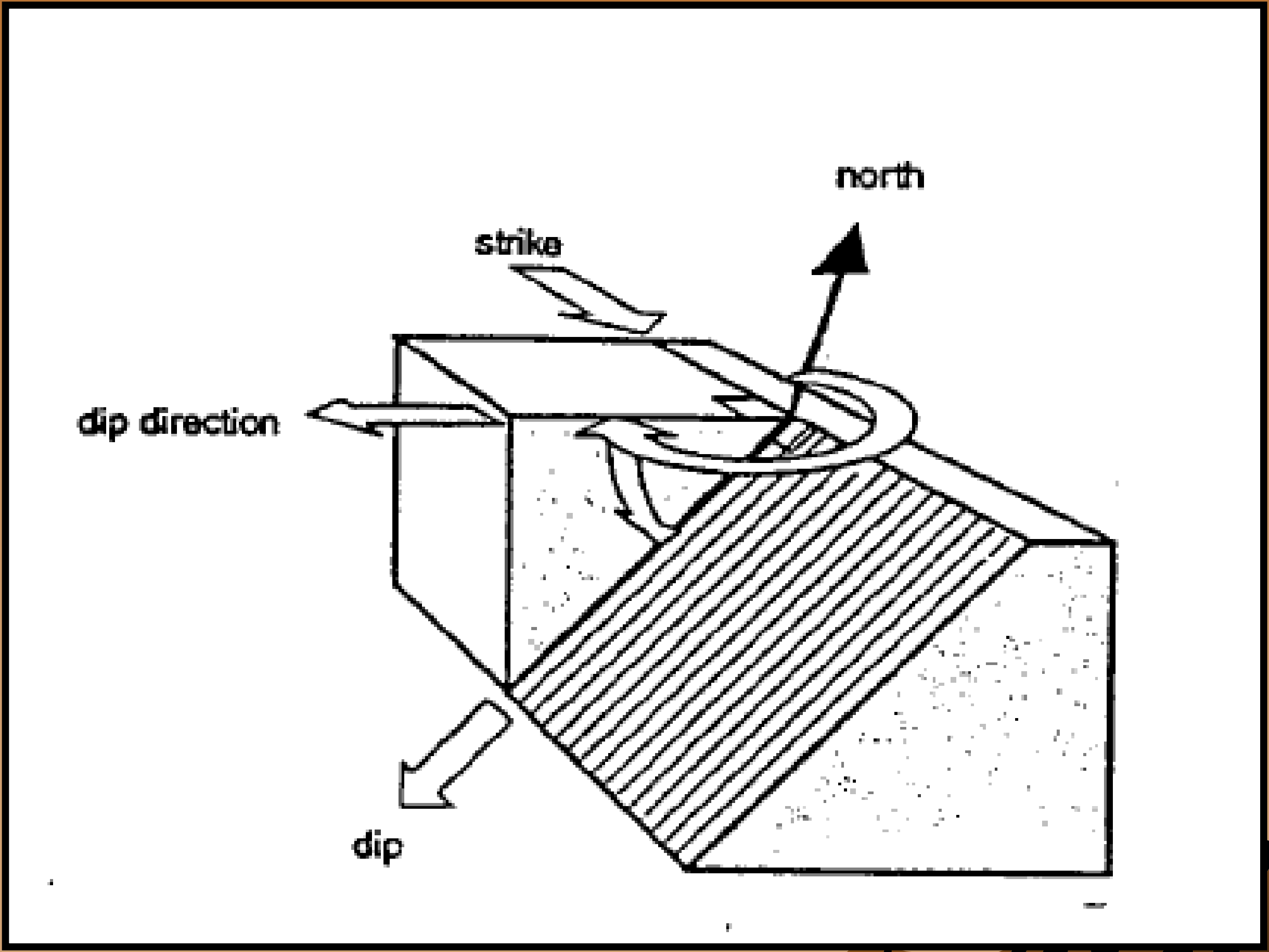



(USDOT 1998)

# Discontinuity Orientation

- **Dip** – angle at which a discontinuity is included from the horizontal, measured normal to the direction of strike.
- **Dip Direction** – the bearing of the dip, measured perpendicular to the direction of the strike.
- **Strike** – the bearing of the outcrop of a discontinuity.

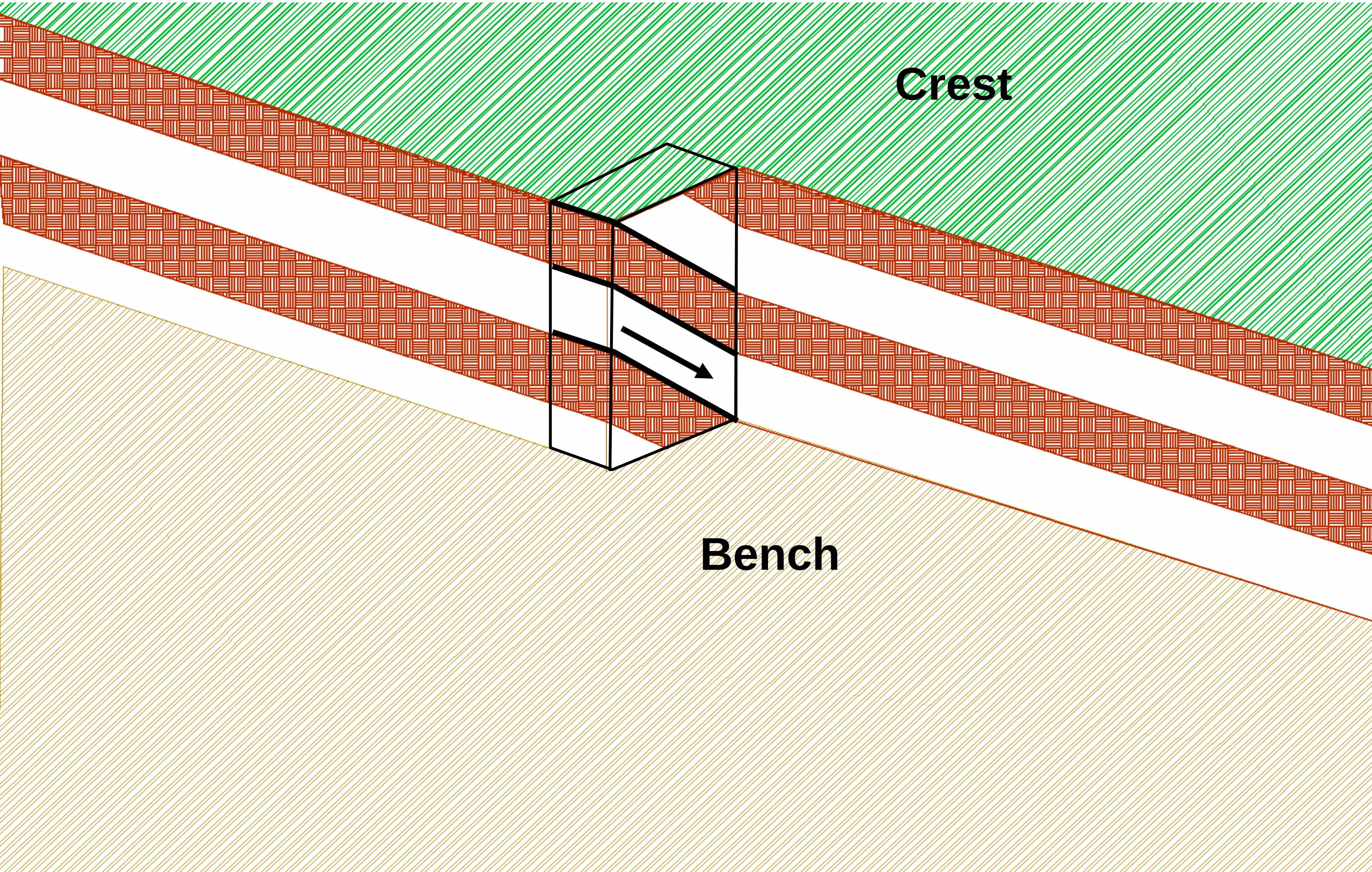
# Orientation Diagram



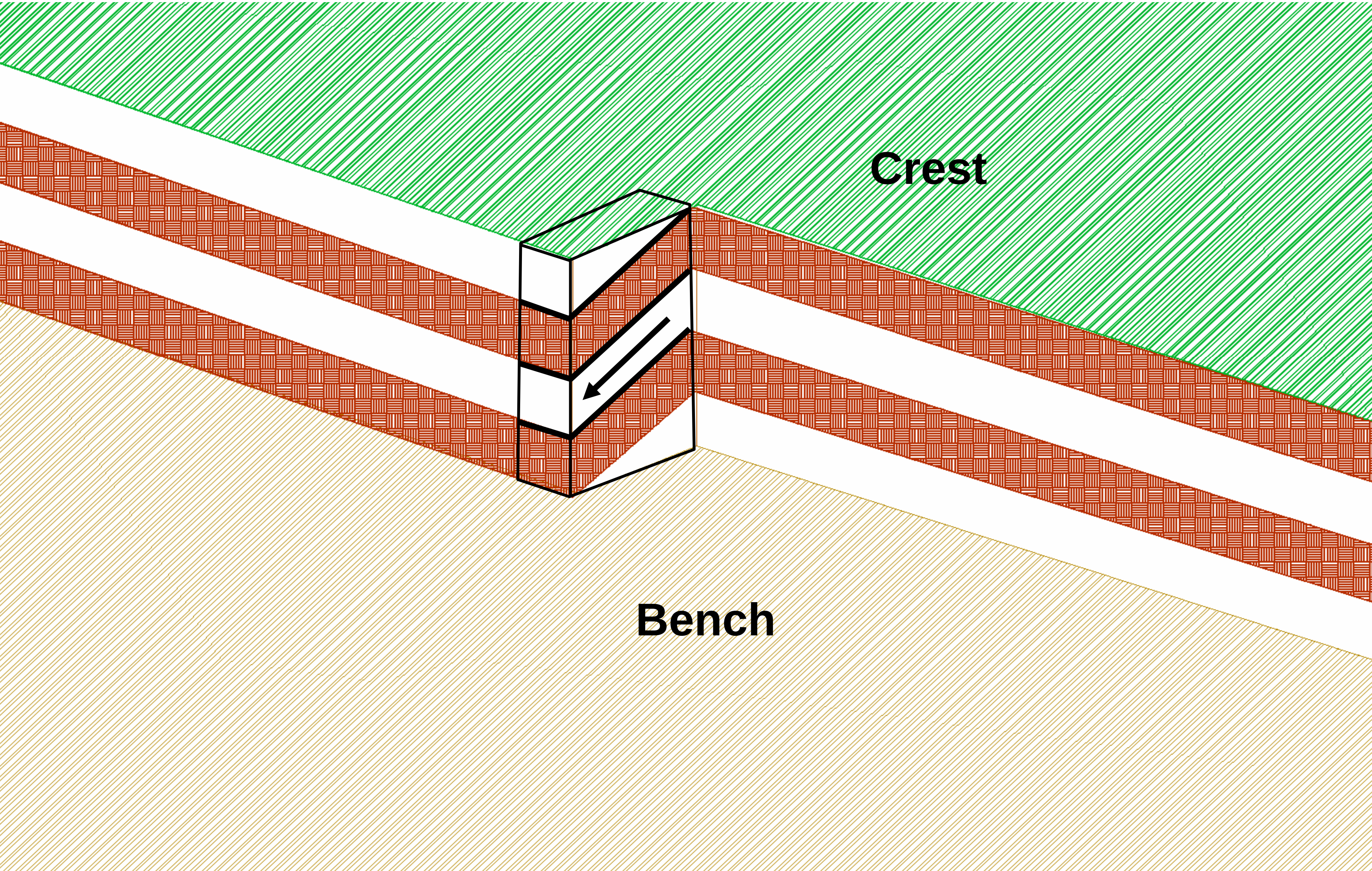

(USDOT 1998)

# Bedding Relative to the Highwall Face

# Favorable Orientation
# Beds Dipping Into Highwall



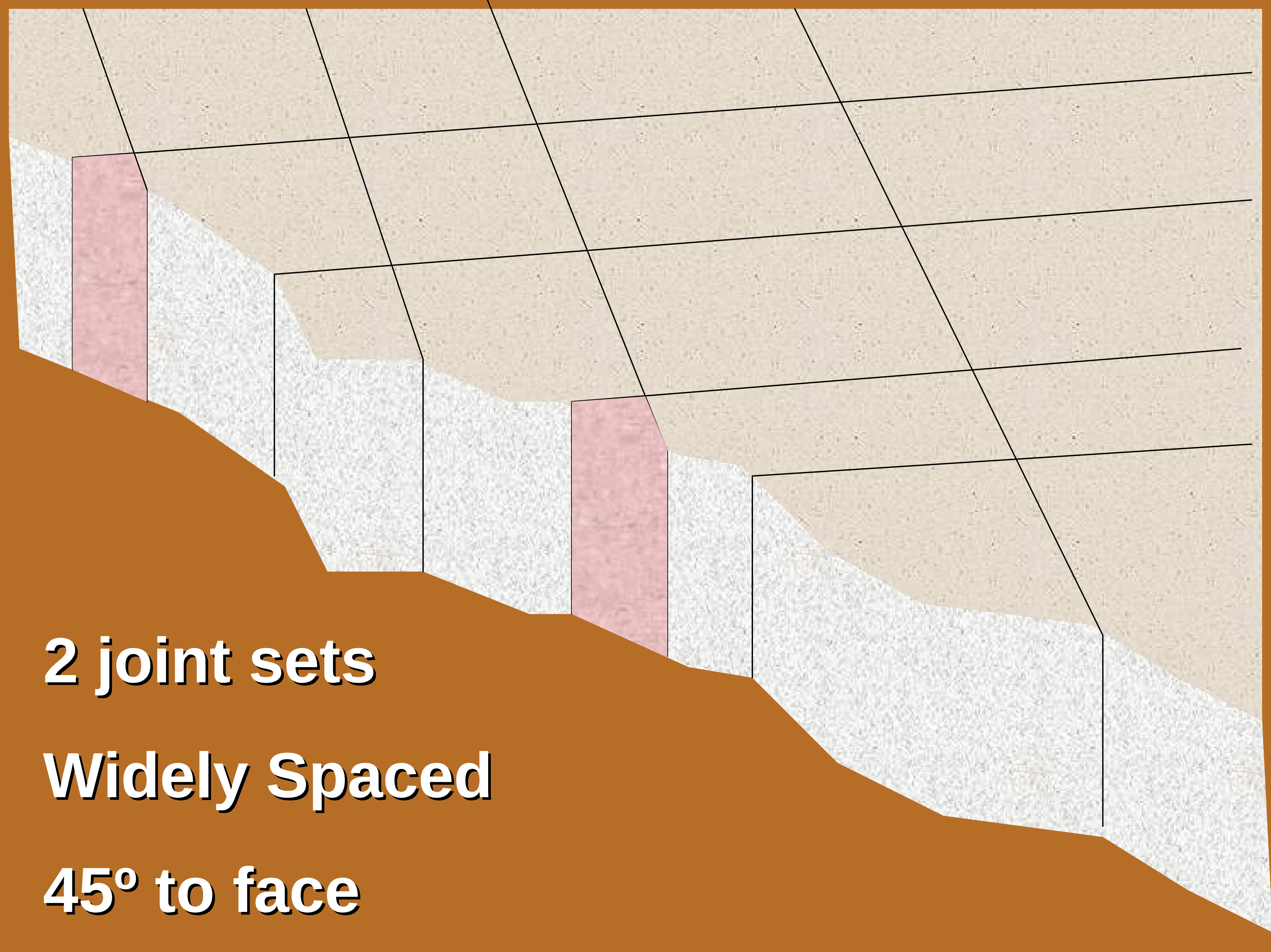
# Unfavorable Orientation
# Beds Dipping Into Pit

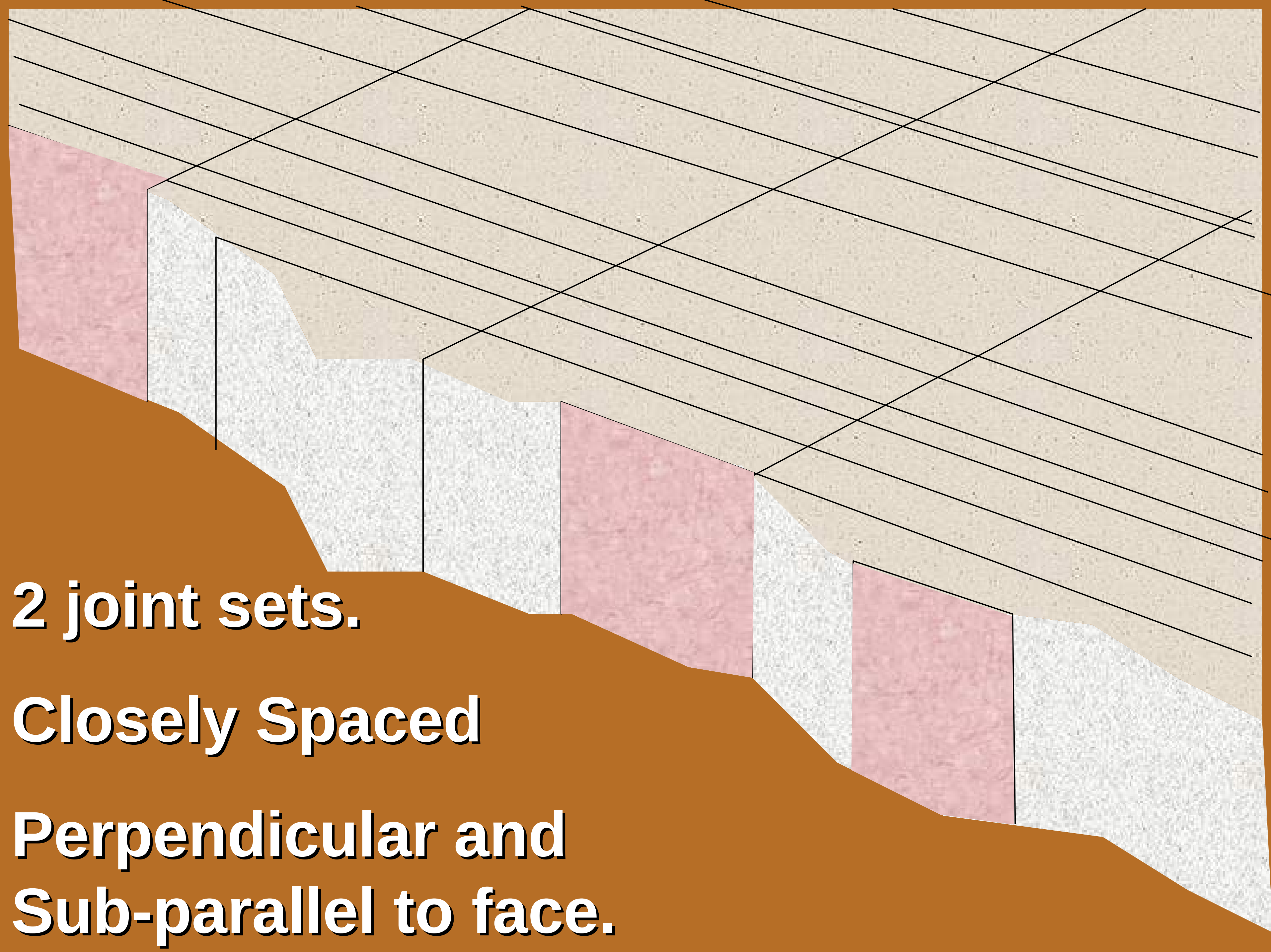



Favorable Dip
Unfavorable Dip

# Dipping Bedding

# Joints Relative to the Highwall Face


2 joint sets
Widely Spaced
45º to face



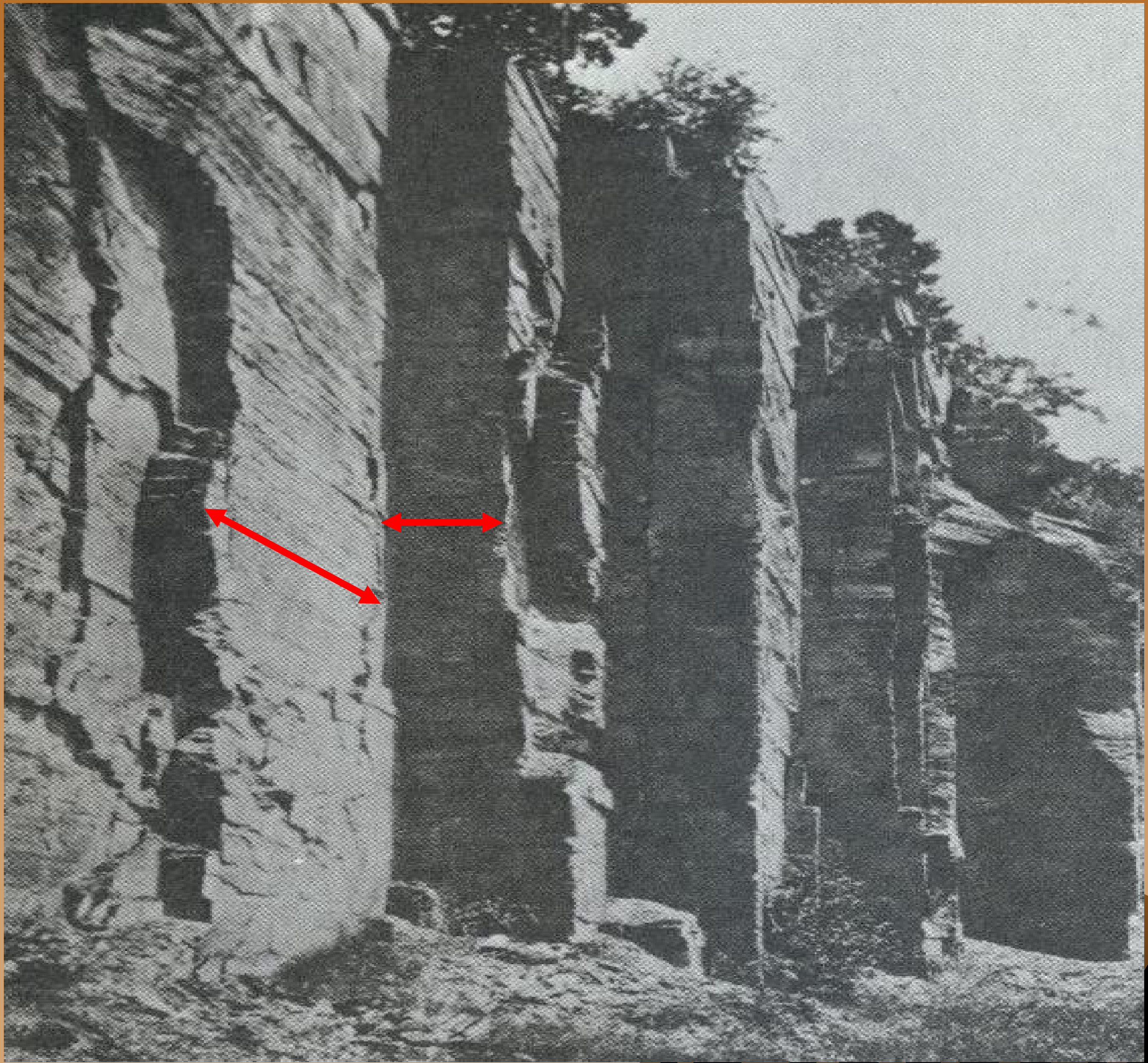
2 joint sets.

Closely Spaced

Perpendicular and
Sub-parallel to face.

# Structure Parallel to Face

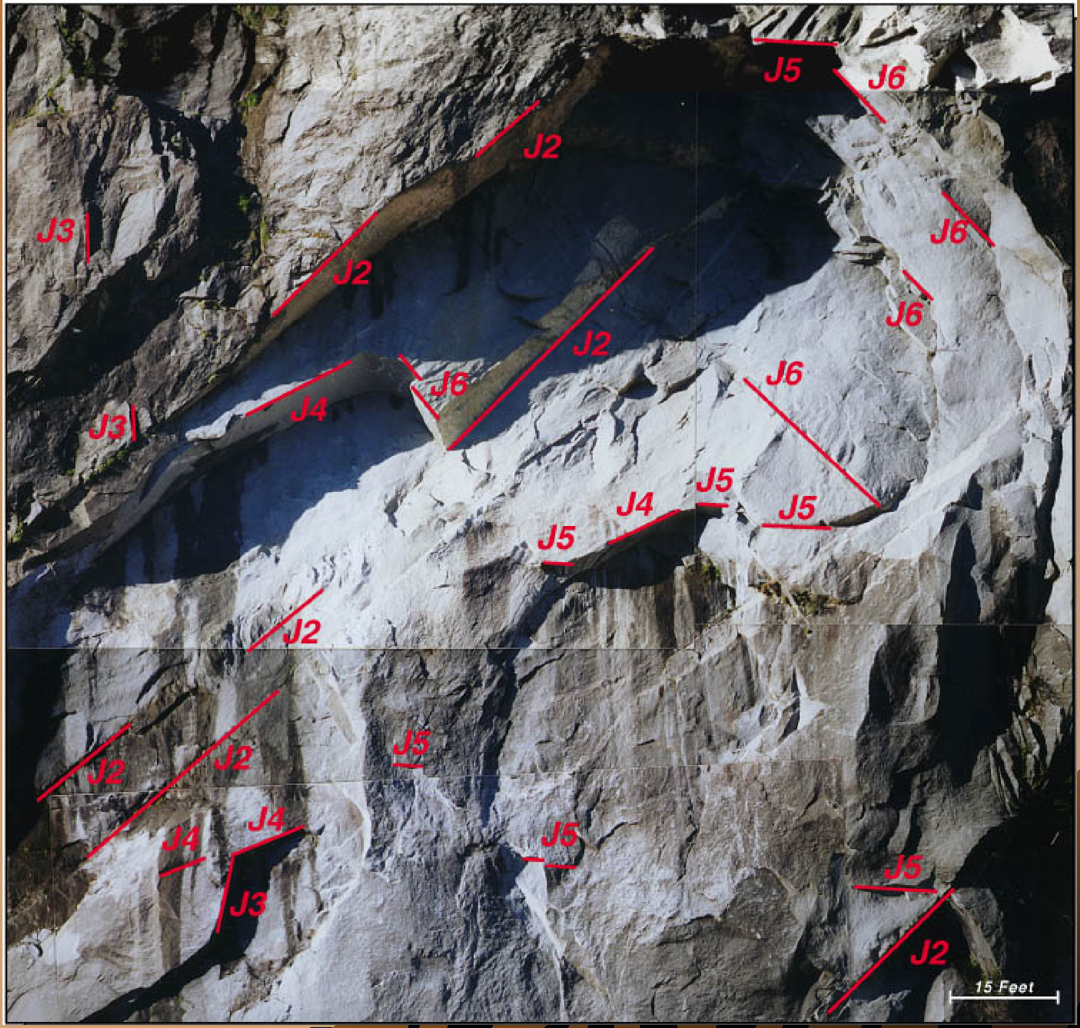
# Two Sets of Vertical Joints



# Intersecting Discontinuities

# Obtaining Data on Discontinuities

- Field mapping
- Core drilling



# Points to Remember

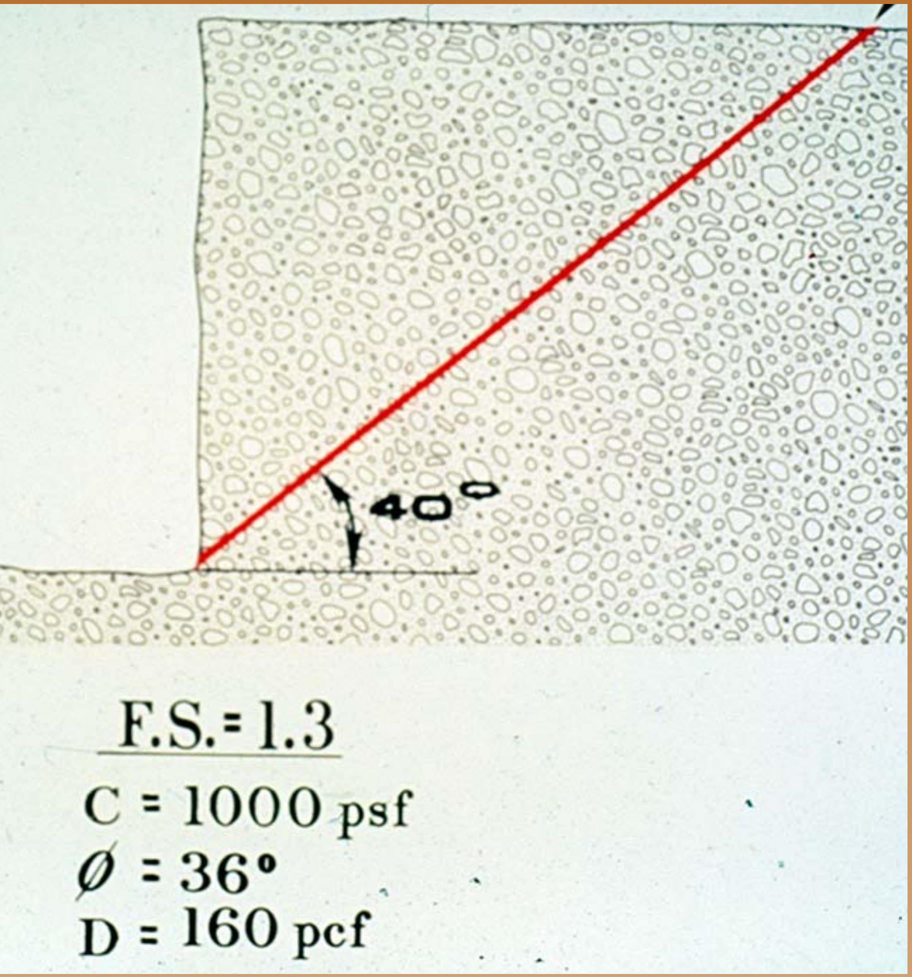
- Discontinuities can occur at any orientation and spacing.
- The way in which discontinuities intersect each other and the highwall face contribute to the failure potential and the damage potential.
- Knowledge of discontinuity properties in the mine environment allows for anticipation, and often the prediction, of hazards.
- Hazards can be reduced or eliminated with good pit layout design.

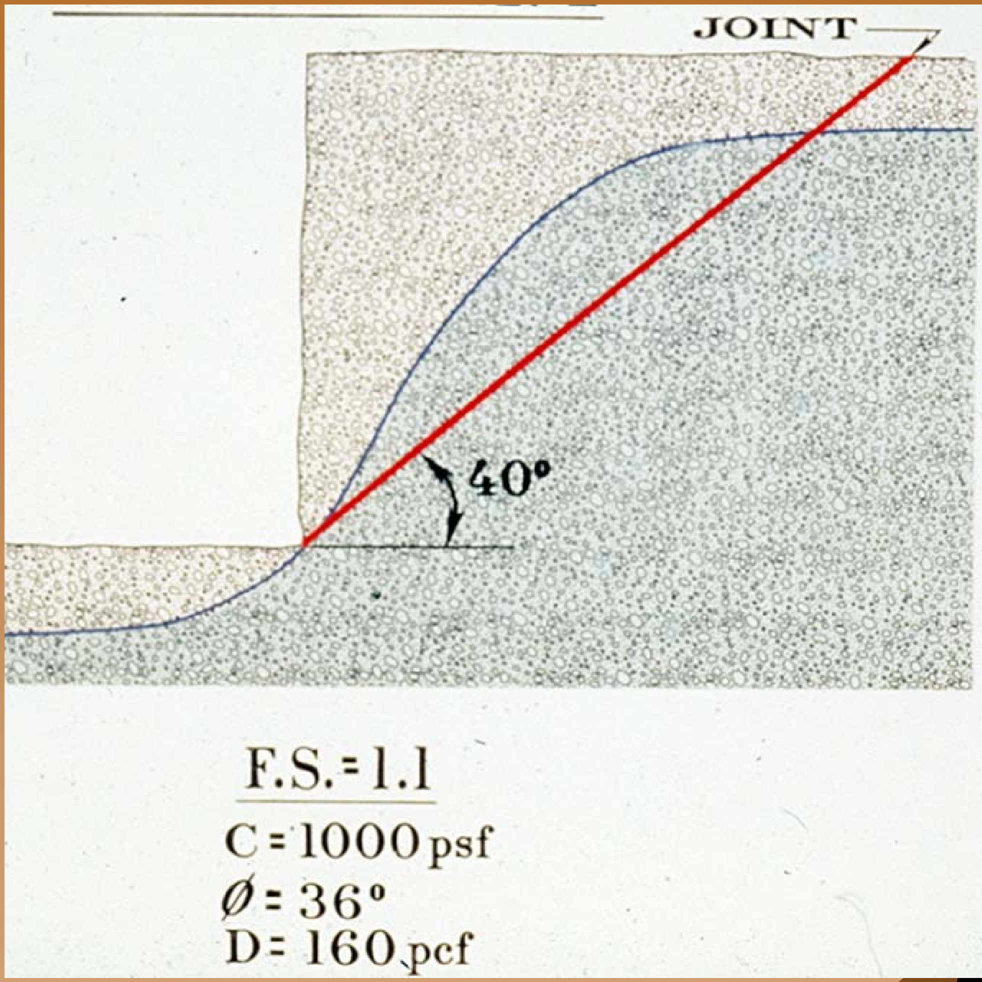
# Seepage

- Seepage is often a contributing factor to highwall failures.
- Effects of seepage:
  - creates driving force in joints
  - erodes supporting material
  - reduces strength of soil/rock
  - adds weight to the potential sliding mass.

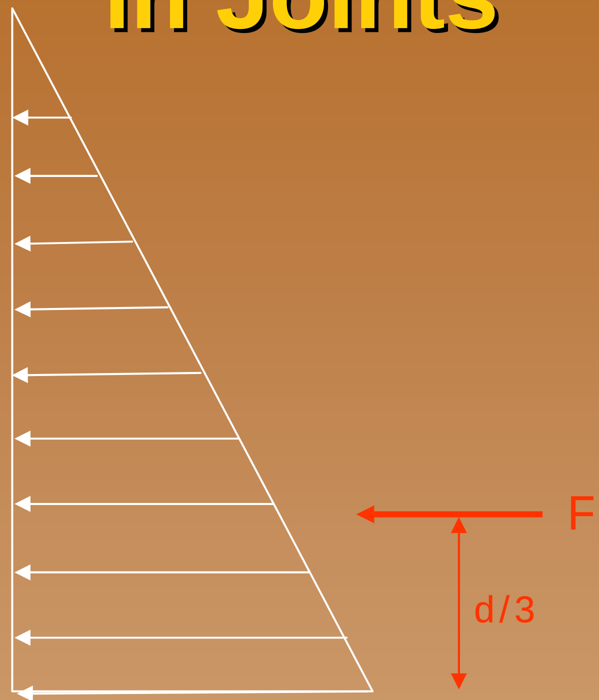
# Seepage on Highwall Face

# Water Issues



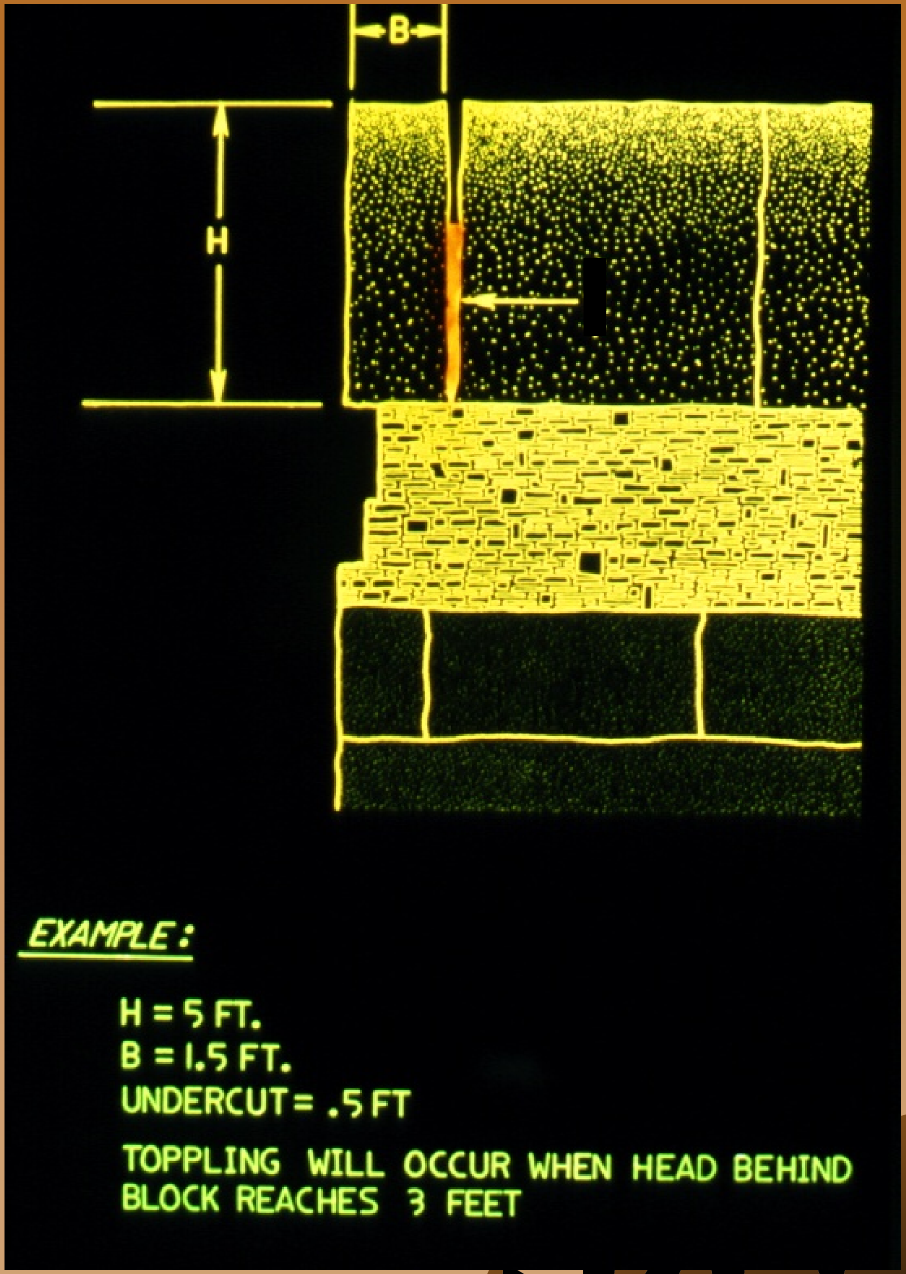
# Water Pressure in Joints



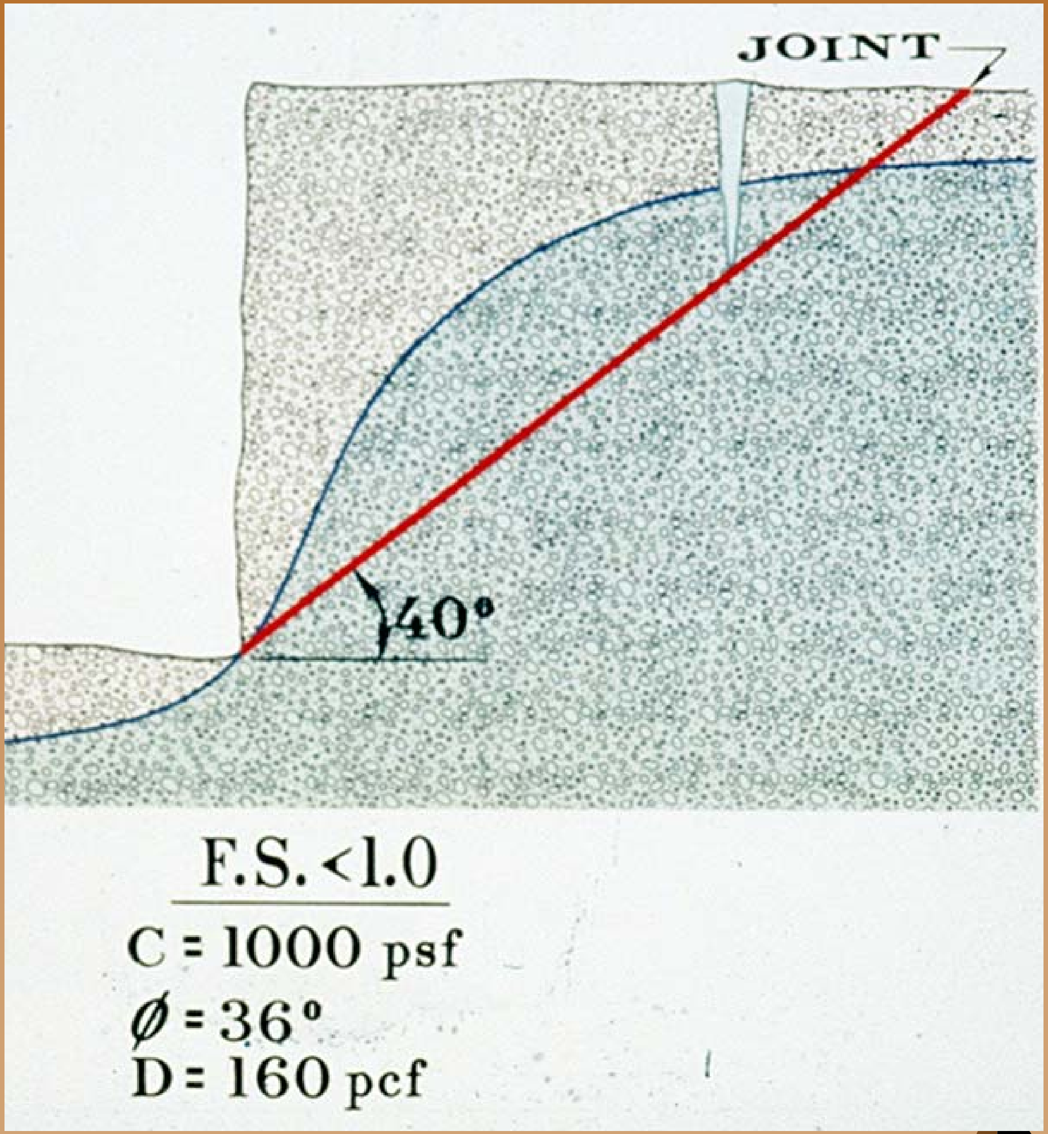

$$P_{\max} = 62.4 \, x \, depth$$

$$F = 0.5(P_{\max} \, x \, depth) / 2000$$

| Depth (ft) | 5 ft | 10 ft |
|---|---|---|
| Pmax (psf) | 312 | 624 |
| Force (tons) | 0.4 | 1.6 |

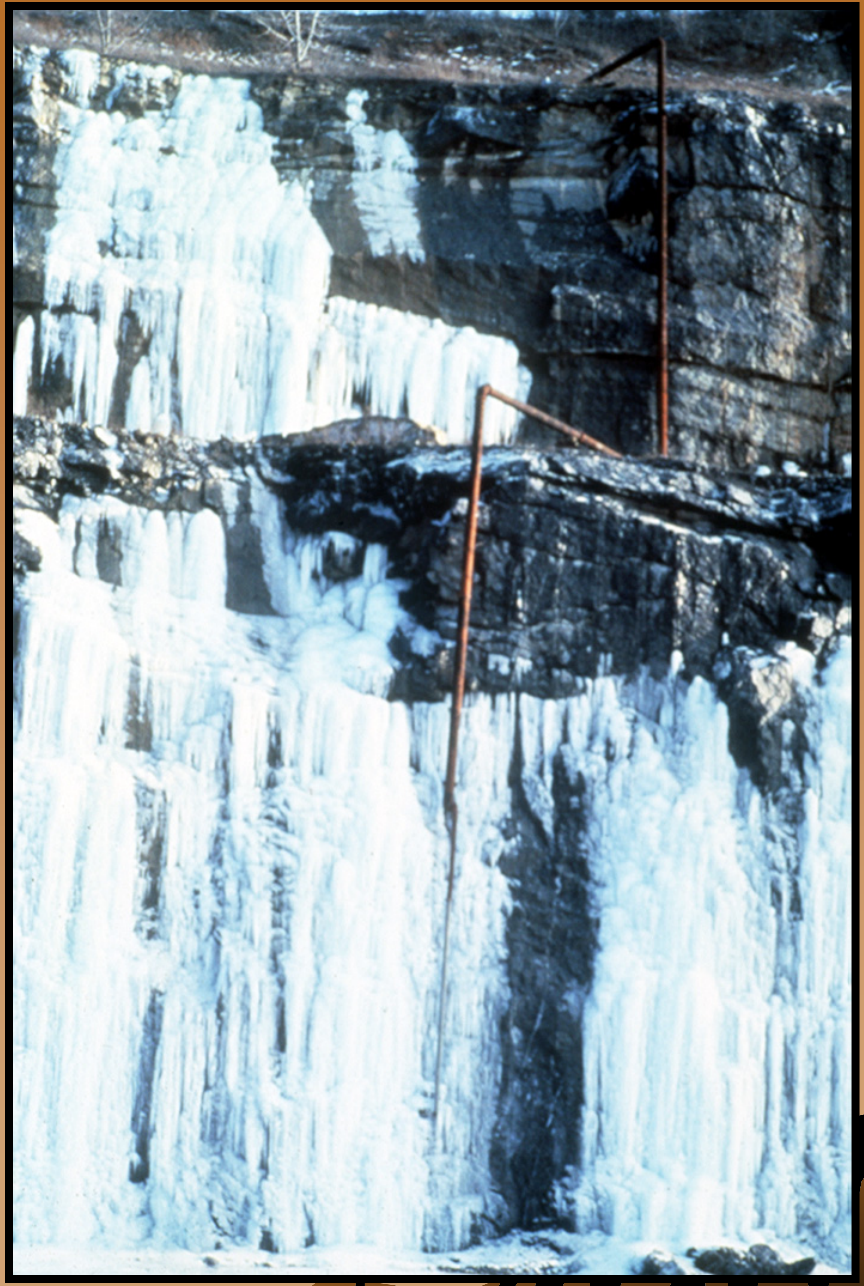


# Water in Joint



# Ice is a Common Sight on Highwalls in Cold Climates

- Ice can cause freeze/thaw damage, restrict water flow to increase pressure, and increase the weight of sliding masses.



# Highwall Failure Modes

# What is a highwall failure?

- A highwall failure is generally the unintended loss of material from a highwall.
- Basically two types of highwall failures:
  - Rock Mass Failures – involve a relatively large amount of material on a large portion of a highwall.  Material or structure controlled.
  - Rock Falls – involve a discrete number of individual rocks on a small portion of a highwall.
- Volume of material involved and exposure contributes to hazard.

# Rock Mass Failure

# Rock Falls

# Some Factors That Contribute to Highwall Instability

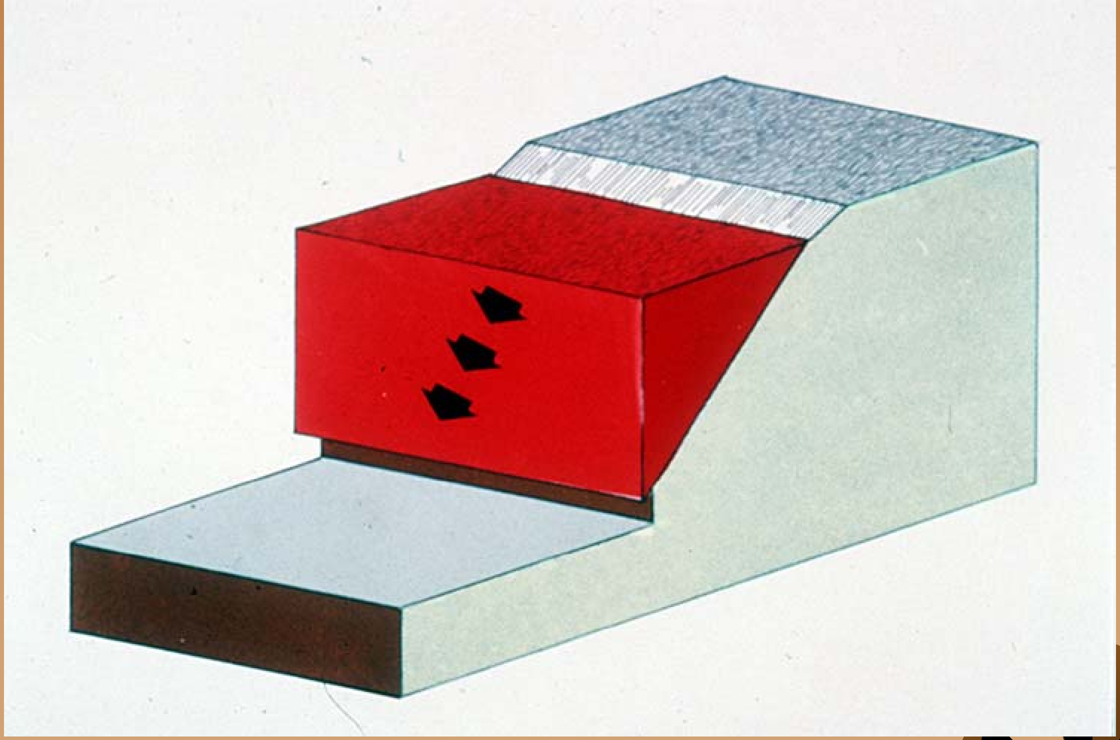
- Rock mass properties (strength, structure, etc.); highwall geometry (angles, heights, etc.); face orientation
- Precipitation (rain, snow)
- Ground water
- Freeze – Thaw Cycles
- Equipment Vibrations and Blasting
- Soil Decomposition
- Burrowing Animals, Tree Roots
- Wind

# Rock Mass Failure Modes

- Planar
- Wedge
- Toppling
- Circular

# Planar Failures

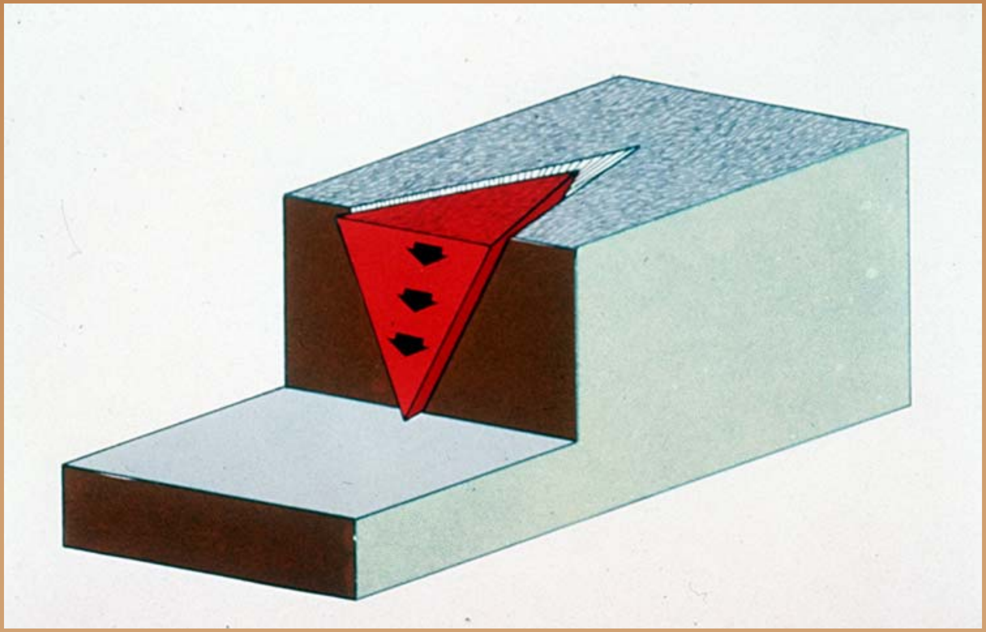
Involve sliding movement along a single discontinuity surface; however, additional discontinuities typically define the lateral extent of the failures.

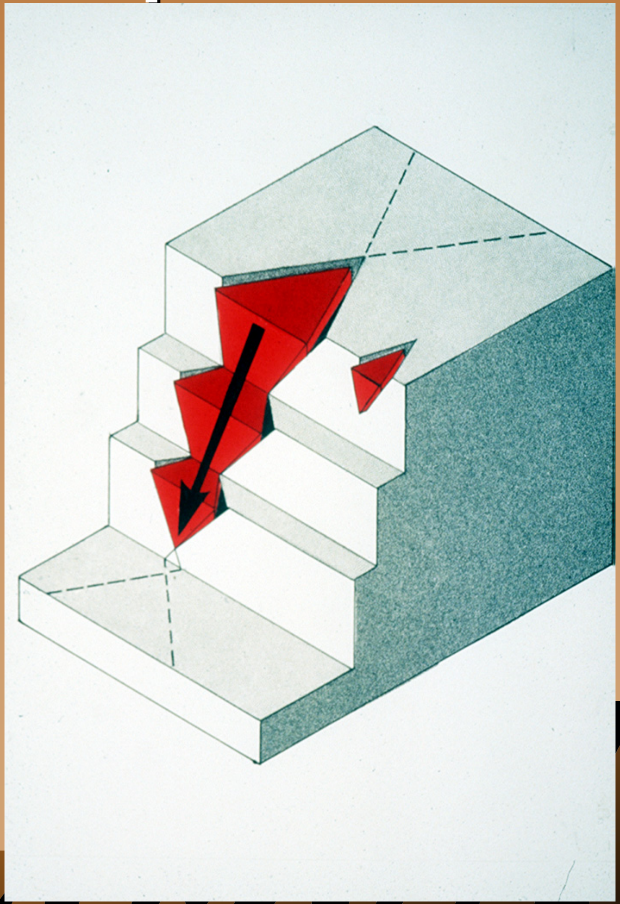


# Planar Failure

# Wedge Failures

**Involve sliding movement along two discontinuity surfaces that intersect at an angle forming a wedge shaped block in the highwall face.**

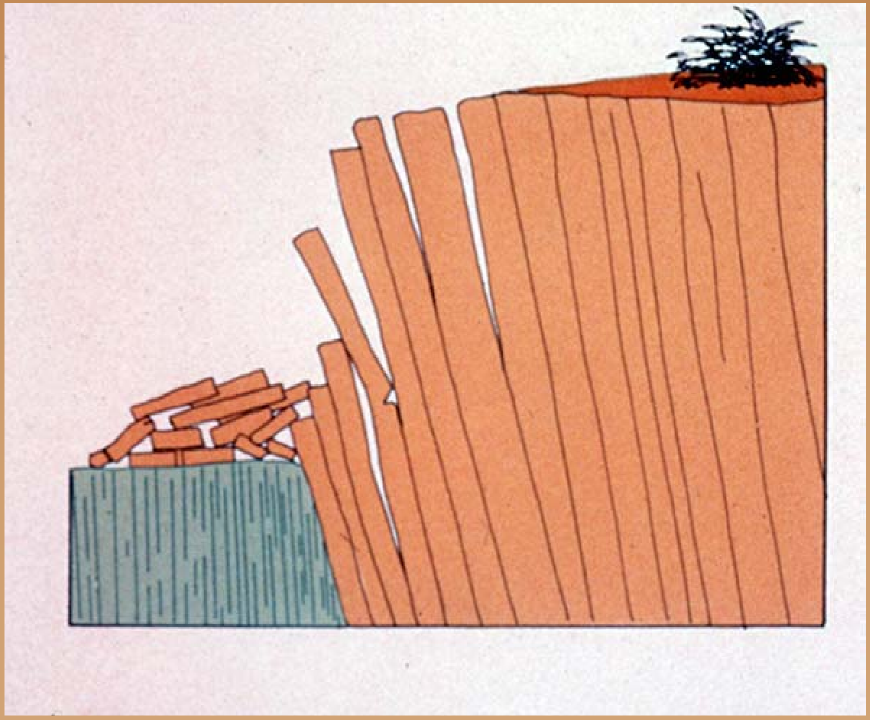




# Wedge Formation

# Toppling Failures

Involve buckling or rotational movement around the base of a slab or column formed by steeply dipping discontinuities oriented parallel or sub-parallel to the highwall face.

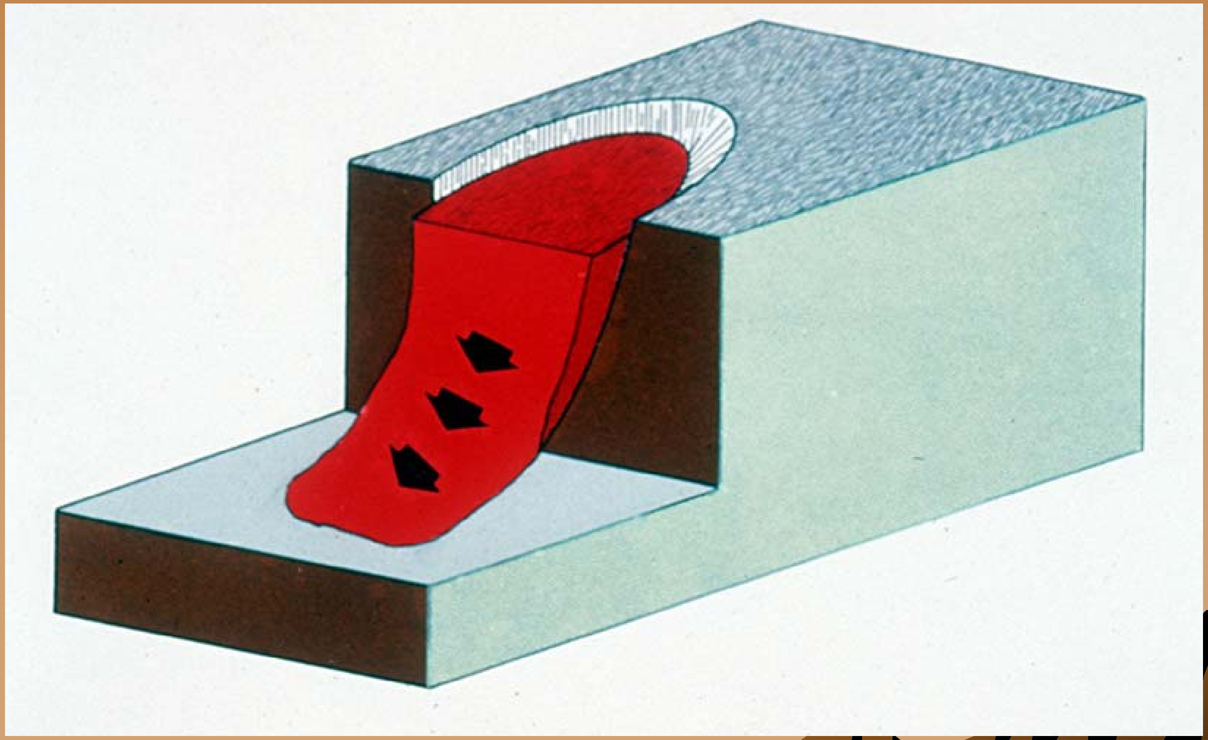


# Toppling Failure

# Toppling Failure

# Circular Failure

Involve rotational and sliding movement along a failure surface that occurs along numerous discontinuities and often approximates the arc of a circle.



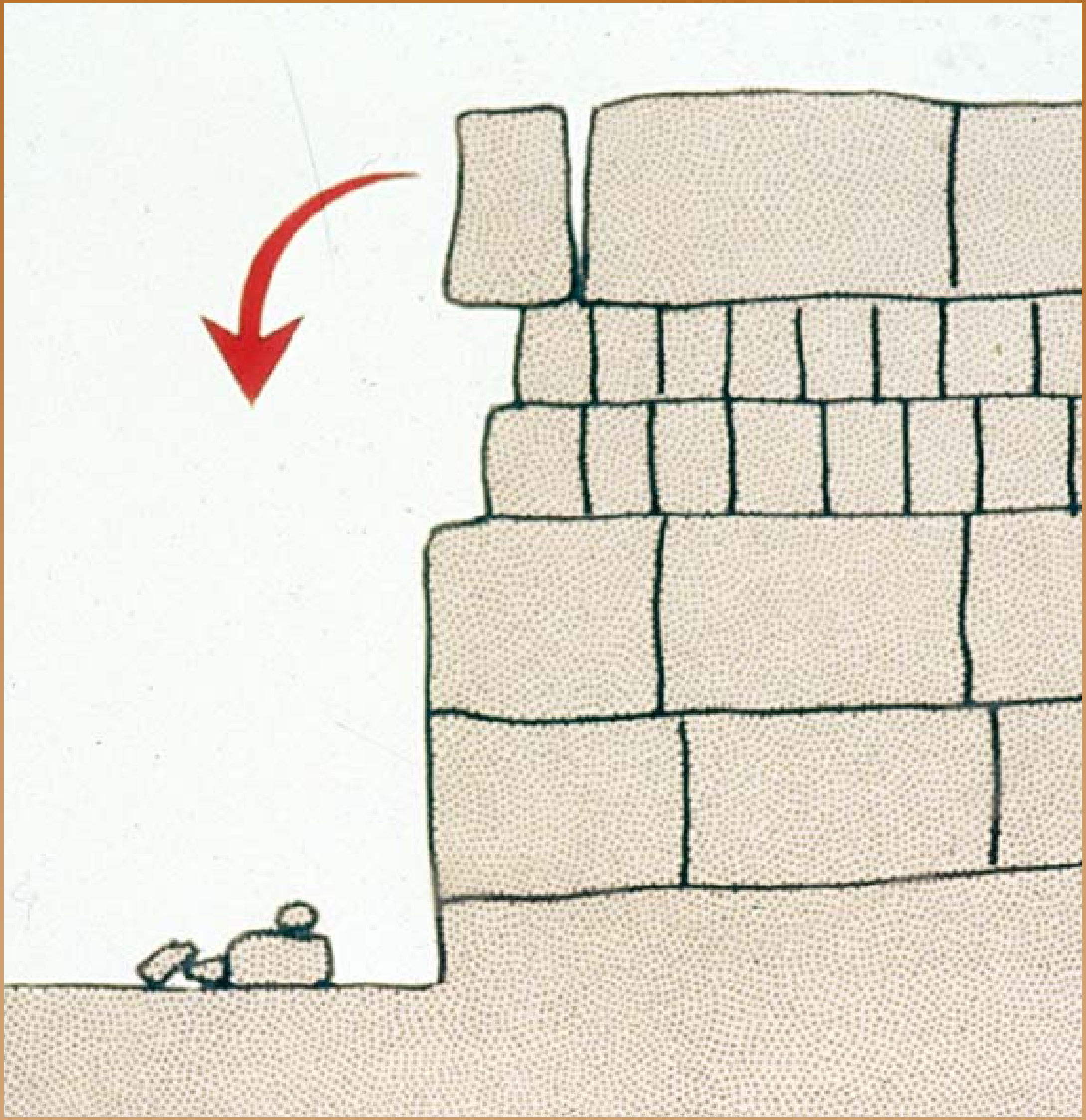
# Circular Failure

# Circular Failure - Before

# Circular Failure - After

# Highly Fractured Rock Mass

# Rock Falls



Intact blocks of rock on the fragmented highwall are susceptible to falling since they are unconfined.

# Rock Falls (cont'd)

- **Exposure, block weight, drop height, and highwall geometry are critical in evaluating rock fall hazards.**
- **Block weight and drop height will determine the damage potential of a falling rock when it strikes.**
- **Geometry of the highwall will affect how a rock falls and where it lands.**

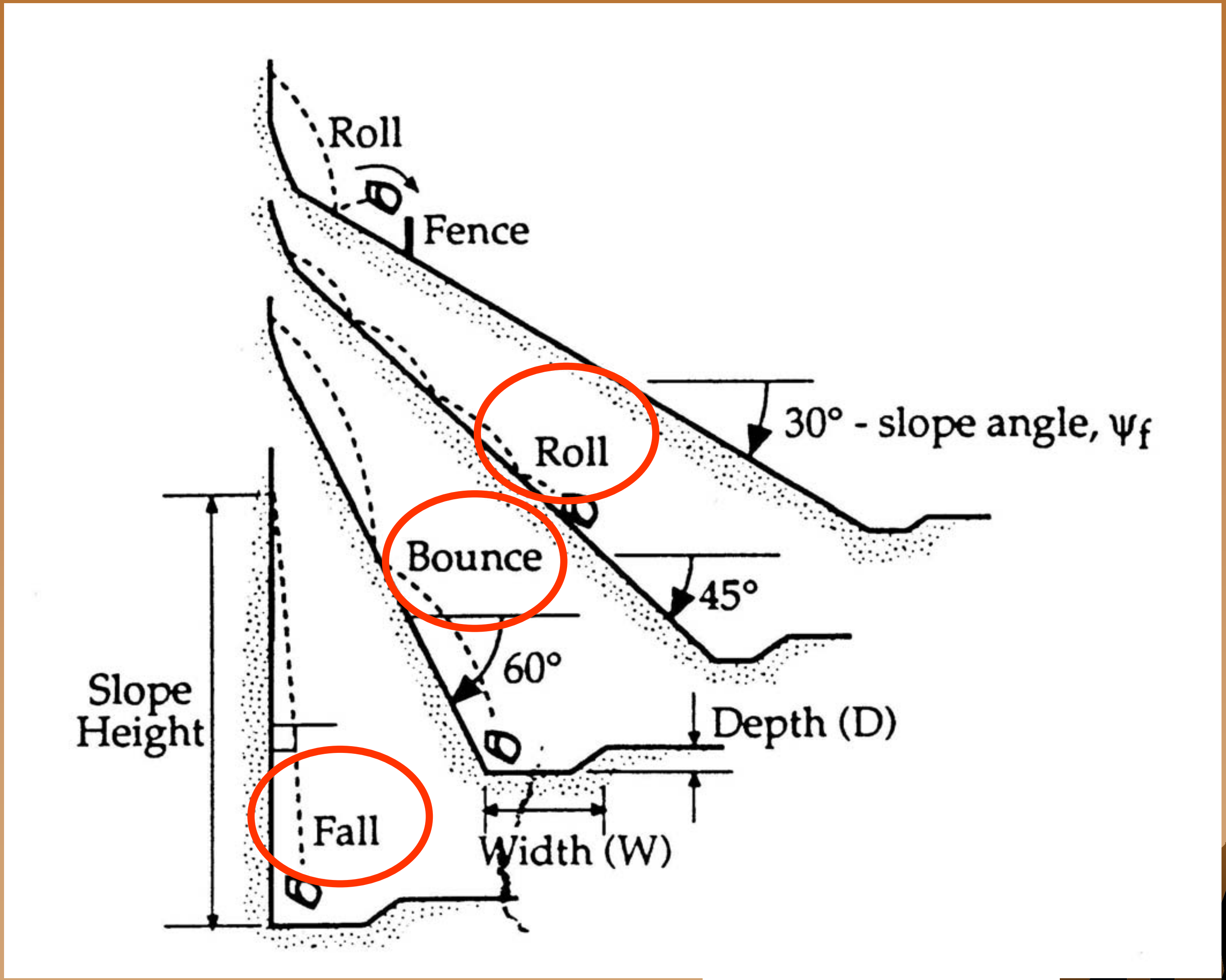
# Energy of a Rock Fall

- The ANSI hardhat standard (ANSI Z89.1) stipulates that an 8 lb. steel ball dropped a distance of 5 feet must result in a hardhat deflection of less than 0.5 in.
- The kinetic energy of the steel ball in this standard is 40 ft.-lbs.
- For comparison, a 3 in. cube of rock falling 50 feet has a kinetic energy of 125 ft.-lbs.

# What About a 230-foot Fall?

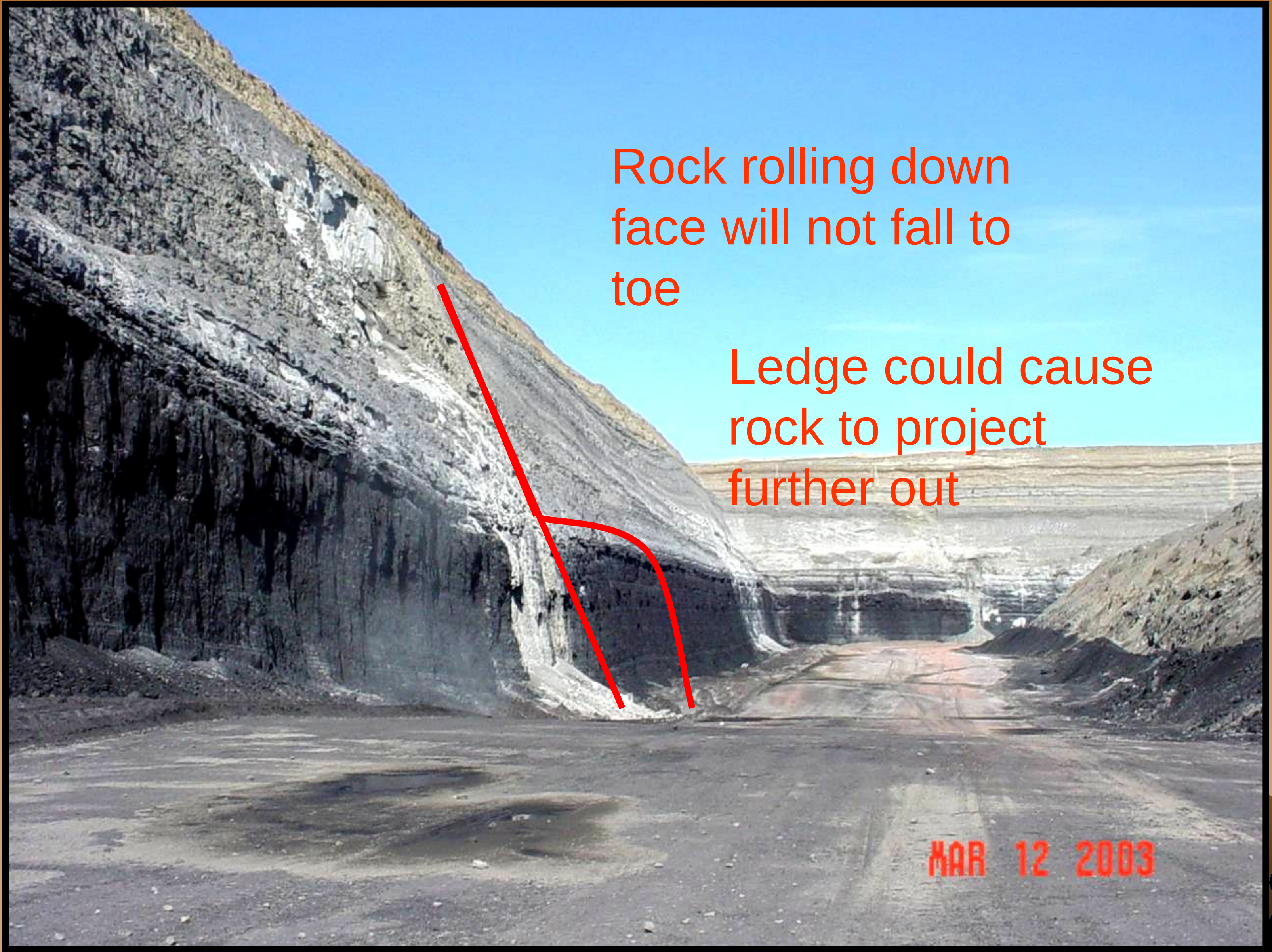
- 1999 (TN) – Driller at base of 230 ft. highwall
- Rock measured 4” x 4” x 3” & weighed under 3 pounds

# Effects of Highwall Geometry on Rock Fall




(Ritchie 1963)

# Highwall Geometry



# Launch Feature

# Loose Material

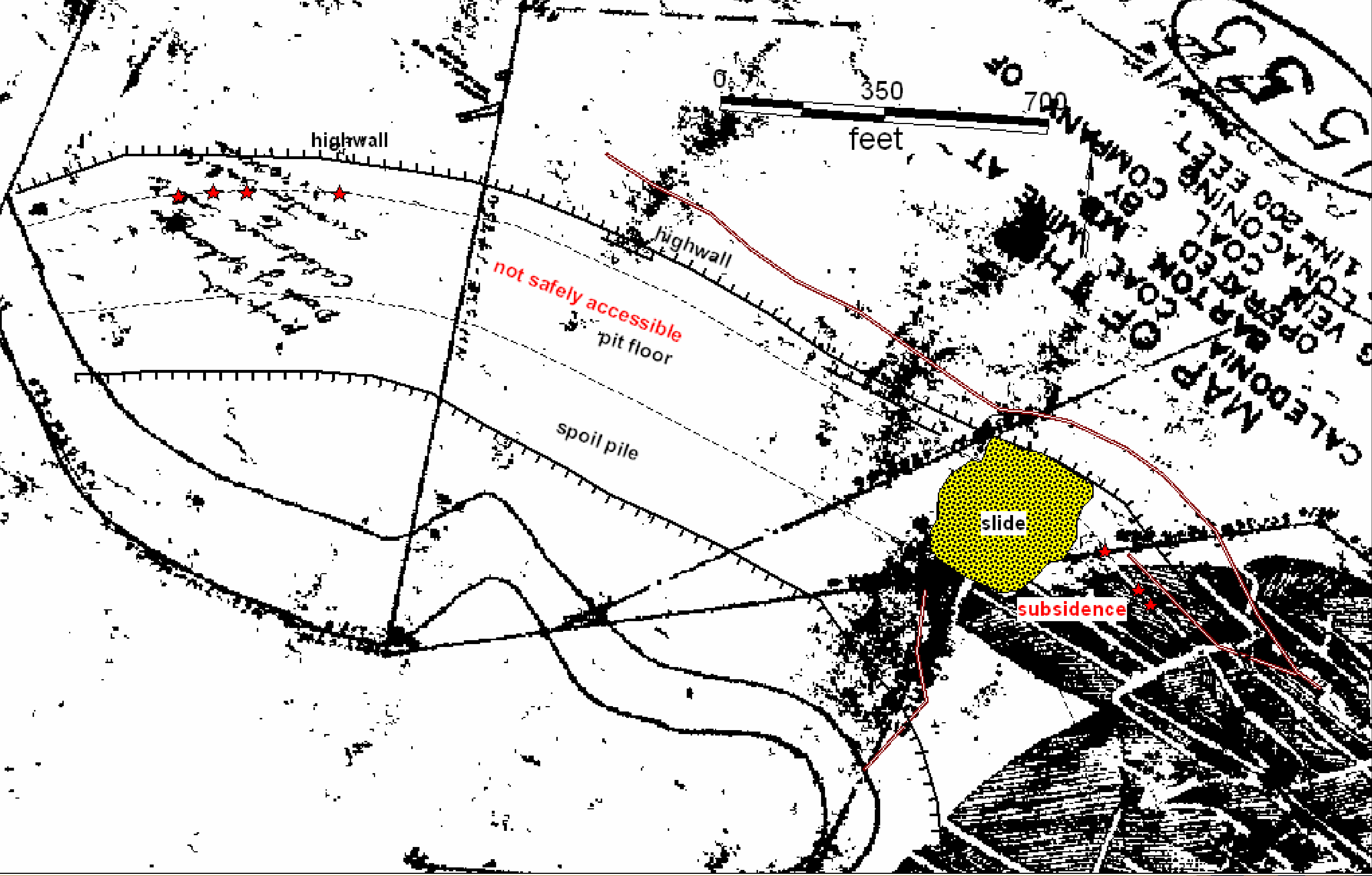
# Risks to Vehicular Traffic

# Underground Mine Workings

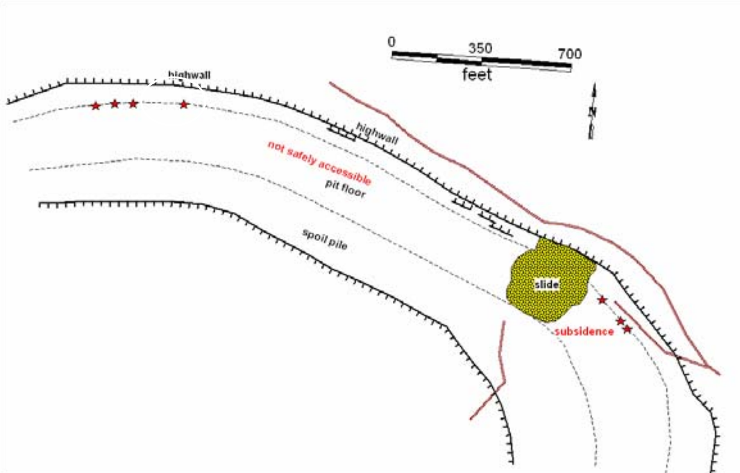
- Underground mine workings in close proximity to a highwall, especially those that daylight in the highwall face, can cause instability.
- This is due to pre-existing subsidence damage or the potential for subsidence damage in the overlying rock strata.
- Unstable highwall conditions in the vicinity of underground mine workings should be anticipated.
- Shorter highwalls and wider benches can improve the stability of the highwall by reducing overburden load as well as the amount of material that could become unstable.


Highwall with Underground Mining Failure, MD. (4 slides)
Approximate Equipment Location after Removing a Large Volume of Failed Rock


**Subsidence with associated failure into the pit on the west side of the accident site.**




Observed areas of subsidence in relation to workings shown on a different map of the Caledonia Coal Co. mine, developed in the Pittsburgh Seam.




**Wood post preserved in completely caved room in old workings of the Pittsburgh (Big Vein) seam. Coal pillars were crushed and had failed.**

# Remediating the Hazard

# Measures Intended to Prevent Failure and Exposure

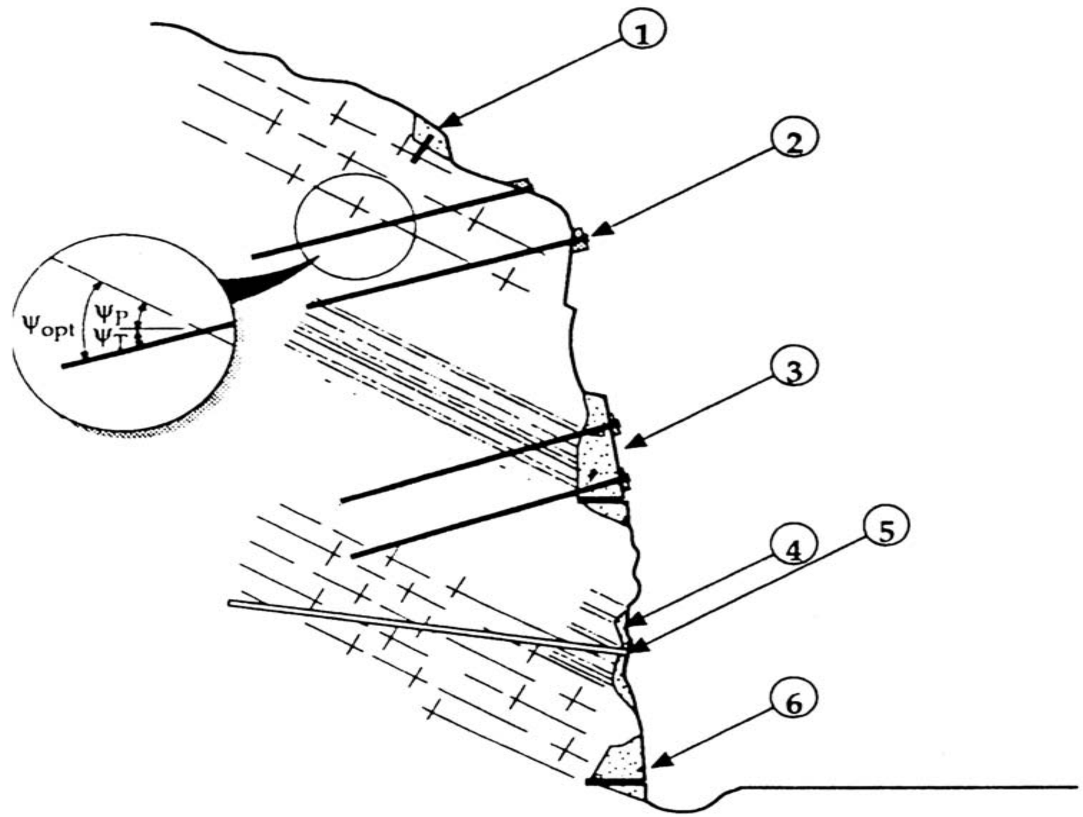
- Rock Cut Stabilization and Protection
  - Stabilization Measures
    - Reinforcement
      - Rock Bolting
      - Dowels
      - Tied-Back Walls
      - Shotcrete
      - Buttresses
      - Drainage
      - Shot-in-Place buttress
    - Rock Removal
      - Resloping
      - Trimming
      - Scaling
  - Protection Measures
    - Ditches
    - Mesh
    - Catch Fences
    - Warning Fences
    - Rock Sheds
    - Tunnels

# Rock Reinforcement

- The goal of rock reinforcement is to secure potentially loose rock on the face of the highwall.

- Rock reinforcement is more appropriate for highwalls that are intended to be permanent.

# Rock reinforcement methods for highwall stabilization.




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

(TRB 1996)

# Rock Bolting

# Shotcrete Face

# Drainage

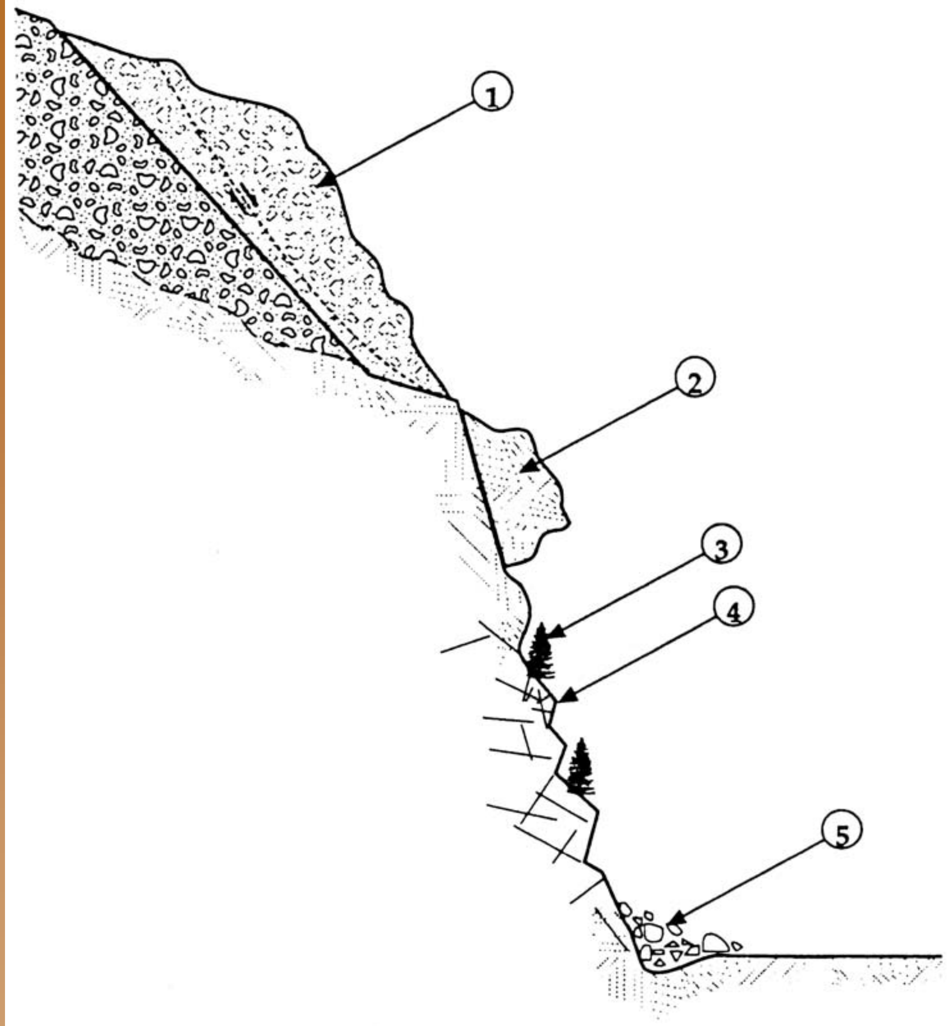
- If a water problem is expected, defensive measures can be taken:
  - Grouting to prevent infiltration,
  - Diversion ditches above the highwall to prevent surface runoff,
  - Vertical wells behind the highwall crest, and
  - Horizontal drains in the highwall face.

# Rock Removal

- The goal of rock removal is to remove potentially loose rock from the face of the highwall.

- Rock removal is preferred over rock reinforcement when a stable face can be achieved.

# Rock removal methods for highwall stabilization.




1. Resloping of unstable weathered material in upper part of slope
2. Removal of rock overhang by trim blasting
3. Removal of trees with roots growing in cracks
4. Hand scaling of loose blocks in shattered rock
5. Clean ditch

(TRB 1996)

# Pre-Splitting Highwall

# Mechanical Scaling

- Mechanical scaling is generally considered to be scaling by heavy equipment.
- It is not very selective and will generally only remove excessively loose material.
- It may also cause damage to the highwall, creating more loose material in the process.
- Dragging the face of the highwall with a chain or similar object is marginally effective at best.

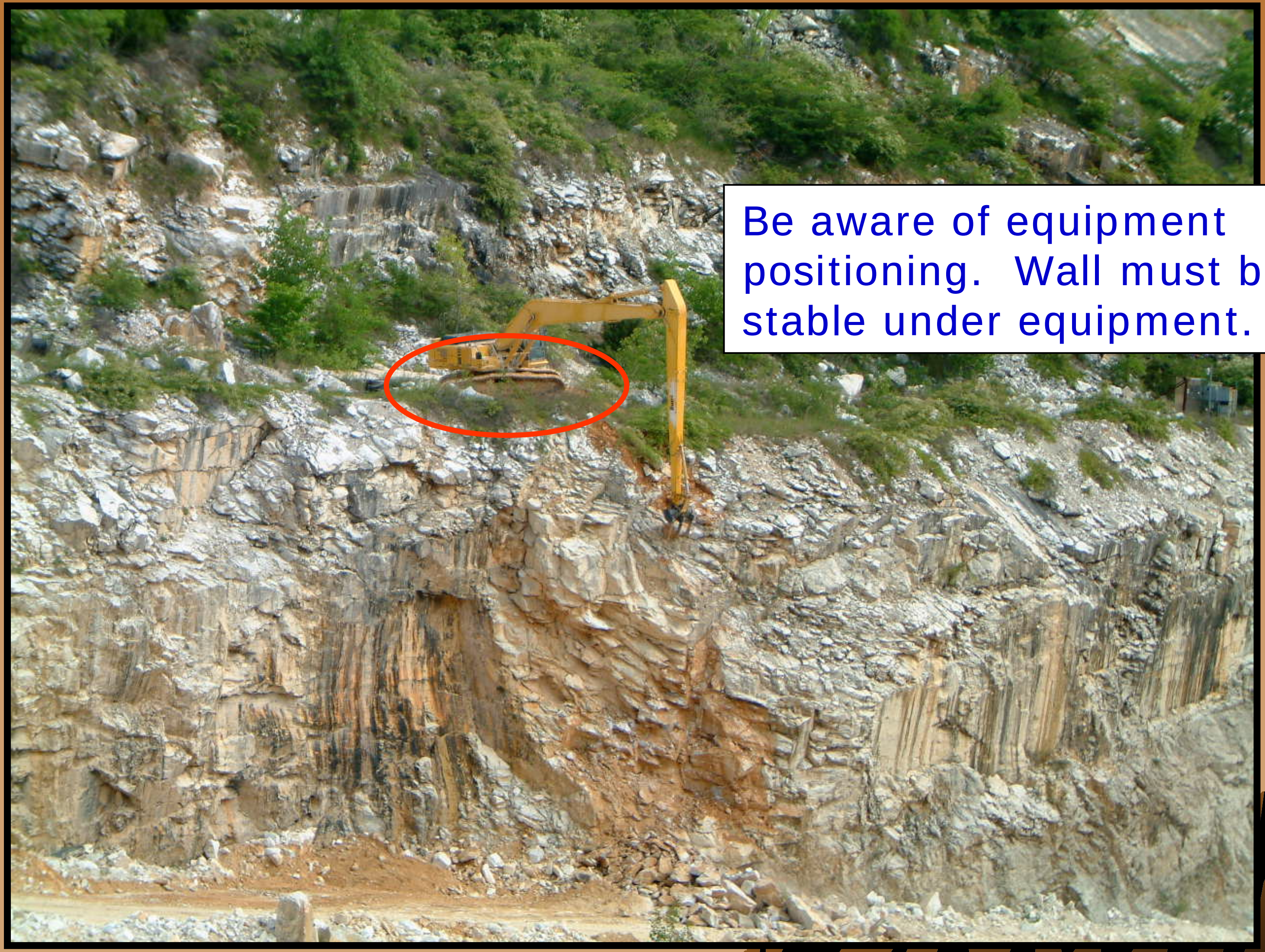
# Scaling Chain

# Dragging the Face

# Scaling with Crane

# Scaling with Excavator

Can be more effective with good communication between operator and person directing.  But still for relatively small areas.



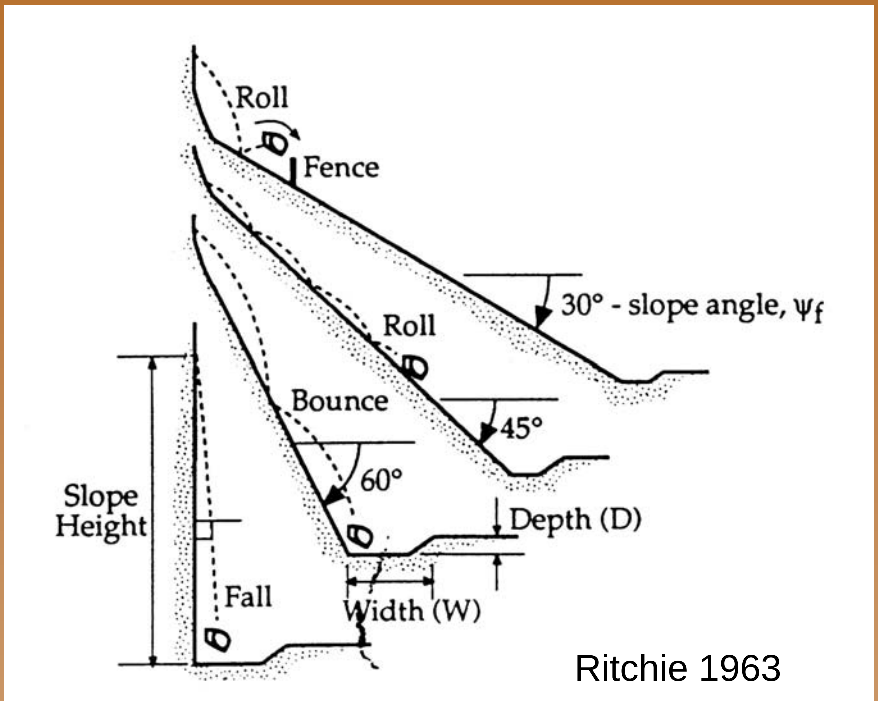
Be aware of equipment positioning.  Wall must be stable under equipment.

# Manual Scaling

- Manual scaling is generally considered to be scaling with hand tools.
- It is very selective and can be very effective with trained scalers.
- However, it can be labor intensive depending on the condition of the face.
- The positioning of personnel and equipment must be carefully considered.

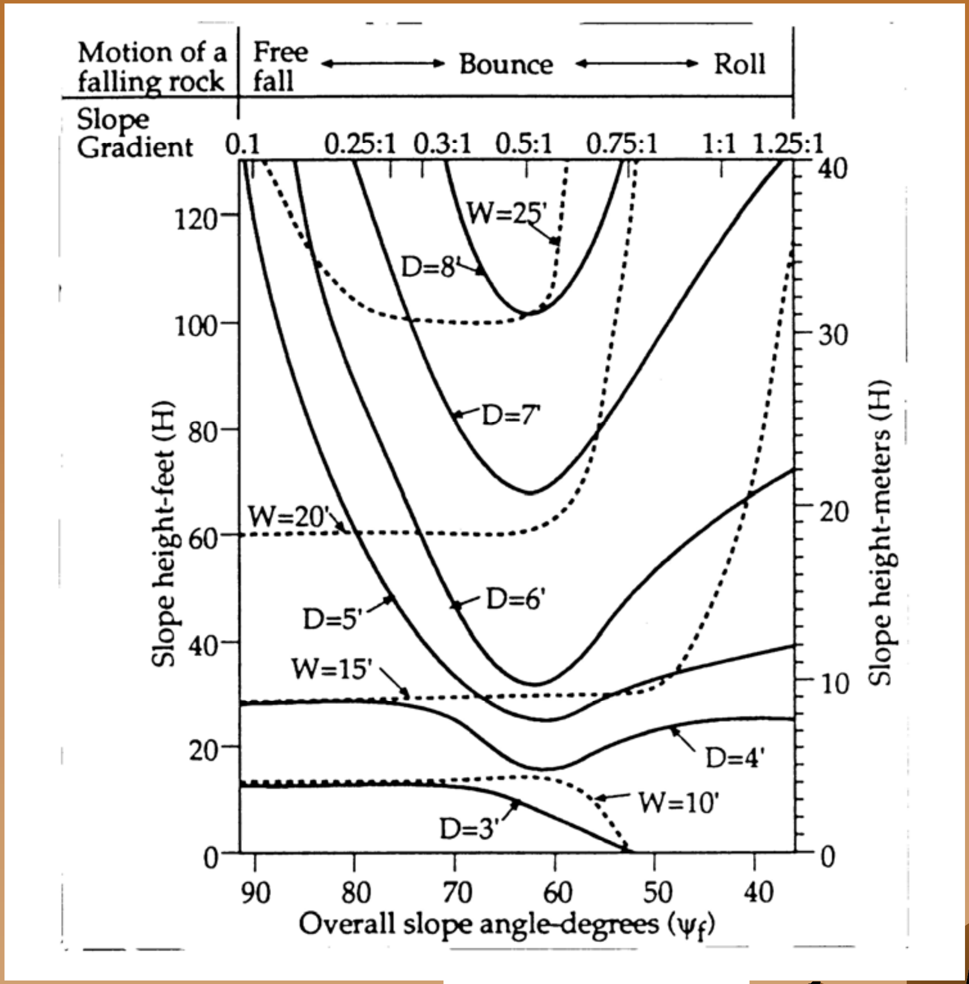
# Scalers Supported by Ropes

# Rock Catch Ditches




Ritchie 1963

**Methodology can also be used to design berms.**




Ritchie 1963

# Wire Mesh on Highwall

# Catch Fence

# Protection Measures More Commonly Used in Mining

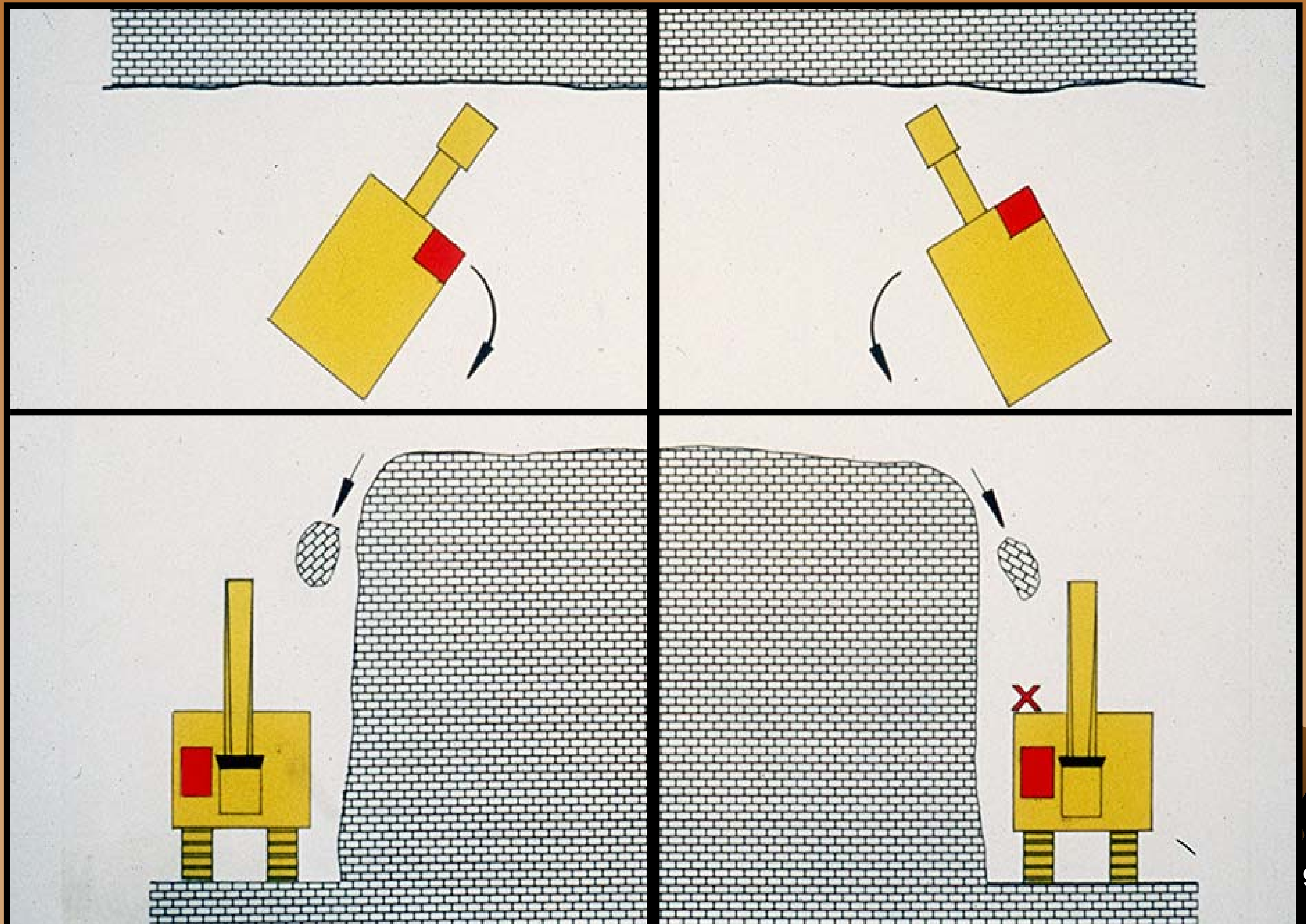
- Examination
- Restrict Access
- Equipment Position
- Benches
- Berms
- Computer Modeling
- Monitoring

# Examination of Ground Conditions

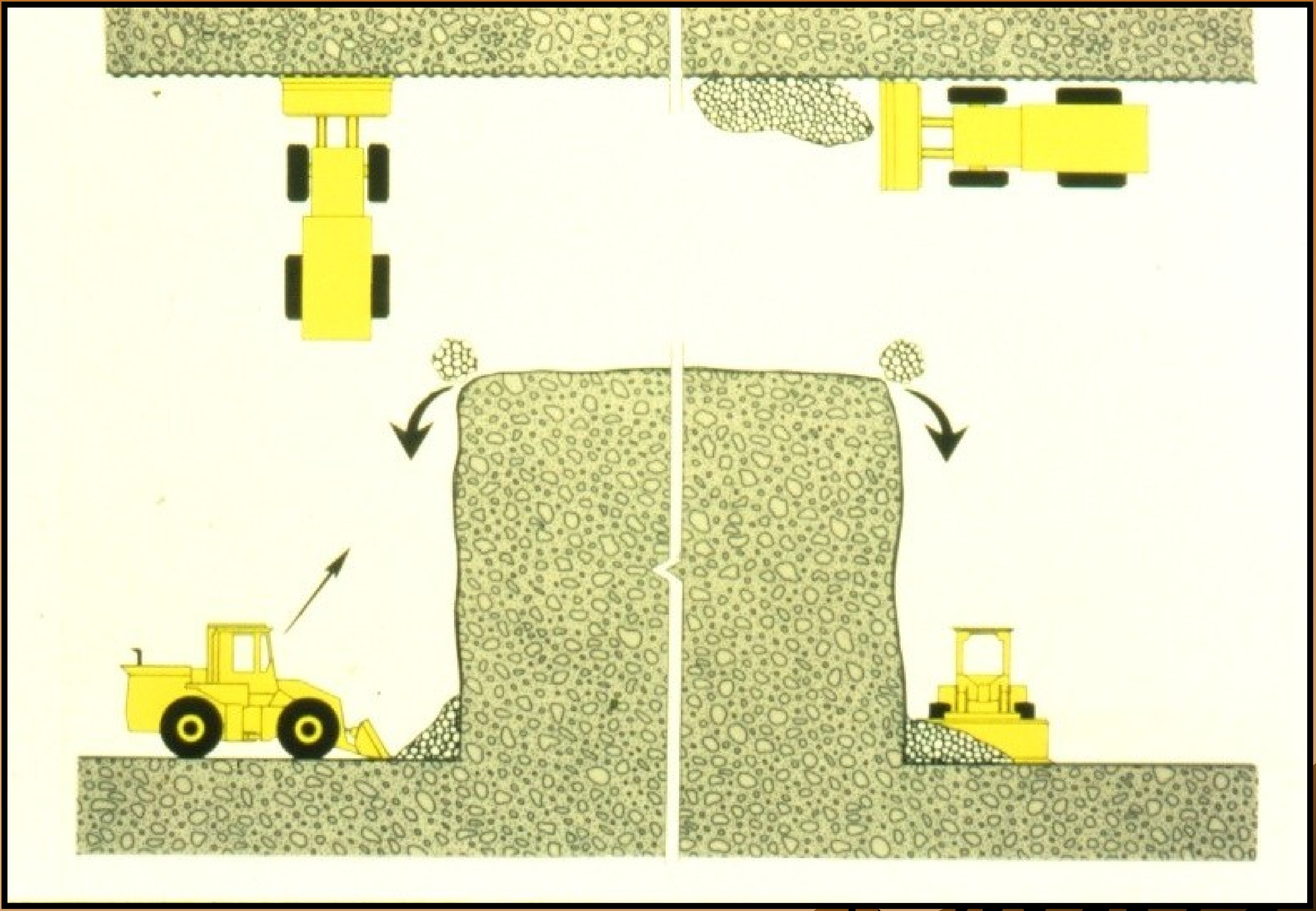
- A critical step in protection.
- Regular, thorough examinations help identify potentially hazardous areas and developing conditions.
- Conditions should be examined from all possible angles.
- Particular attention should be paid to the toe and crest areas.
- Fallen rock at the toe and cracks behind the highwall crest are often signs of developing stability problems.

# Warning Signs and Barriers to Restrict Access

# Equipment Position Relative to the Highwall Face



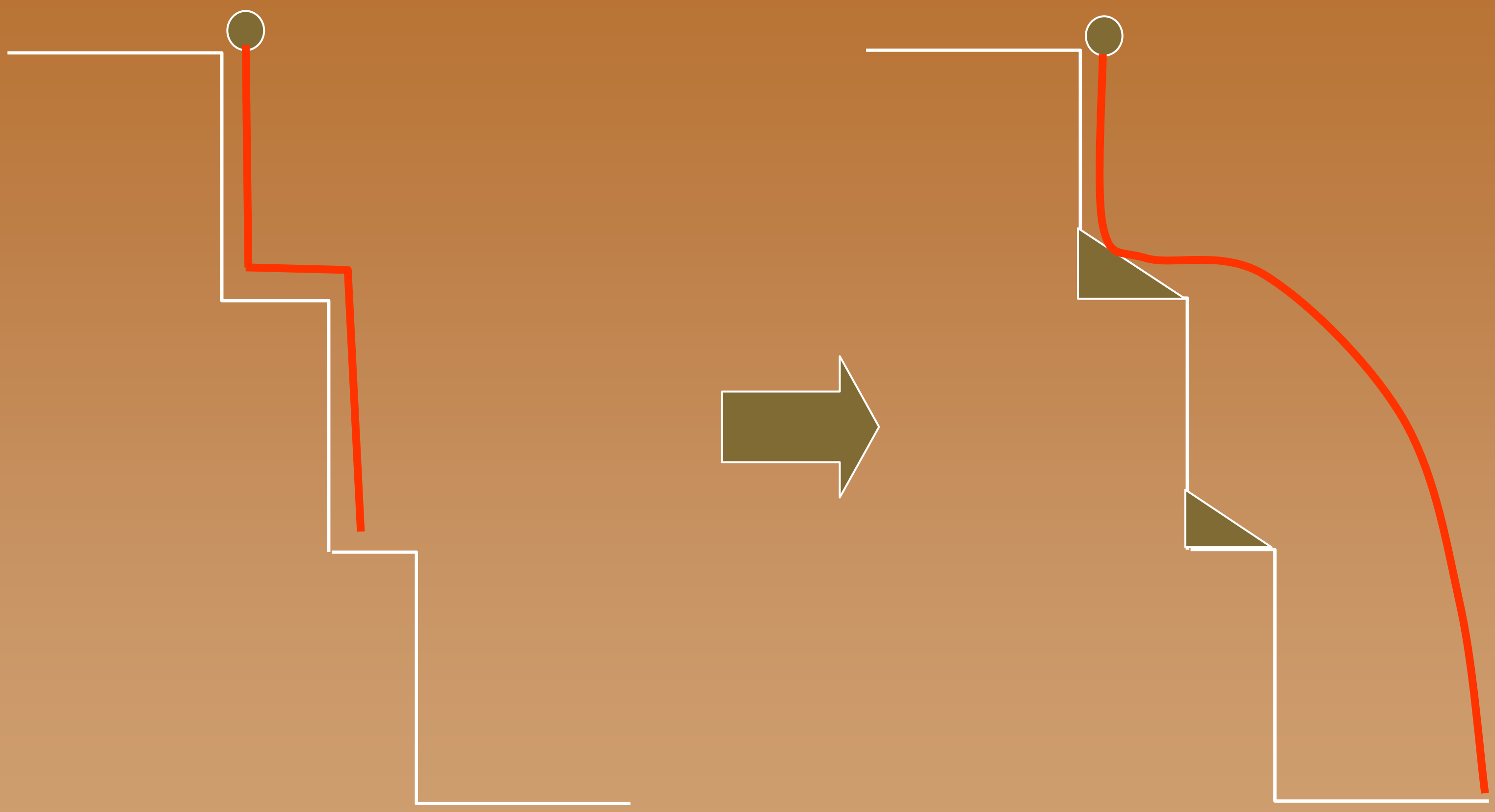
# Equipment Position Relative to Highwall Face



# Benches reduce the distance a rock can fall

# Full Benches

# The Problem of Full Benches



# Berms

- Berms can effectively be used to control rock fall hazards.
- Berms create a catch basin to contain falling material.
- Berms are also an effective barrier to keep personnel out of area.
- Berms must be properly sized and located.
- Berms must be maintained.

# Berm Containing Material

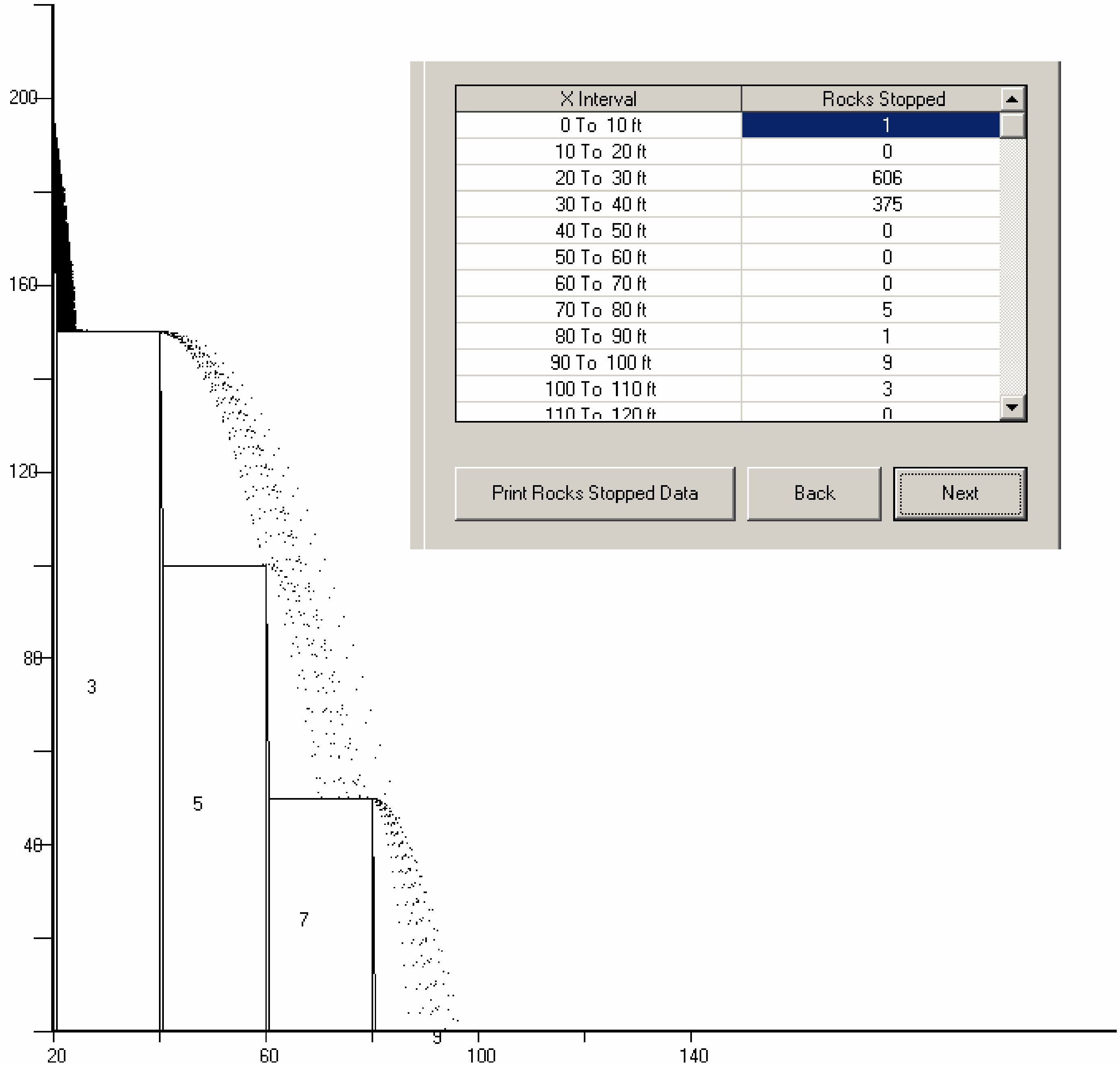
# Berm Not Containing Material

# Is Berm Properly Sized and Located?

# Computer Modeling

- Computer models such as the Colorado Rockfall Simulation Program (CRSP) can be used to design rockfall protection measures.
- Computer programs:
  - model field conditions,
  - apply random affects,
  - run many simulations, and
  - analyze patterns.

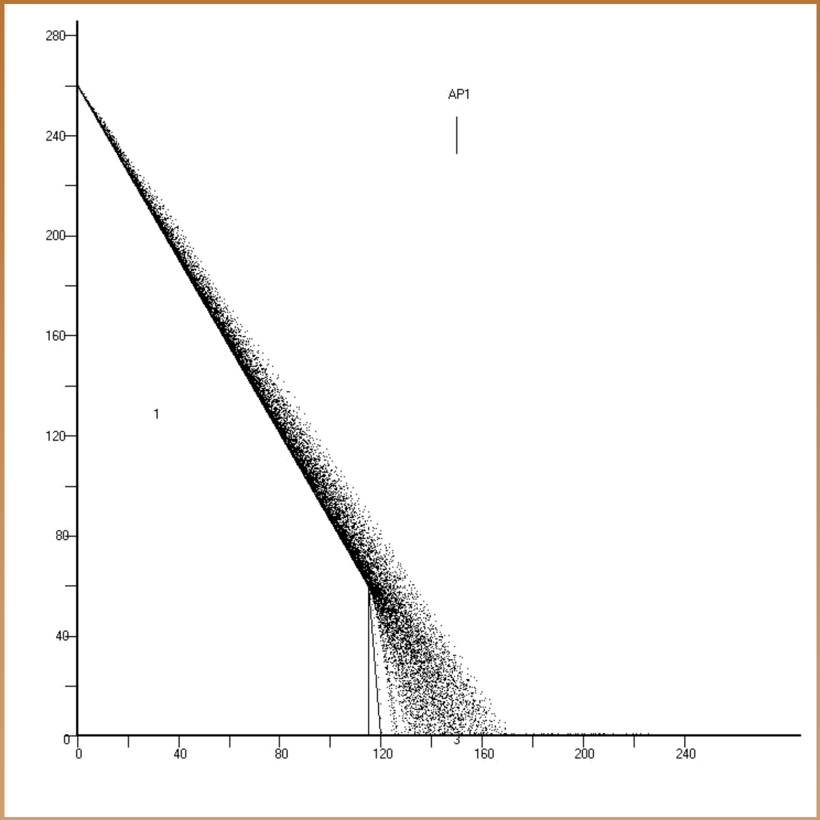
# 90-Degree Face, 50-foot face heights with 20-foot-wide bench

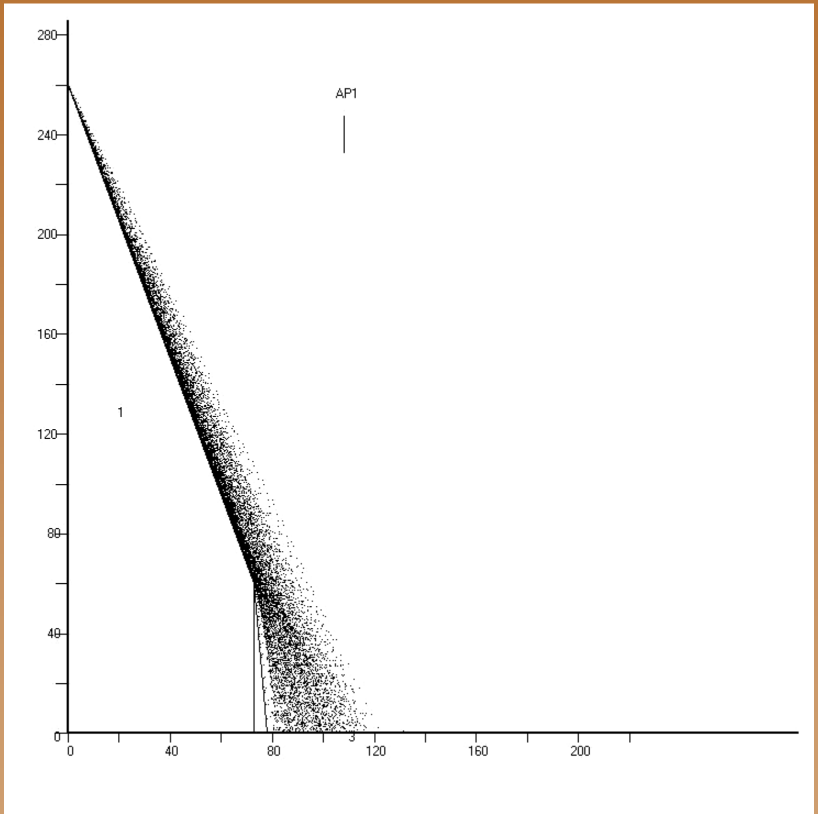



| X Interval | Rocks Stopped |
|---|---|
| 0 To 10 ft | 1 |
| 10 To 20 ft | 0 |
| 20 To 30 ft | 606 |
| 30 To 40 ft | 375 |
| 40 To 50 ft | 0 |
| 50 To 60 ft | 0 |
| 60 To 70 ft | 0 |
| 70 To 80 ft | 5 |
| 80 To 90 ft | 1 |
| 90 To 100 ft | 9 |
| 100 To 110 ft | 3 |
| 110 To 120 ft | 0 |

Print Rocks Stopped Data | Back | Next

# 70-degree vs. 80-degree slope angles

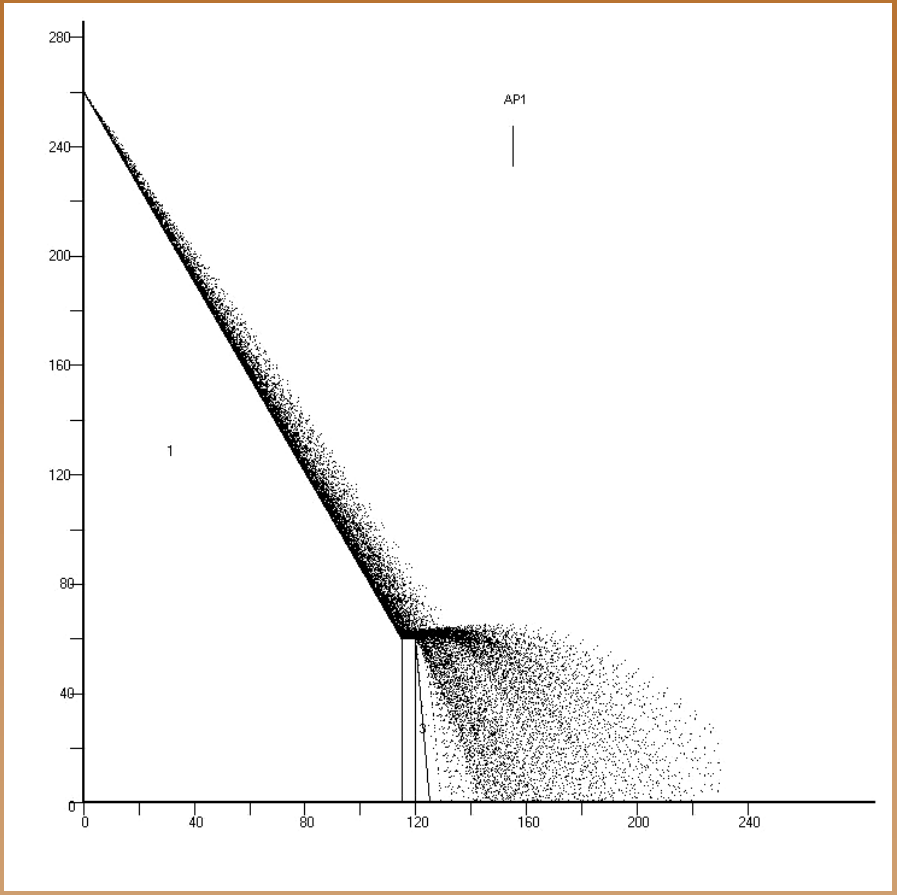


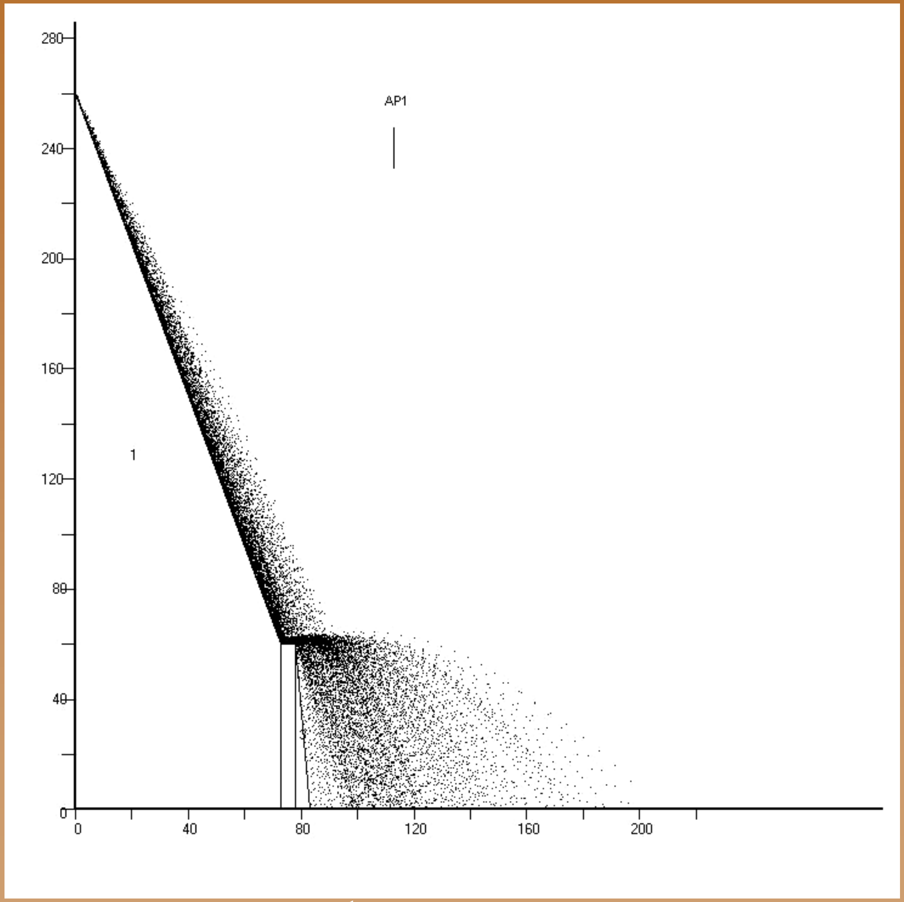




**60 feet**

**25 feet**

# Highwalls with a Ledge

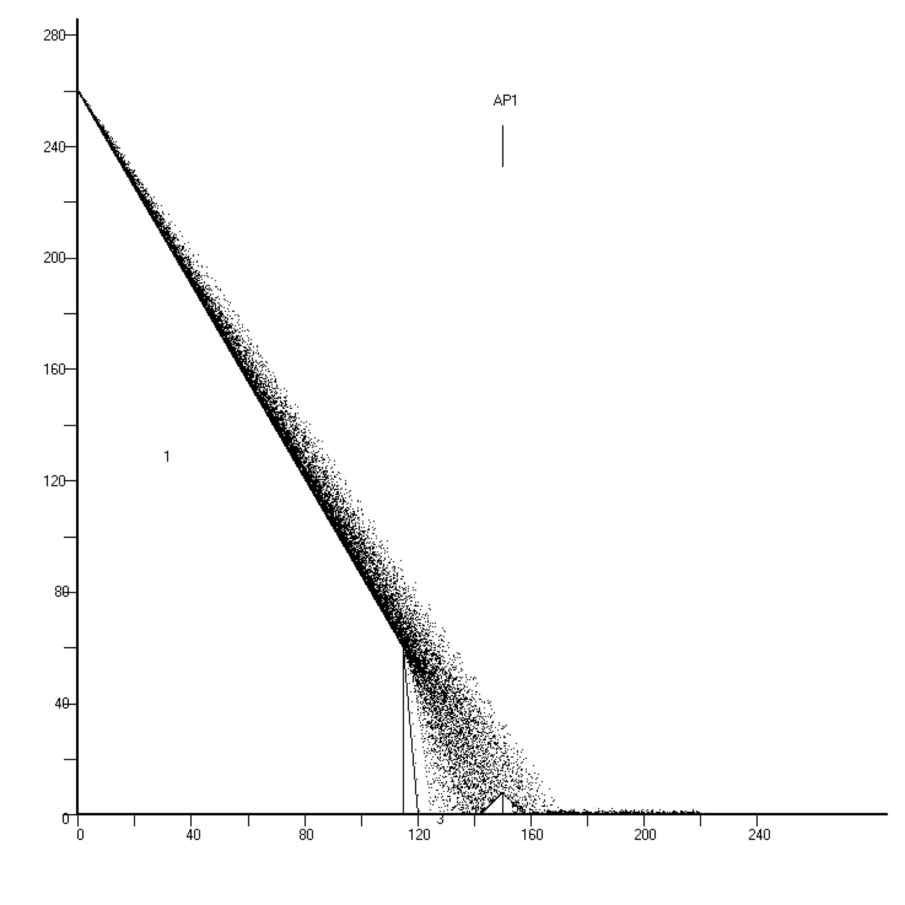


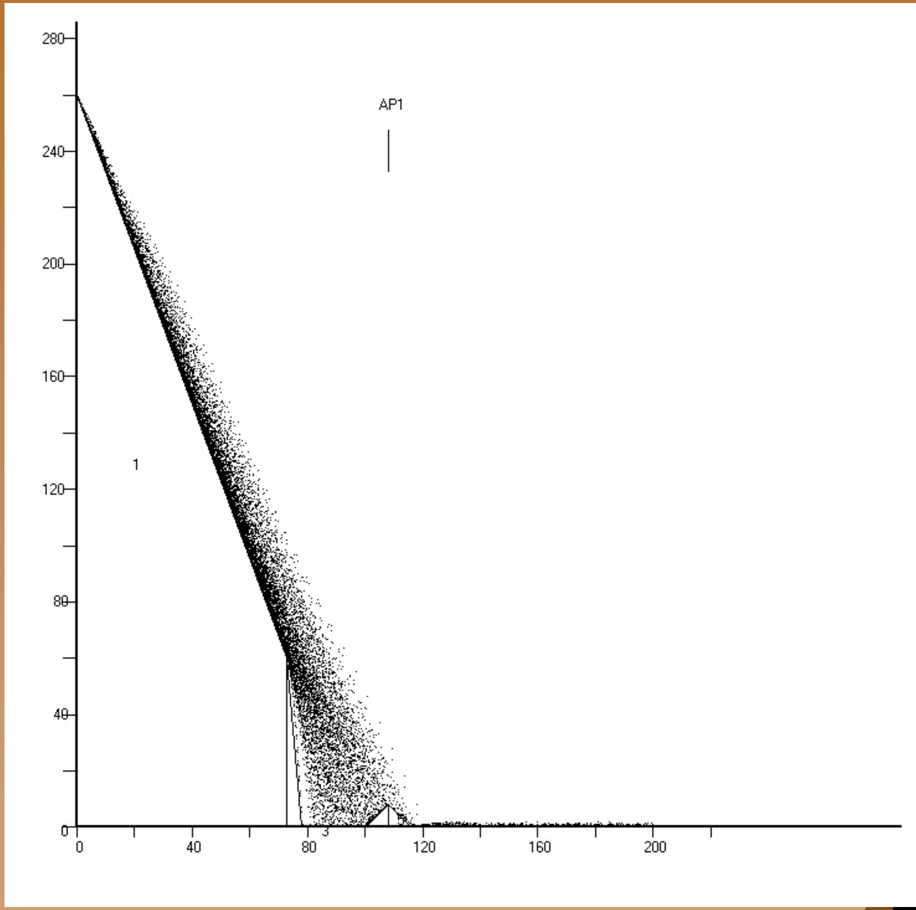

120+ feet

120 feet

# Highwalls with a Berm




**70 degree slope angle**




**80 degree slope angle**

# Highwall Monitoring

- **Monitoring is surveillance of the highwall either visually or with the aid of instruments.**
- **Objectives of monitoring:**
  - **Maintain a safe operation.**
  - **Provide advance notice of instability allowing for the timely evacuation of personnel.**
  - **Provide information on the extent and rate of failure to help identify appropriate remedial measures, modify the mining plan, or redesign the slope.**

# Visual Monitoring (aka Spotters)

- Visual monitoring of a highwall often has limited value.
- Visual monitoring is often not sufficiently consistent or quantitative for informed decision making.
- Spotter reaction time, as well as means of sounding alarm are critical considerations.

# Example of Spotter Log

1:00 a.m. Light illumination is very poor

3:00 a.m. Saw an owl come and snatch up a mouse . . .

7:00 a.m. The trucks help keep me awake.

18 shovel spotters Full (hourly wage) Report

11/23/04 C shift spotter crew 2
1:00 am 11/24/04 nothing light illumination is very poor to see small activity if any.
2:00 am see 1 am.
3:00 am - saw an owl come and snatch up a mouse most movement I have seen yet. that was cool at least it looked like a mouse. (1)
4:00 am another exciting moment "lunch" (1)
4:20 am mining activities Resume to normal (1)
5:00 am and all is well
6:00 am Real exciting now cause 18 shovel is down
7:00 am 18 running again the trucks help keep me awake.
I saw a real pretty sunrise. But no rocks Falling. (1)
8:00 am Long shift everything was quite so that is good. time to get out of here. all is well that ends well.

Summary: Long night and easy way to get paid. Definitely gives a new definition to long grave yard. Plus you get to much time on your hands to think of stuff like this.

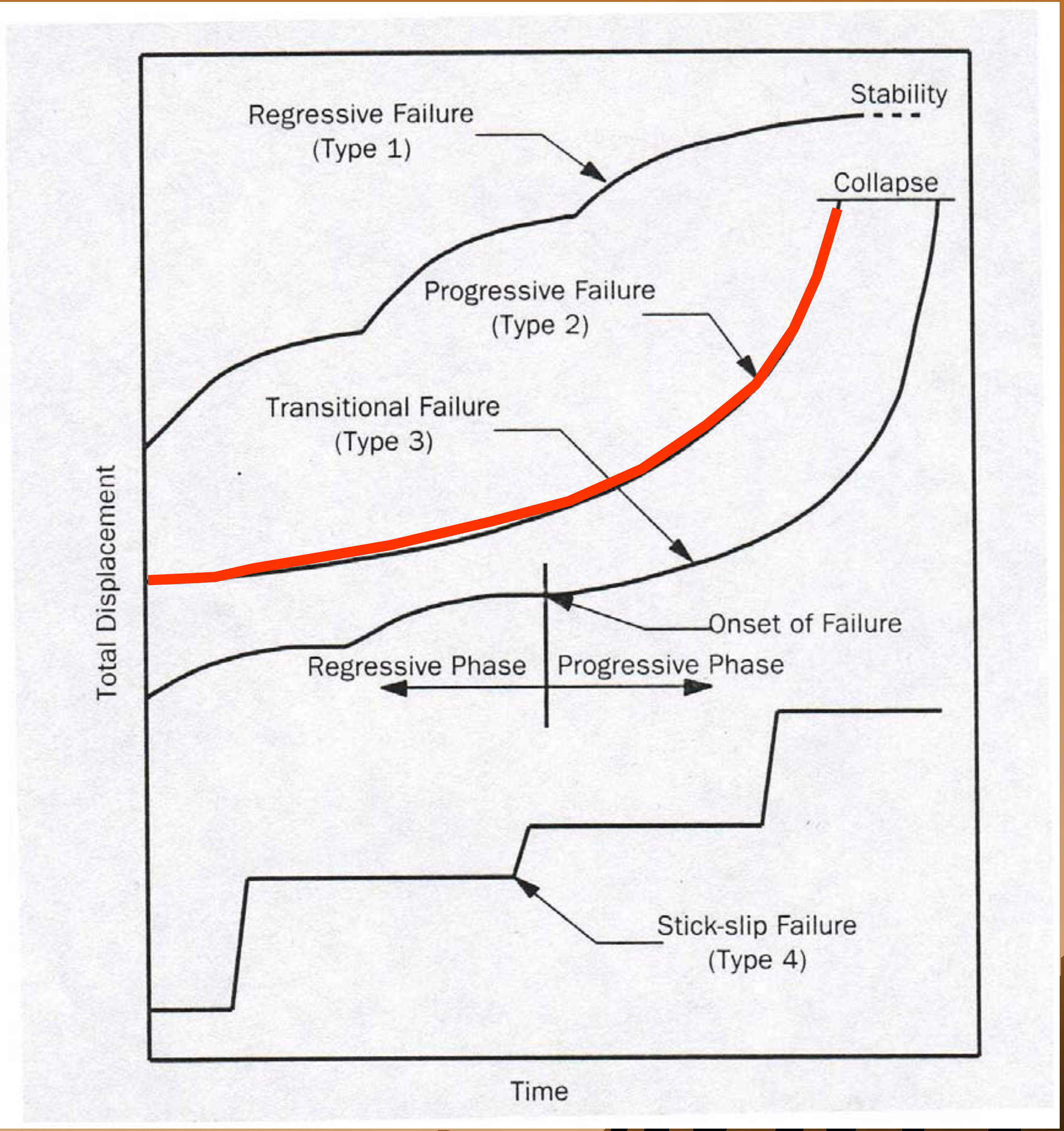
Rules to remember
(1) Falling rocks are Bad
(2) Remember to get up & stretch. (can't) (see) (rocks) (w/eyes) (closed)
(3) See rules 1 & 2 if nessecary ask supervisor for futher explanation of rules 1 & 2

common sense Rule
(1) caffine, caffine

(1) all sarcasm for self entertainment only.

# Highwall Monitoring

- **An accurate historical movement vs. time record of highwall behavior is critical in evaluating the hazard potential.**




(Broadbent and Zavodni 1982)

# Monitoring with Instruments

- Monitoring with instruments provides quantitative information on minute highwall movements.
- New technologies can provide this information in real time, all the time.
- Example of new technologies include:
  - Wireline Extensometers;
  - Prism Surveying;
  - Global Positioning Systems (GPS);
  - Laser Imaging; and
  - Slope Scanning Radar.

# Manual Crack Growth Monitoring

# Wireline Extensometers

# Prism Surveying – Robotic Theodolite

# GPS Receiver

# Slope Stability Radar

# For Additional Assistance

**Contact Your Local MSHA Office**

**Or**

**Stan Michalek**
**Chief, Mine Waste and Geotechnical Engineering Division**
**Pittsburgh Safety and Health Technology Center**
**Mine Safety and Health Administration**
**(412) 386 - 6974**