HAZARDOUS HIGHWALLS – GROUND CONTROL FOR SURFACE MINES

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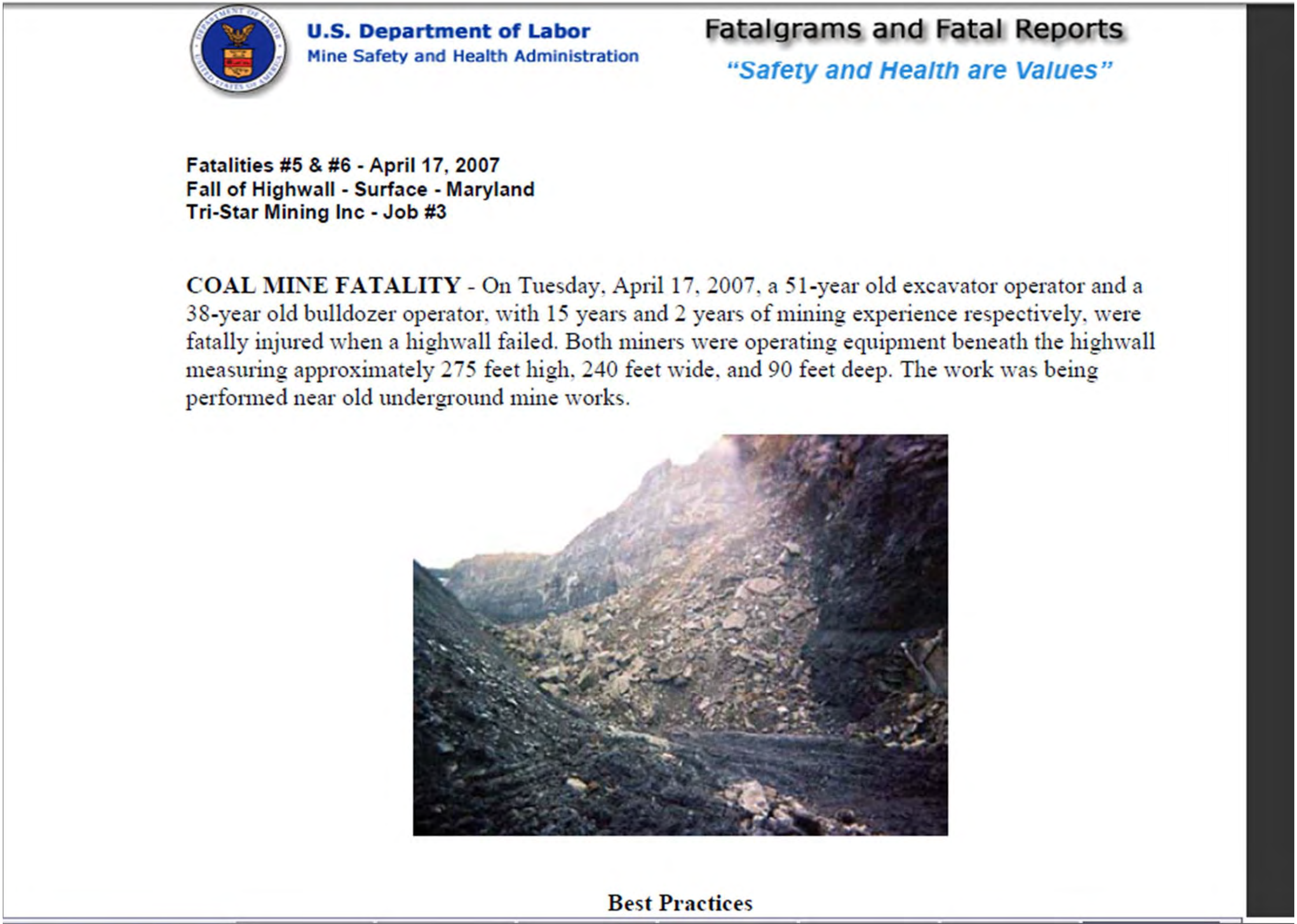


U.S. Department of Labor
Mine Safety and Health Administration

Fatalgrams and Fatal Reports

"Safety and Health are Values"

Fatalities #5 & #6 - April 17, 2007
Fall of Highwall - Surface - Maryland
Tri-Star Mining Inc - Job #3

COAL MINE FATALITY - On Tuesday, April 17, 2007, a 51-year old excavator operator and a 38-year old bulldozer operator, with 15 years and 2 years of mining experience respectively, were fatally injured when a highwall failed. Both miners were operating equipment beneath the highwall measuring approximately 275 feet high, 240 feet wide, and 90 feet deep. The work was being performed near old underground mine works.

Best Practices

GENERAL INFORMATION

Coal Mine Fatal Accident 2007-05 & 06

Operator: Tri-Star Mining, Inc.
Mine: Job #3
Accident Date: April 17,2007
Classification: Fall of Highwall
Location: Dist. 3, Allegany County, Maryland
Mine Type: Surface Coal Mine
Employment: 71
Production: 2,100 Tons/Day

MINING SAFETY IS NOT JUST FOR UNDERGROUND MINES!!

- GROUND CONTROL IS VERY IMPORTANT TO SURFACE MINES
- HIGHWALL FAILURES CAN BE DEADLY
- UNDERSTANDING THE ROCK MECHANIC PROPERTIES IS CRUCIAL

How are highwall hazards created?

- Highwall hazards are created when workers are exposed to highwalls with the potential for failure.
- It is critical that all impacts to a given highwall are identified, analyzed, and provisions incorporated into the highwall design to account for all potentials hazards.

MINIMUM ROCK MECHANIC AND PHYSICAL FEATURES THAT MUST BE CONSIDERED FOR HIGHWALL SAFETY:

HIGHWALL DESIGN GEOMETRY

GEOLOGIC STRUCTURE

ROCK FRACTURING PATTERNS

HYDROGEOLOGIC CONDITIONS

HIGHWALL DESIGN GEOMETRY

Typical Highwall

GEOLOGIC STRUCTURE

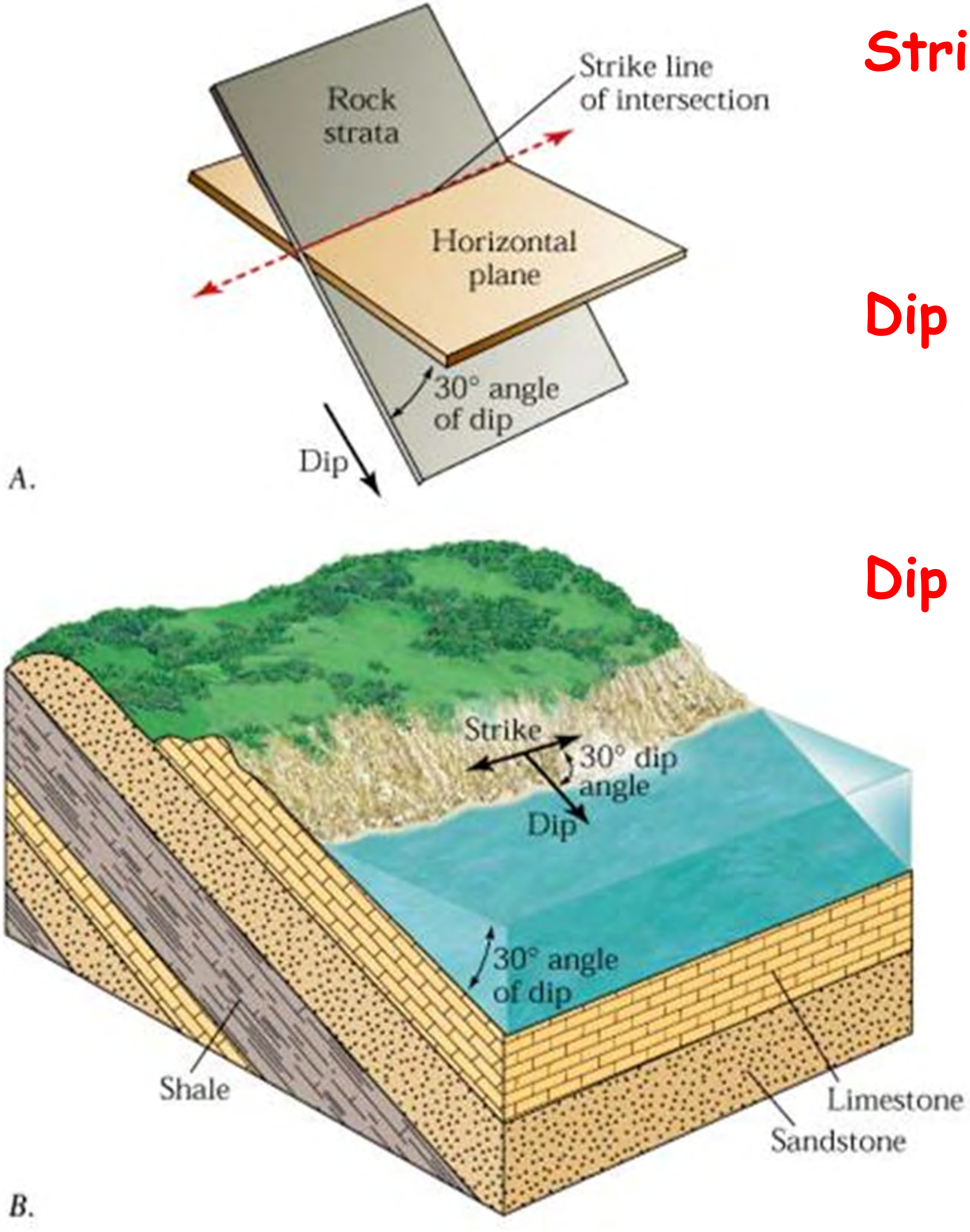
A little geometry: A plane can be defined by two lines

For geology, we use either

- **-Strike and Dip**

or

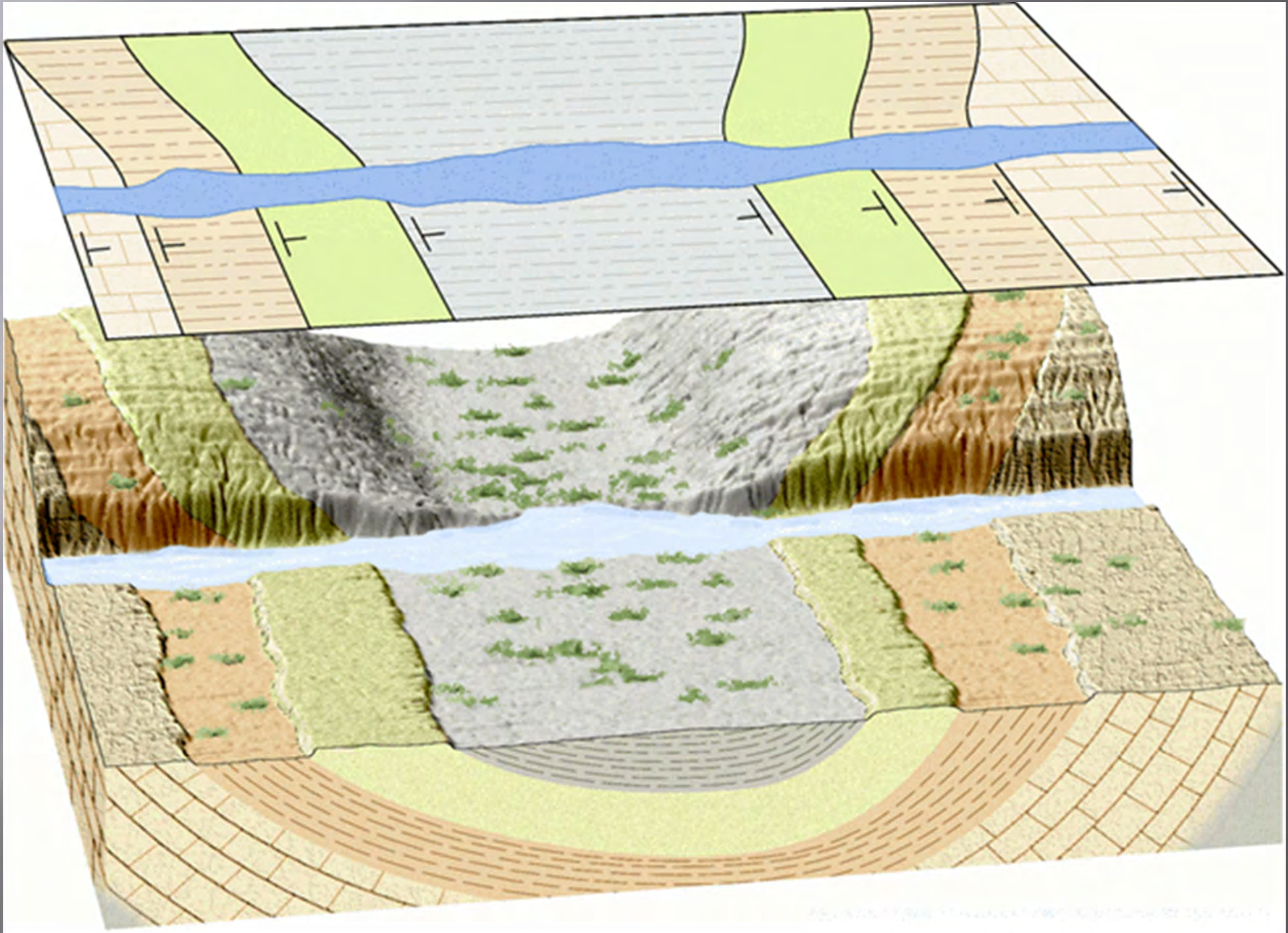
- **-Dip and Dip direction**



Strike – Direction of
ontal line in a dipping

Dip – The true maximum
of a bed measured
horizontal

Dip Direction – Direction
e maximum dip; also
rom strike



ROCK MECHANICS DISCONTINUITIES:

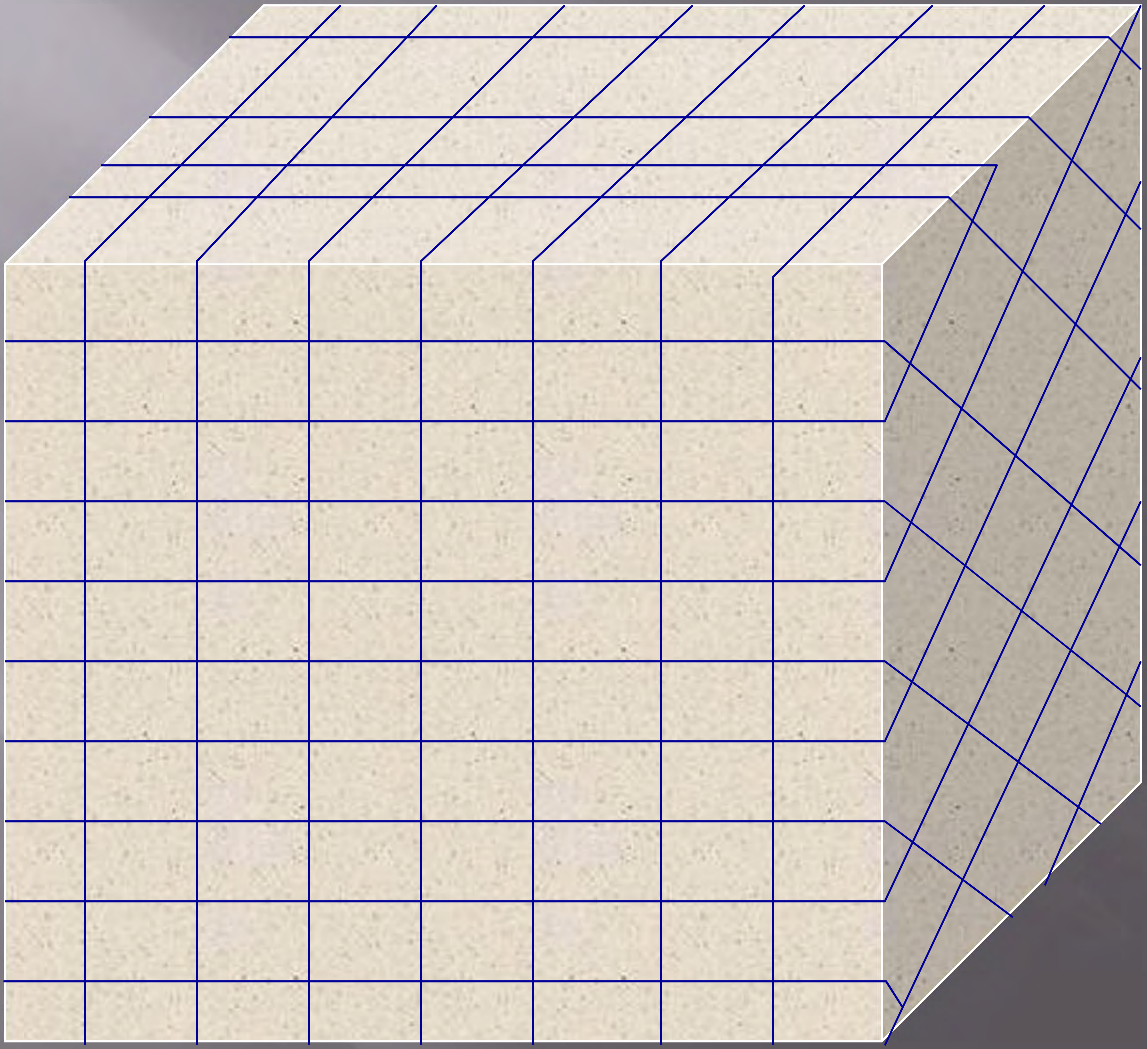
BEDDING
JOINTS
FRACTURES

GENERALLY THE HIGHWALL ROCK MASS PROPERTIES CAN DIFFER GREATLY FROM THE INTACT INDIVIDUAL ROCK BLOCKS

Discontinuities

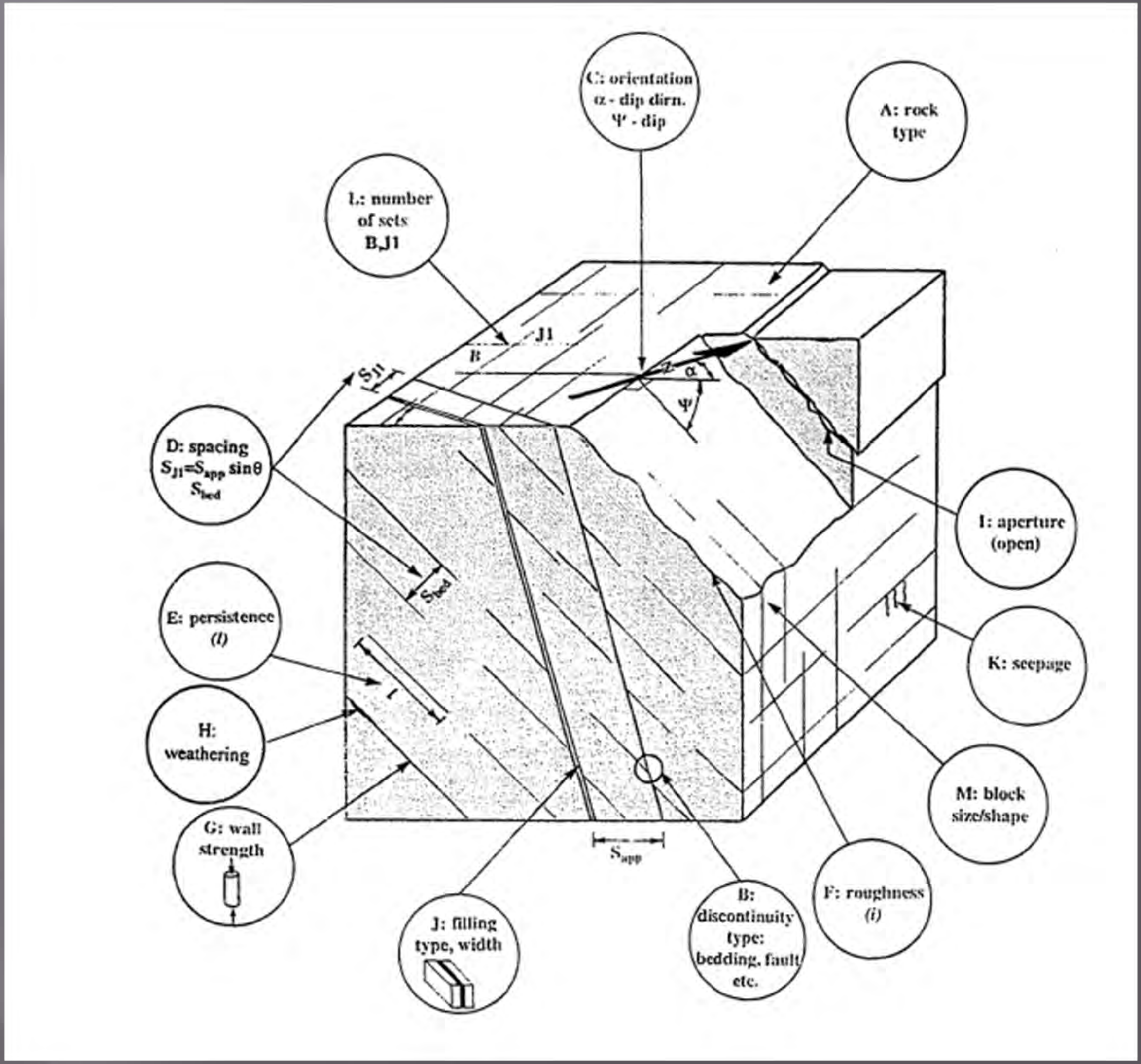
- A discontinuity is defined as a disconnect in the continuity of rock material.
- It creates a weak structural plane where movement and failure can occur.

Effect of Discontinuities on Intact Rock



Properties of Discontinuities

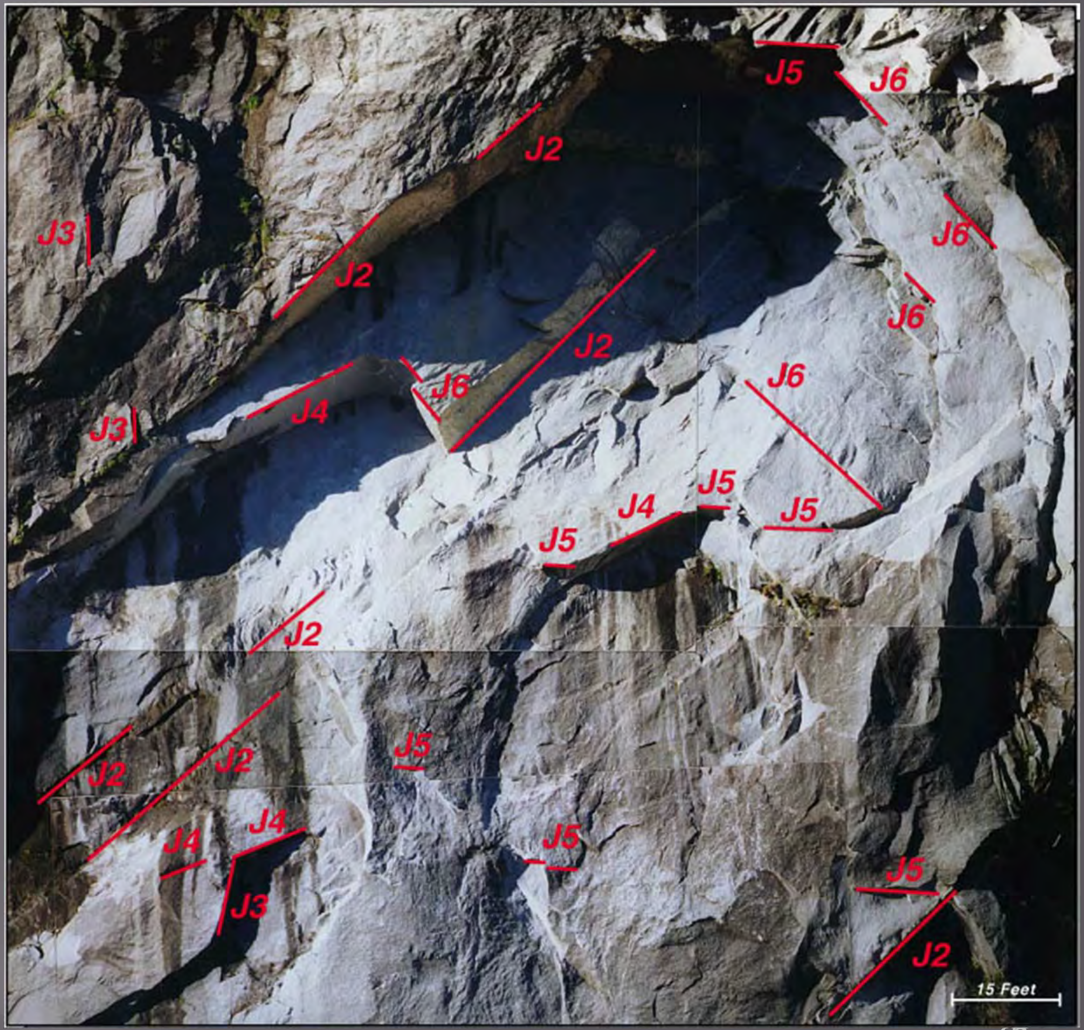
- Orientation
- Spacing
- Persistence
- Roughness
- Aperture
- Infilling
- Seepage
- Number of Sets
- Block Size



(USDOT 1998)

Obtaining Data on Discontinuities

- Field mapping
- Core drilling



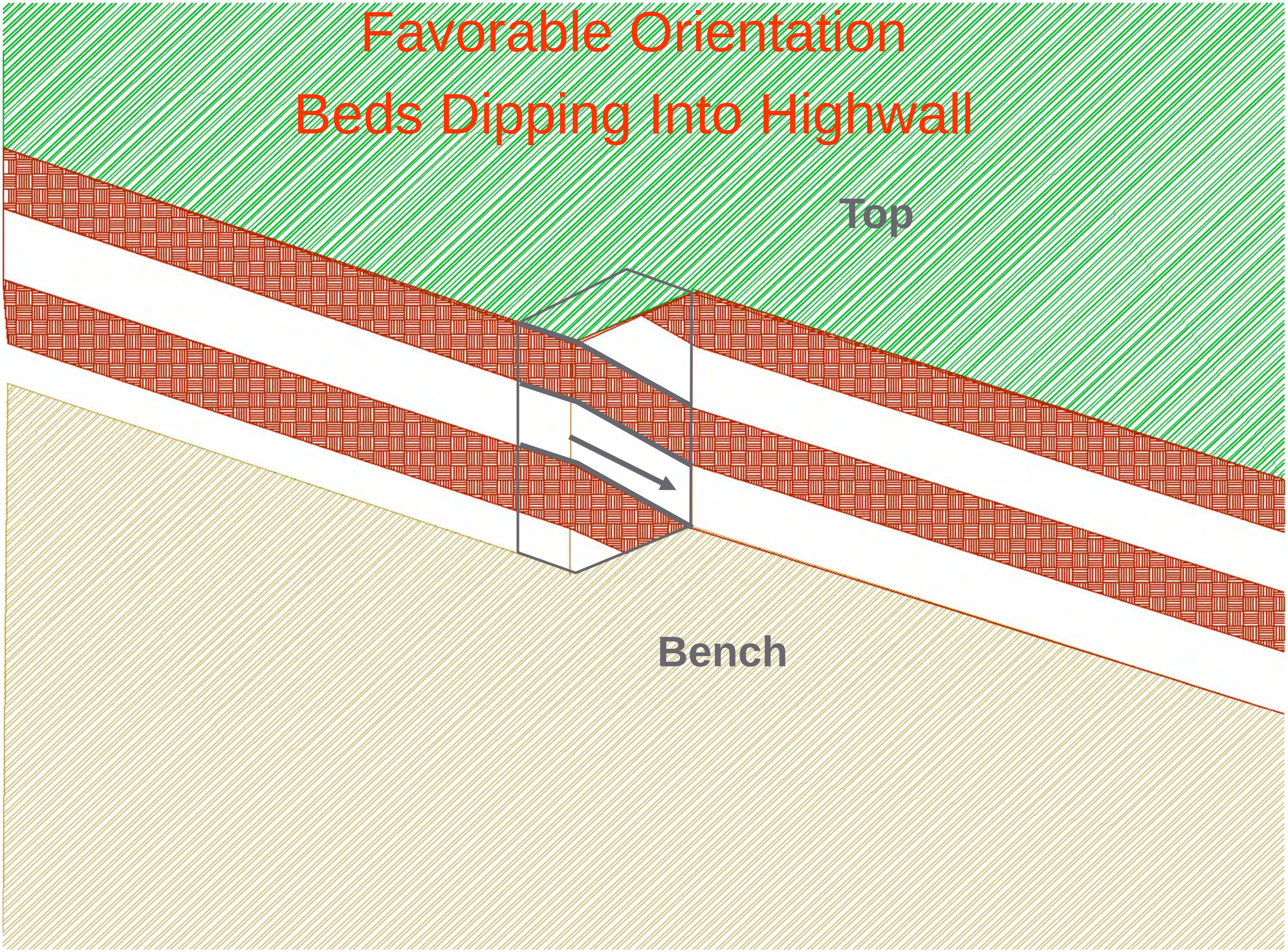

Dip
Dip

Bedding

Bedding

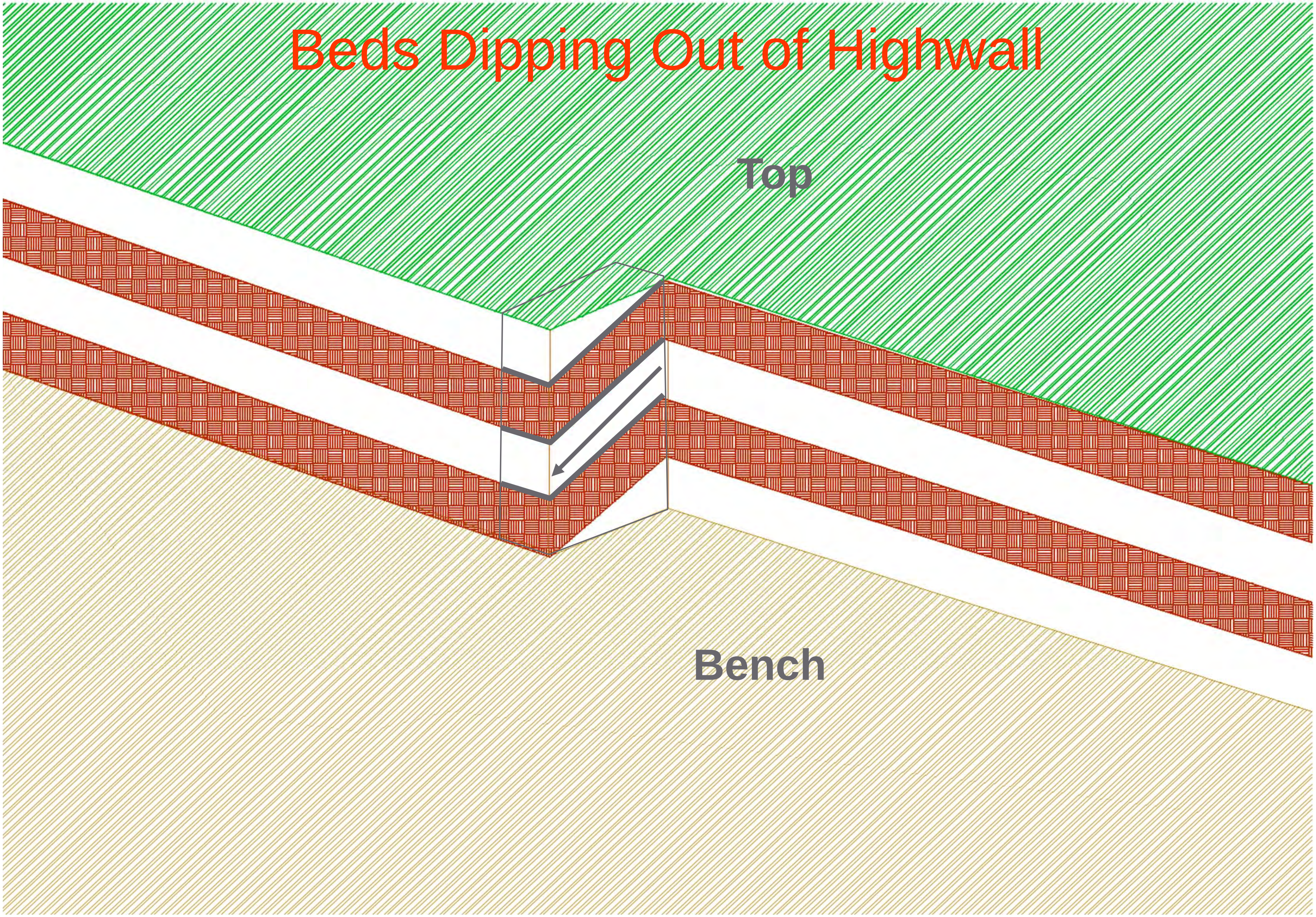
Moderately Dipping Bedding

Favorable Orientation
Beds Dipping Into Highwall



Unfavorable Orientation

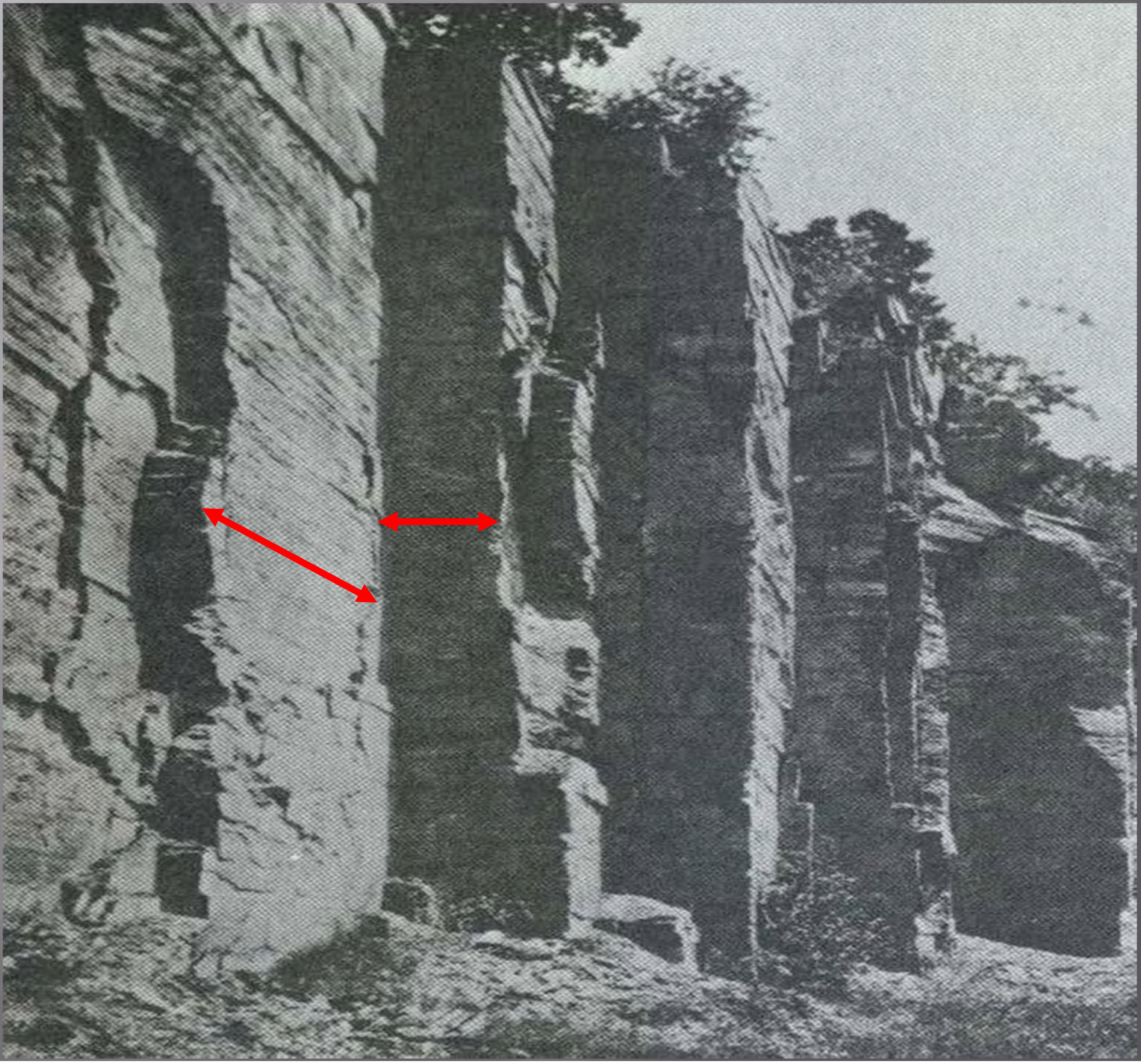
Beds Dipping Out of Highwall

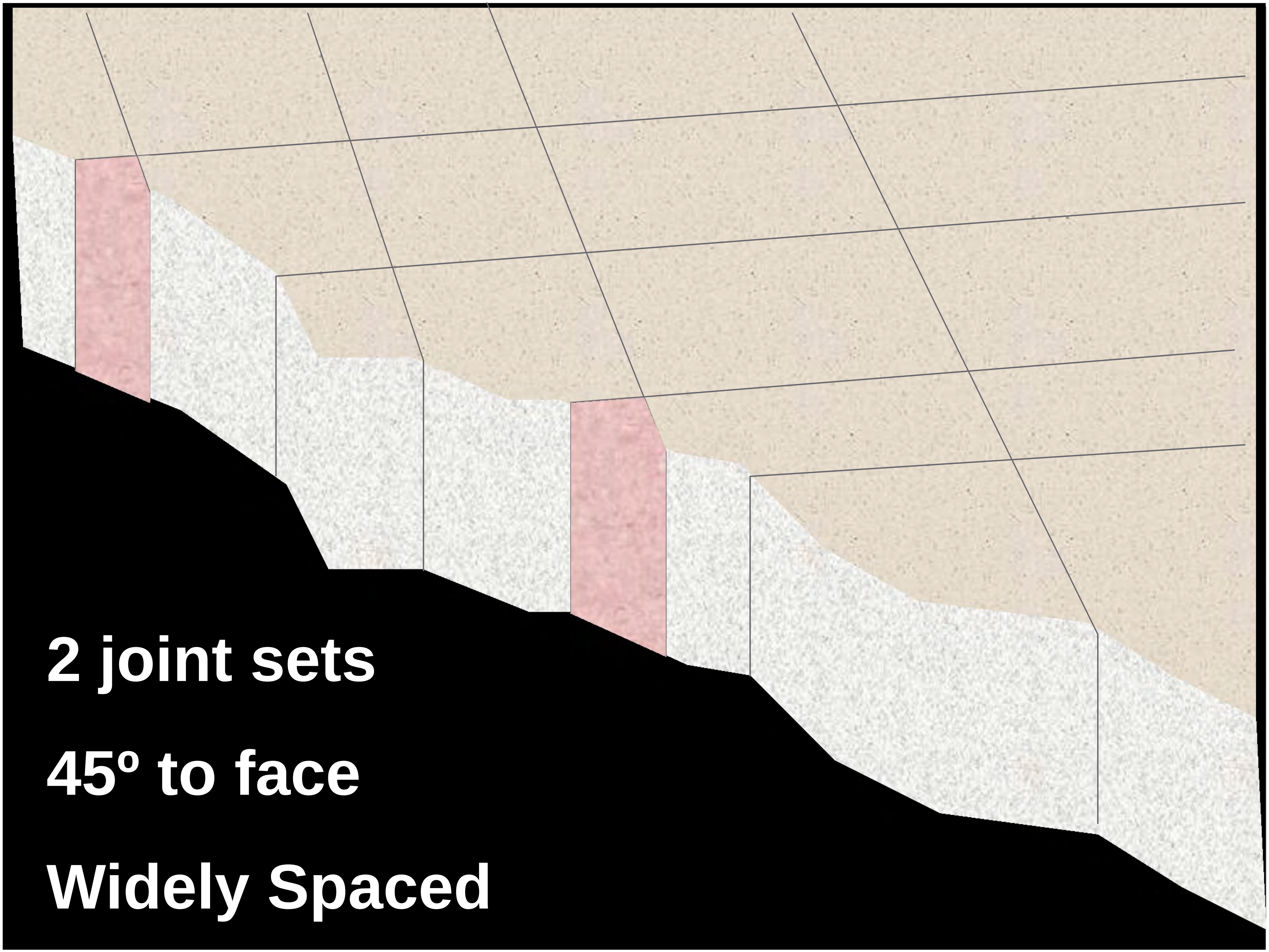


Joints

Joints

Two Sets of Vertical Joints (3-D)

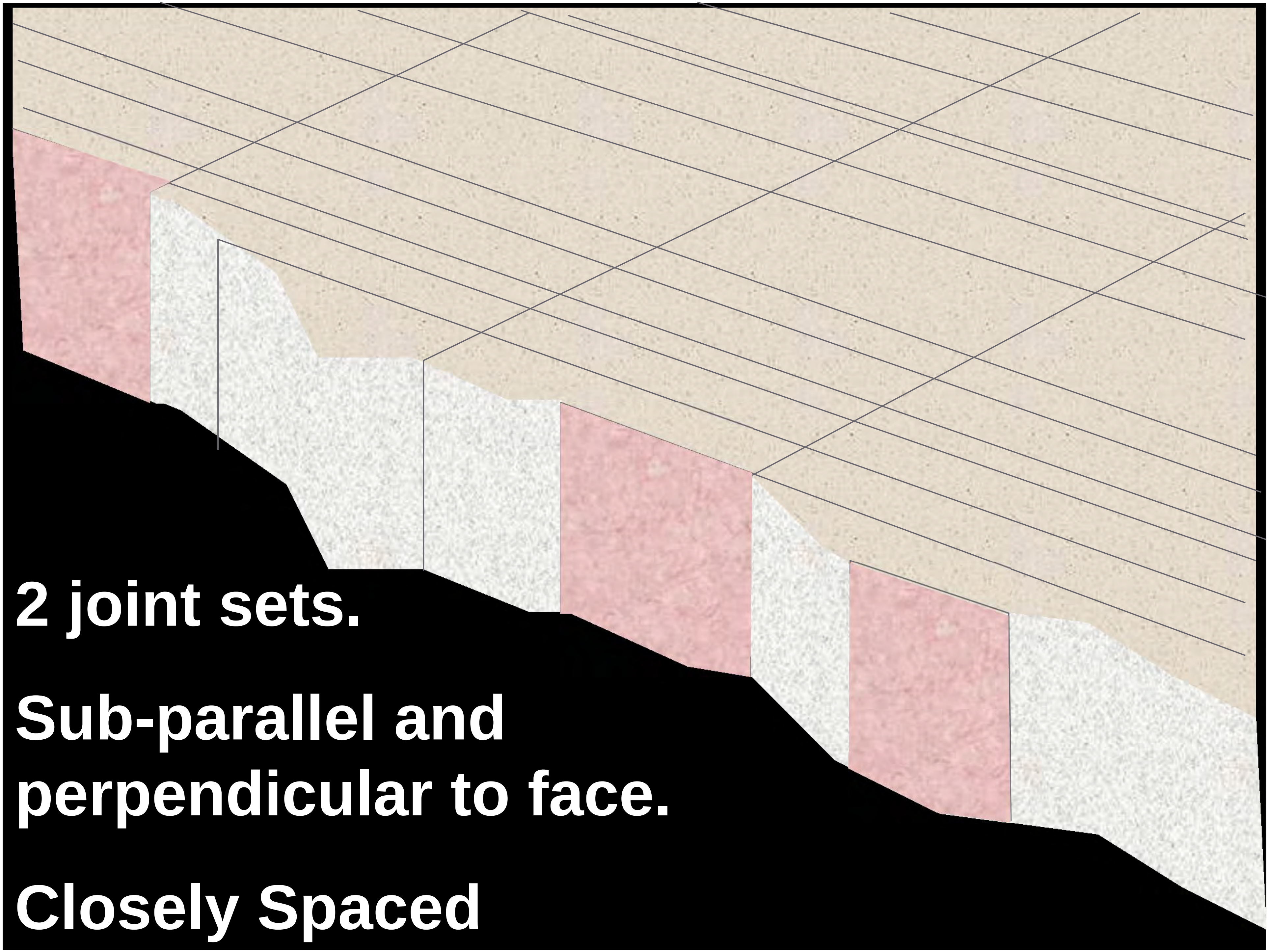




2 joint sets

45º to face

Widely Spaced



2 joint sets.

Sub-parallel and perpendicular to face.

Closely Spaced

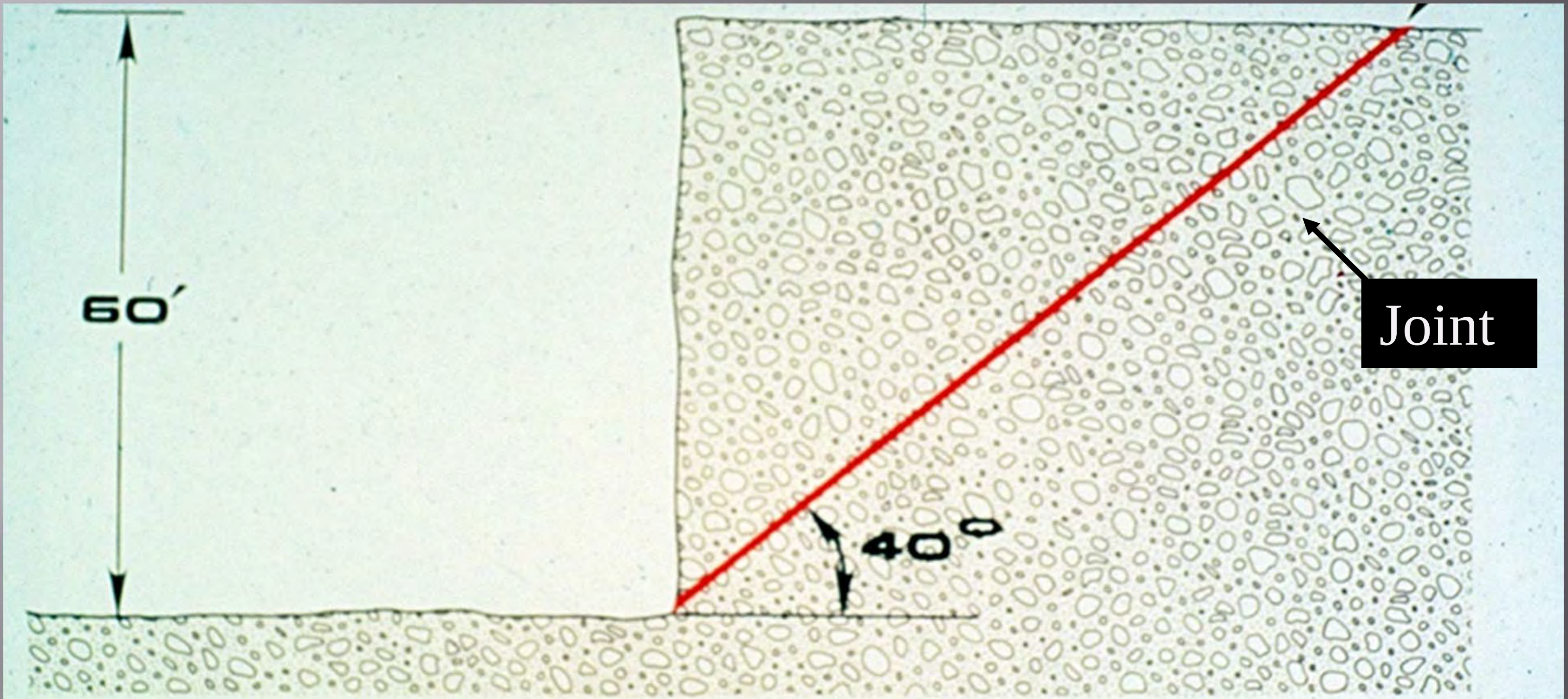
Non-Perpendicular Joint Intersection Near Face

HYDROGEOLOGIC CONDITIONS

Seepage

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

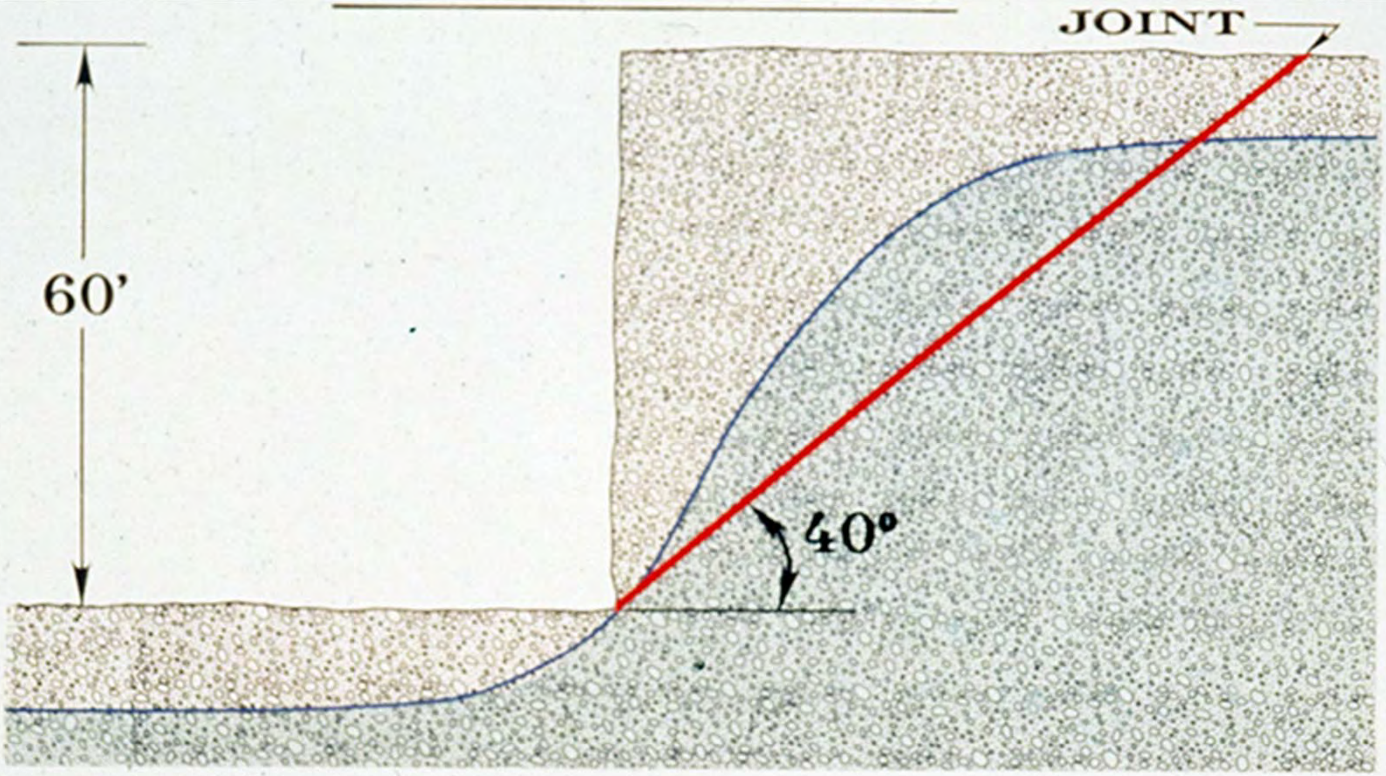
Dry Highwall FS=1.3



F.S. = 1.3

C = 1000 psf
Ø = 36°
D = 160 pcf

Saturated Highwall FS = 1.1



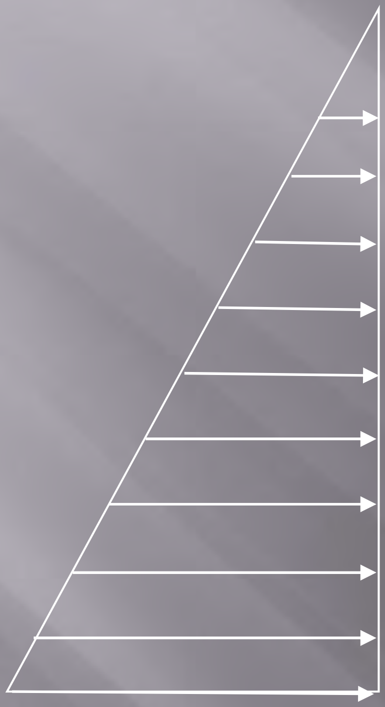
F.S. = 1.1

C = 1000 psf

Ø = 36°

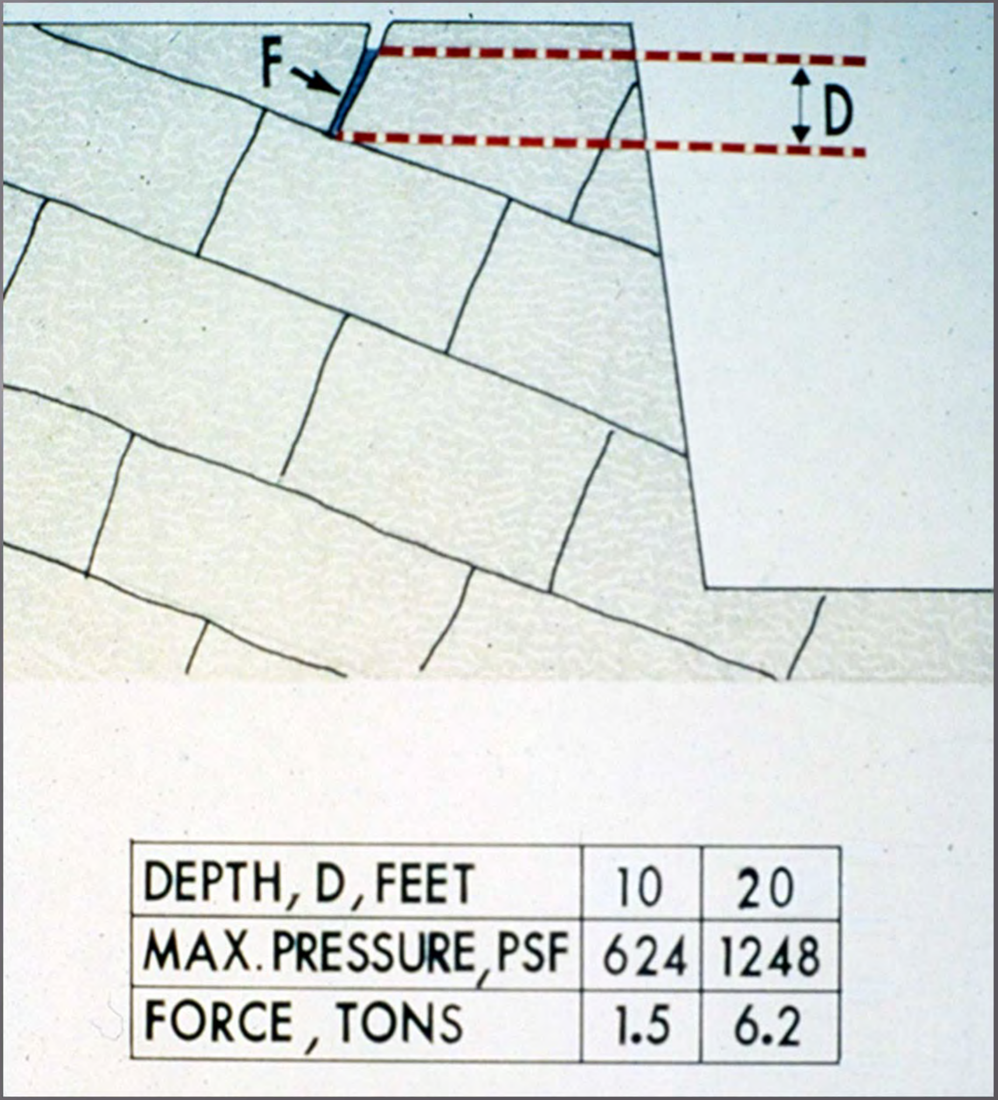
D = 160 pcf

Water Pressure in Joints



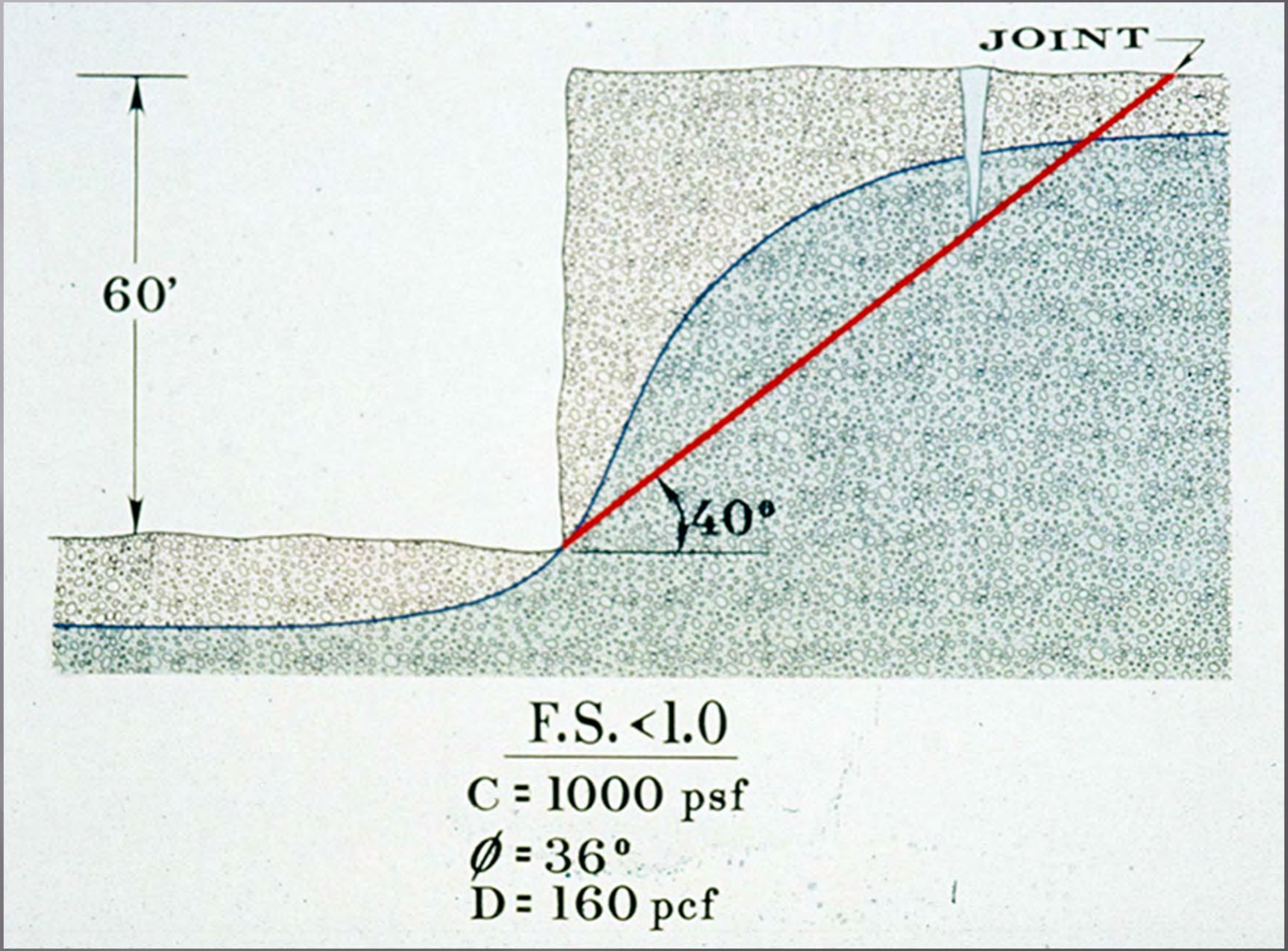
$$P_{\max} = 62.4\, x\, depth$$

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

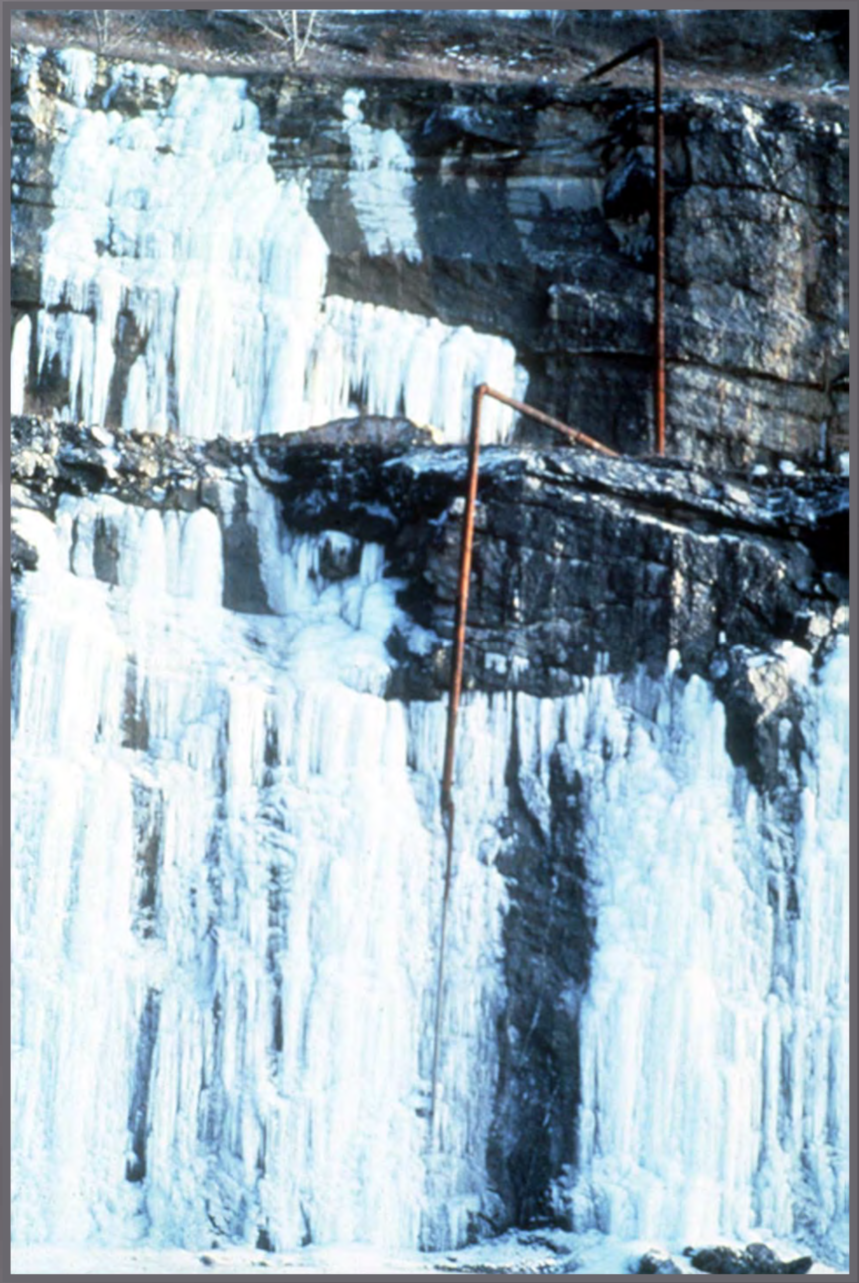


DEPTH, D, FEET	10	20
MAX. PRESSURE, PSF	624	1248
FORCE, TONS	1.5	6.2

Saturated Highwall with Water Column FS < 1.0

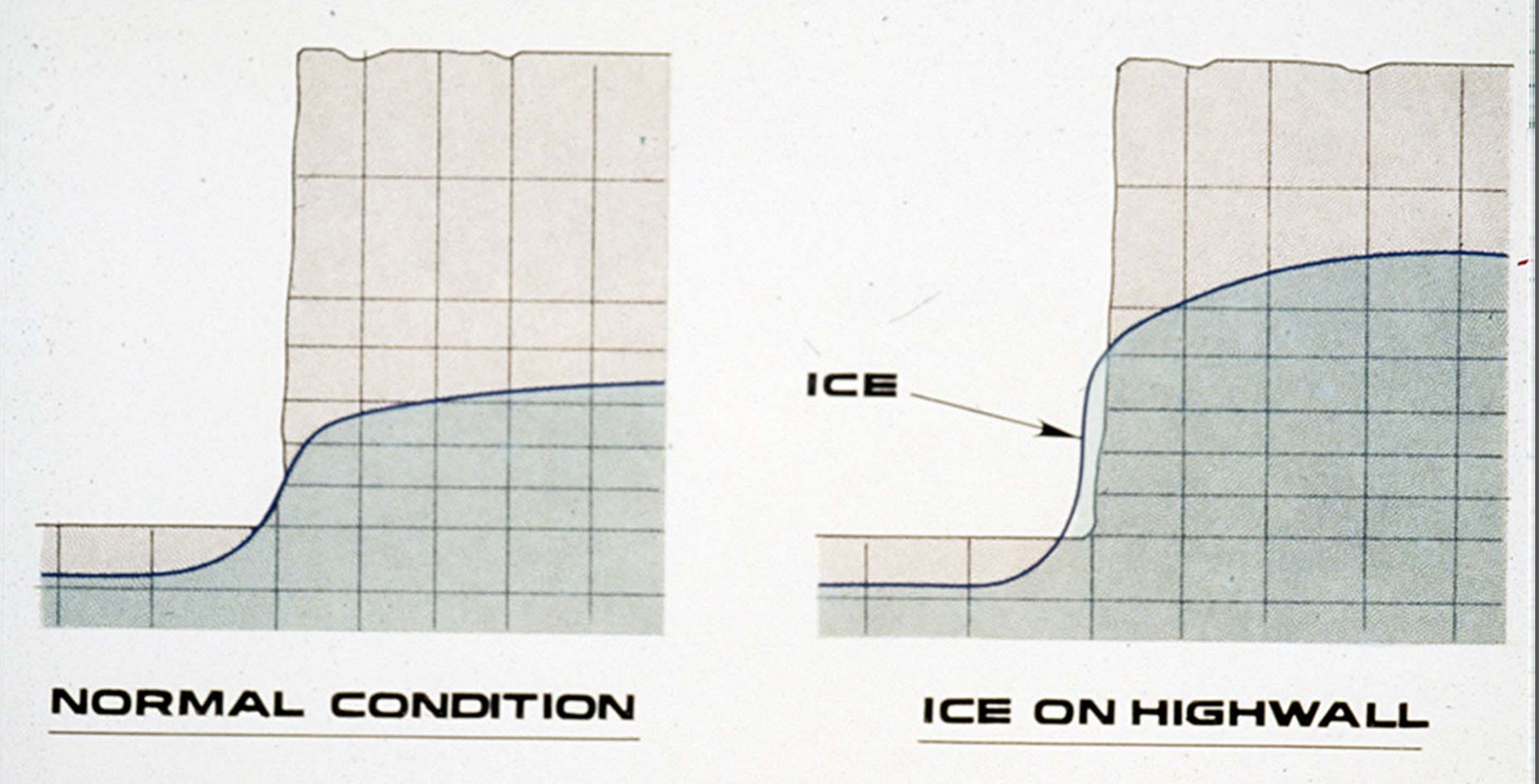


Ice is a Common Sight on Highwalls



- **It identifies seepage locations.**

Effects of Ice



- The ice acts as a dam on the face of the highwall which raises the internal water elevation.
- The ice also adds weight to the wall.

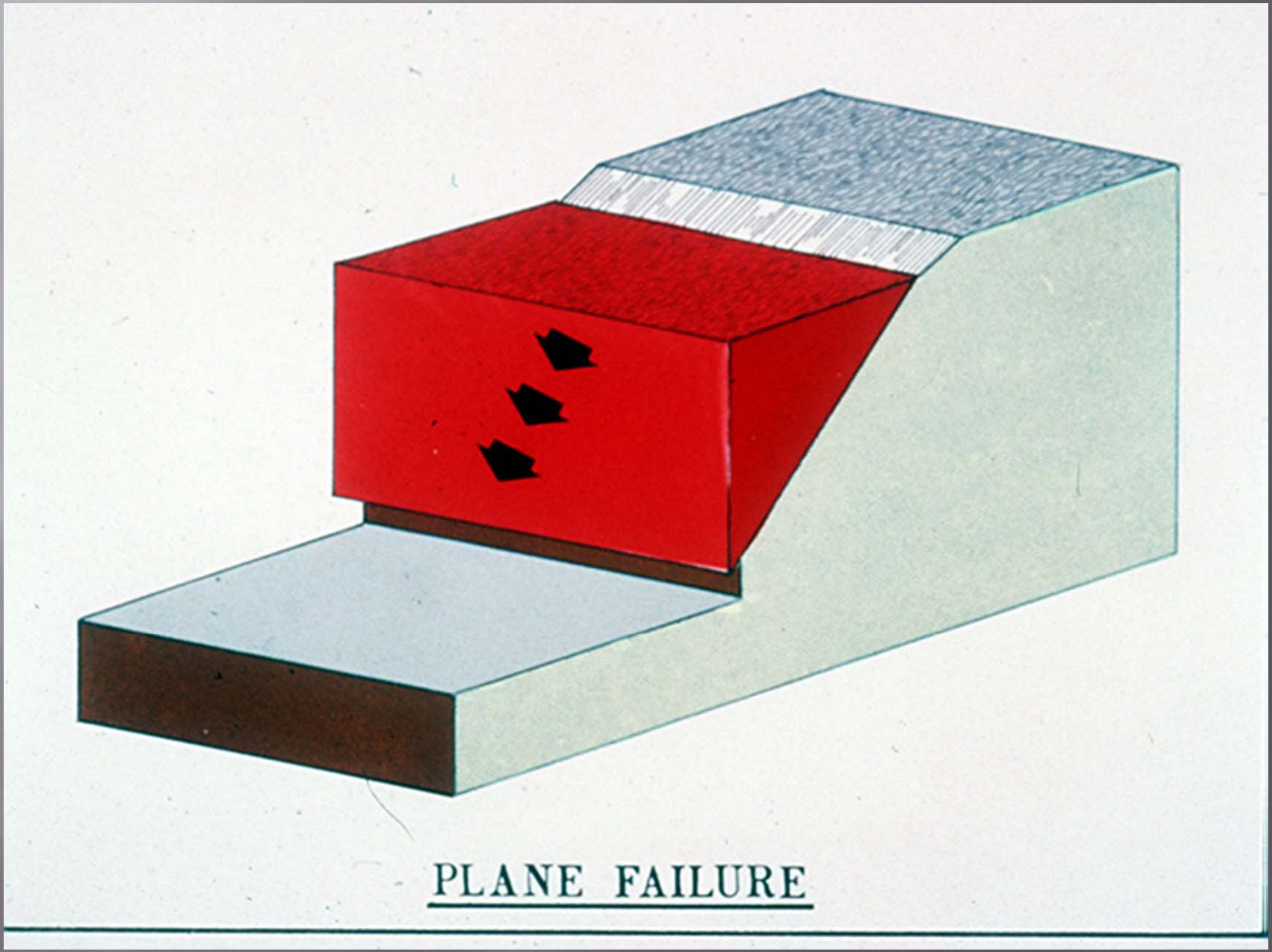
HIGHWALL FAILURE MODES

Rock Mass Failure Modes

- Planar
- Wedge
- Toppling
- Circular

Rock Mass Failure

Planar Failure



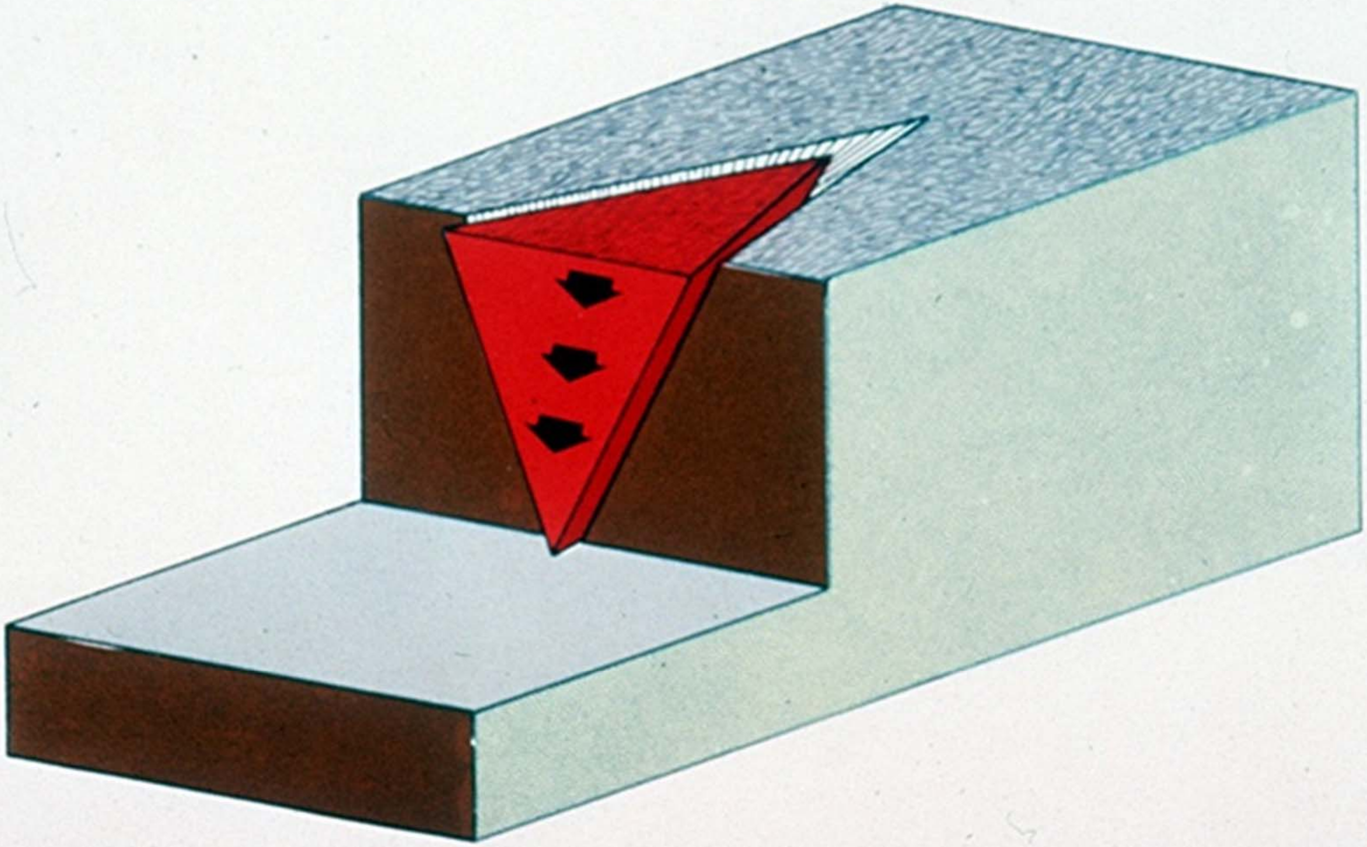
PLANE FAILURE

Planar Failure

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

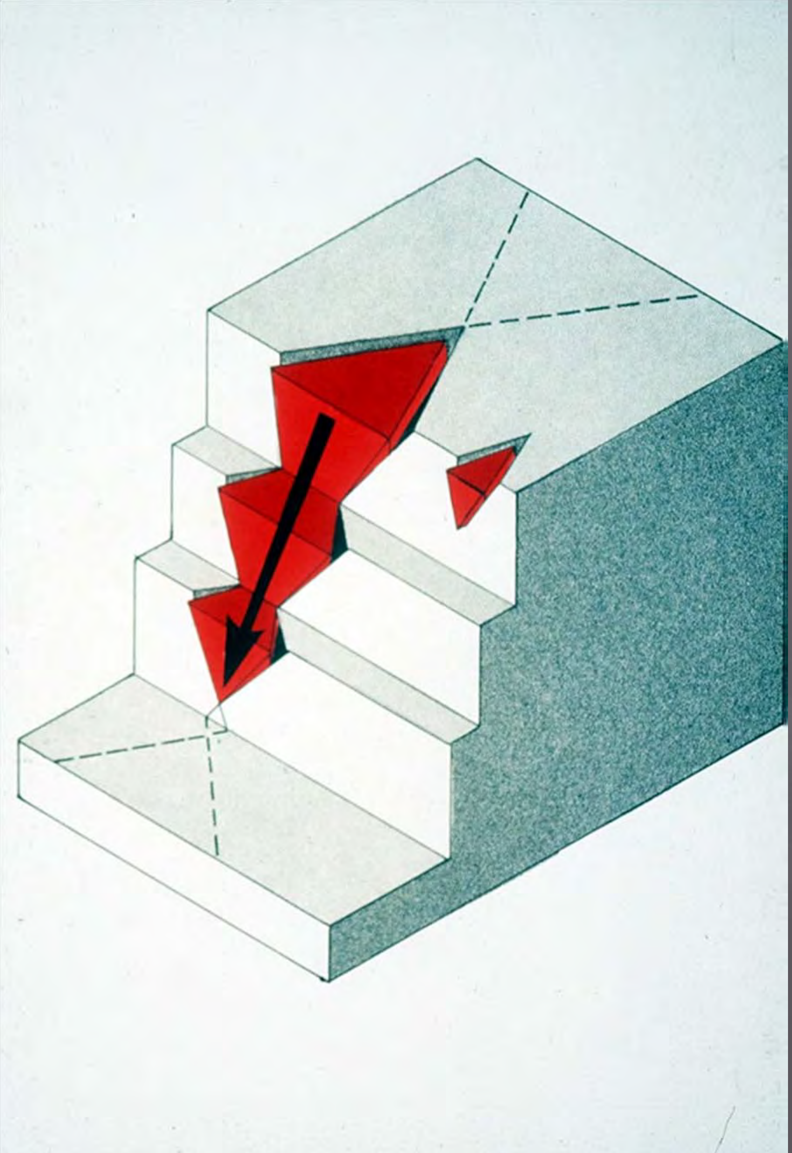
Planar Failure

Wedge Failure



WEDGE FAILURE

Wedge Failure

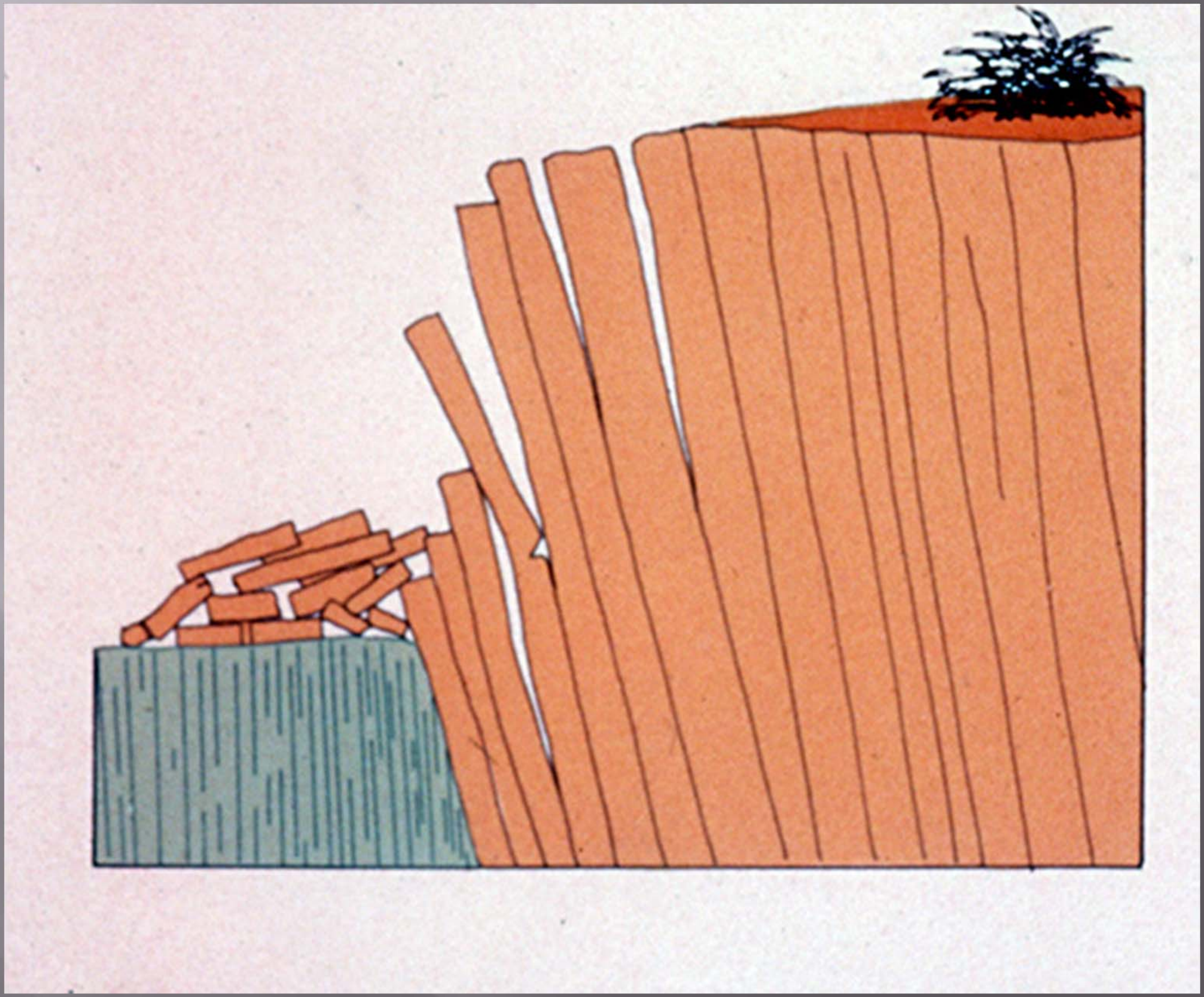


Wedge Failure

- Wedge failures involve sliding movement along two discontinuity surfaces that intersect at an angle forming a wedge shaped block in the highwall face.

Wedge Failure

Toppling Failure



Toppling Failure

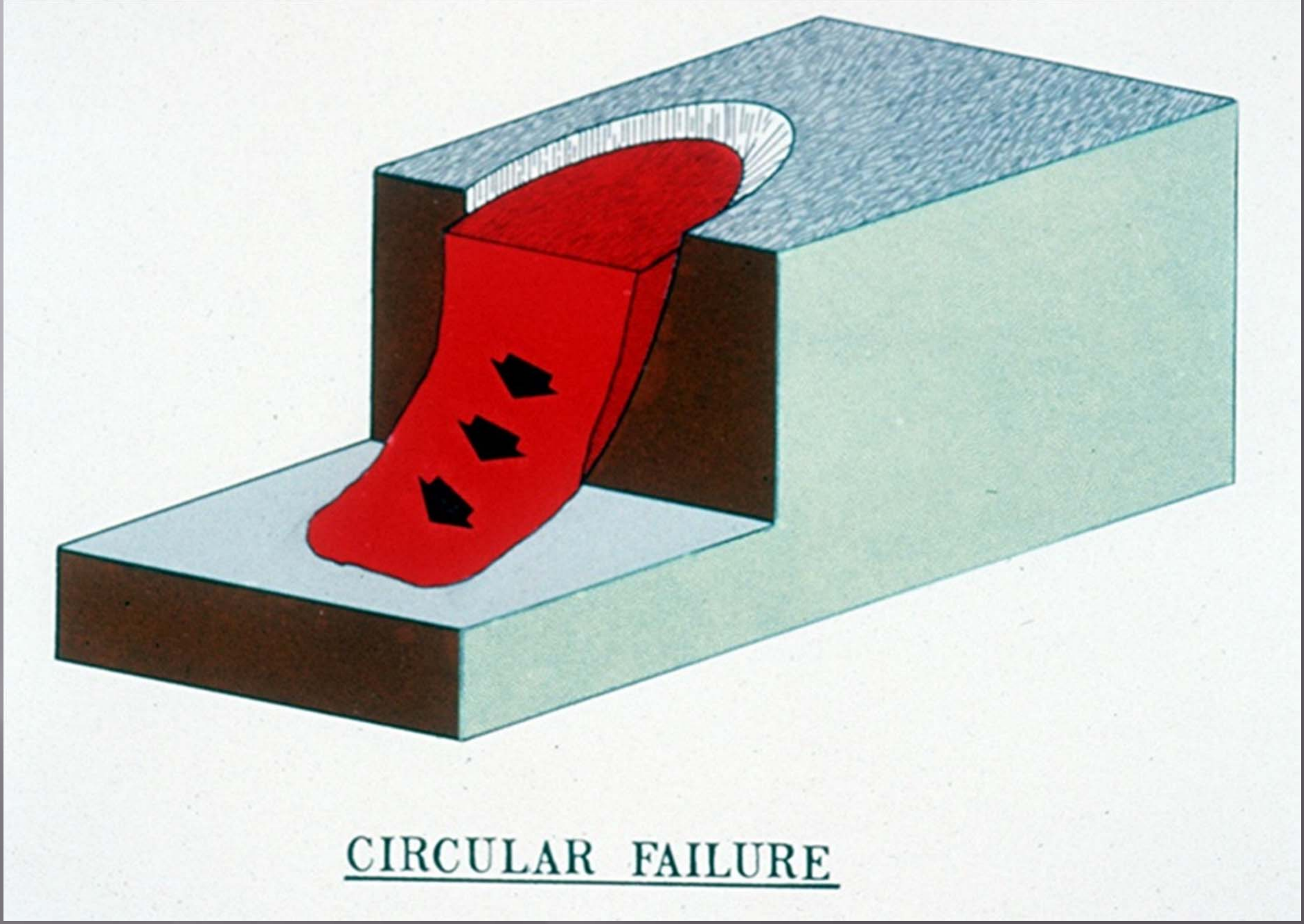
- Toppling failures involve rotational movement around the base of a slab or column formed by steeply dipping discontinuities oriented parallel or sub-parallel to the highwall face.

Non-Fatal Toppling Failure Accident

APR 26 2001

Non-Fatal Toppling Failure Accident

Circular Failure



Circular Failure

- Circular failures involve rotational and sliding movement along a failure surface. Circular failures are not common in small highwall situations < 100′. However, circular failures can and have occurred when highwalls are oriented near or parallel to fractures.

Circular Failure – Before

Circular Failure – After

Rock Falls

04/22/2003

GENERAL INFORMATION

Coal Mine Fatal Accident 2006-35

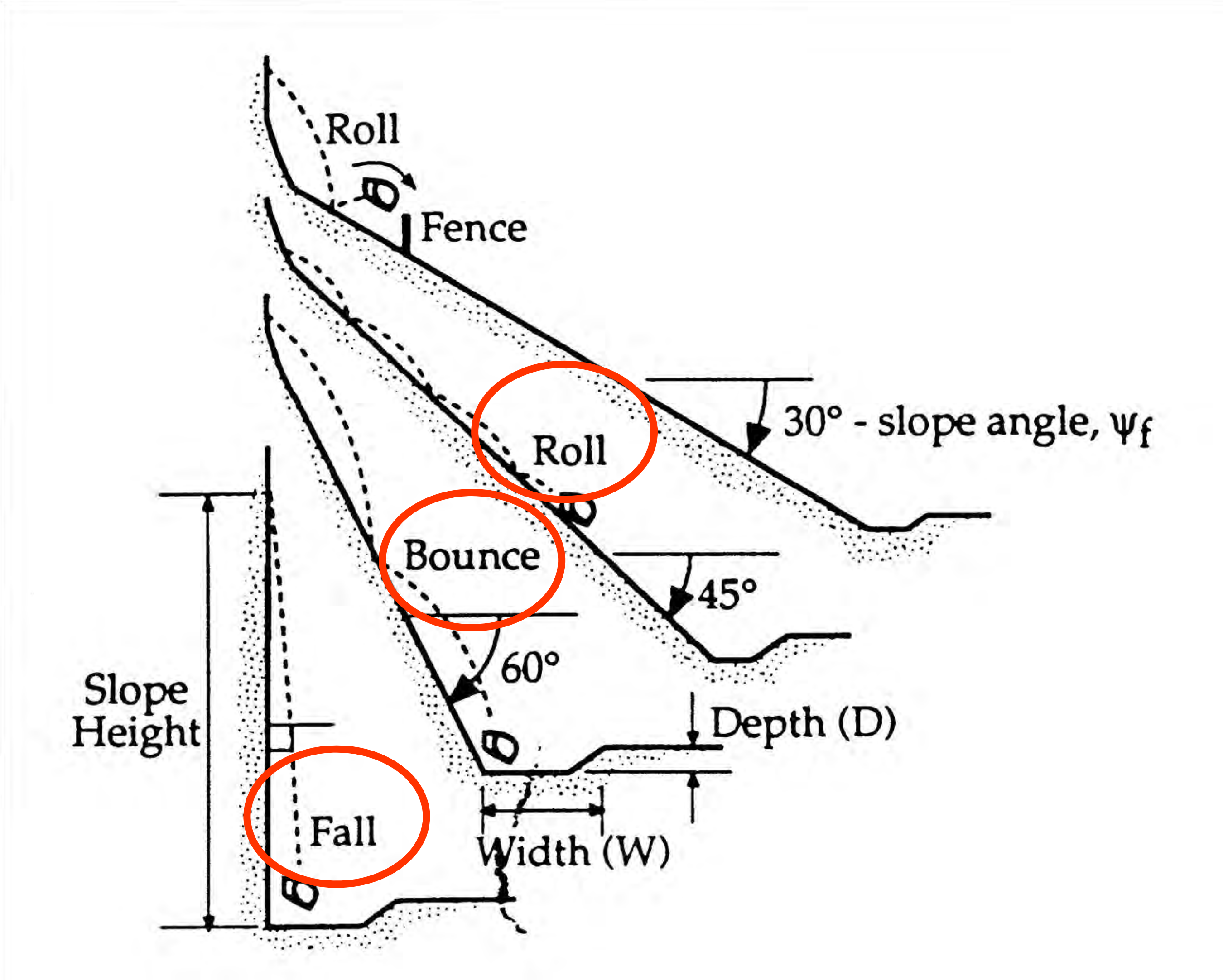
Operator: Hendrickson Equipment, Inc.
Mine: Smith Branch No. 1
Accident Date: July 18, 2006
Classification: Fall of Highwall
Location: Dist. 6, Knott County, Kentucky
Mine Type: Surface Coal Mine
Employment: 7
Production: 150 Tons/Day

Rock Fall Energy

Height of Fall (feet)	Approx. Weight (lbs)	Equivalent Cube Size (inches)	Max. Speed (mph)	Kinetic Energy (ft-lbs)	Approx. Force of Impact [1] (lbs)
50	2.5	3	39	125	500
100	2.5	3	55	250	1,000
125	2.5	3	61	313	1,250
160	2.5	3	69	400	1,600
50	20	6	39	1000	4,000
100	20	6	55	2000	8,000
125	20	6	61	2500	10,000
160	20	6	69	3200	12,800

[1] Assuming that the ground surface is soft enough that the rock penetrates the ground surface 3-inches upon impact. A smaller penetration results in a larger force of impact.

Effects of Highwall Geometry on Rock Fall



(Ritchie 1963)

Highwall Geometry

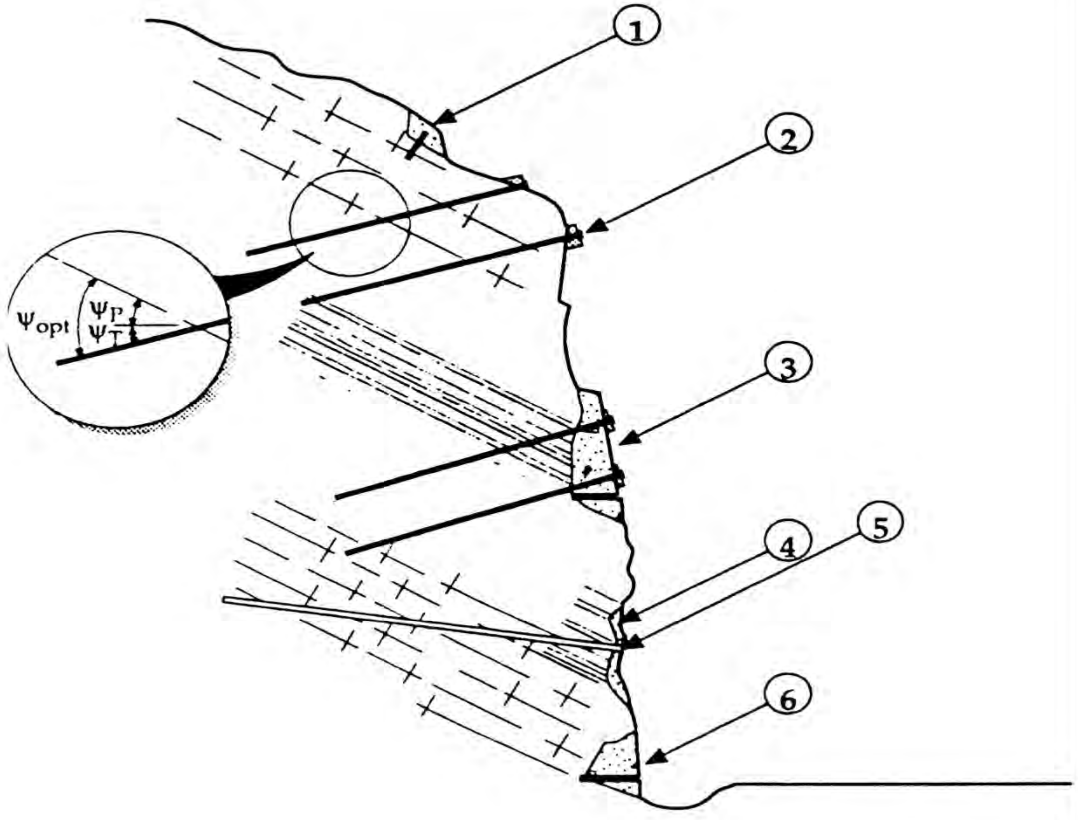
Rock rolling down face will not fall to toe

Ledge could cause rock to project further out

Launch Feature

REMEDIATING THE HAZARD

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 Anchors

Shotcrete Face

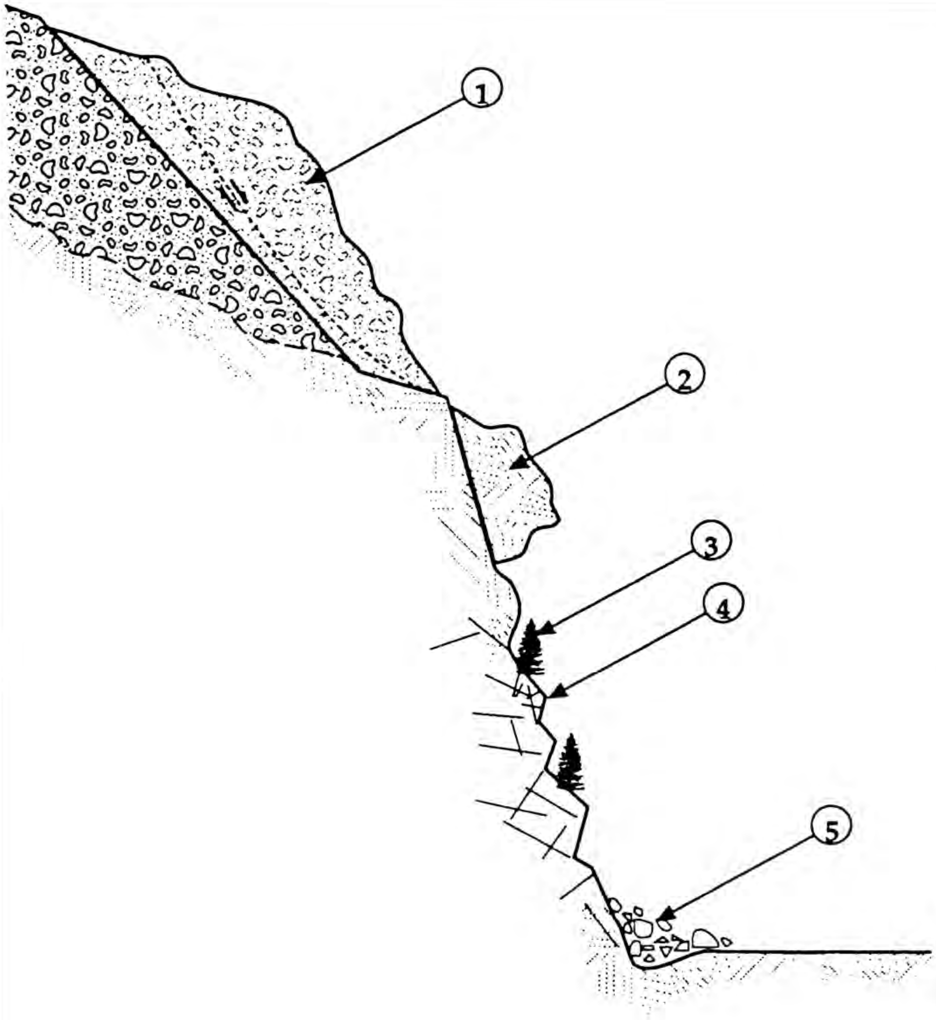
Drainage

- 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.**
- **Pre-splitting during blasting helps reduce broken rock in highwall face.**

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)

Scalers Supported by Ropes

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

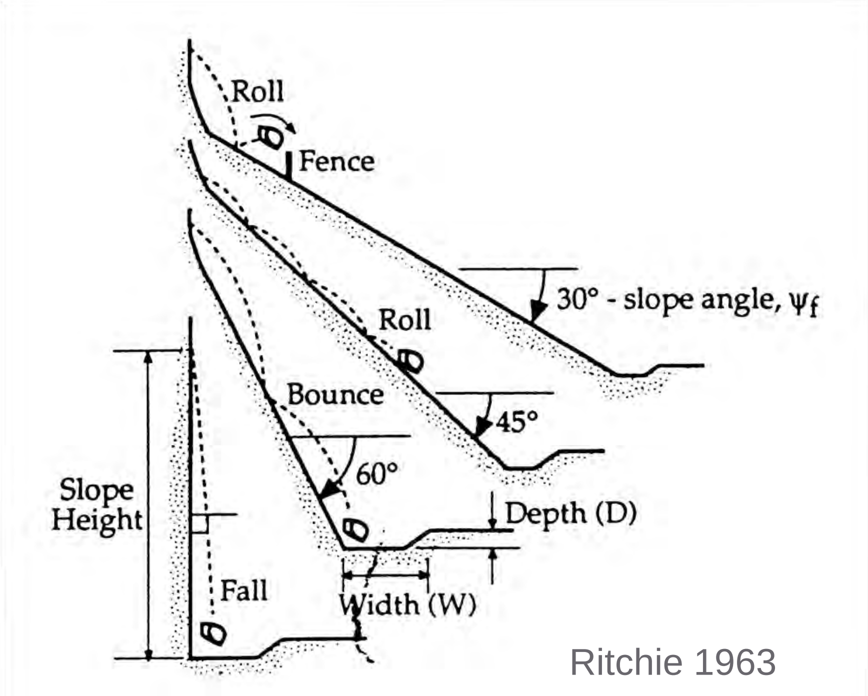
Mesh on Highwall

Catch Fence

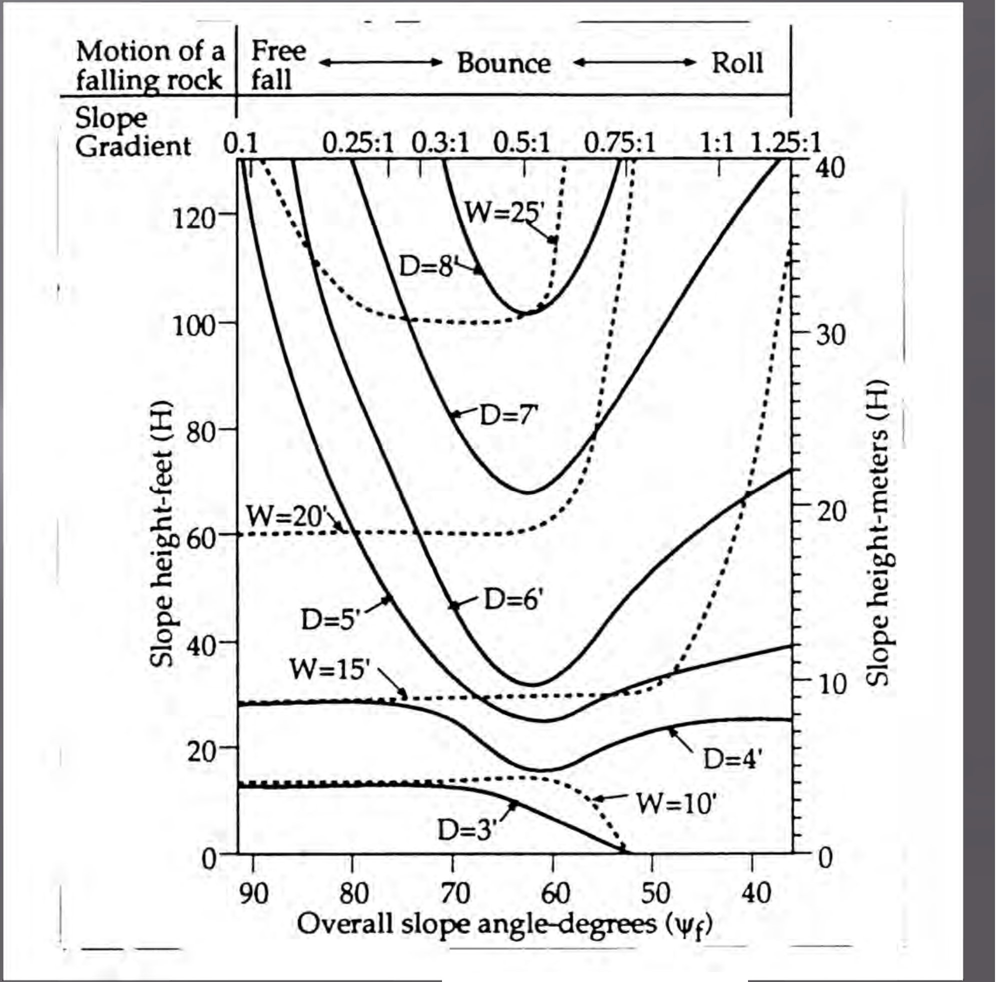
Protection Measures More Commonly Used in Mining

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

Rock Catch Ditches



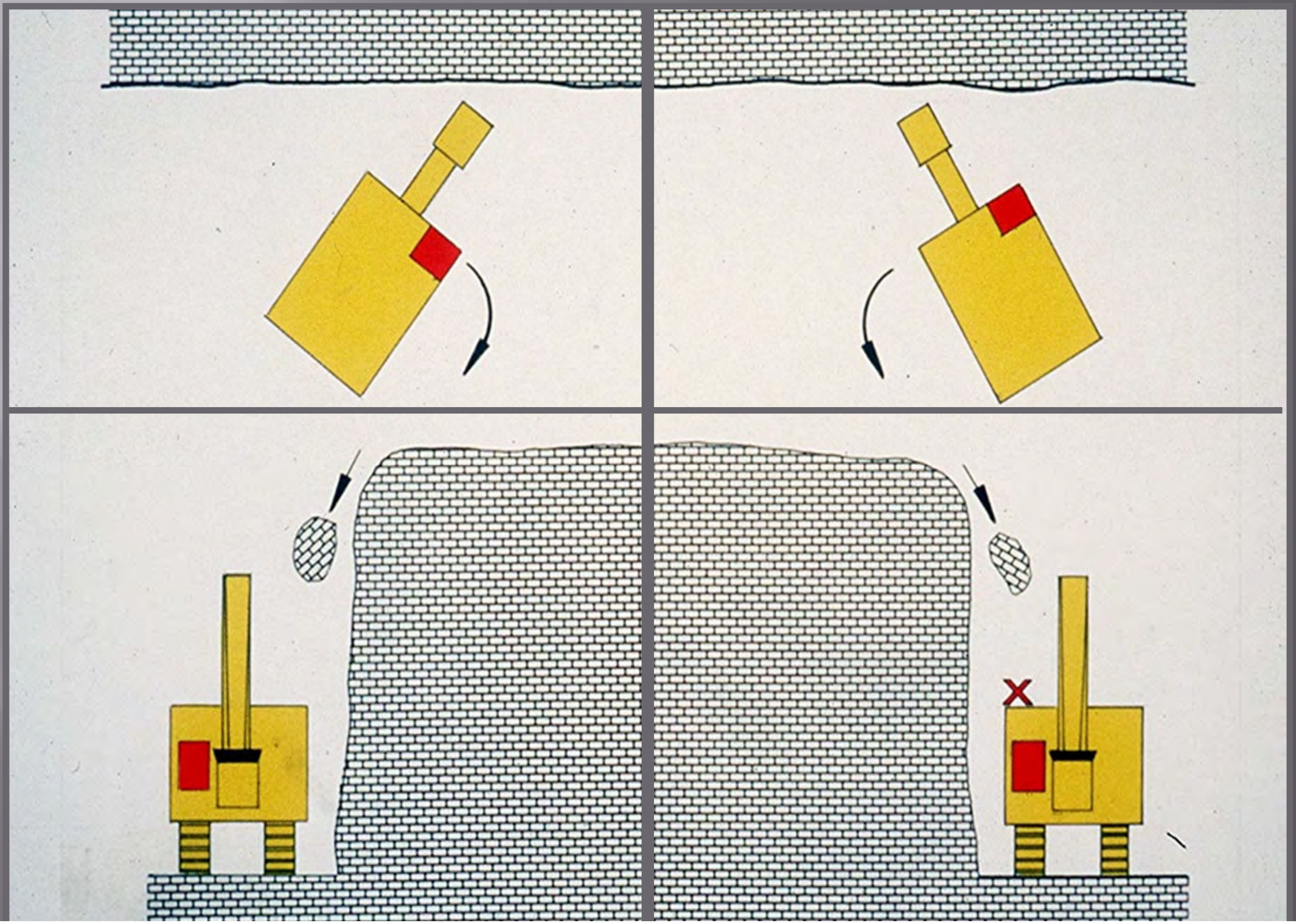
Ritchie 1963



Ritchie 1963

Methodology can also be used to design berms.

Equipment Position Relative to the Highwall Face



Benches reduce the distance a rock can fall

Full Benches

Berm Containing Material

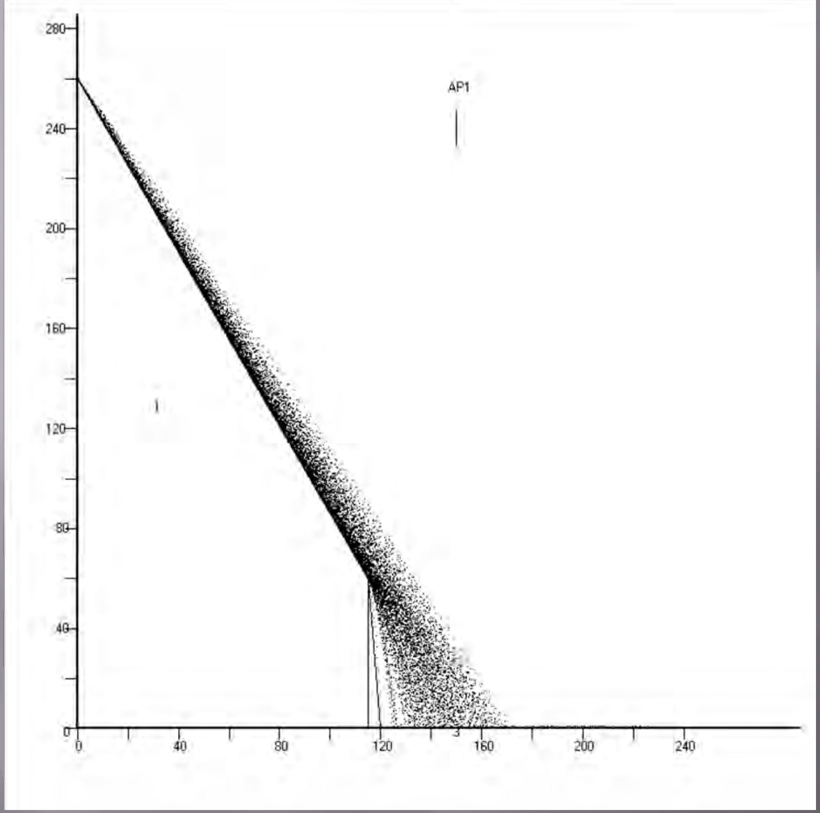
Berm Not Containing Material

Is Berm Properly Sized and Located?

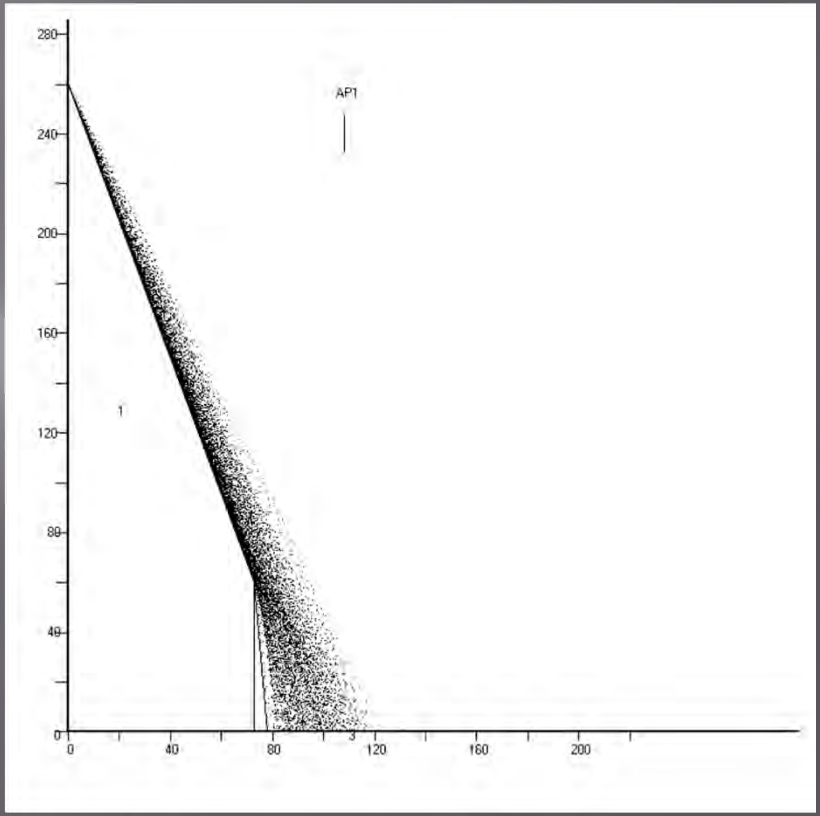
Computer Modeling

- **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.**

70-degree vs. 80-degree slope angles

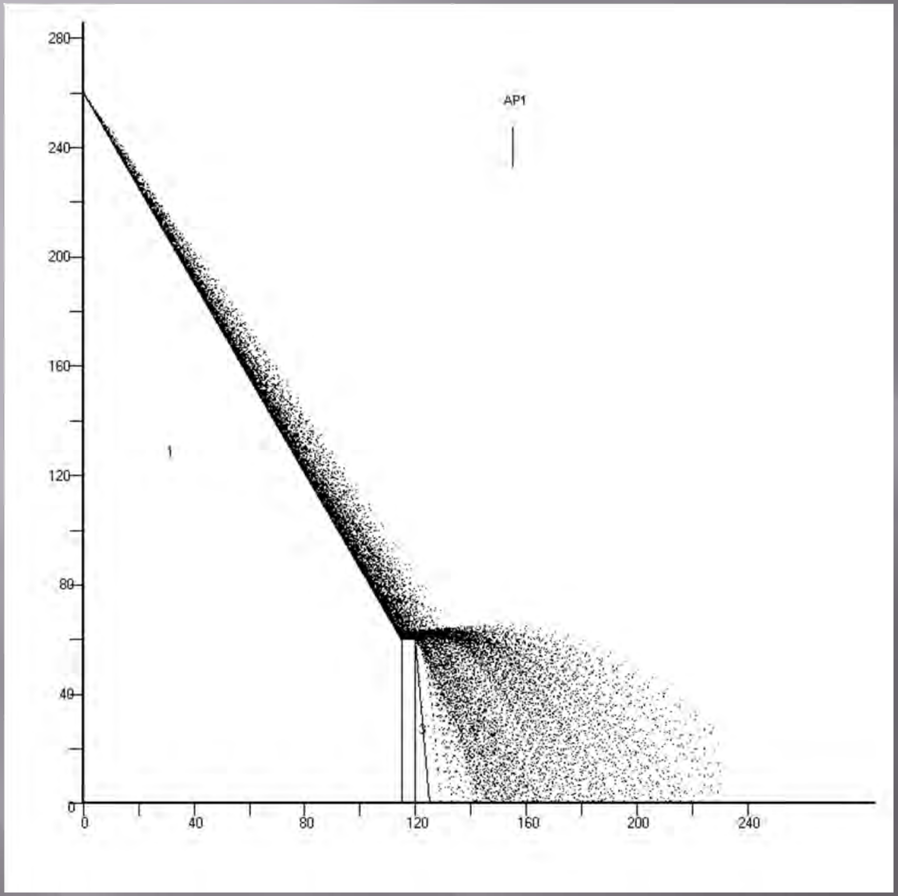


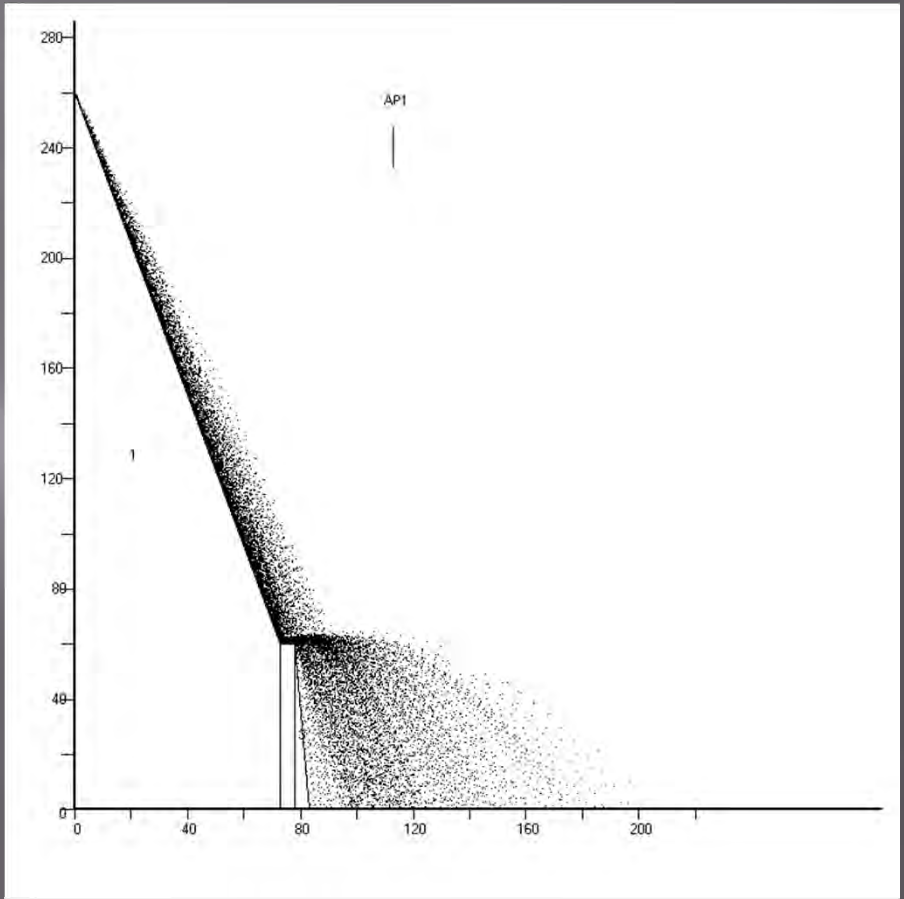
60 feet



25 feet

Highwalls with a Ledge





120+ feet

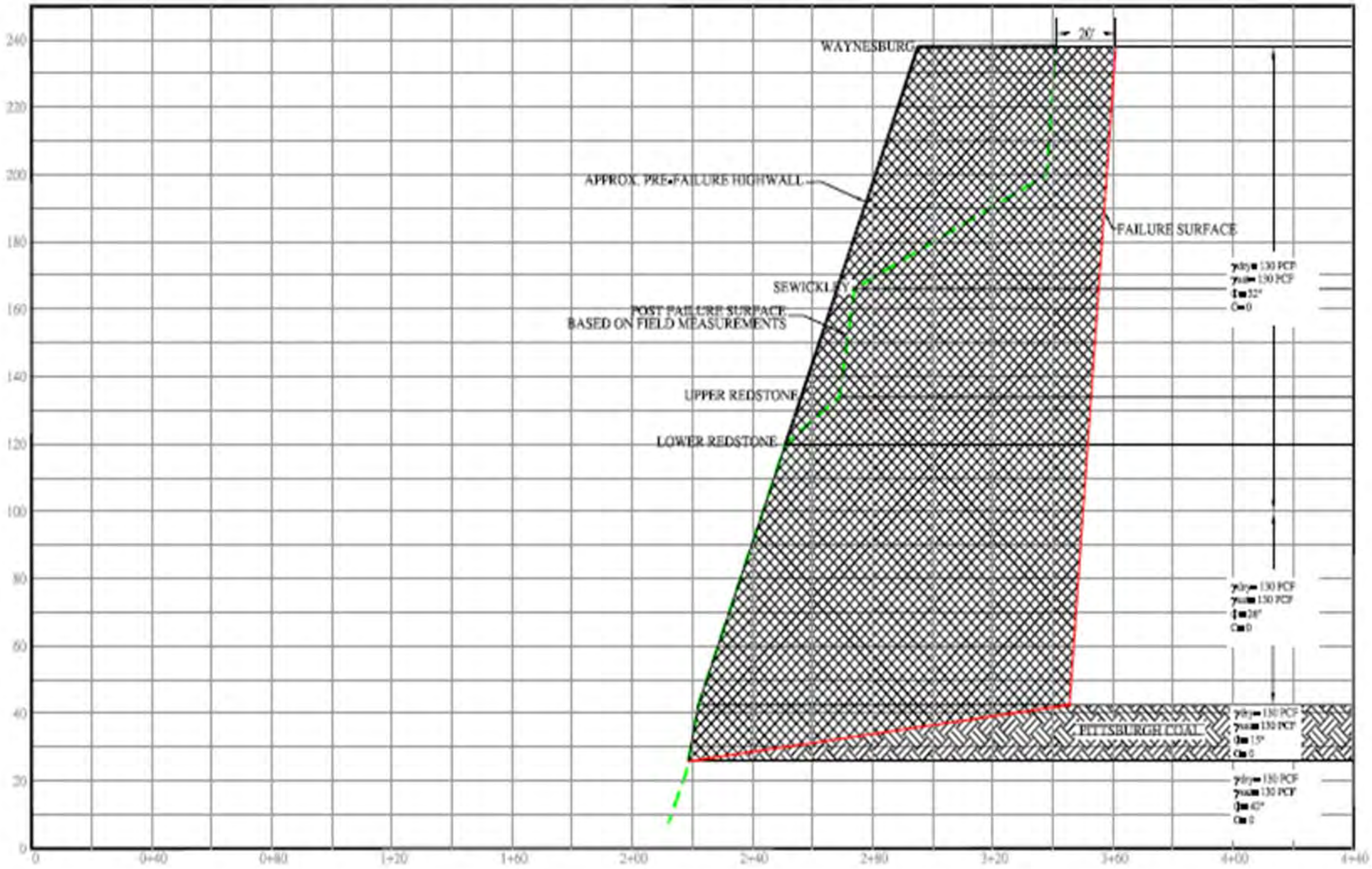
120 feet

- MSHA IS NOW REQUIRING THAT ALL SURFACE MINES SUBMIT A GROUND CONTROL PLAN TO ENSURE HIGHWALL STABILITY EXCEEDS A STATIC FACTOR OF SAFETY OF 1.3.
- AFTER MUCH RESEARCH AND ANALYSIS, WE HAVE DEVELOPED A STABILITY MODEL WHEREBY WE CAN ANALYZE THE OVERALL FACTOR OF SAFETY FOR ALL HIGHWALLS.

GENERAL INFORMATIO

Operator:	Tri-St
Mine:	Job #
Accident Date:	April
Classification:	Fall o
Location:	Dist. Cour
Mine Type:	Surfa
Employment:	71
Production:	2,10

EXISTING MASS FAILURE FACTOR OF SAFETY = 1.040



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One Corps, One Regiment, One Team

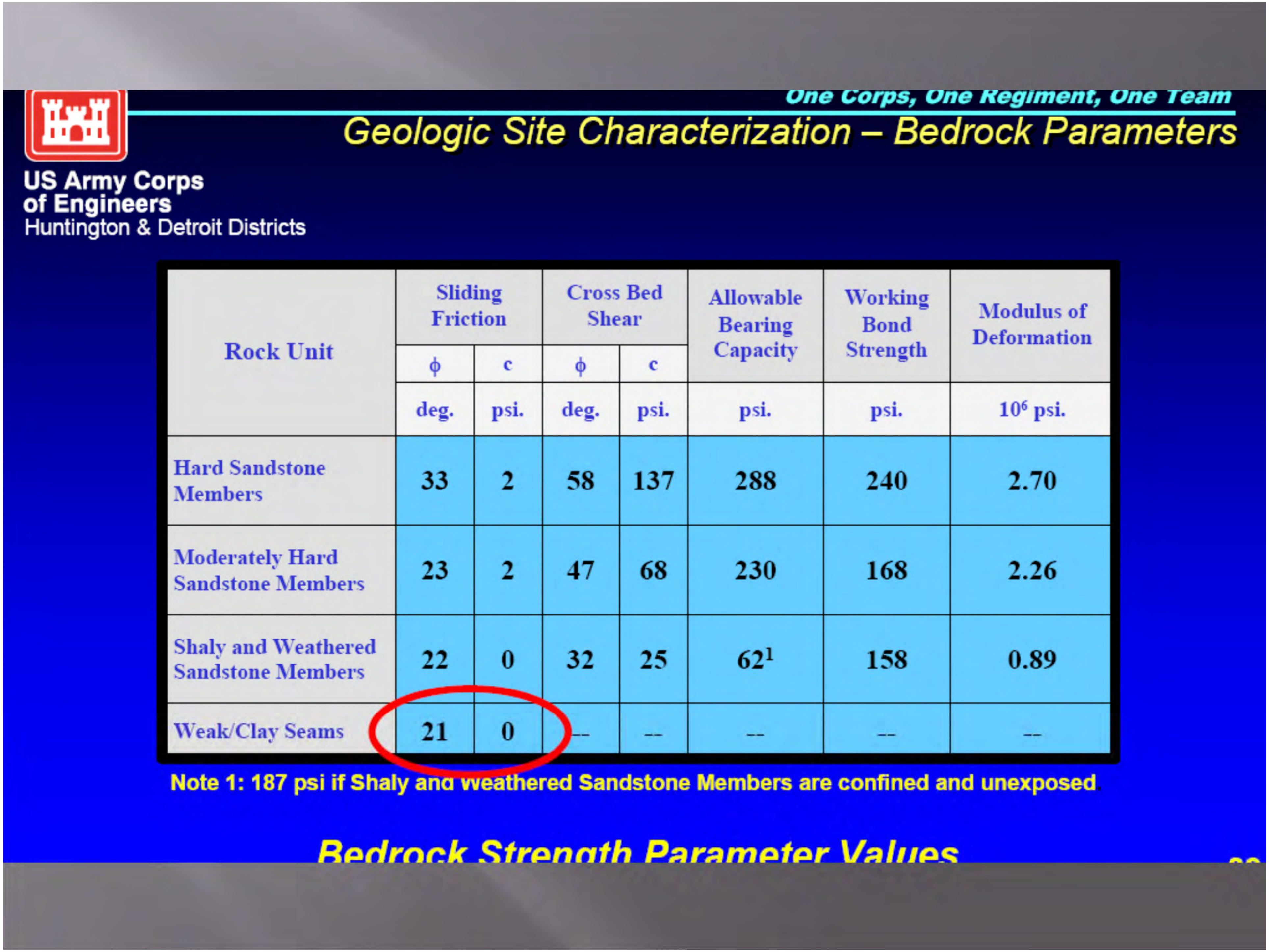
US Army Corps of Engineers
Huntington & Detroit Districts

Engineering Geology Design Challenges at the Soo Lock Replacement Project

Infrastructure Systems Conference
25-29 July, 2007

Geologic Site Characterization – Bedrock Parameters

- Bedrock strength parameters were established in accordance with EM 1110-1-2908 "Rock Foundations," dated 30 Nov 1997 while utilizing:
  - Rock mechanics testing data
    - Unconfined Compressive (elastic modulus & Poisson's Ratio)
    - Anchor Bond Pull-out
    - Direct Shear Tests (intact, natural fracture, grout-on-rock)
    - Direct Tensile
    - Unit Weight
  - Rock mass characteristics
  - Data from current and past exploration
  - Foundation reports of the construction of the Poe Lock



One Corps, One Regiment, One Team

Geologic Site Characterization – Bedrock Parameters

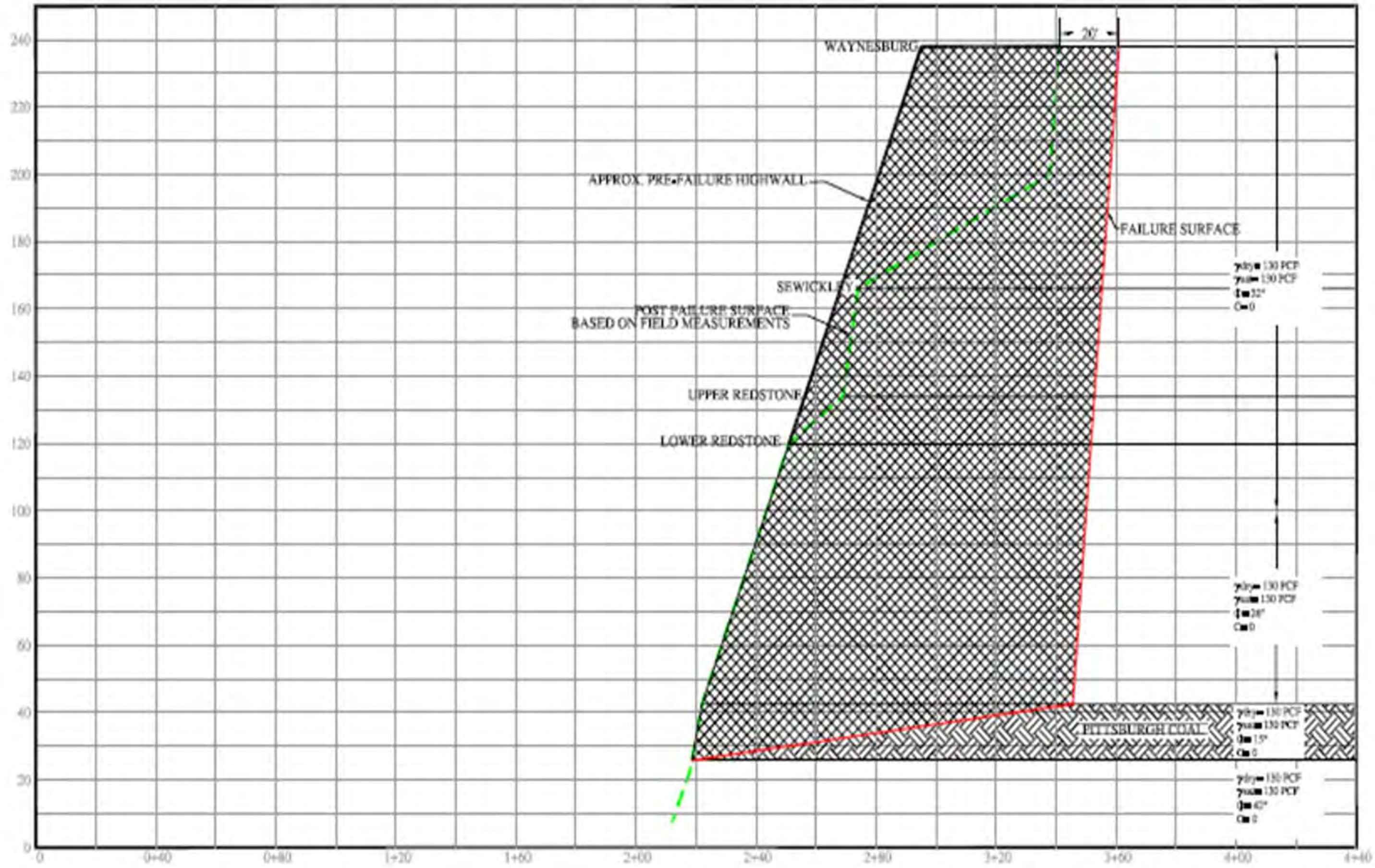
US Army Corps of Engineers
Huntington & Detroit Districts

Rock Unit	Sliding Friction		Cross Bed Shear		Allowable Bearing Capacity	Working Bond Strength	Modulus of Deformation
	ϕ	c	ϕ	c			
	deg.	psi.	deg.	psi.	psi.	psi.	10^6 psi.
Hard Sandstone Members	33	2	58	137	288	240	2.70
Moderately Hard Sandstone Members	23	2	47	68	230	168	2.26
Shaly and Weathered Sandstone Members	22	0	32	25	62[1]	158	0.89
Weak/Clay Seams	21	0	--	--	--	--	--

Note 1: 187 psi if Shaly and Weathered Sandstone Members are confined and unexposed.

Bedrock Strength Parameter Values

EXISTING MASS FAILURE FACTOR OF SAFETY = 1.040



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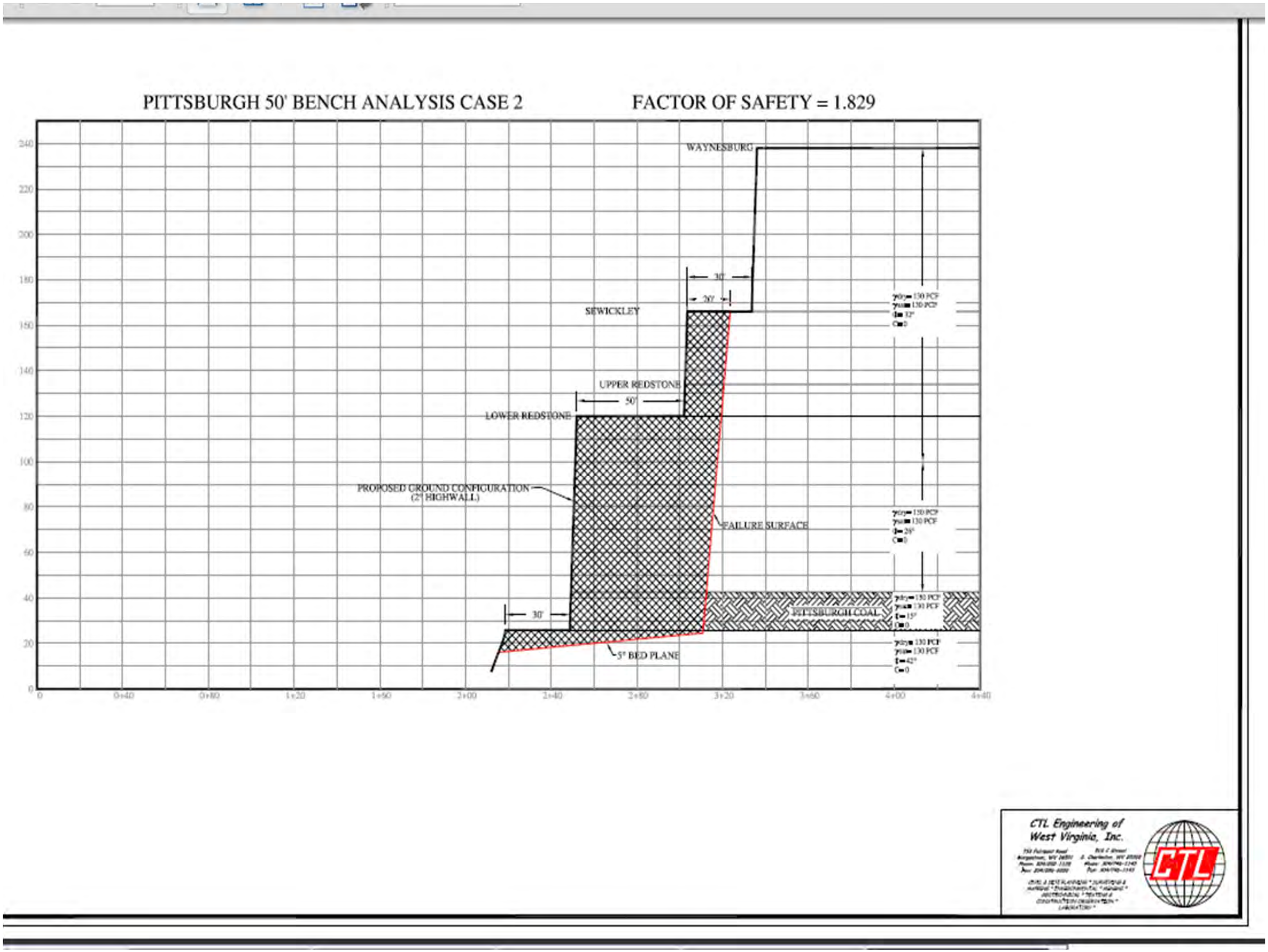

PITTSBURGH 50' BENCH ANALYSIS CASE 2 FACTOR OF SAFETY = 1.829

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02/05/2003


VICTOR CUSHWA
MEMORIAL BRIDGE

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- **Miscellaneous POWERPOINT INFORMATION from Stan Michalek, P.E.**