ROCK SLOPES

National Highway Institute

No. 132035

National Highway Institute

FHWA

Office of Bridge Technology
Geotechnical Program

Norm Norrish
Wyllie & Norrish Rock Engineers

Brendan Fisher
Fisher & Strickler Rock Engineering, LLC

Parsons Brinckerhoff, Inc. New York, NY

Geotechnical and Foundation Engineering Courses

- 132031A - Subsurface Investigations
- 132033A - Soil Slope and Embankment Design
- 132034A - Ground Improvement Methods
- 132035A - Rock Slopes
- 132036A - Earth Retaining Structures
- 132037A - Shallow Foundations
- 132039A - Earthquake Engineering
- 132040A - Pavements
- 132041A - Geotechnical Instrumentation
- 132079A – Subsurface Investigation Qualification

Agenda

- **Day 1**

A) Data Collection

		Chap	Instructor
8:00 AM	Introduction and basic mechanics of rock slope design	1	Norrish
8:45 AM	Structural geology, data collection	2	Fisher
9:30 AM	Coffee break		
9:45 AM	Stereographic analysis methods	2	Norrish
10:15 AM	Student exercise – Stereonets	2	Norrish
11:00 AM	Coffee break		
11:15 AM	Shear strength of discontinuities	3	Fisher
11:45 PM	Student exercise – Direct Shear Test		
12:00 PM	LUNCH		
1:00 PM	Strength of rock masses and intact rock	3	Fisher
1:30 PM	Groundwater	4	Norrish
2:00 PM	Student exercise – Influence of geology and weather on groundwater levels		Norrish
2:15 PM	Coffee break		

B) Stability Analysis

2:30 PM	Plane failure	5	Norrish
3:30 PM	Coffee break		
3:45 PM	Student exercise – Plane failure		Norrish
4:30 PM	Adjourn		

Agenda

- **Day 2**

B) Stability Analysis

Time	Topic	Chap	Instructor
8:00 AM	Wedge failure	6	Fisher
9:00 AM	Student exercise – Wedge failure		Fisher
9:30 AM	Coffee break		
9:45 AM	Circular failure	7	Norrish
10:30 AM	Student exercise – Circular failure		Norrish
11:15 AM	Coffee break		

C) Stabilization Methods

Time	Topic	Chap	Instructor
11:30 AM	Causes of rock falls, slope inventory procedures, selection of stabilization methods, environmental and contracting issues	10.1 – 10.5	Fisher
12:00 PM	LUNCH		
1:00 PM	Stabilization by reinforcement	10.6	Fisher
2:00 PM	Coffee break		
2:15 PM	Student exercise – Rock bolt design		Fisher
2:45 PM	Coffee break		
3:00 PM	Stabilization by rock removal	10.7	Norrish
3:25 PM	Rock fall protection measures	10.8	Norrish
3:50 PM	Final Review and Learning Assessment Test		
4:30 PM	Adjourn		

Lesson 1 – Principles of Rock Slope Engineering for Highways

Learning Outcomes -

- Demonstrate Influence of Rock Slides and Rock Falls on Highway Safety;
- List Important Parameters Influencing Rock Slope Stability;
- Identify Common Modes and Mechanism of Failure for Rock Slope Stability;
- List important Geological Parameters of Discontinuities

Lesson 1 - Rock slopes

- ***Principles of Rock Slope Engineering for Highways***

Landslide closed highway for 71 days – 200,000 cy
(I-40, Pigeon River Gorge, NC)

540 ft. high wedge failures on continuous bedding planes in meta-shale

7 months to stabilize

(I-40, Pigeon River Gorge, NC)

Rock fall in strong, blocky granite during heavy rainfall ***(Trans Canada H/way, Yale, BC)***

Influence of Discontinuities on Stability

- ***Rock Slope Design for Highways is Concerned Primarily with the Stability of Rock Containing Discontinuities - Joints, Bedding, Faults.***
- ***Classification of Rock Slope Failures:***
  - ***Plane failure (Chapter 5)***
  - ***Wedge failure (Chapter 6)***
  - ***Circular failure (Chapter 7)***
  - ***Toppling failure (Chapter 8) – not part of course***

Plane failure on persistent bedding dipping at 75º

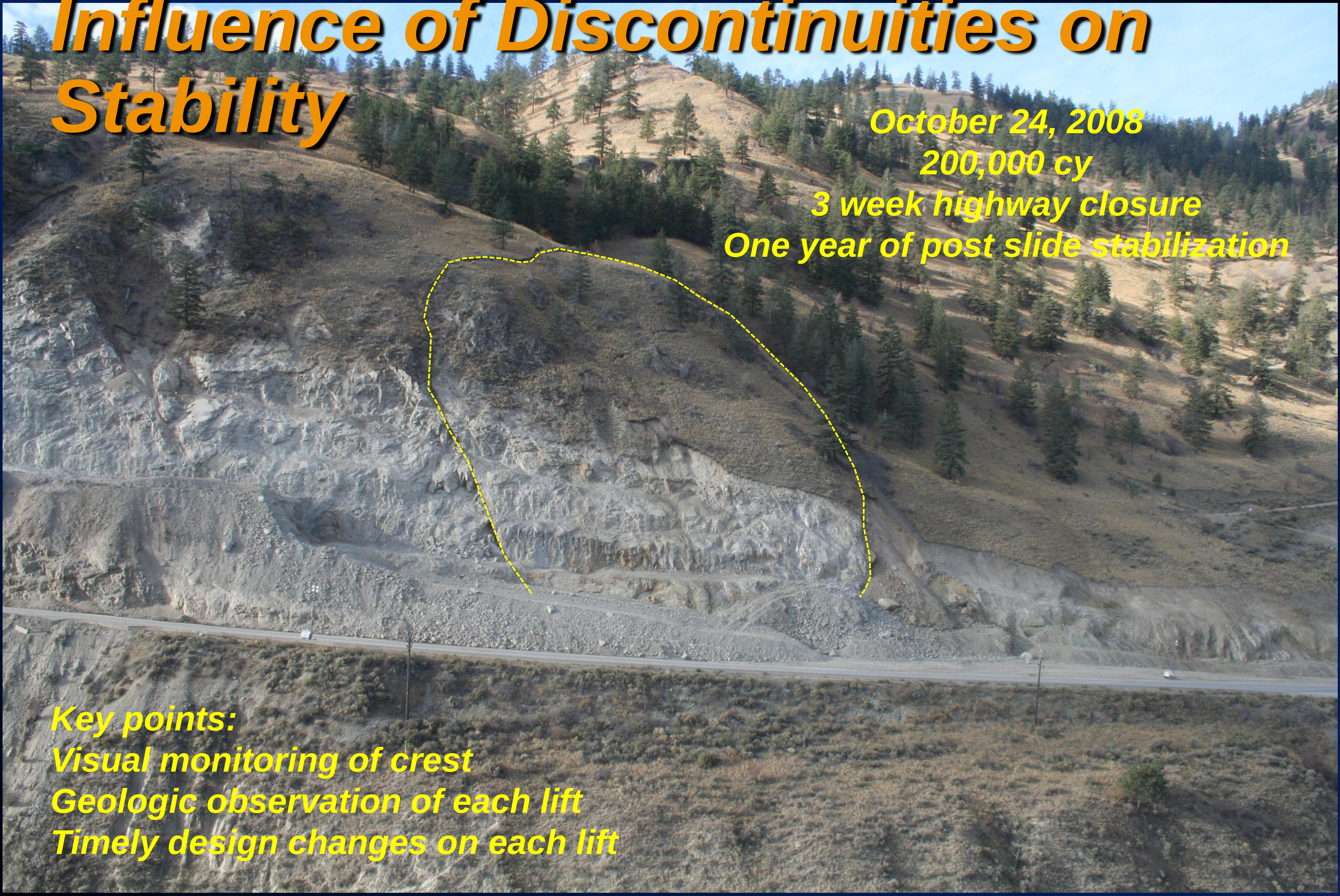
(US19, Waynesville, NC)

Wedge failure formed by two intersecting joints

Influence of Discontinuities on Stability

- **Characteristics of Discontinuities Relevant to Slope Design:**
  - Orientation, position
  - Length (persistence)
  - Spacing
  - Shear strength

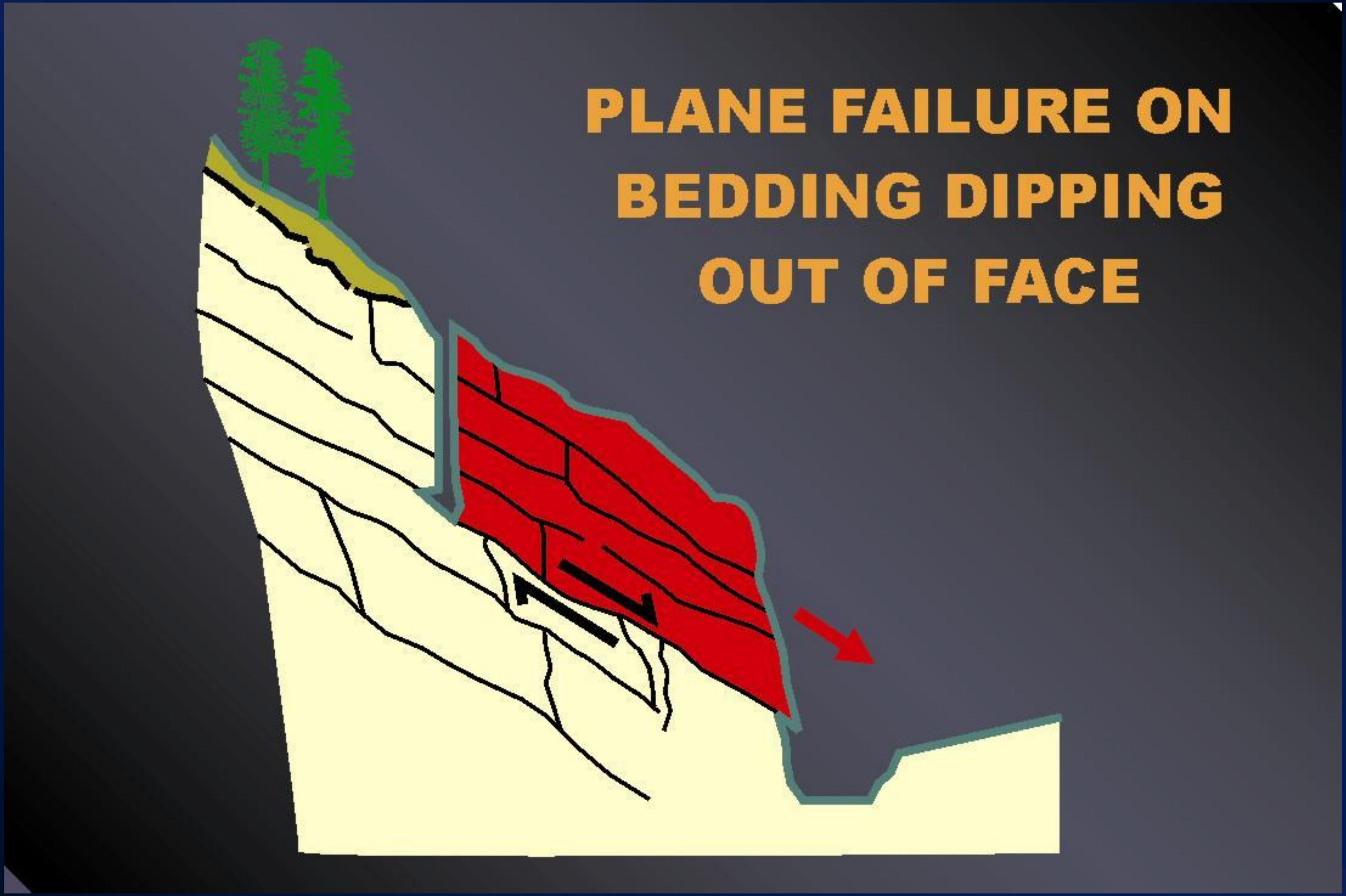
Influence of Discontinuities on Stability



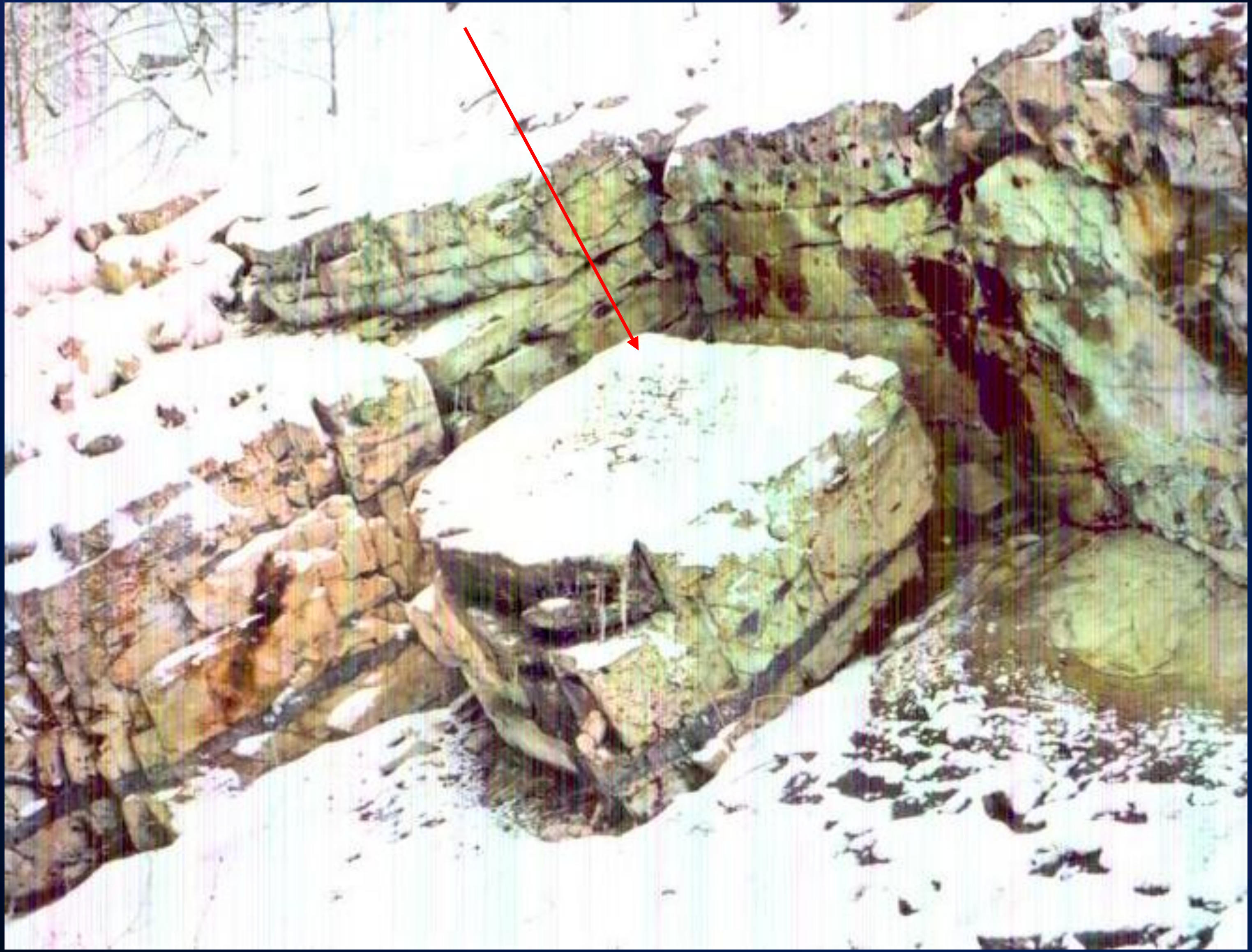
October 24, 2008
200,000 cy
3 week highway closure
One year of post slide stabilization

Key points:
Visual monitoring of crest
Geologic observation of each lift
Timely design changes on each lift

Influence of Geology on Stability

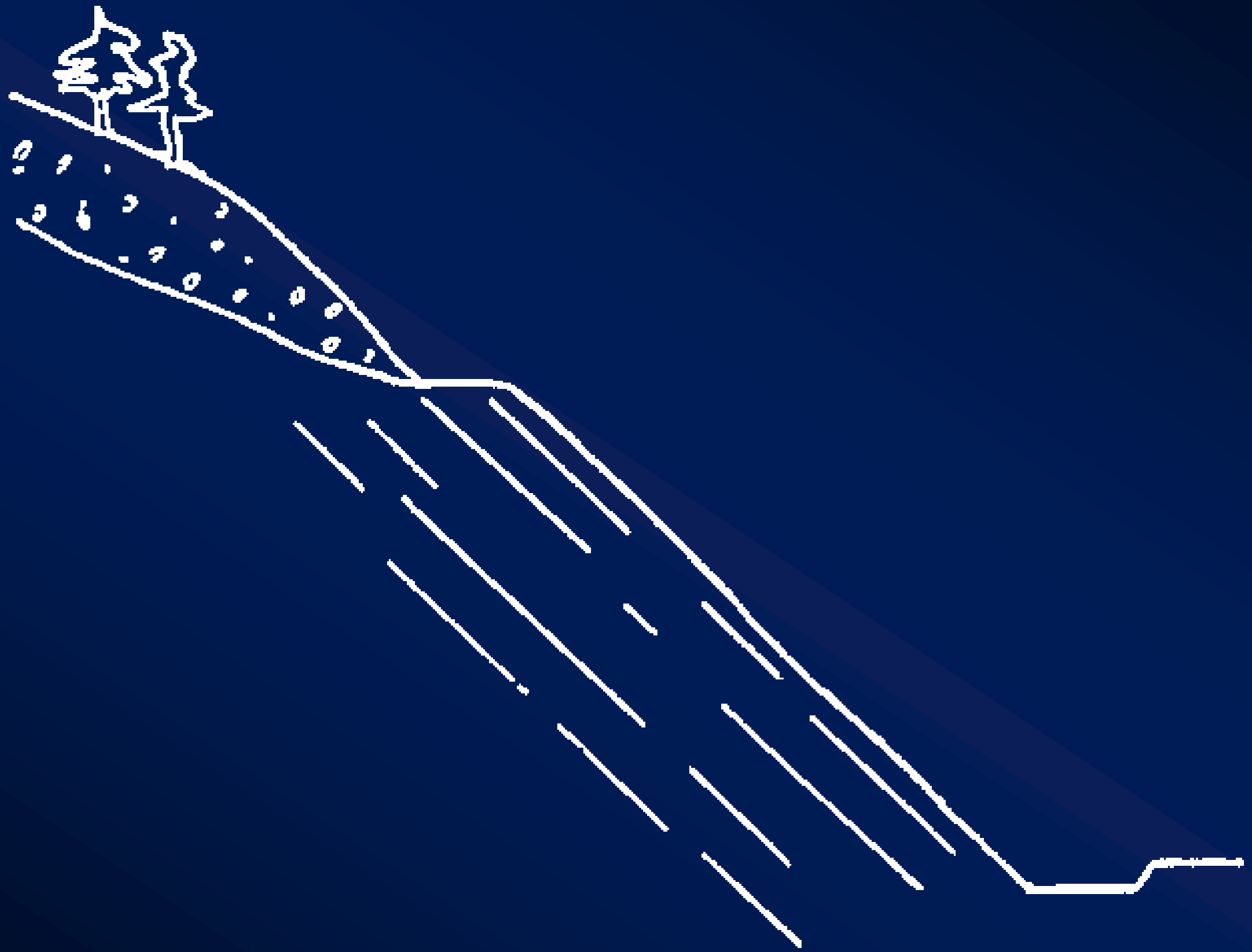


A) Potential Instability - Discontinuities “Daylight” in Face



Block sliding on bedding plane dipping out of face ***(Crowsnest Pass, AB)***

Influence of Geology on Stability



B) Stable Slope - Face Excavated Parallel to Discontinuities

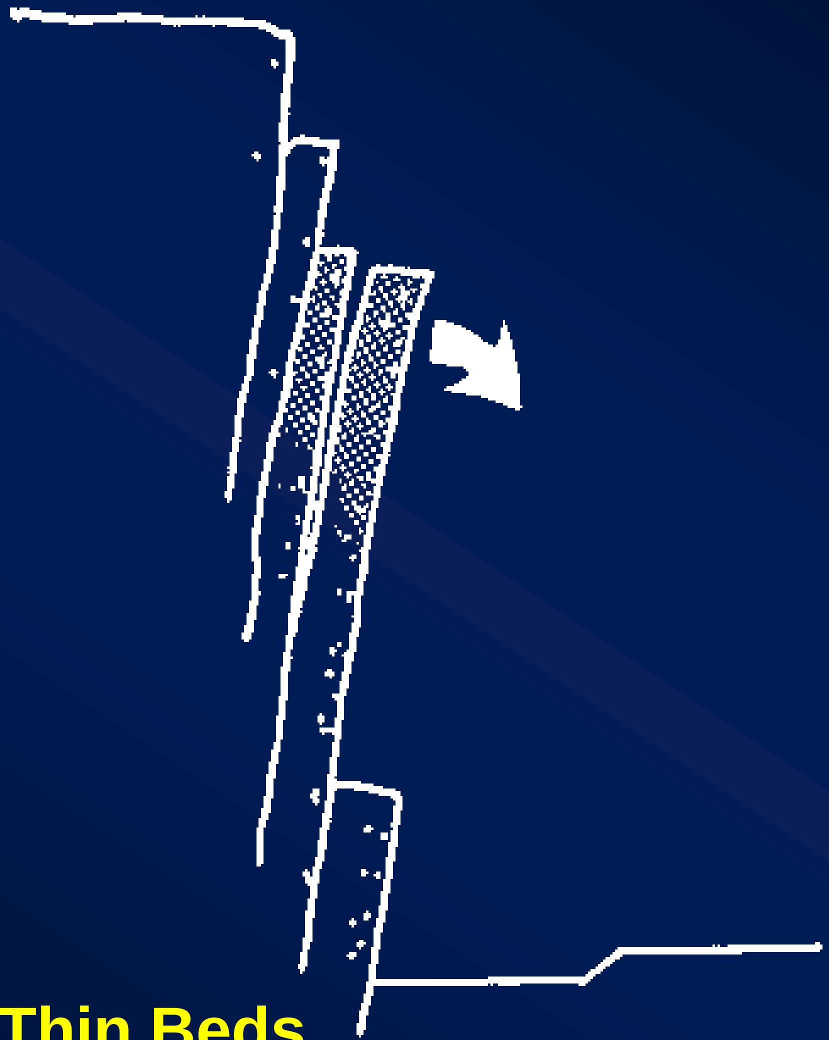
Face formed on smooth bedding planes dipping steeper than friction angle ***(Lake Louise, AB)***

Wedge forms face at right angles to strike of bedding ***(Lake Louise, AB)***

Influence of Geology on Stability

C) Stable Slope - Discontinuities Dip into Face

Influence of Geology on Stability

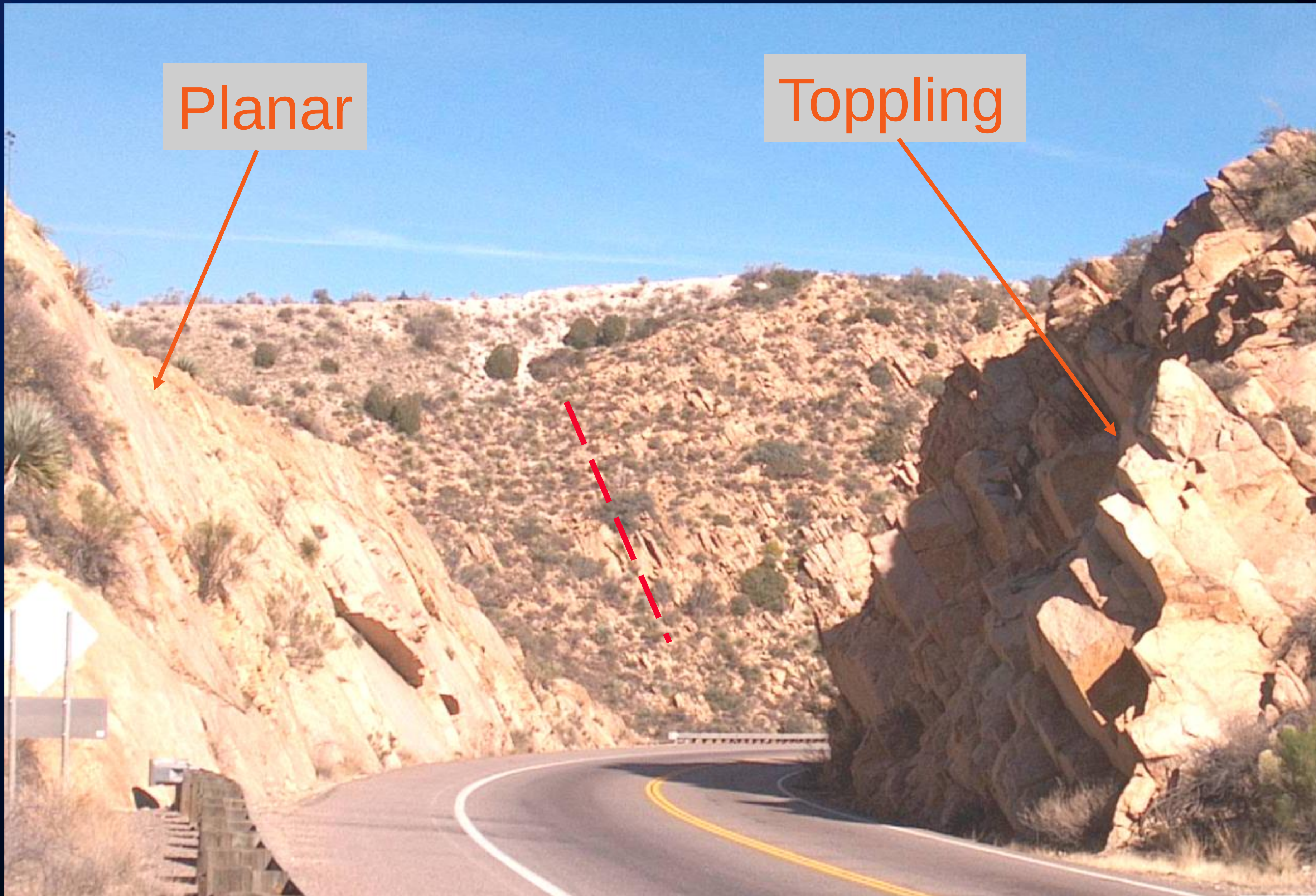


D) Toppling Failure of Thin Beds Dipping Steeply into Face

Toppling slabs formed by joints dipping steeply into face

Toppling columns in sandstone with vertical joints; weak shale at base

(Mesa Verde NP, CO)



Stability conditions in through cut

(US 60, AZ)

Influence of Geology on Stability

E) Weathering of Shale Beds Undercuts Strong Sandstone Beds to Form Overhangs

Overhanging face formed in strong sandstone overlying weak shale

(Telluride, CO)

Influence of Geology on Stability

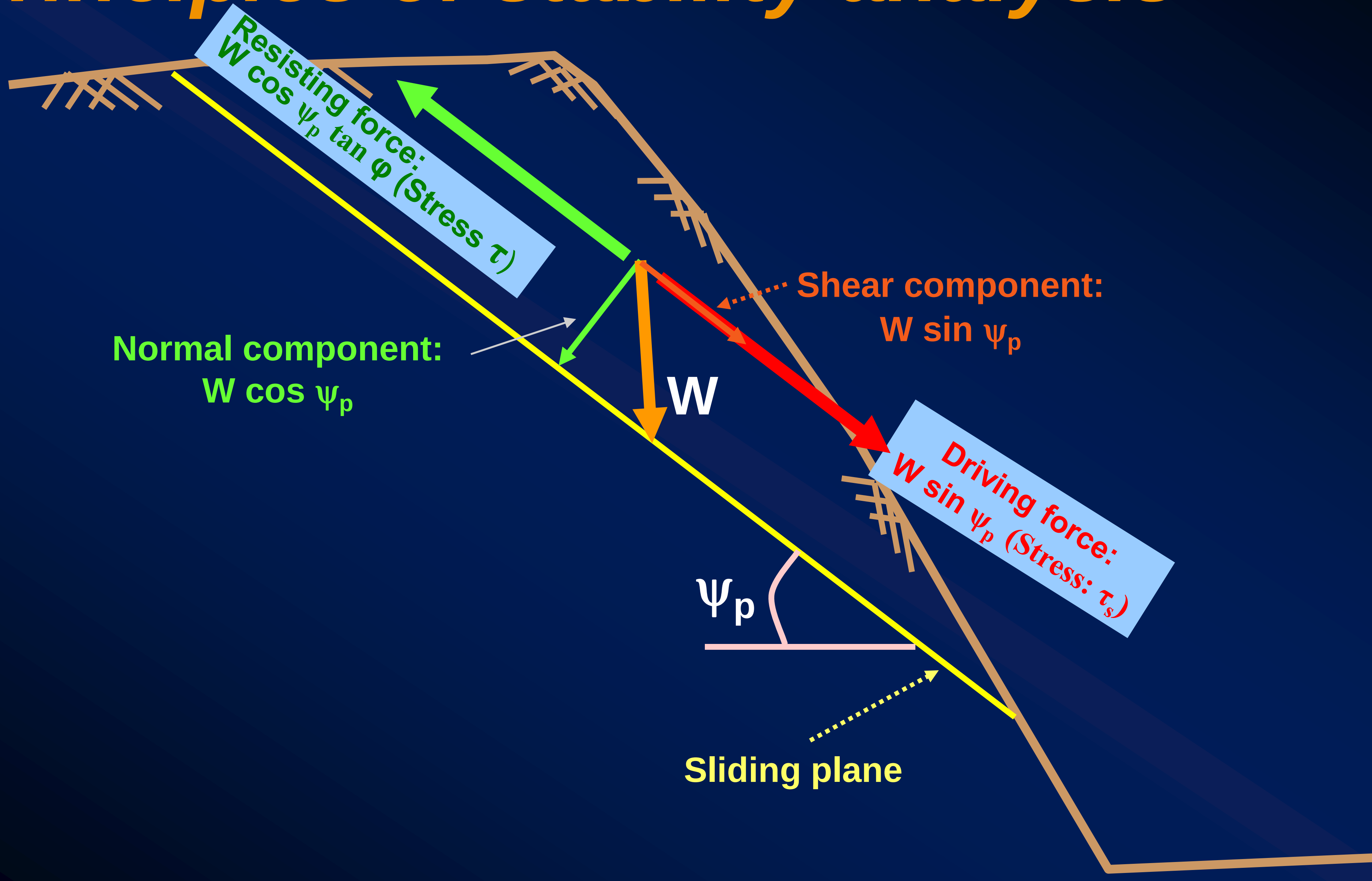
F.) Potential Shallow Circular Failure in Closely Fractured, Weak Rock

Circular failure in highly weathered granite
(Highway 1, Pacifica, CA)

Frank Slide (35 million cu. yd.) in strong limestone

(Frank, Alberta)

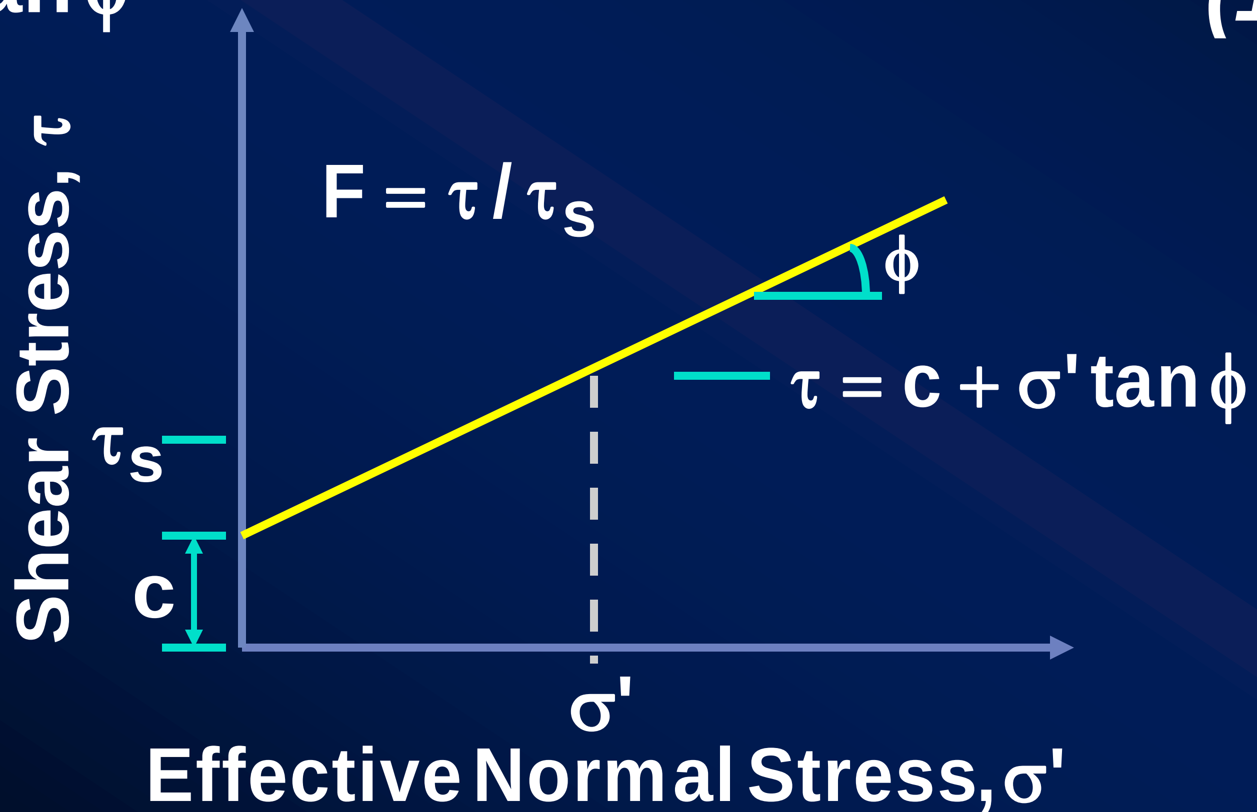
Principles of stability analysis



Mechanics of Rock Slopes Stability

- ***Strength of Mohr-Coulomb Materials - Cohesion (c) and Friction Angle (ϕ)***

$$\tau = c + \sigma' \tan\phi \qquad \textit{(1-1)}$$



Factor of Safety Calculation (Limit Equilibrium Analysis)

$$F = \left[\frac{\text{resisting forces}}{\text{driving forces}}\right] \qquad (1\text{-}5)$$

$$F = \left[\frac{cA + W\cos\psi_p \tan\phi}{W\sin\psi_p}\right] \qquad (1\text{-}6)$$

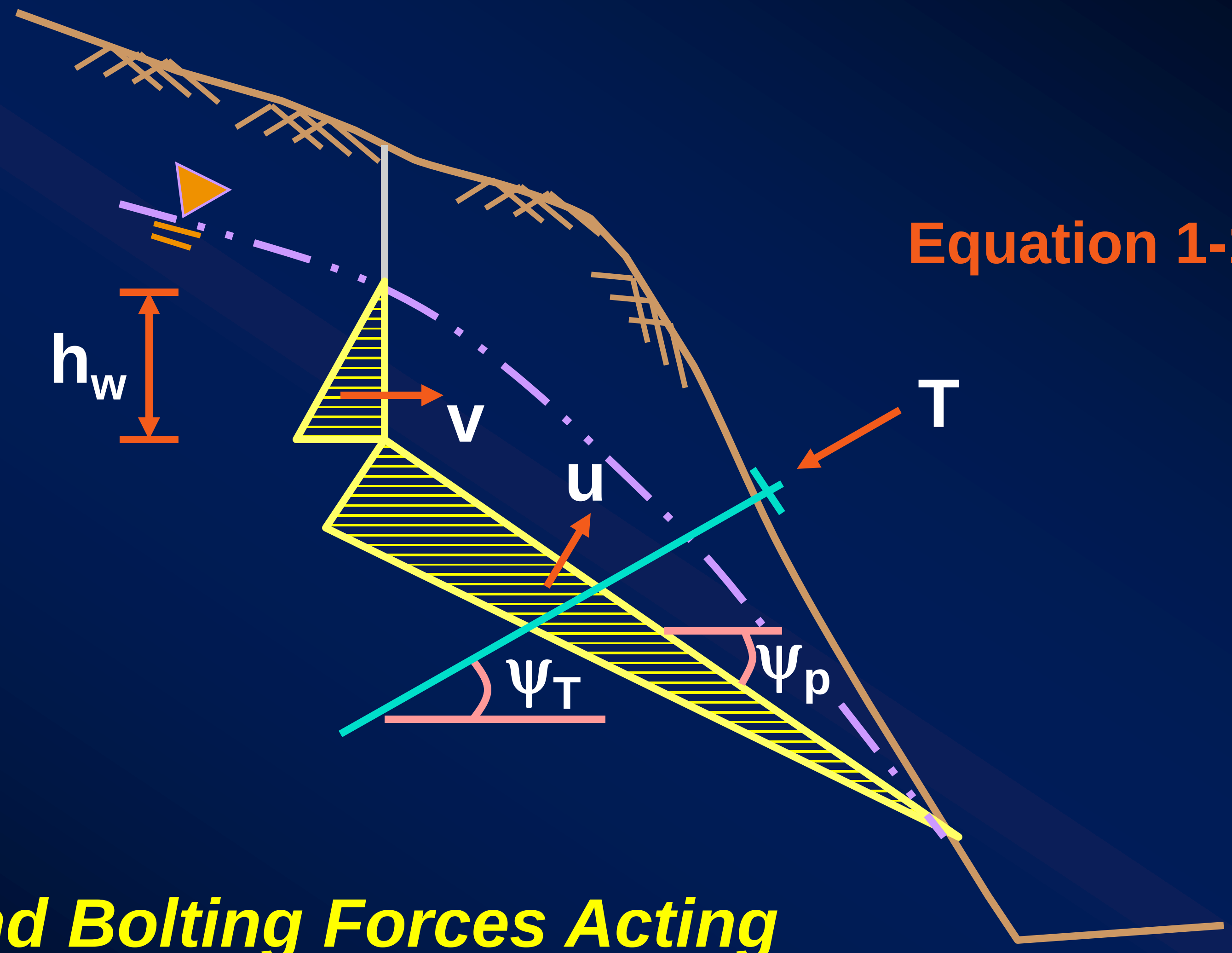
For Sliding Surface with no Infilling, c = 0

$$\sin\psi_p / \cos\psi_p = \tan\phi \qquad (1\text{-}7)$$

or F = 1 when

$$\psi_p = \phi \qquad (1\text{-}8)$$

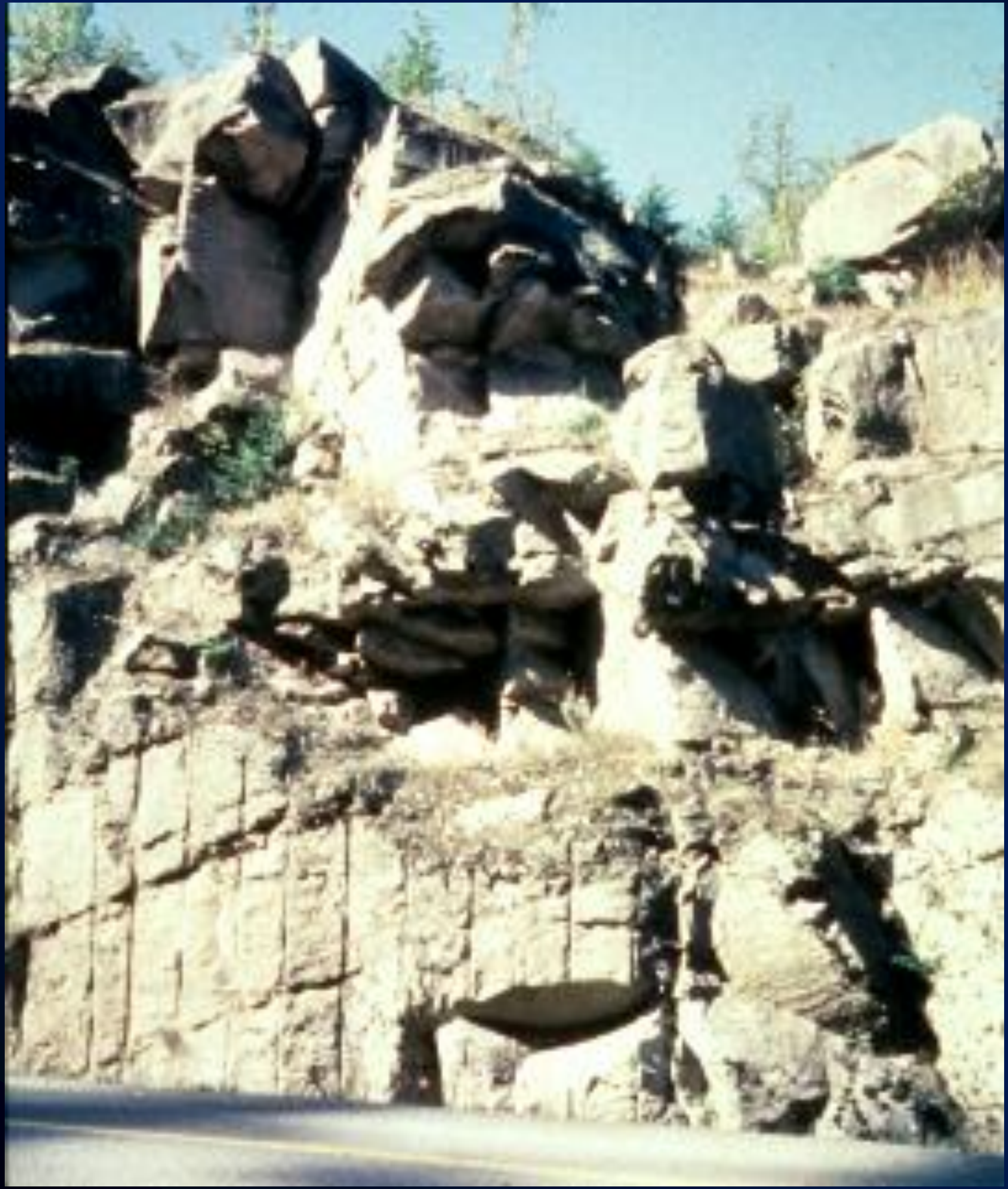
Groundwater/Bolting Effects on Stability



Water and Bolting Forces Acting on Sliding Surface

Influence of Blasting on Stability

- ***Controlled Blasting Required on Final Faces to Limit Damage to Rock Behind Face.***



Blasting in strong, blocky granite:
• upper bench, extensive damage;
•lower bench, controlled blasting

(Coquihalla Highway, BC)

Lesson 1 – Principles of Rock Slope Engineering for Highways

Learning Outcomes -

- Demonstrate the Influence of Rock Slides and Rock Falls on Highway Safety;
- List Important Parameters Influencing Rock Slope Stability;
- Identify Common Modes and Mechanism of Failure for Rock Slope Stability.