Slope Stabilization Methods

Learning Objectives

- Understand driving and resisting components of slope stability and leverage these concepts towards landslide repair.
- Understand common means of repairing and mitigating slope failures.

Slope Stabilization Methods

- Seldom used independently
- Most efficient method is usually some combination of methods
- Drainage is always part of slope stabilization
- Should not be (finally) selected until the subsurface model is complete
- Should be selected based on desired level of performance
- Safety during construction and for the life of the structure should be the first consideration

Stabilizing Approaches

- Decrease driving force
  - Change geometry
  - Lower groundwater
- Increase resisting force
  - Change geometry
  - Lower groundwater
  - Increase shear strength of soil mass
- Surface Erosion Protection
- Soil Improvement
  - Densification
    - Dynamic Compaction
    - Stone columns
    - Vibrocompaction

Stabilizing Approaches

- Soil improvement
  - Consolidation
    - Surcharge loading
    - Drains
  - Soil reinforcement
    - Geosynthetic reinforcement
    - Soil nailing
    - Micropiles
  - Physicochemical Changes
    - Chemical grouting
    - Lime stabilization
    - Cement stabilization

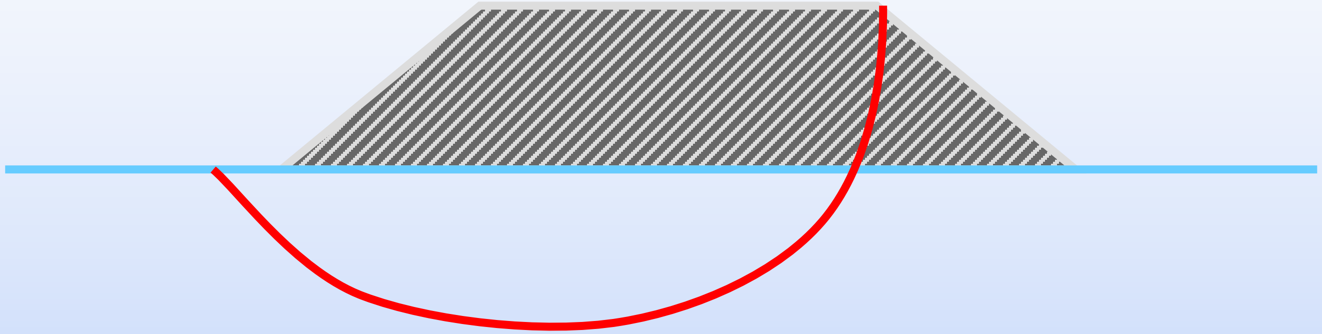
Stabilizing Approaches

- Column Supported Embankments
- Earth retaining systems
  - MSE walls
  - Gravity walls
  - Soldier beams and lagging
  - Soldier beams and shotcrete
  - Tangent pile walls
  - Secant pile walls

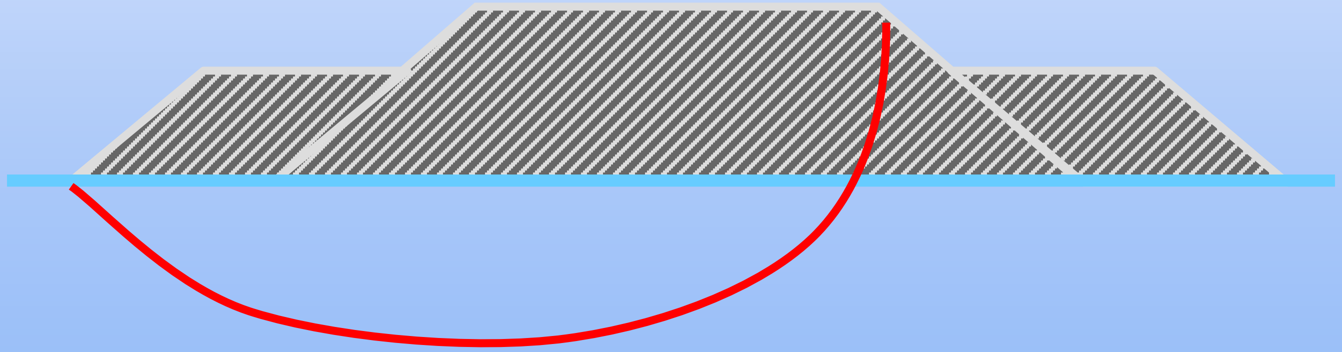
Changing Slope Geometry

Increase resisting shear stresses and/or decrease driving stresses.

Stabilizing Methods – Changing Geometry



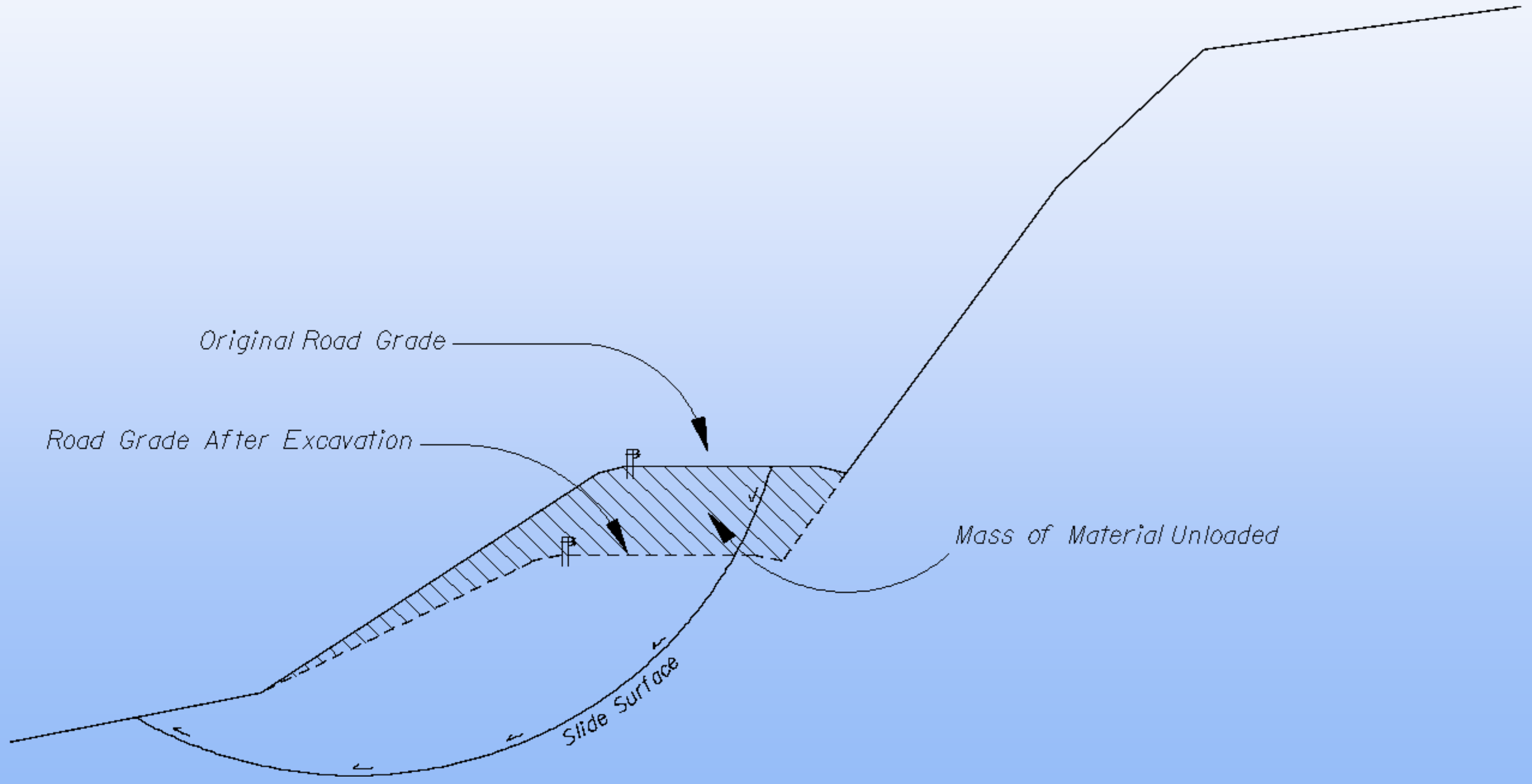
Unstable



Stable

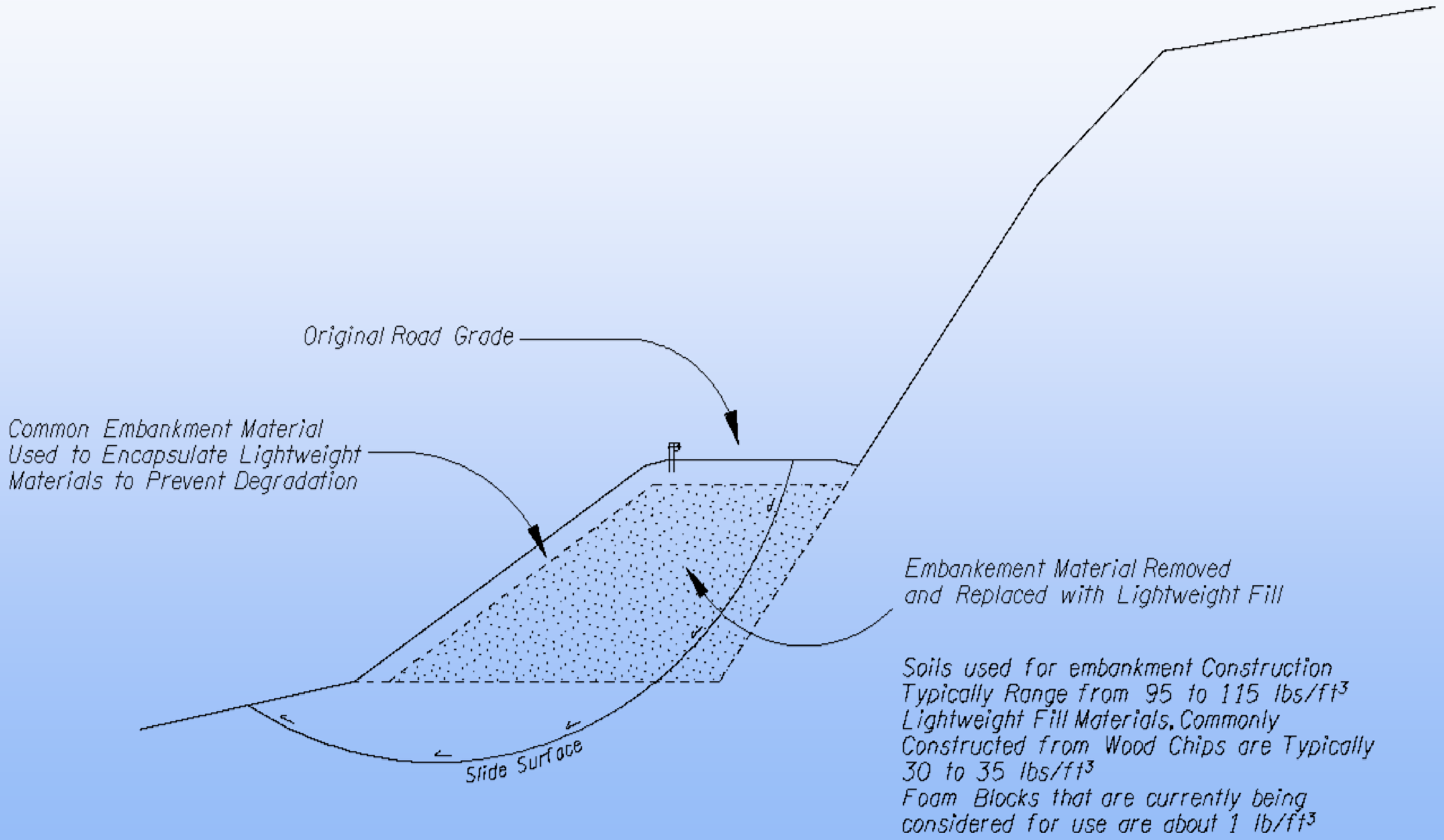
Unloading

Unload Slide Mass
(Reduce Driving Force)



Unloading

Unloading – Light Weight Fill

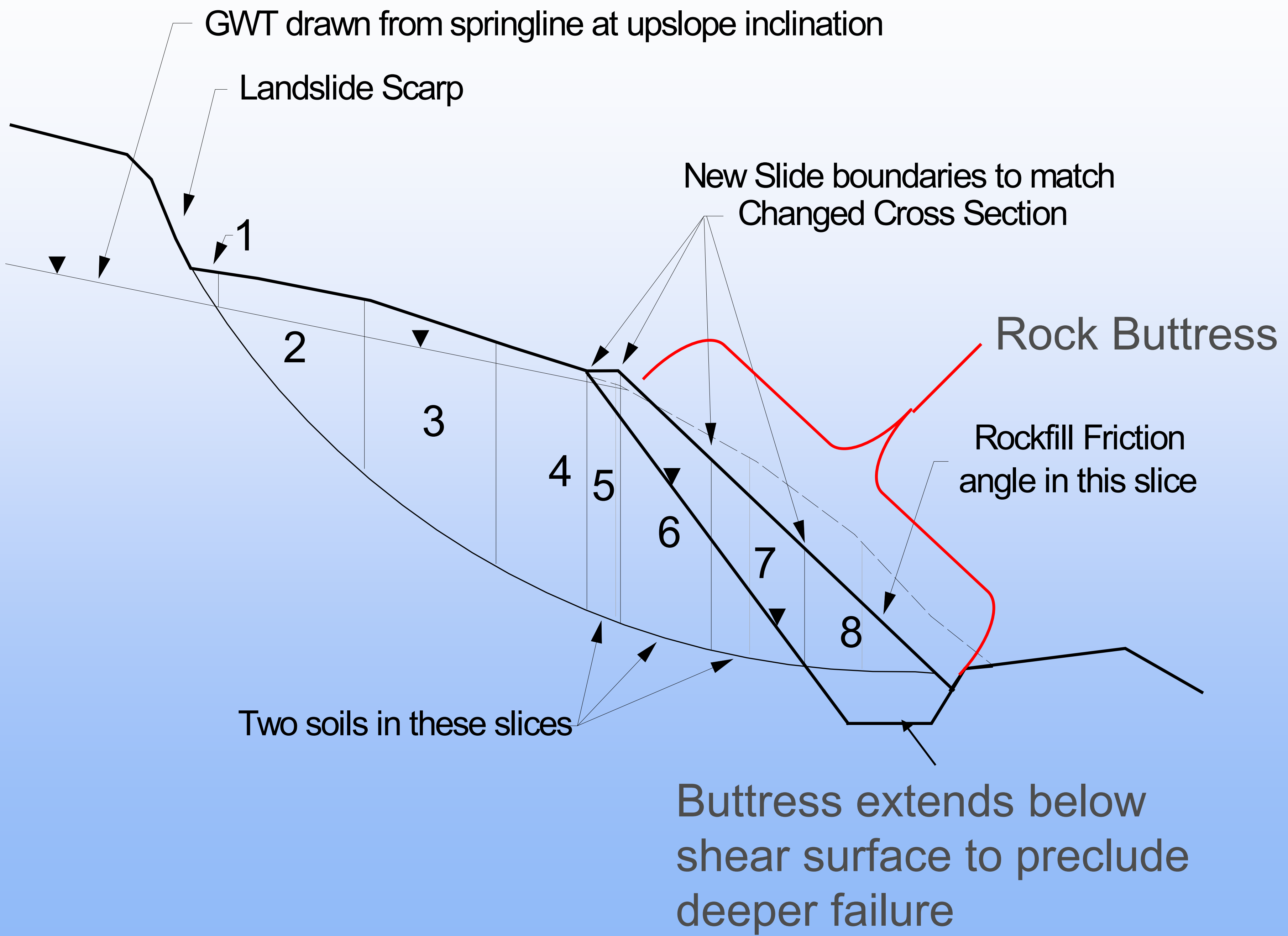


Unloading – Light Weight Fill

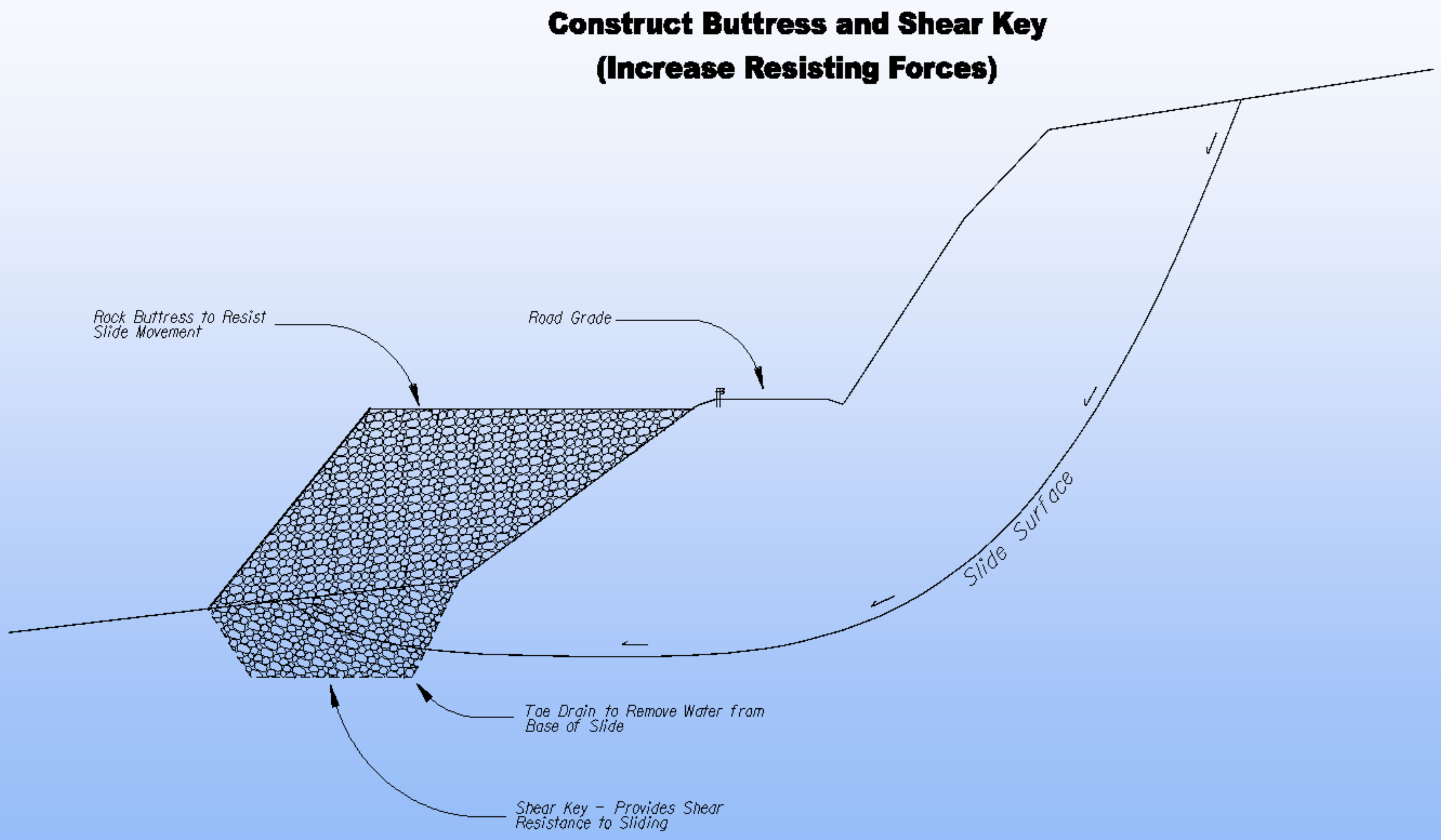
Buttressing and Shear Keys

Increase shear resistance and increase shear strength.

Increasing shear strength – shear key


GWT drawn from springline at upslope inclination
Landslide Scarp
New Slide boundaries to match Changed Cross Section
Rock Buttress
Rockfill Friction angle in this slice
1
2
3
4
5
6
7
8
Two soils in these slices
Buttress extends below shear surface to preclude deeper failure

Buttressing

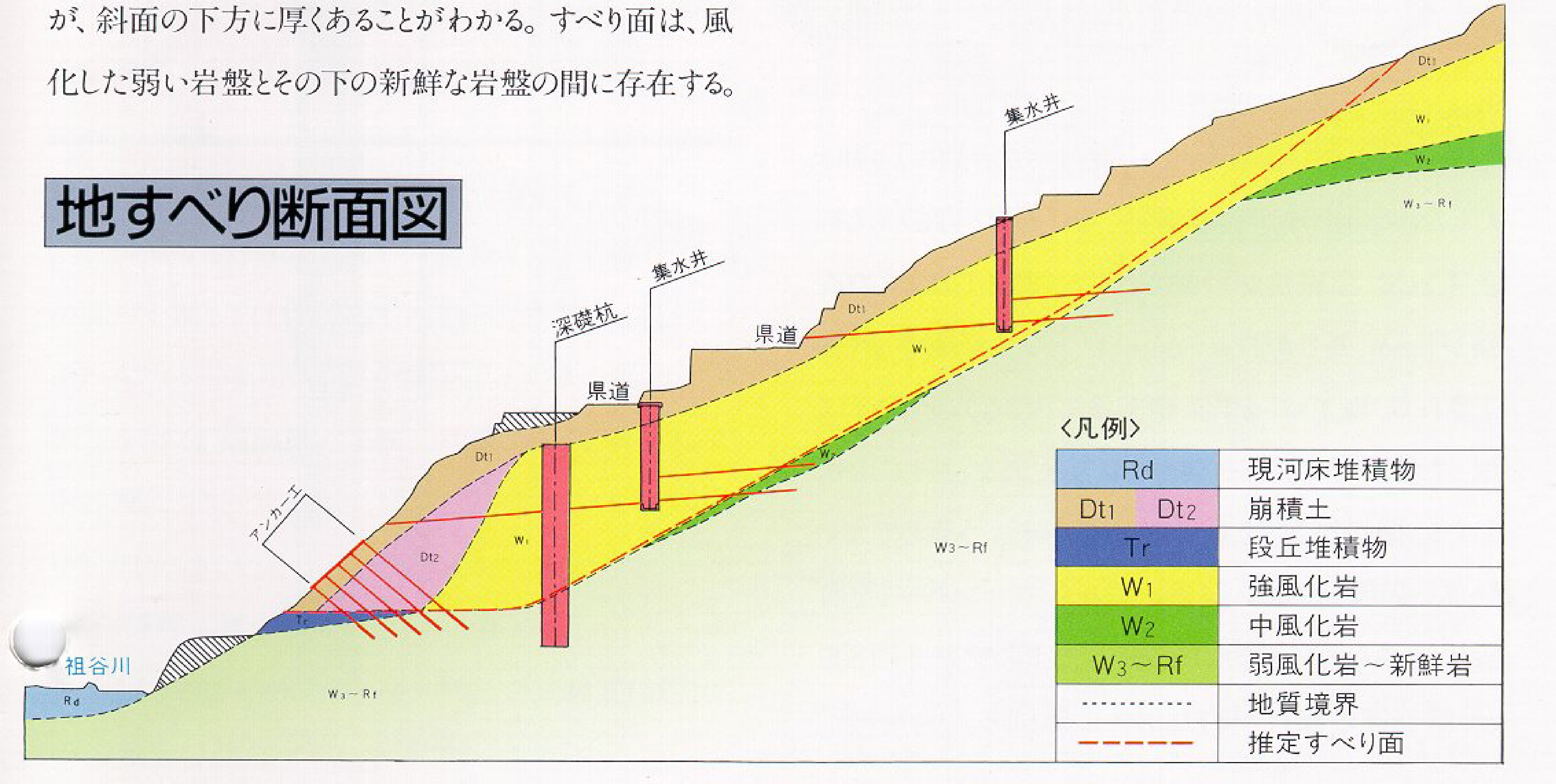


Shear Key Construction

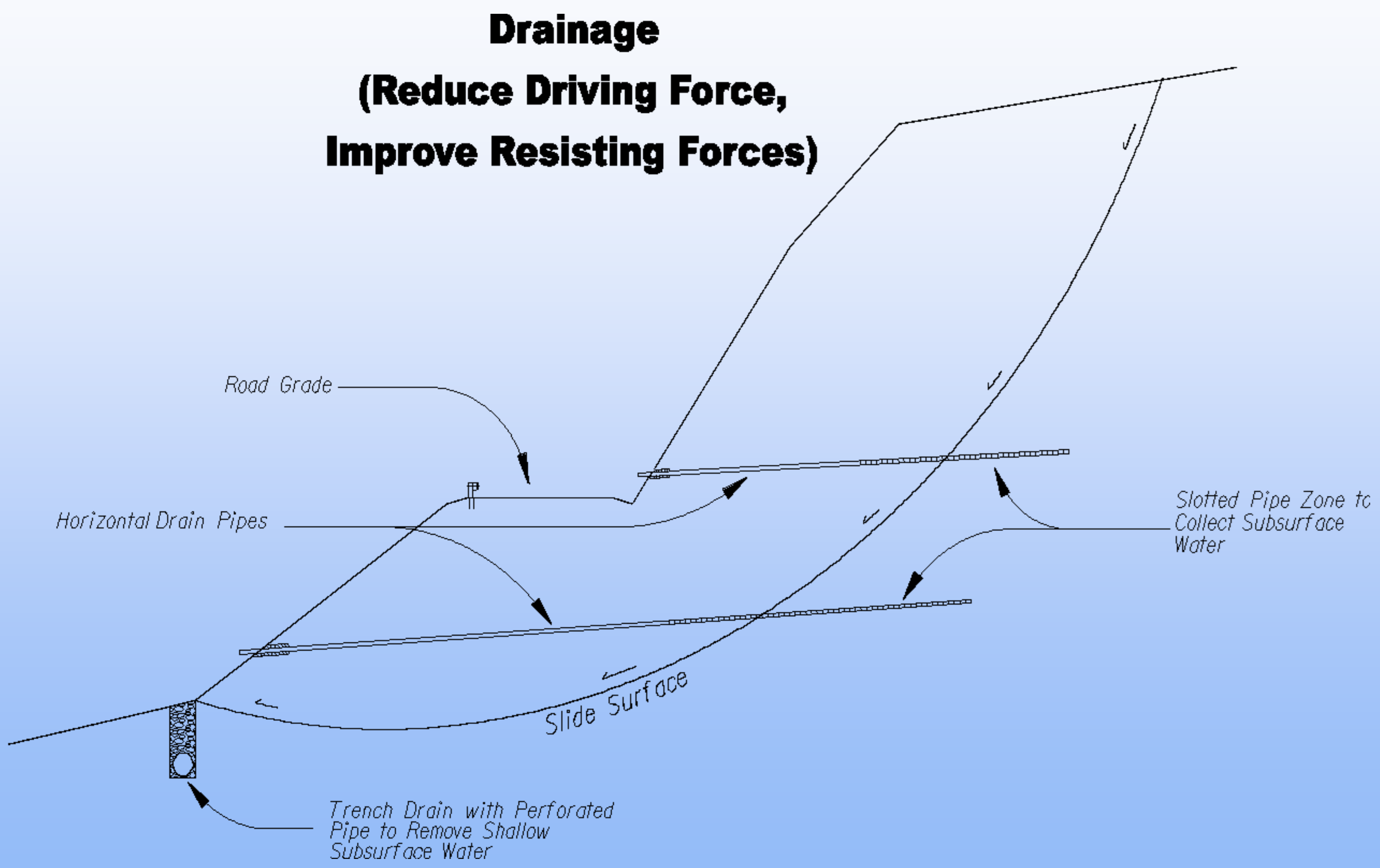
Drainage

Increasing shear strength.

Stabilization Method – Lower groundwater

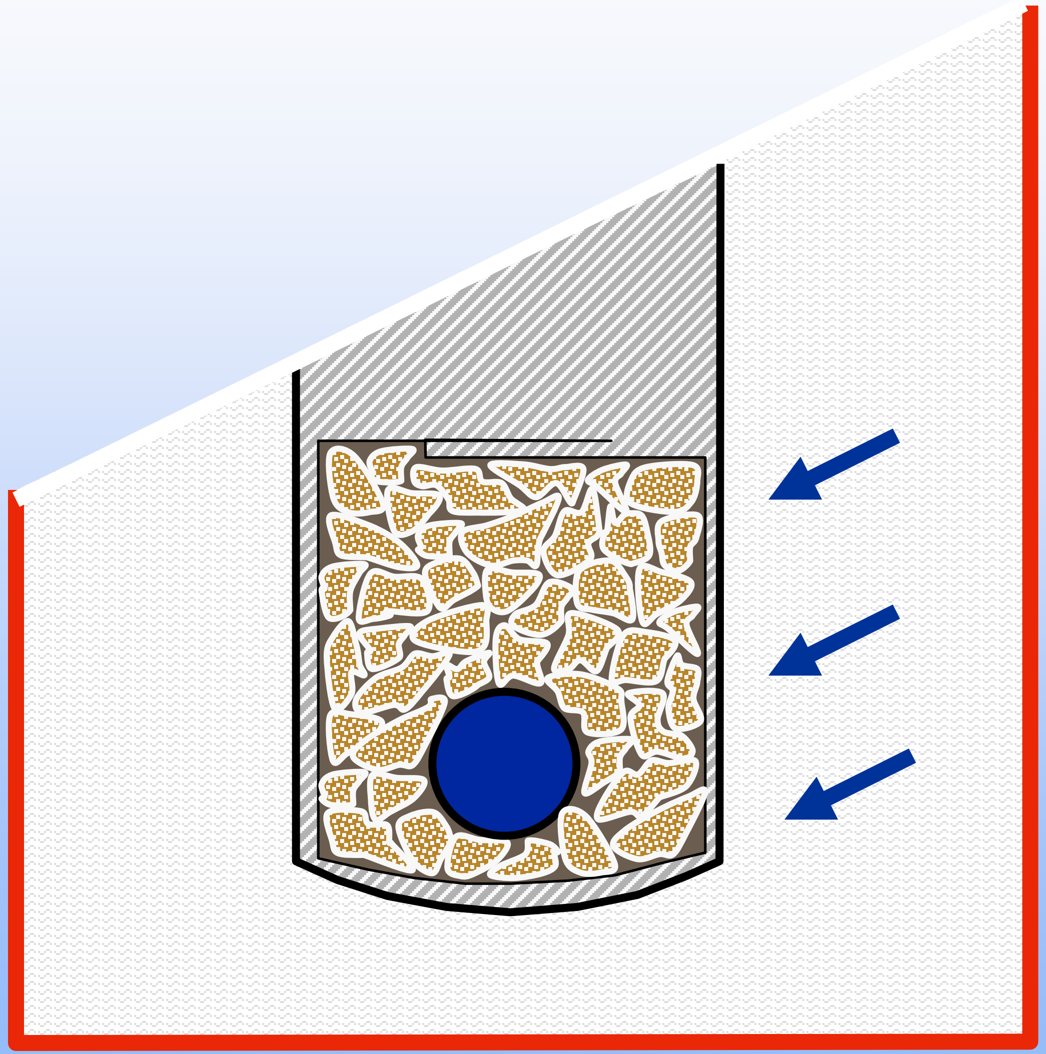


Drainage



Drainage
(Reduce Driving Force,
Improve Resisting Forces)
Road Grade
Horizontal Drain Pipes
Slotted Pipe Zone tc
Collect Subsurface
Water
Slide Surface
Trench Drain with Perforated
Pipe to Remove Shallow
Subsurface Water

Interceptor Drain



Reinforced Slopes and Walls

Recreating a new slope with higher shear strength and controlled drainage.

Soil Reinforcement

- Geosynthetic Reinforced Soil Slopes
- In-situ Soil reinforcement – soil nailing
- MSE Walls

Reinforced Soil in a Nutshell

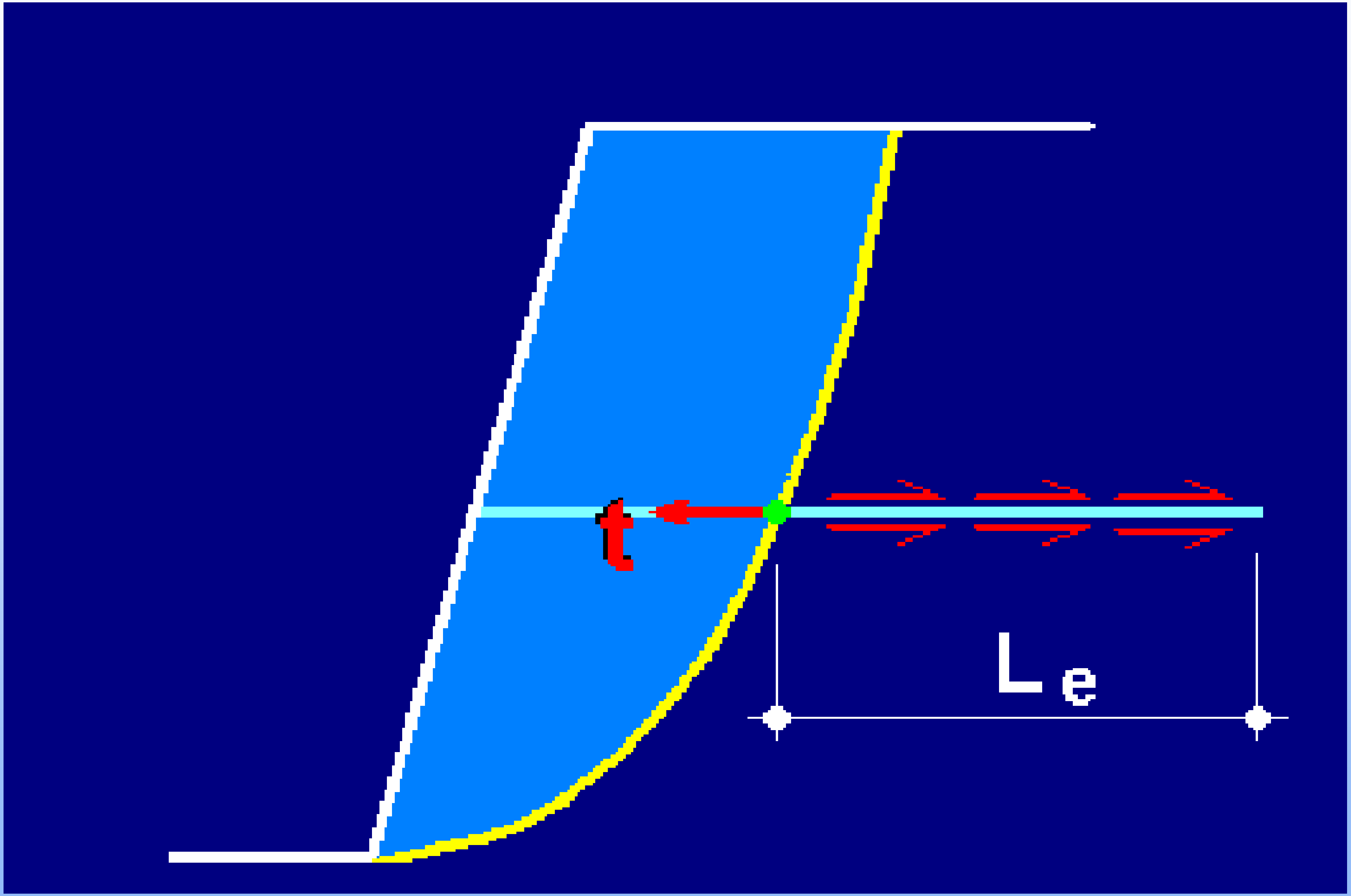
- Soil: Strong in compression, weak in tension
- Reinforcement can carry tensile stresses
- Soil + Reinforcement $\Rightarrow$ Structure strong under both compression and tension
- Analogous to reinforced concrete

History: Reinforced Soil Structures

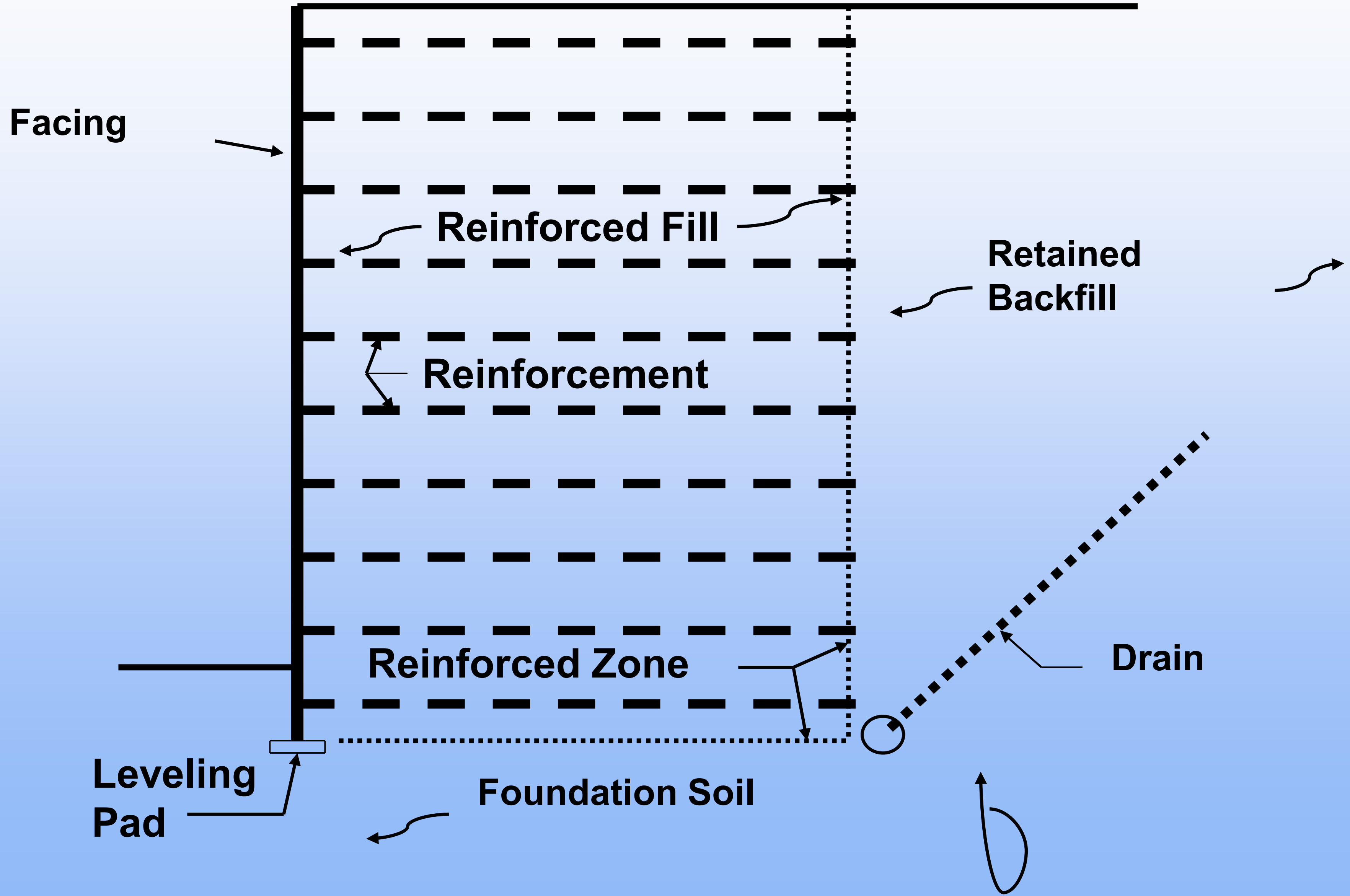
3000 B.C. - Mesopotamia
“Reeds” placed in horizontal layers used to reinforce soil

Great Wall of China – in western desert

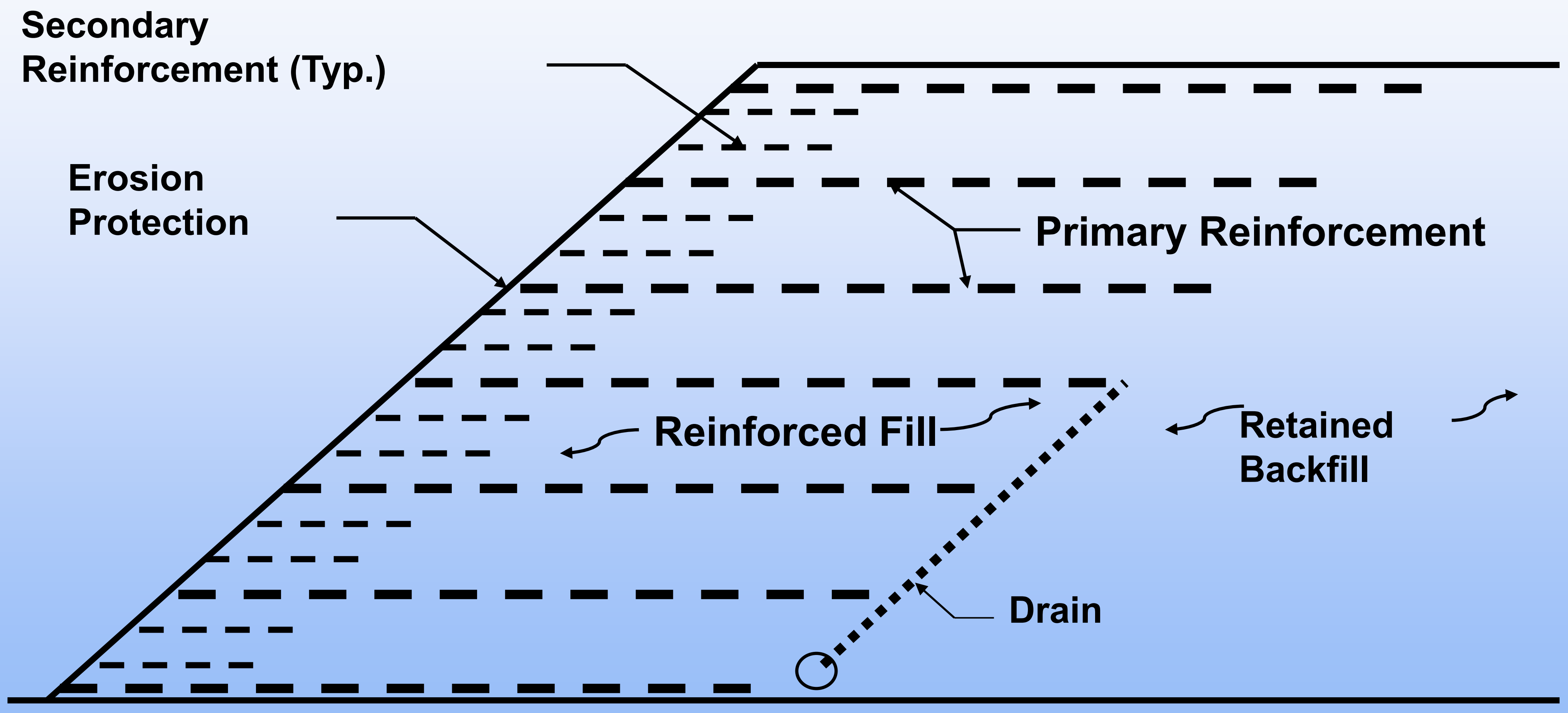
How Does Reinforcement Work?



Components of an MSE Wall



Reinforced Soil Slope



Major Advantages

MSEW

- Simple and rapid construction
- Cost effective
  - Less site preparation
  - Unskilled labor and small equipment
  - Reduced ROW acquisition
  - Less space needed in front during construction
  - No deep foundations
- Technically feasible to heights > 100 ft

RSS

- Cost effective where ROW is available
- Can use lower quality reinforced fill + higher seismic accelerations than MSEW

Potential Disadvantages

- Requires large space behind facing
- Requires select fill (MSEW)
- Requires considerations of reinforcement corrosion/degradation

MSEW / RSS Components

Major Components

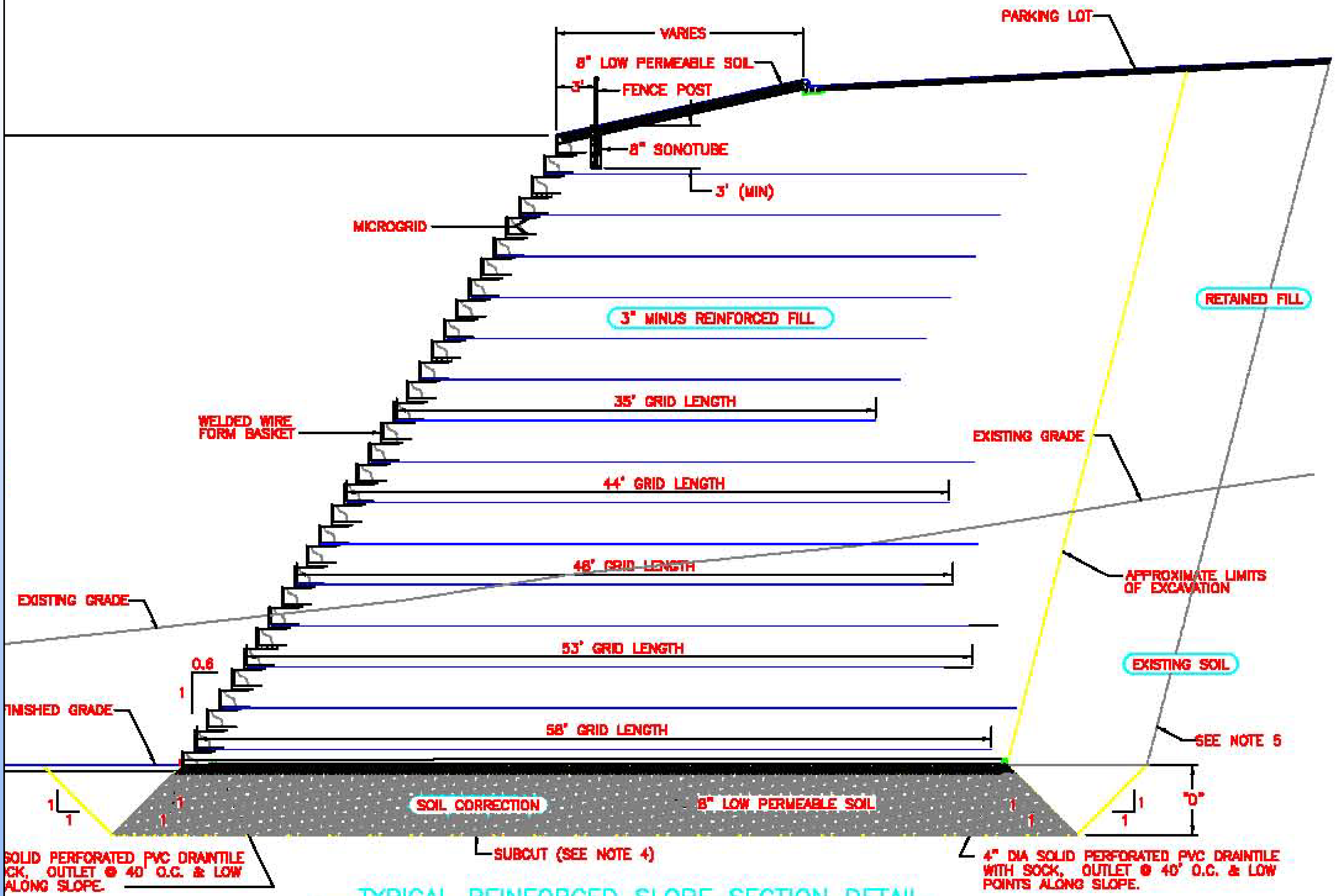
- Reinforced fill material (soil)
- Reinforcement
- Facing

Other Components

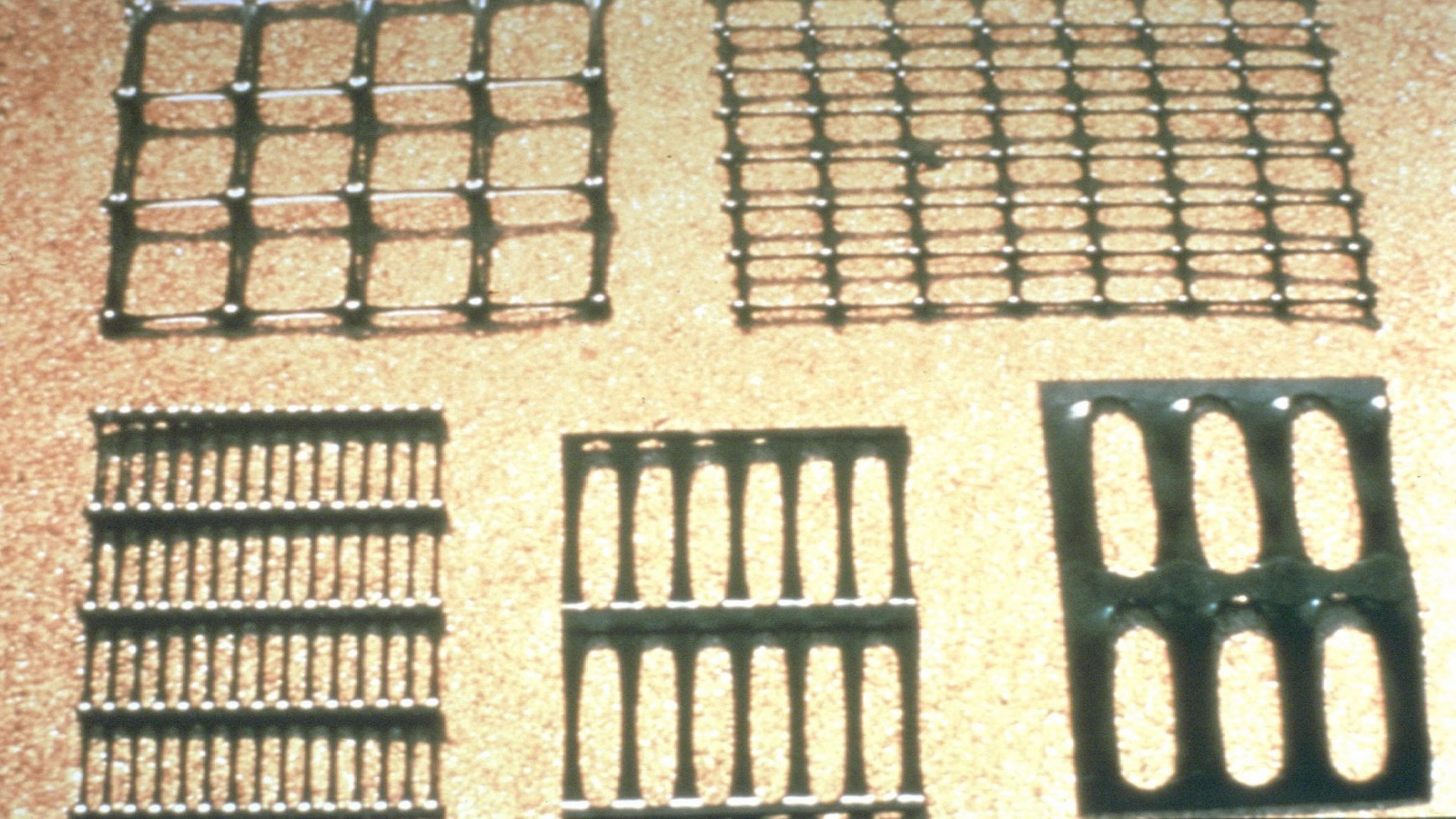
- Joint Materials
- Leveling Pads
- Coping
- Drainage
- Membrane (salts)
- Connections
- Traffic Barrier
- Ground Improvement (if needed)

Common Facing Systems

- Precast concrete panels (wet cast)
- Modular blocks (dry cast)
- Gabions
- Welded wire mesh
- Cast-in-place
- Timber
- Shotcrete
- Vegetation
- Geosynthetic: wrap around, geocells



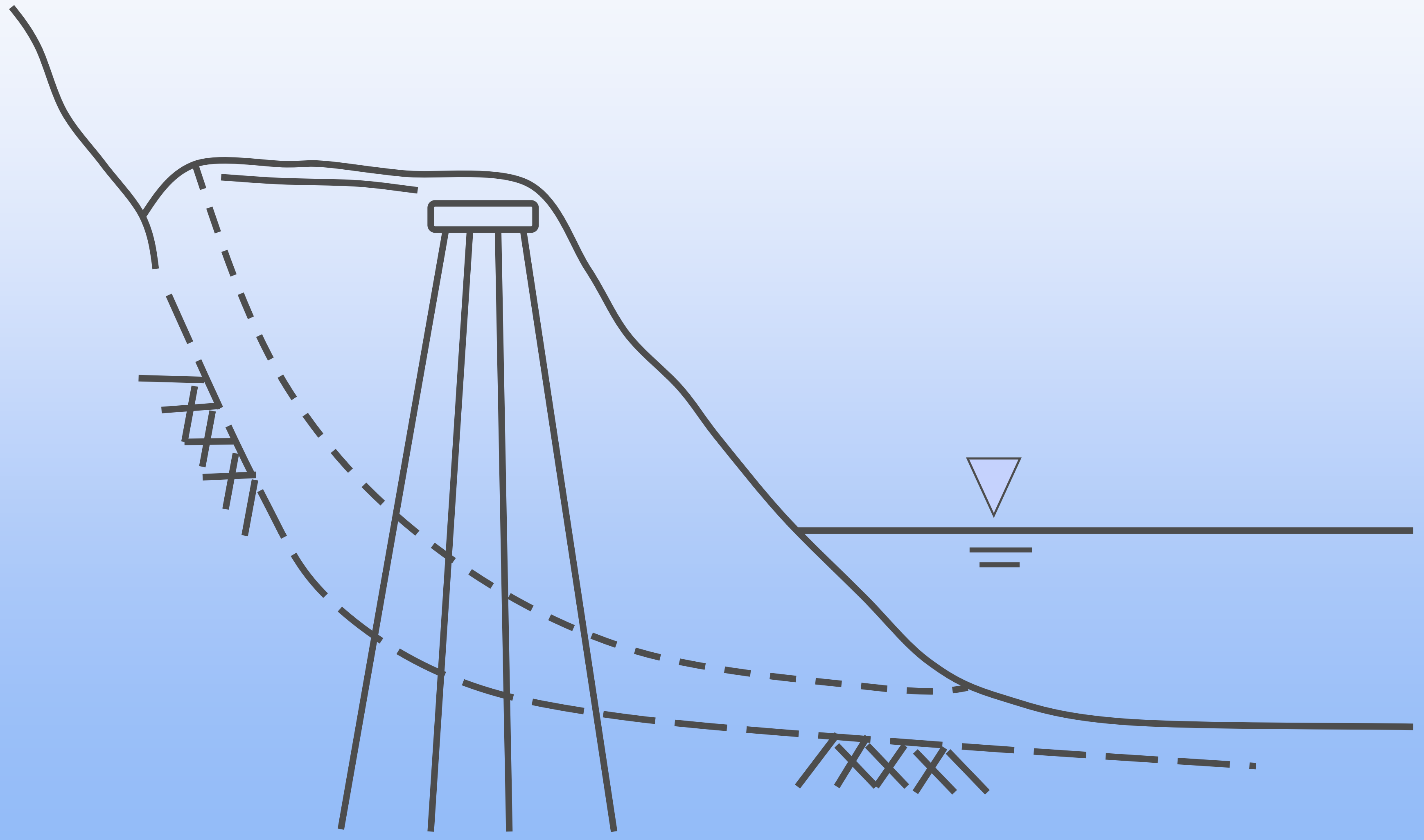
TYPICAL REINFORCED SLOPE SECTION DETAIL



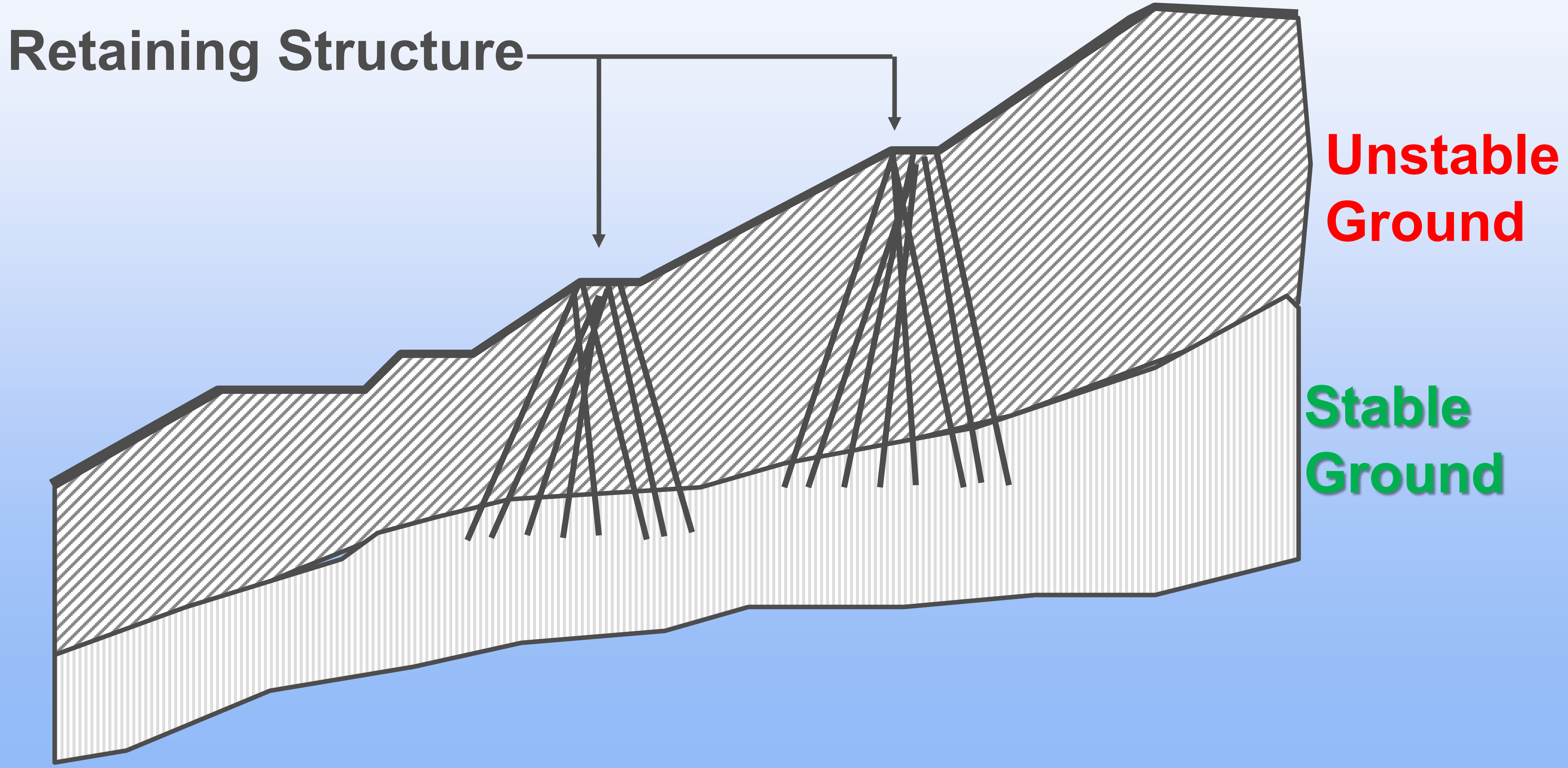
Soil Nails and Micropiles

Increase resisting stresses.

Micro-Pile Wall Roadway Stabilization



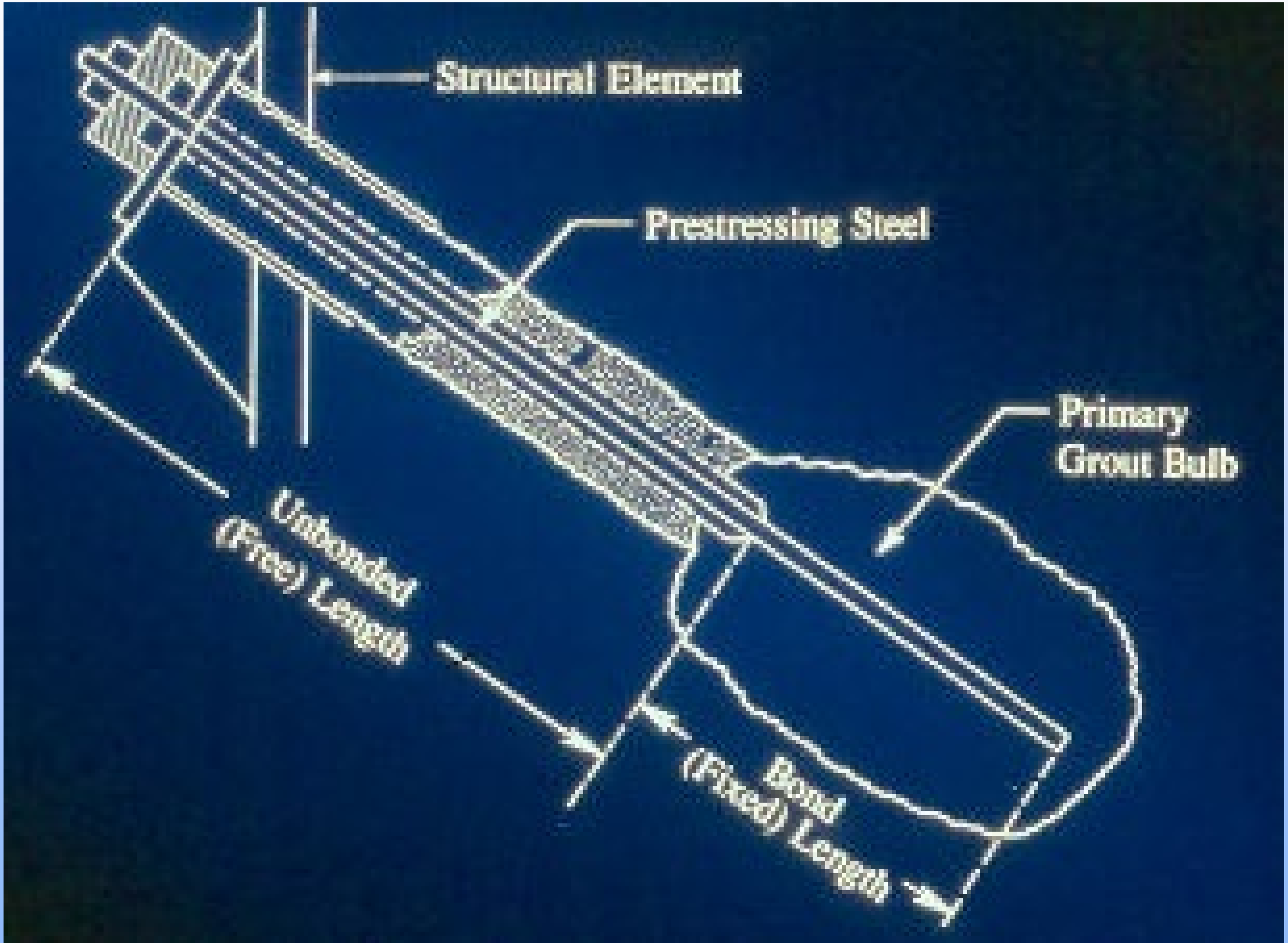
Micro-Pile Wall Slope Stabilization




FON EDILE

H Pile and Lagging Tieback Wall

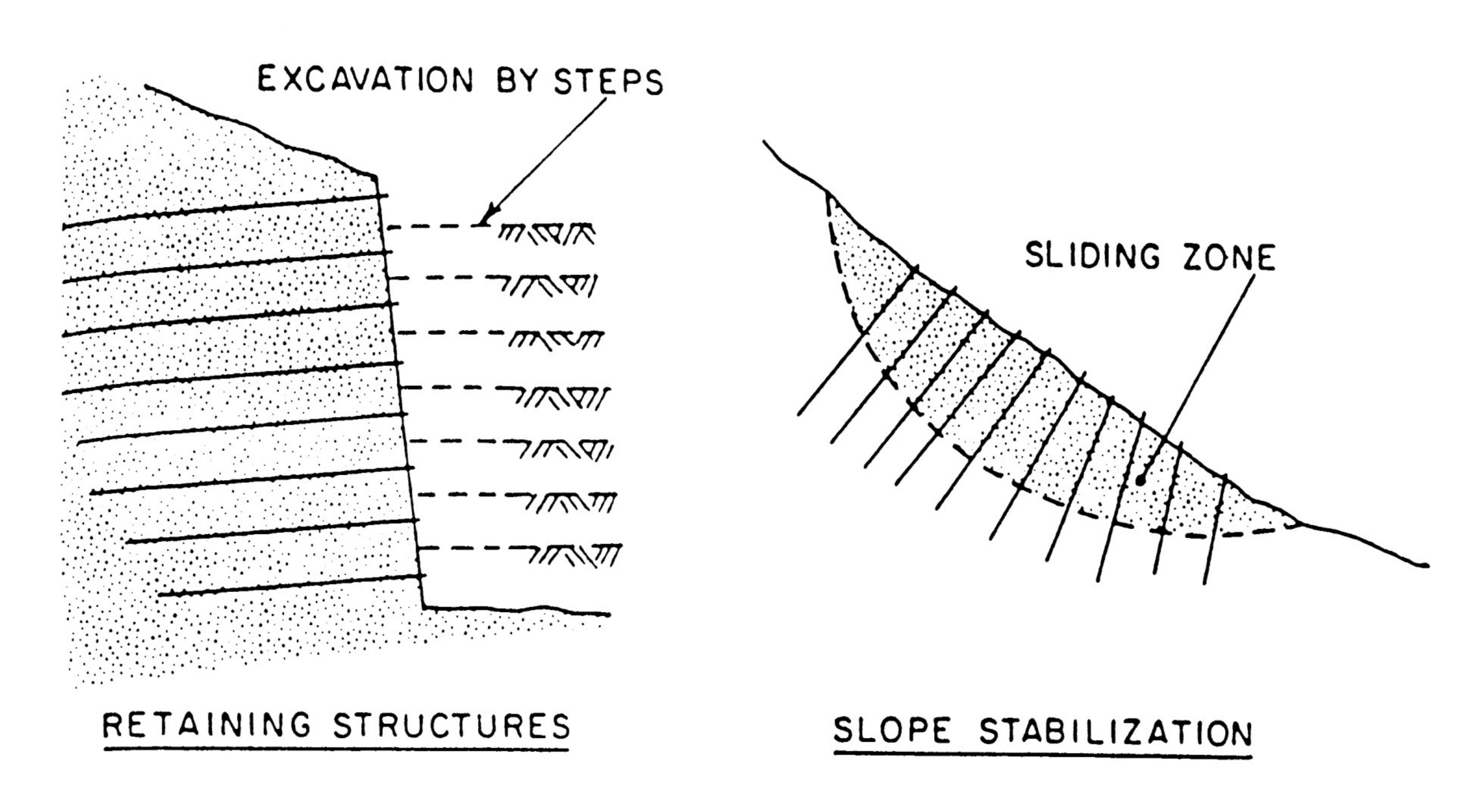
Typical Tieback



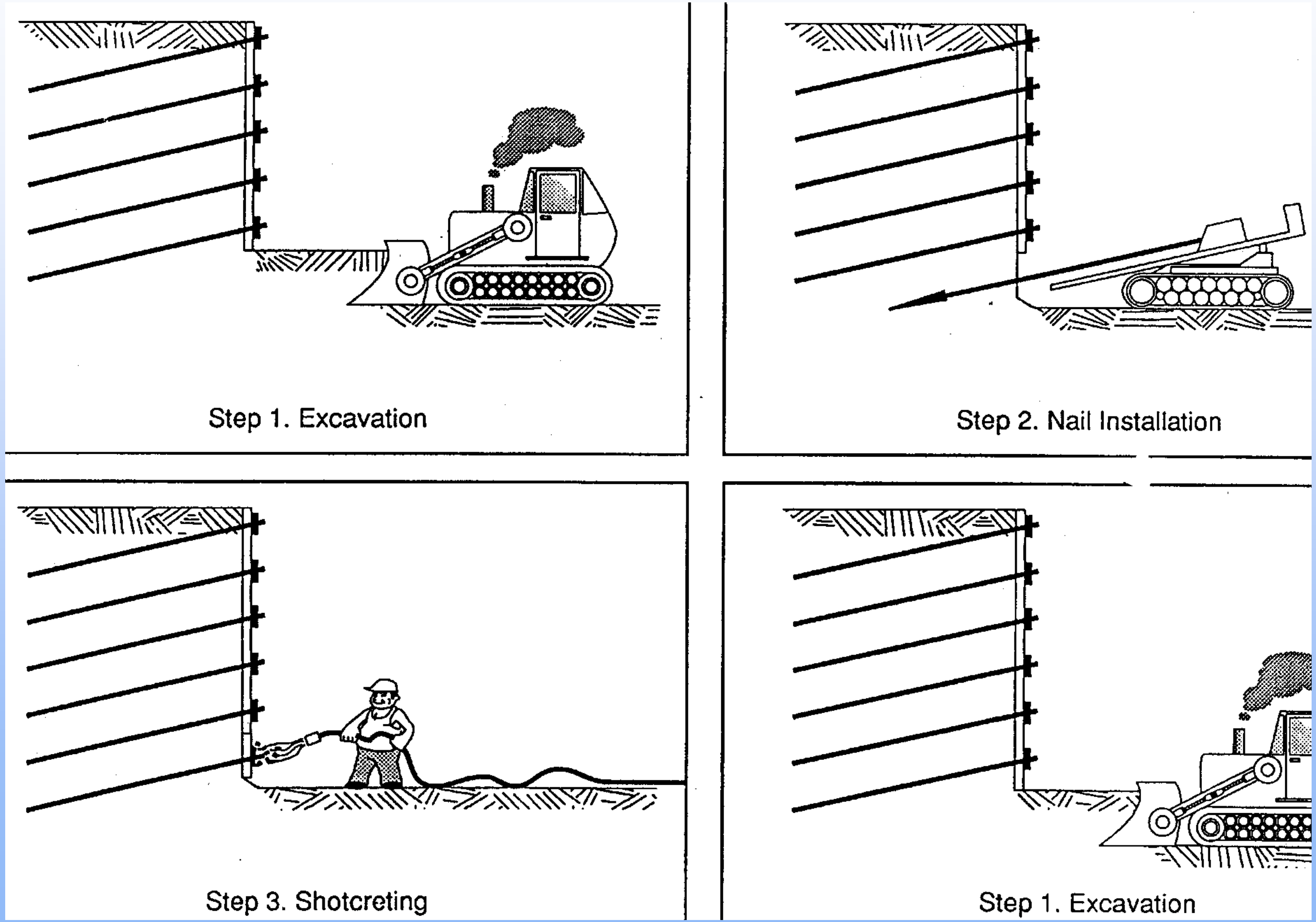
H Pile and Shotcrete

Soil Nails

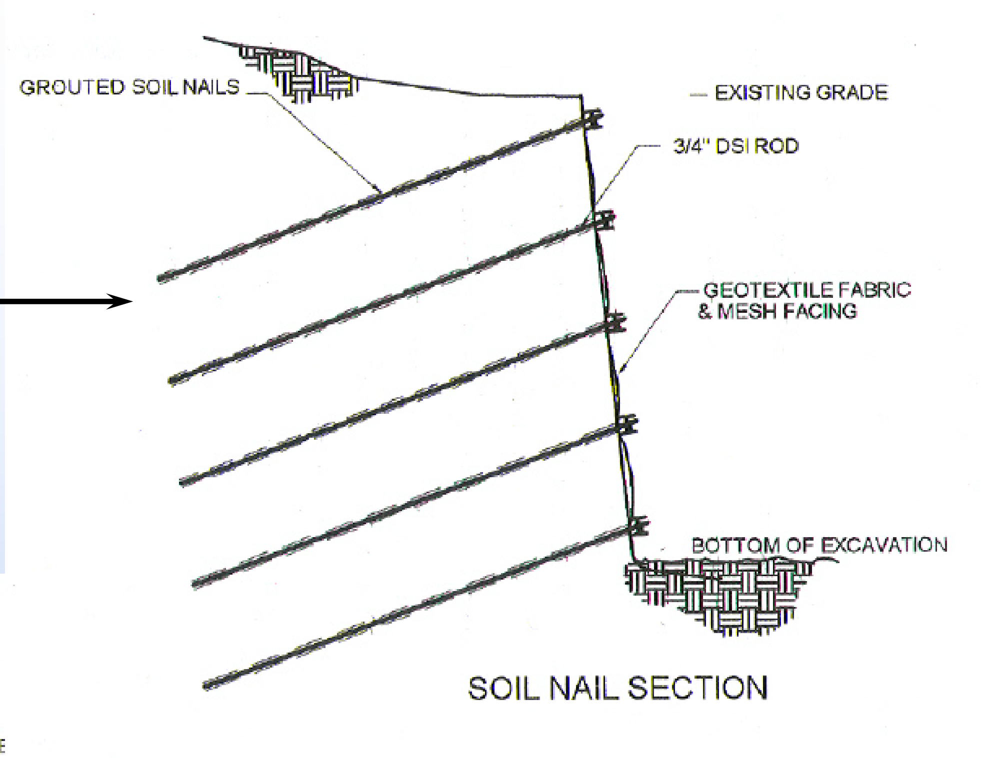
- Soil Nailing - an in situ technique for reinforcing, stabilizing and retaining excavations and deep cuts through the introduction of relatively small, closely spaced inclusions (usually steel bars) into a soil mass, the face of which is then locally stabilized.
- The “nails” are passive – they required soil movement to mobilize their strength.
- Reinforced earth looks similar, but the fill material in which the reinforcement is placed is fill rather than insitu soil.
- Earth Anchors look similar, but they are active elements – tensioned.

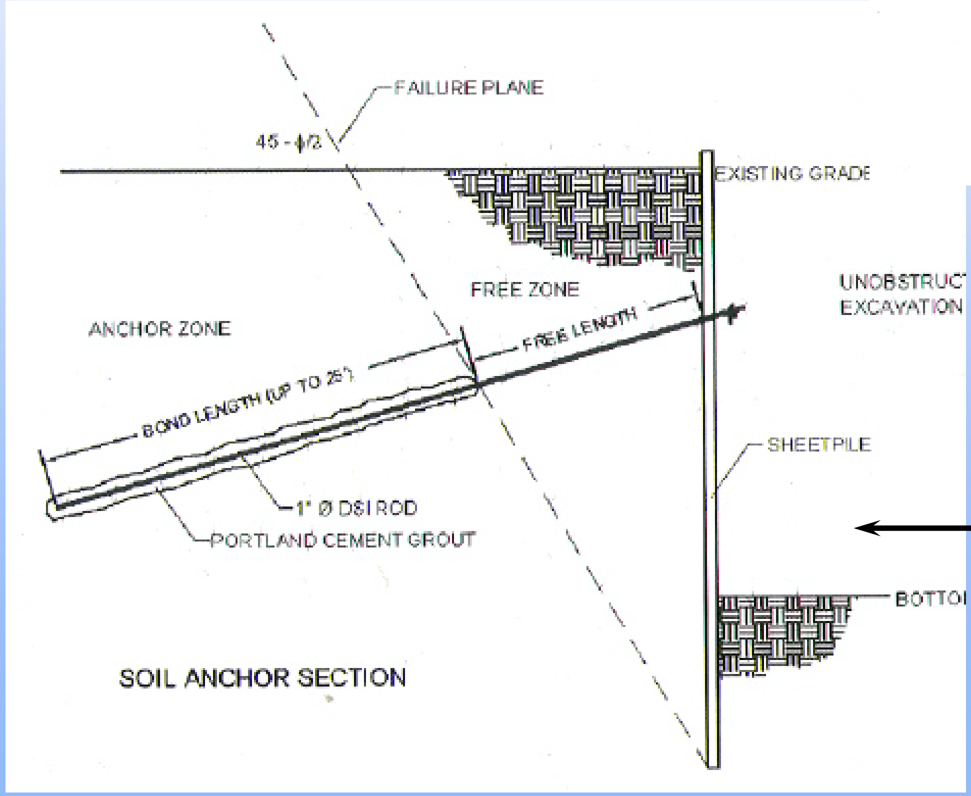

EXCAVATION BY STEPS
SLIDING ZONE
RETAINING STRUCTURES
SLOPE STABILIZATION

Construction Process



Soil Nail system – full length grouting of nails – no initial load.



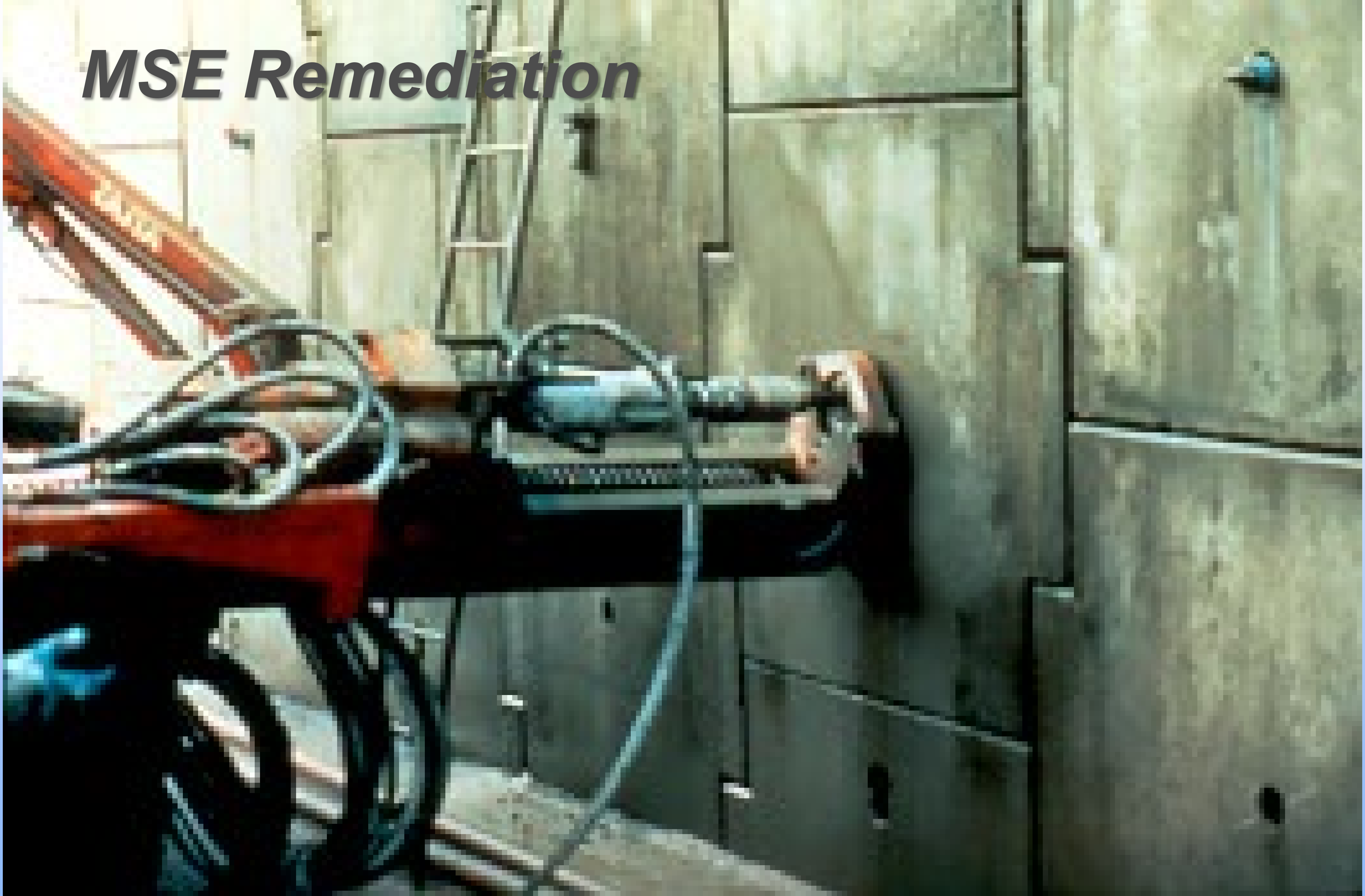


Earth Anchor system – only the portion of the anchor behind the assumed failure surface is grouted to provide load transfer – anchors are tensioned.

Applications

- Slumps, creeping slopes, often used for cuts and fills
- Vertical or near vertical cut construction (i.e. road widening projects)
- Tunnel portals
- Repair existing walls (i.e., MSE)

MSE Remediation



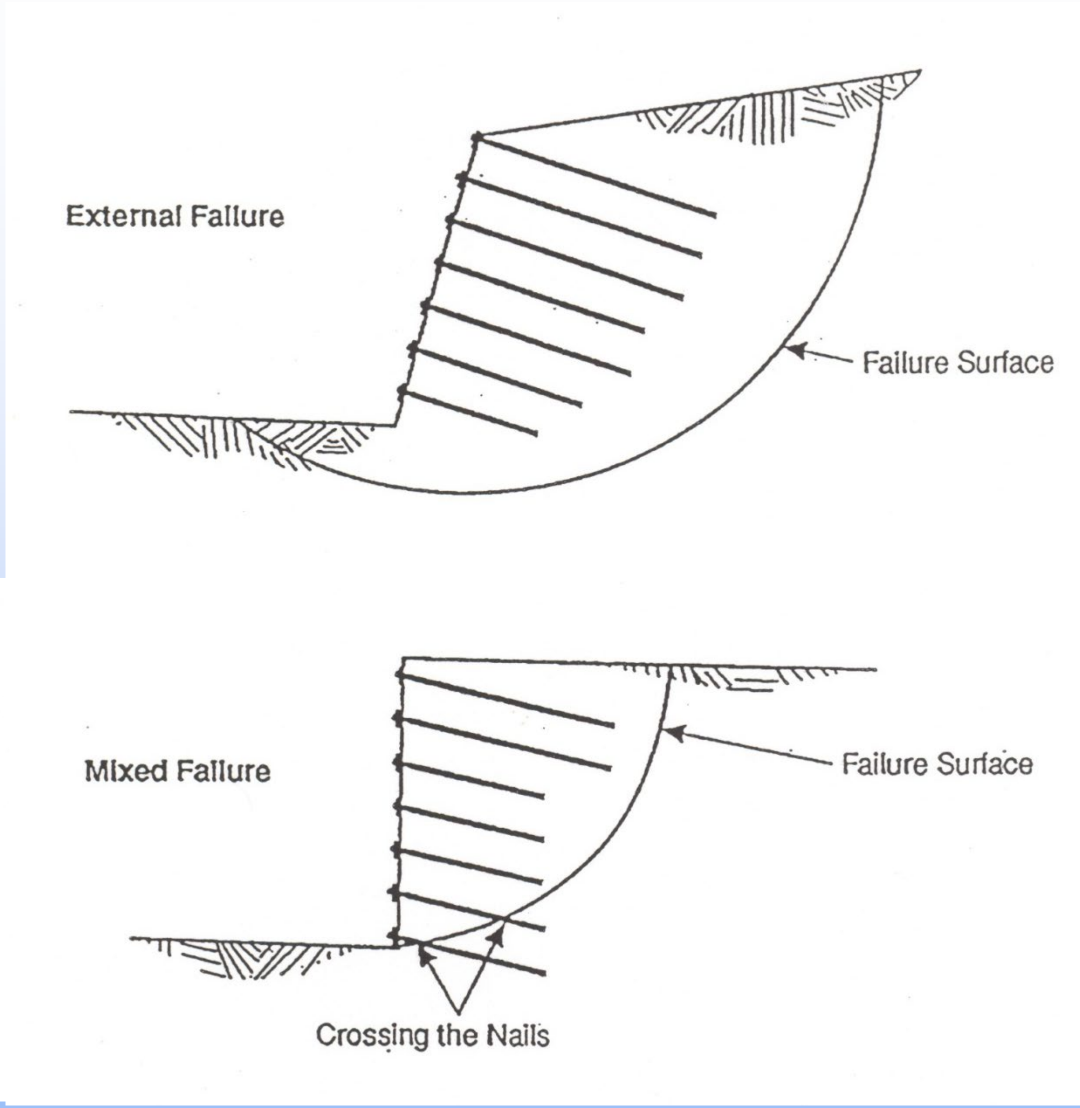
What are the advantages of Soil Nailing?

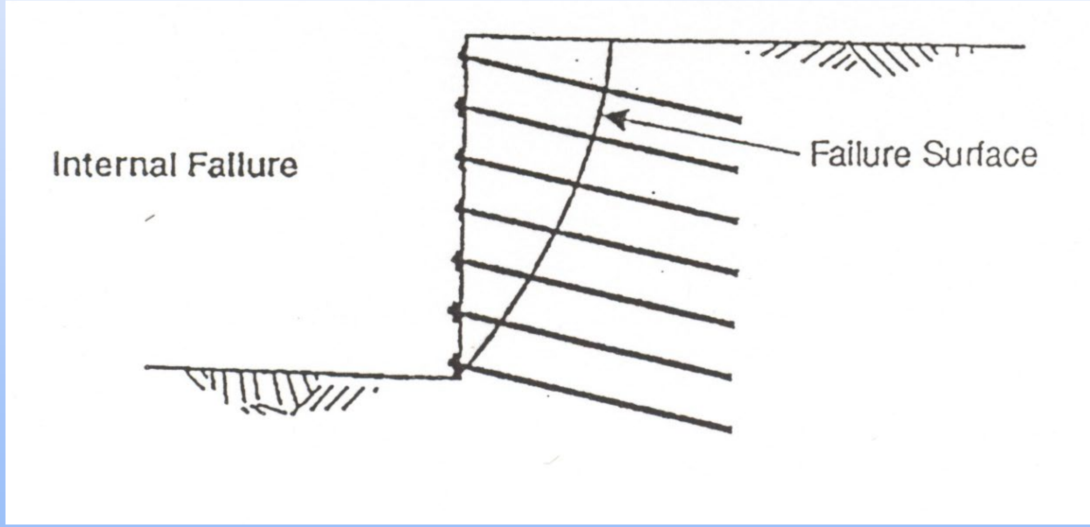
- Incorporation of temporary support in final structure
- Reduction in cut excavation
- Potential reduction in right-of-way
- Rapid construction
- Large # of nails - redundant system
- Cost effective

What are the disadvantages of Soil Nailing?

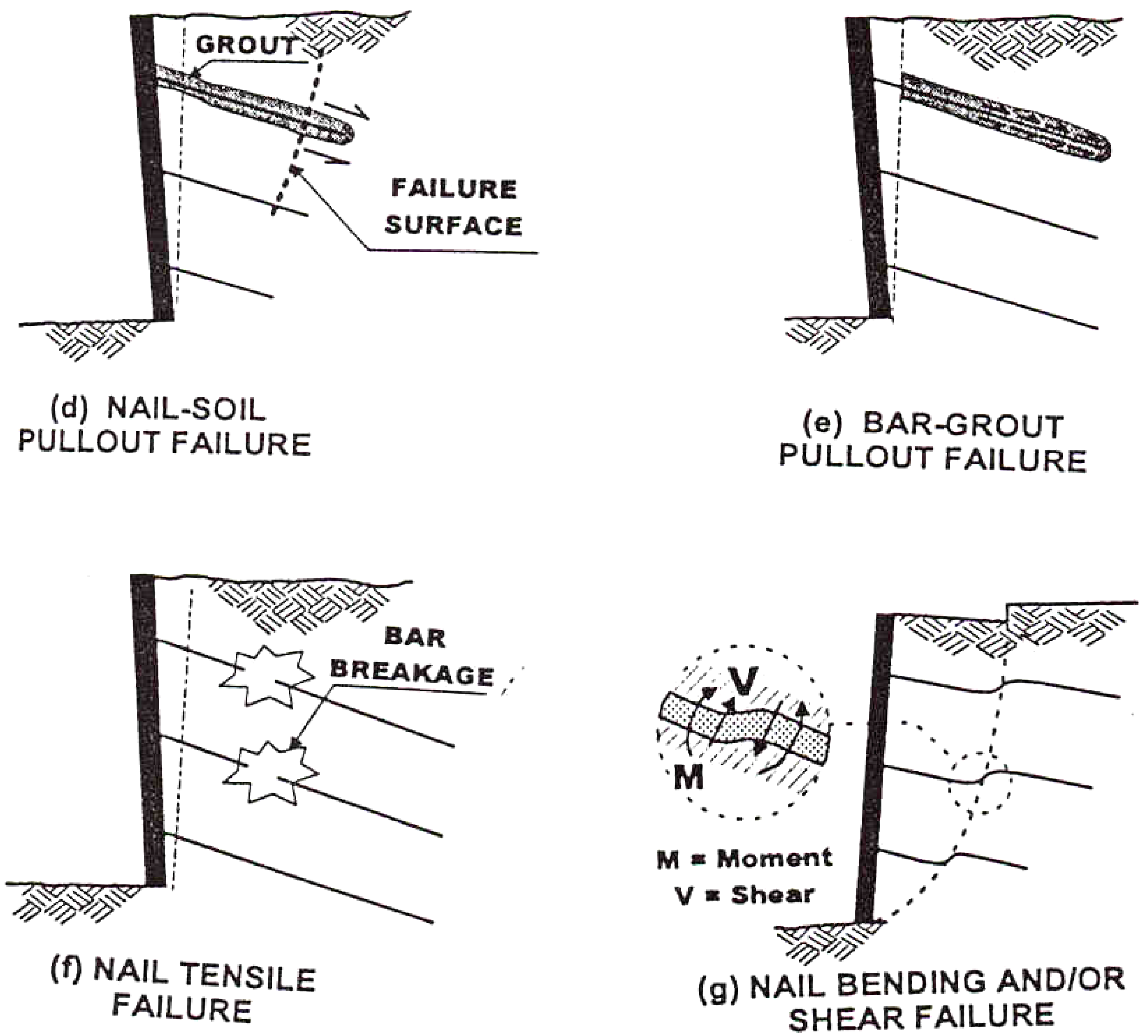
- Permanent underground easements may be required
- Difficult to construct wall with high groundwater
- Utility conflicts
- Nail capacity may not be economical in highly plastic clays
- Ground displacements
- Durability of shotcrete with respect to freeze thaw
- Soil face must exhibit sufficient stand up time

Soil Nail Design – Failure Modes





Internal Failure Modes




Construction: ~5 feet increments

Good Root Reinforcement


Grout, then…

Wire mesh and drain behind face


Happily apply shotcrete

What are common issues/problems with soil nailing?

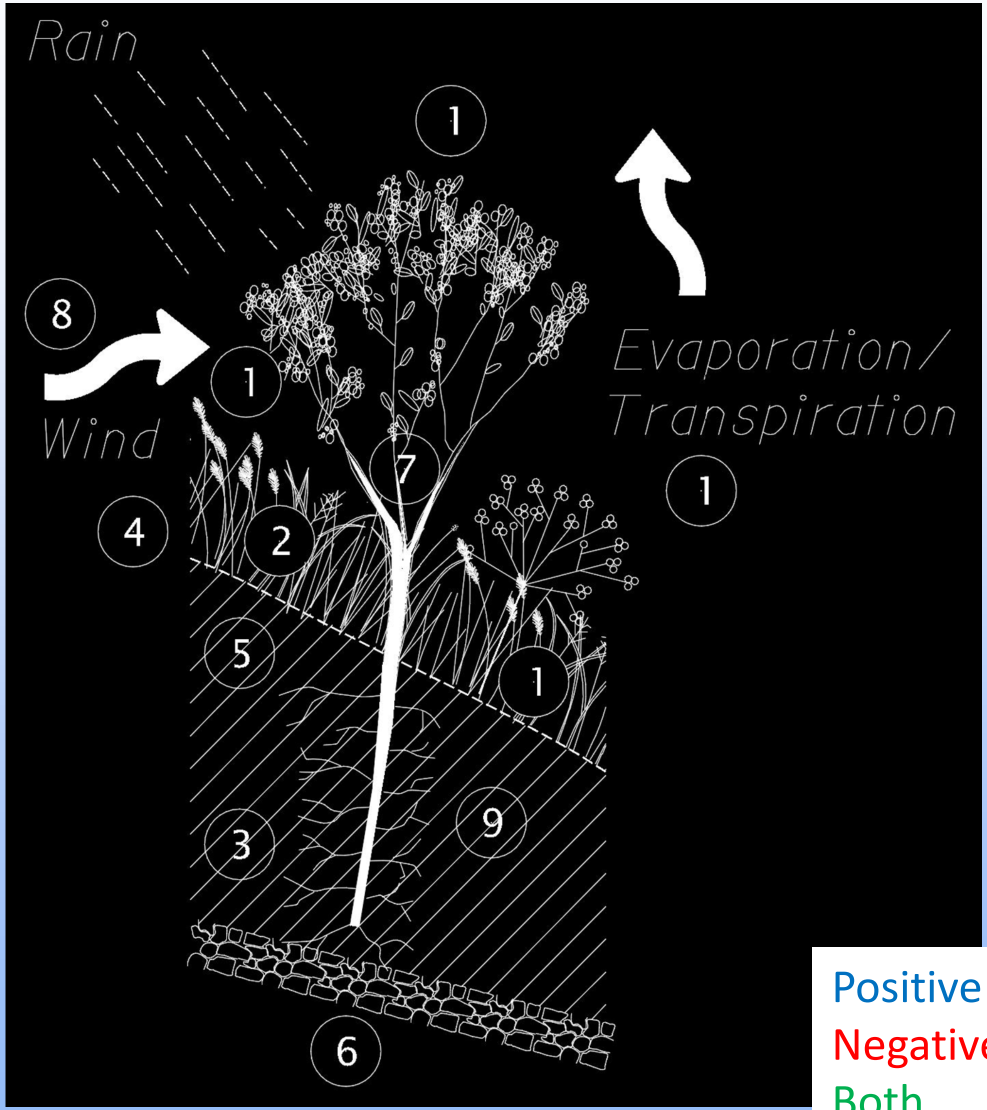
- Not economical in soils with poor standup time or requiring cased drill holes
- Not economical in cohesive soils with low to medium strength below groundwater table
- May require freeze-thaw consideration in northern climates
- Deformation

Note wetness - freeze impact

Vegetation and Surface Protection

Decreasing erosion potential and oversteepening (decreasing driving forces).

The Role of Vegetation in Slope Stability



Positive
Negative
Both

From Cornforth, 2005

Hydrologic Effects

1. Foliage intercepts rainfall reducing the rate at which water seeps into the subsurface. Absorption and evaporation reduce the amount that reaches the soil
2. Roots and stems increase surface roughness, increasing infiltration
3. Roots extract moisture from the soil which is transpired to the atmosphere
4. Soil moisture depletion can dessicate the soil and cause cracking that allows increased infiltration

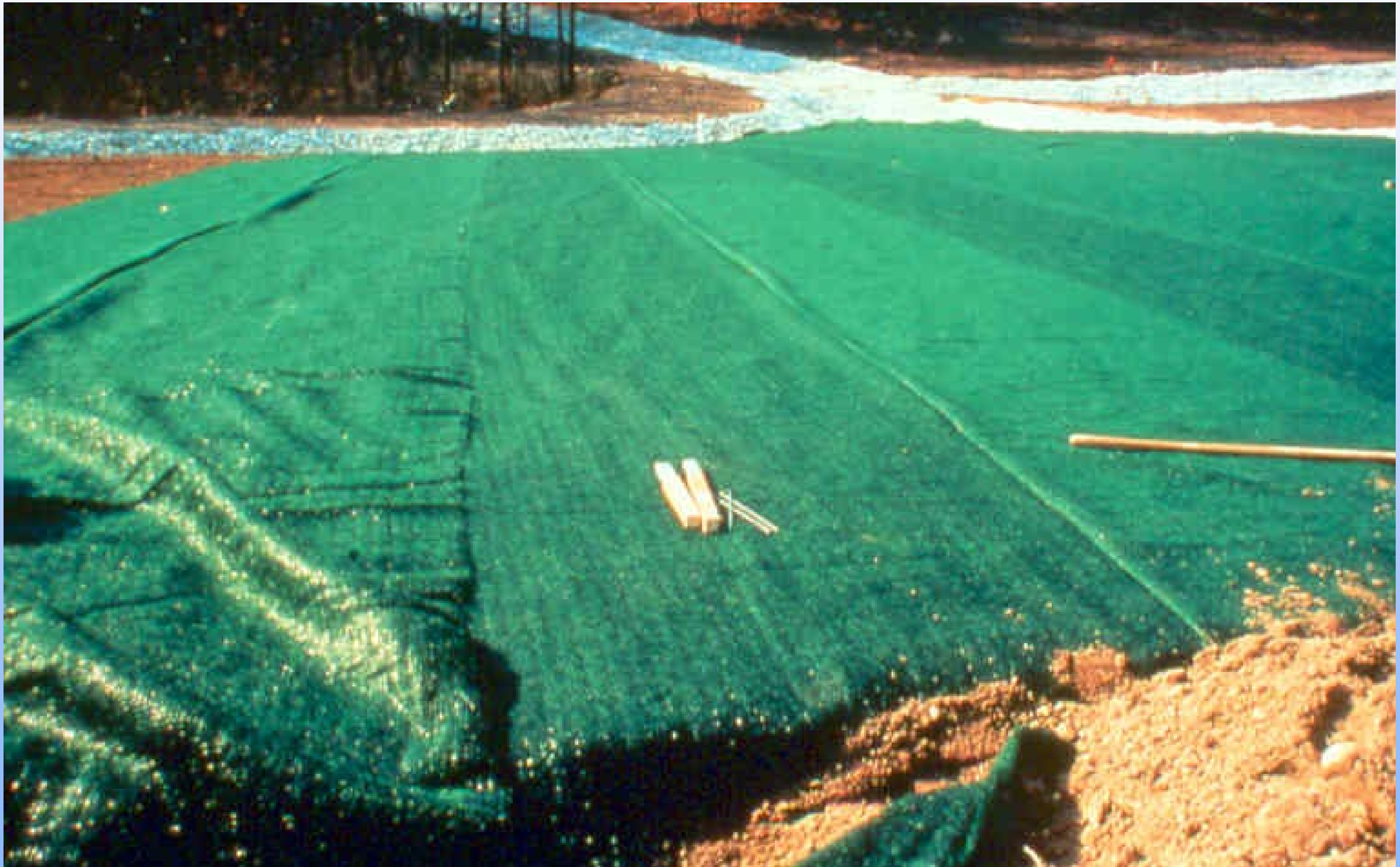
Mechanical Effects

5. Roots reinforce the soil ,increasing shear strength
6. Tree roots may anchor into underlying rock, supporting the overlying soil
7. Weight of trees surcharges the slope. Increasing normal and down-slope force components
8. Vegetation exposed to wind transmits dynamic forces into the slope
9. Roots bind soil particles at the ground surface and increase surface roughness which reduces erosion.

Surface Protection

Surface Treatments

Stabilization Method – Erosion Control

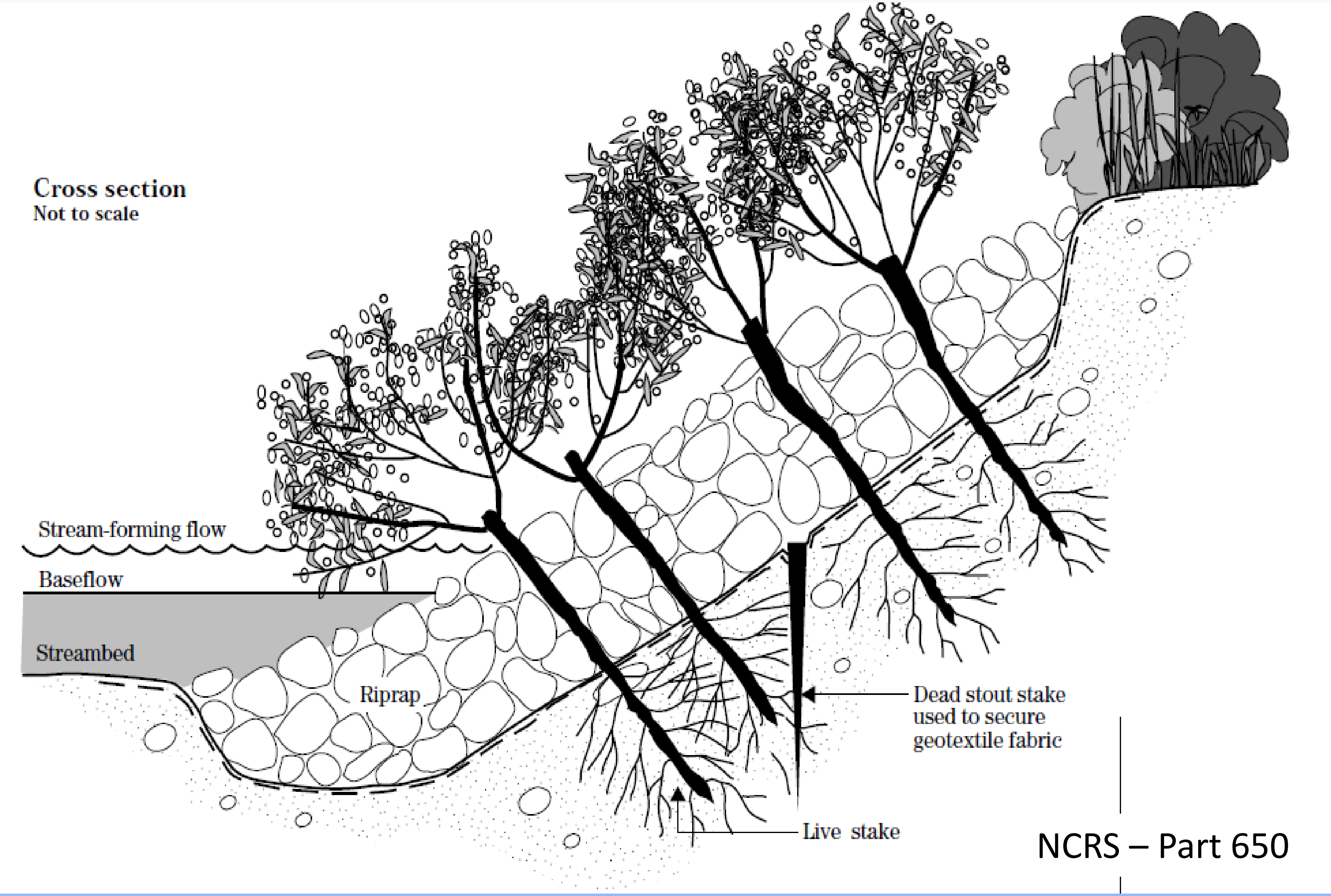


Stabilization Method – Erosion Control

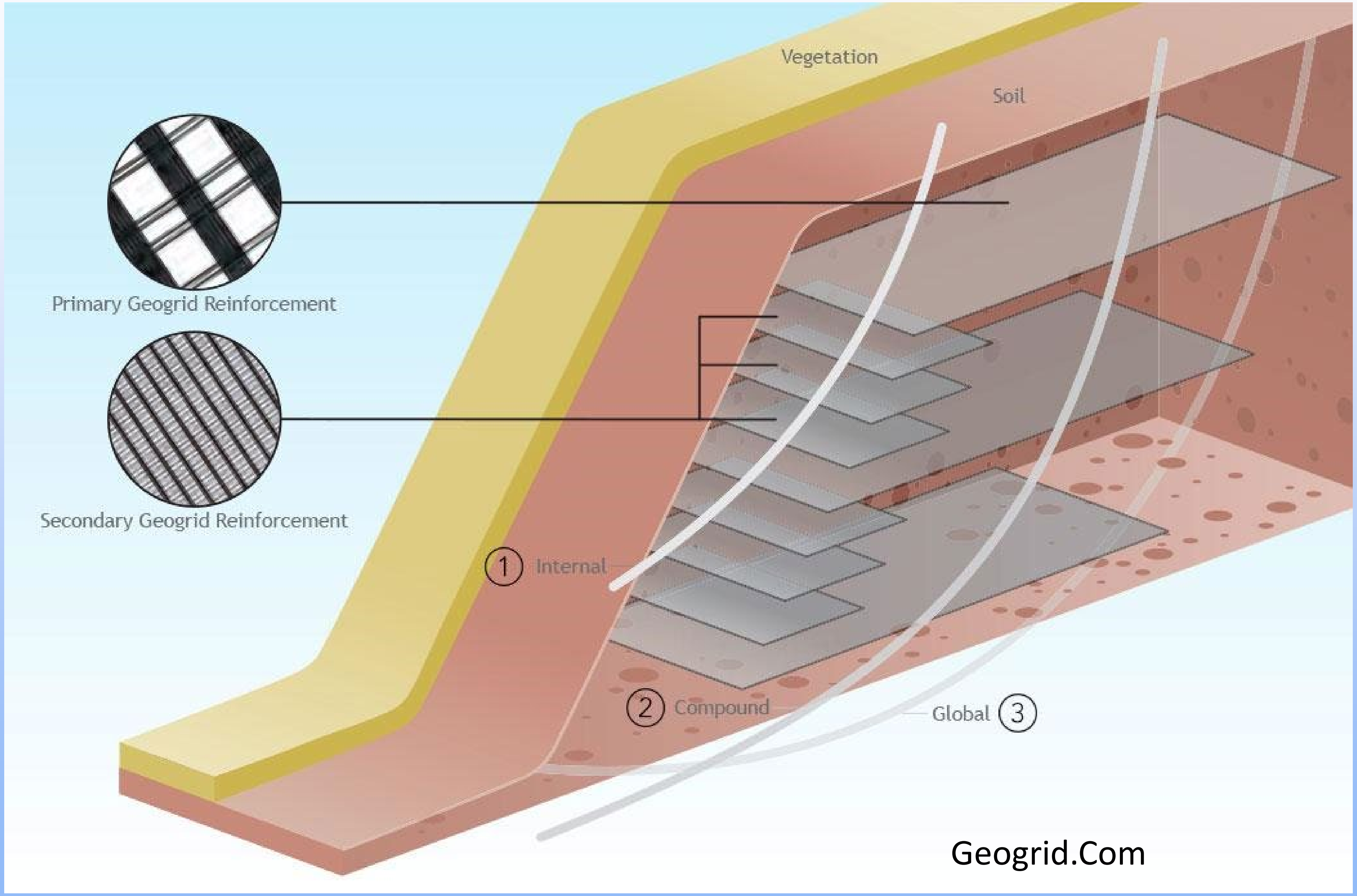
Stabilization Method – Erosion Control

Avoidance

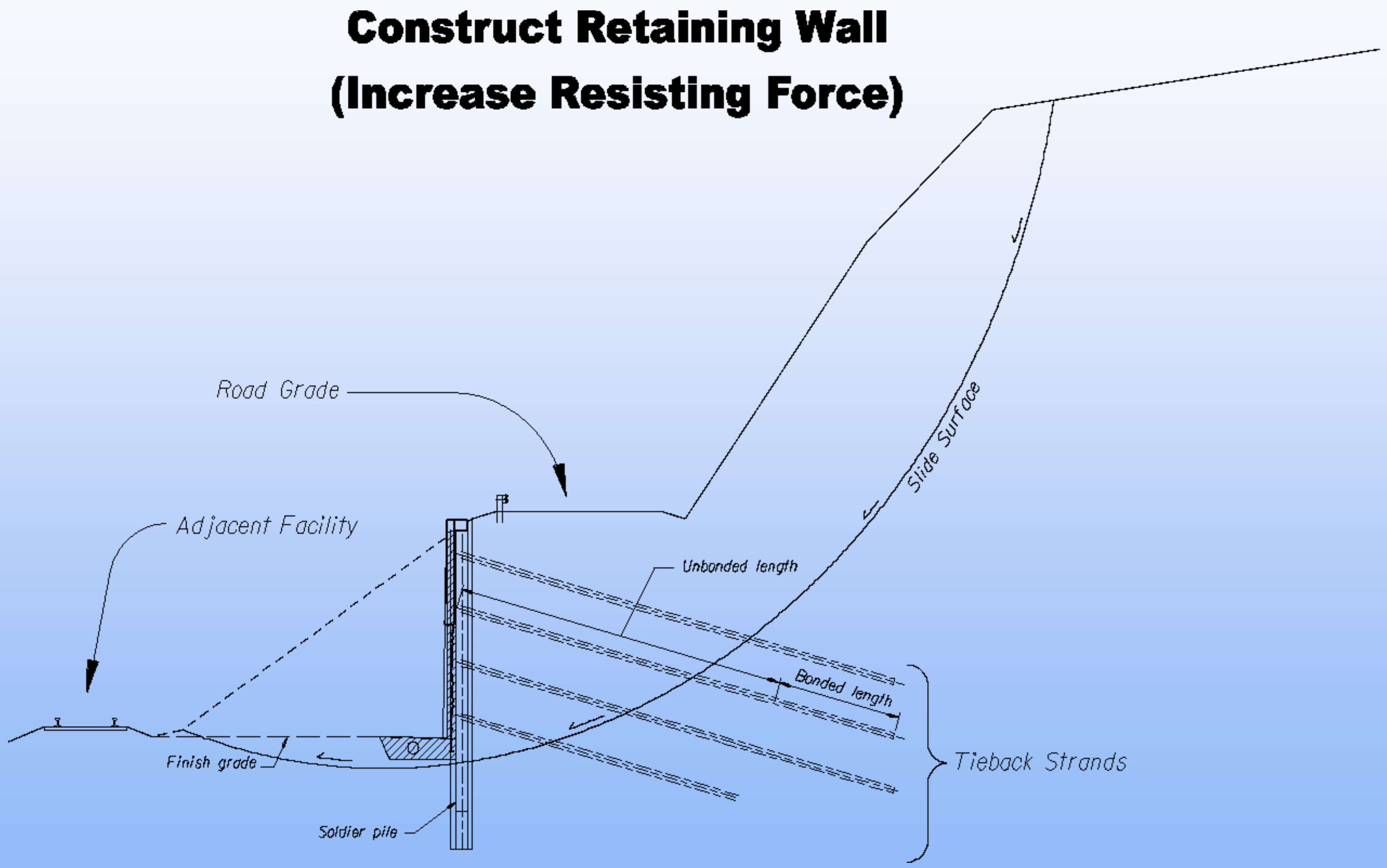
Addressing Toe Erosion of Buttresses



Reinforcement



Earth Retention Structures



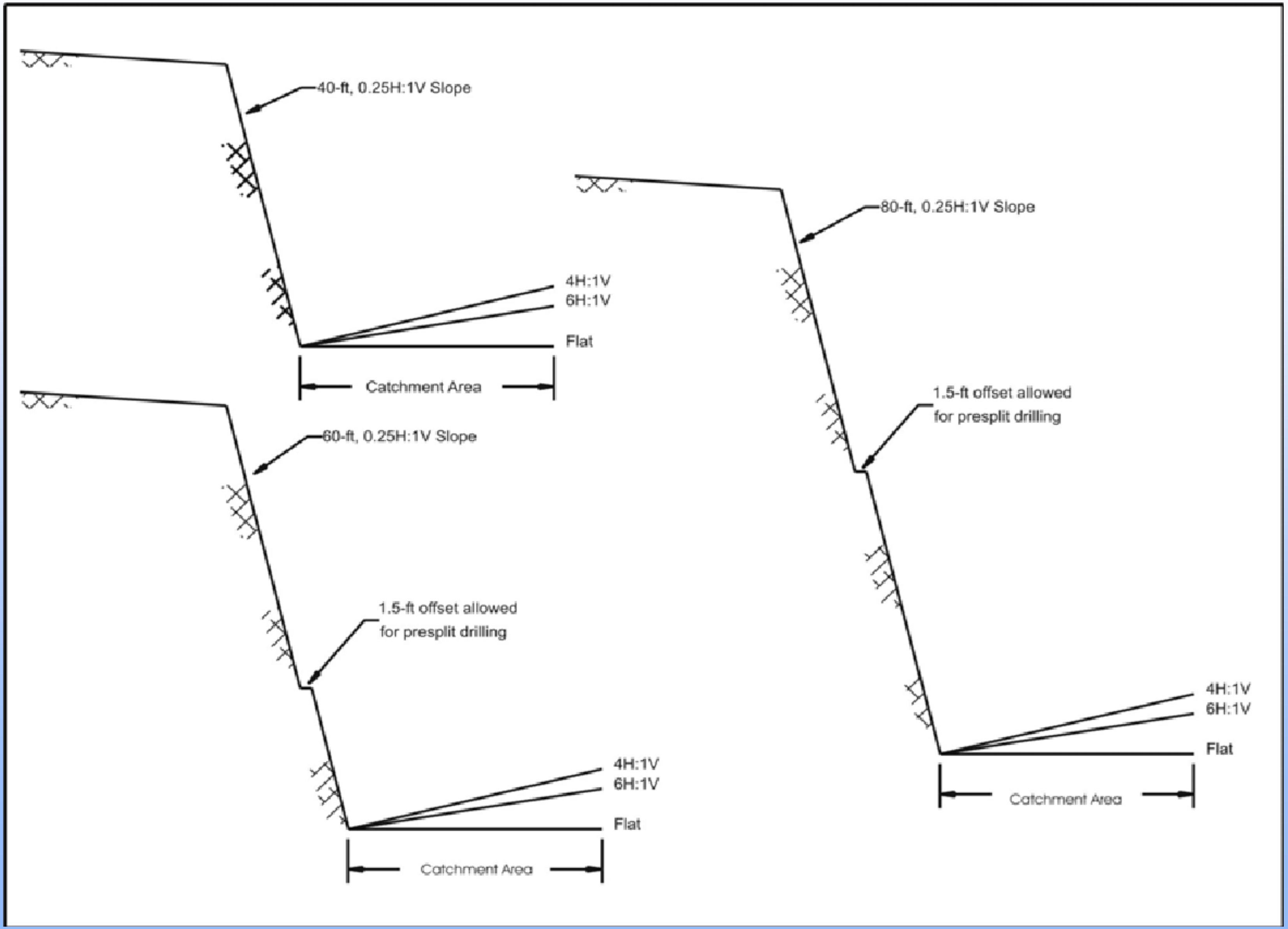
Tieback Wall Construction

Rockfall Mitigation

Rock Slope Stabilization

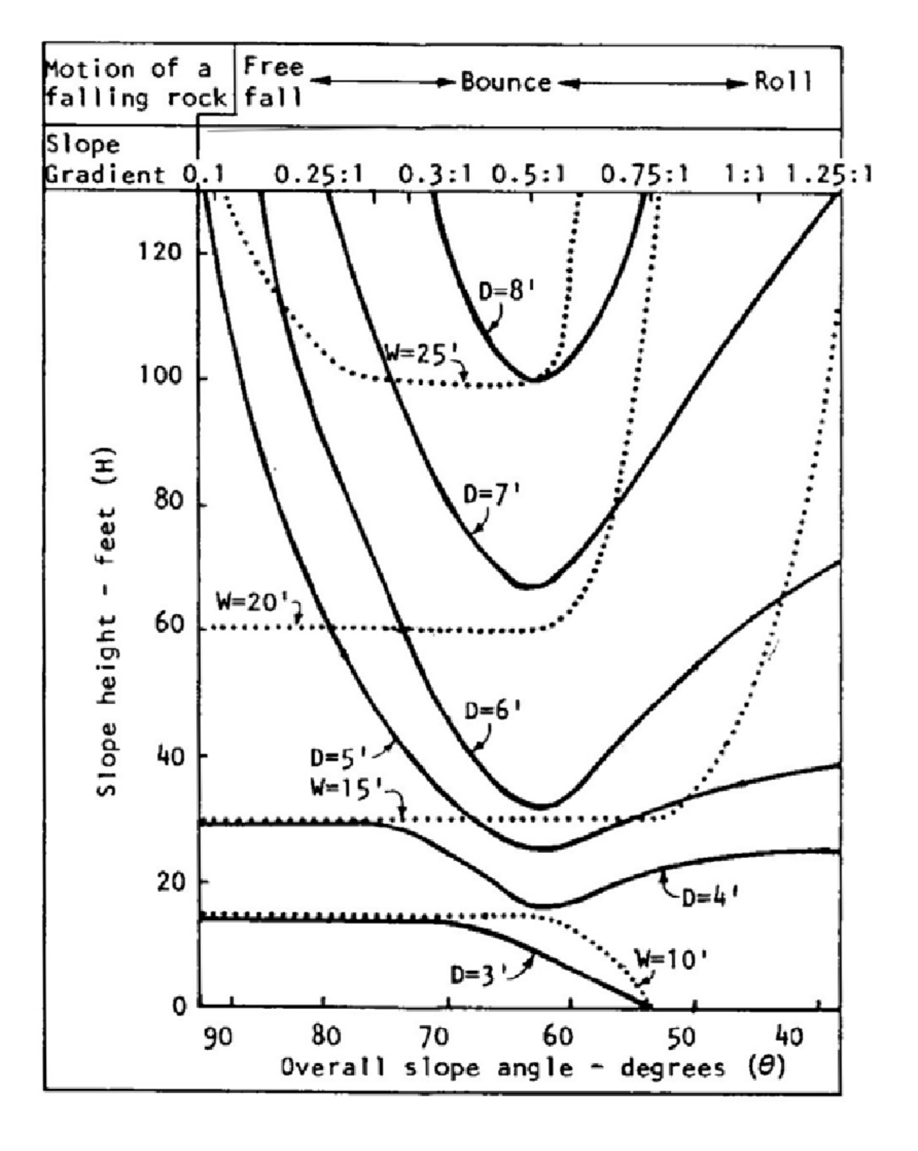
Stephen Hay

Avoidance



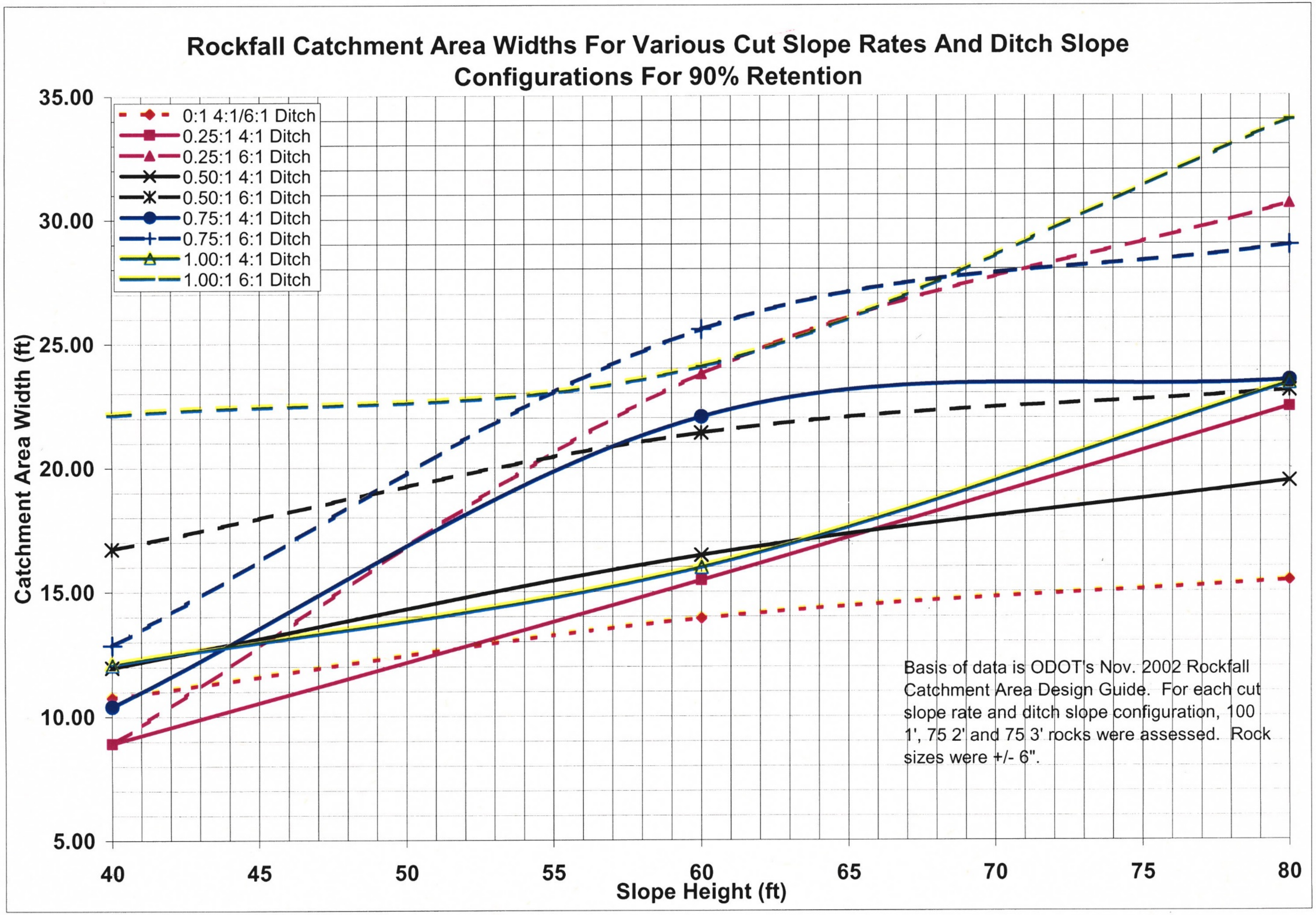
40-ft, 0.25H:1V Slope
4H:1V
6H:1V
Flat
Catchment Area
60-ft, 0.25H:1V Slope
1.5-ft offset allowed
for presplit drilling
4H:1V
6H:1V
Flat
Catchment Area
80-ft, 0.25H:1V Slope
1.5-ft offset allowed
for presplit drilling
4H:1V
6H:1V
Flat
Catchment Area

Slope/Catchment Design



No Catchment

Catchment Modification



Rockfall Catchment Area Widths For Various Cut Slope Rates And Ditch Slope Configurations For 90% Retention
0:1 4:1/6:1 Ditch
0.25:1 4:1 Ditch
0.25:1 6:1 Ditch
0.50:1 4:1 Ditch
0.50:1 6:1 Ditch
0.75:1 4:1 Ditch
0.75:1 6:1 Ditch
1.00:1 4:1 Ditch
1.00:1 6:1 Ditch
Catchment Area Width (ft)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
40
45
50
55
60
65
70
75
80
Slope Height (ft)
Basis of data is ODOT's Nov. 2002 Rockfall Catchment Area Design Guide. For each cut slope rate and ditch slope configuration, 100 1', 75 2' and 75 3' rocks were assessed. Rock sizes were +/- 6".

Scaling

Scaling – Trim Blasting

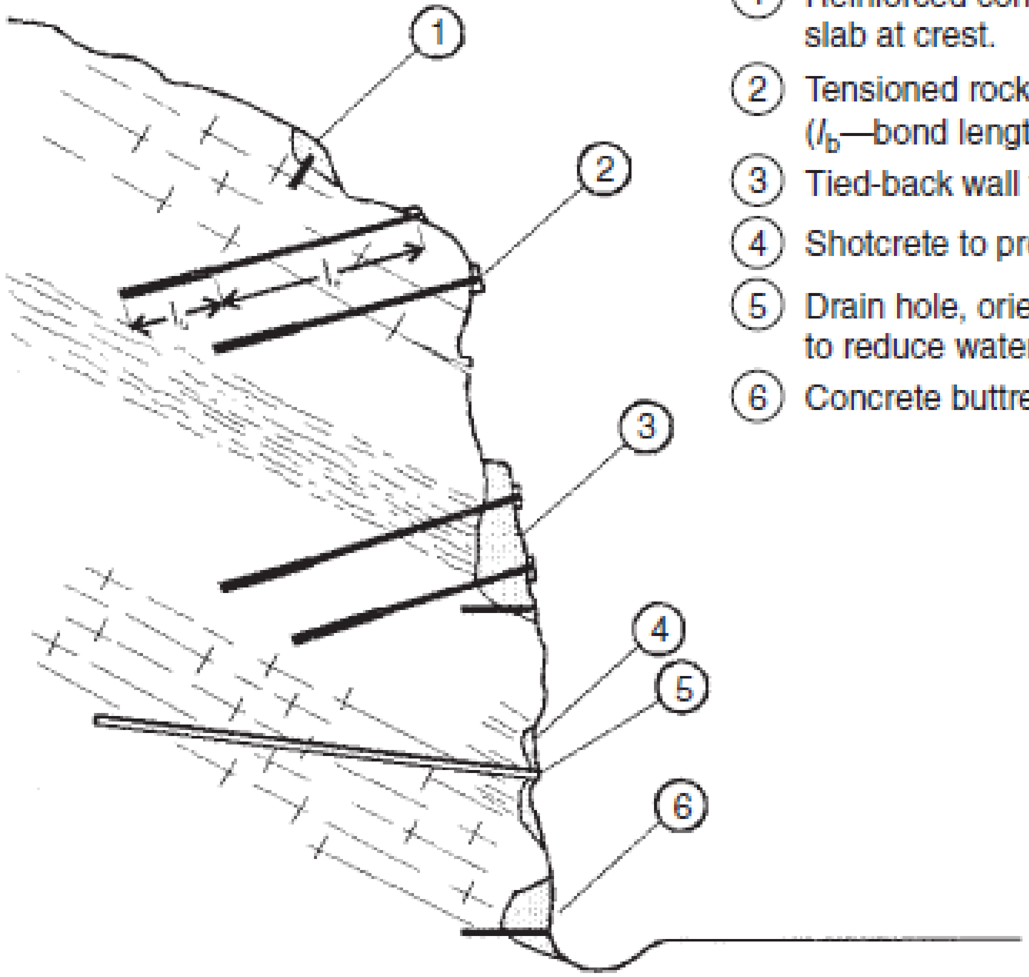
Slope Mats

Rock Fences

Rock Bolts

Rock Bolt

Other Mechanical Methods



1. Reinforced concrete shear key to prevent loosening of slab at crest.
2. Tensioned rock anchors to secure sliding blocks along crest (l_b—bond length; l_f—unbonded length).
3. Tied-back wall to prevent sliding on fault zone.
4. Shotcrete to prevent raveling of zone of fractured rock.
5. Drain hole, oriented to intersect water-bearing joints, to reduce water pressure within slope.
6. Concrete buttress to support rock above cavity.

TRB 1996

Questions?