Slope Stability 101

Basic Concepts and NOT for Final Design Purposes!

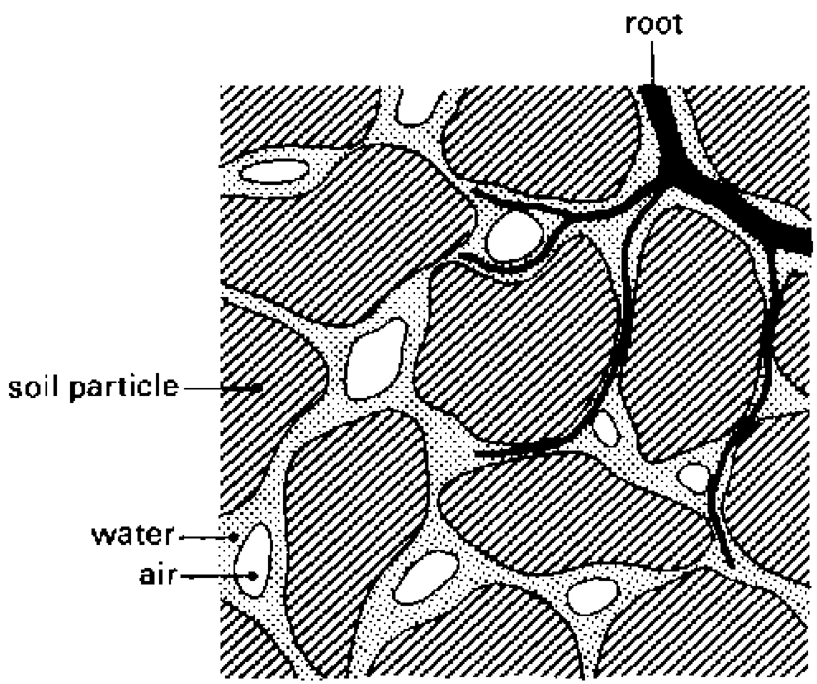
Slope Stability Analysis Basics

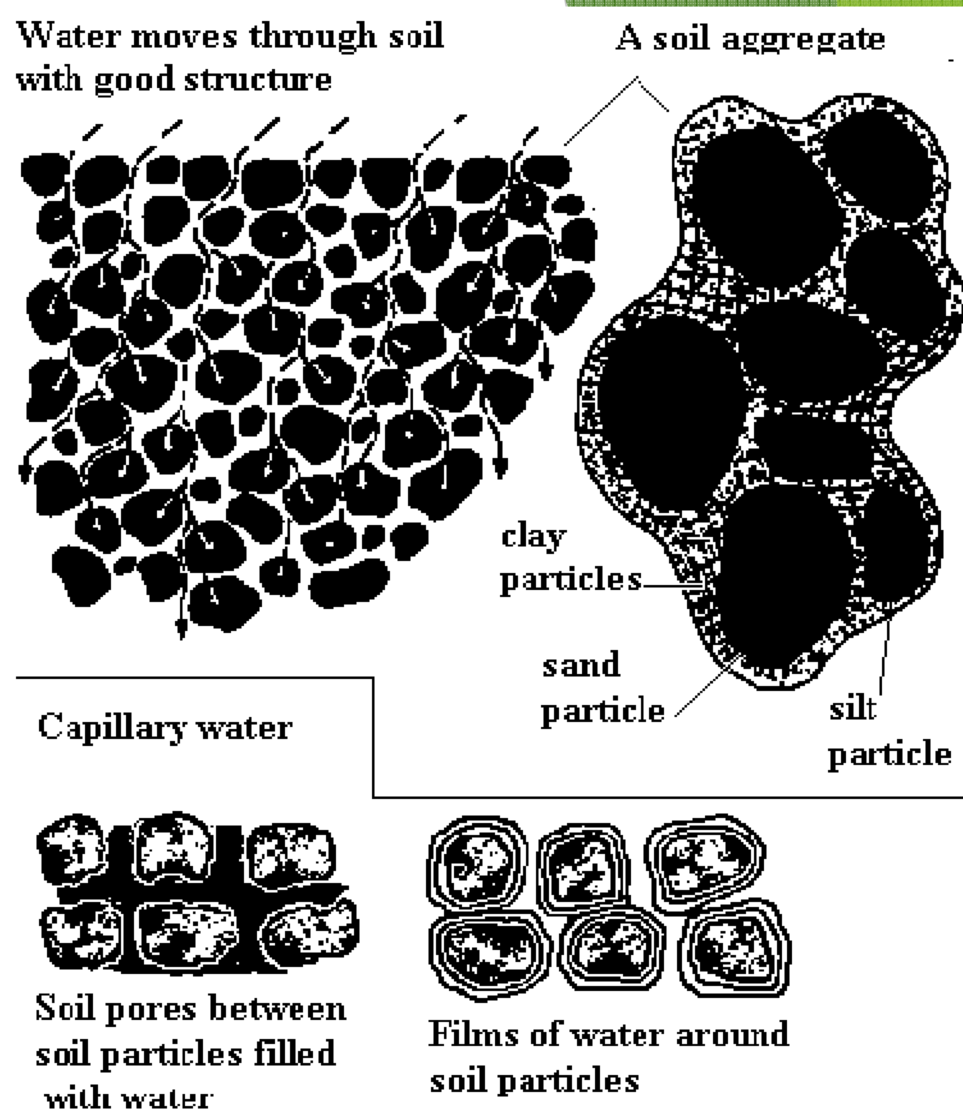
- Shear Strength of Soils
  - Ability of soil to resist sliding on itself on the slope

Angle of Repose

- **definition**
- *n***1.** the maximum angle to the horizontal at which rocks, soil, etc, will remain without sliding


Sand
Silt
Clay


root
soil particle
water
air


Water moves through soil with good structure
A soil aggregate
clay particles
sand particle
silt particle
Capillary water
Soil pores between soil particles filled with water
Films of water around soil particles

Shear Strength Parameters and Soils Info

- Φ angle of internal friction
- C cohesion (clays are cohesive and sands are non-cohesive)
- Θ slope angle
- γ unit weight of soil

Internal Angles of Friction Estimates for our use in example

- Silty sand Φ = 25 degrees
- Loose sand Φ = 30 degrees
- Medium to Dense sand Φ = 35 degrees
- Rock Riprap Φ = 40 degrees

Slope Stability Analysis Basics

- Explore Site Geology
- Characterize soil shear strength
- Construct slope stability model
- Establish seepage and groundwater conditions
- Select loading condition
- Locate critical failure surface
- Iterate until minimum Factor of Safety (FS) is achieved

Rules of Thumb and "Easy" Method of Estimating Slope Stability

- Geology and Soils Information Needed (from site or soils database)
- Check appropriate loading conditions (seeps, rapid drawdown, fluctuating water levels, flows)
- Select values to input for Φ and C
- Locate water table in slope (critical for evaluation!)
- 2:1 slopes are typically stable for less than 15 foot heights
- Note whether or not existing slopes are vegetated and stable
- Plan for a factor of safety (hazards evaluation)
- FS between 1.4 and 1.5 is typically adequate for our purposes

No Flow Slope Stability Analysis

- $FS = \tan \Phi / \tan \Theta$
  - Where Φ is the effective angle of internal friction of soil
  - Where Θ is the slope angle

Flow Parallel to Slope

- FS = $(\gamma' / \gamma sat)$ $(\tan \Phi / \tan \Theta$
  - Where γ' = buoyant unit weight of soil γsat - $\gamma water$
  - Where γsat = saturated unit weight of soil
  - Where $\gamma water$ = unit weight of water = 62.4 pcf (pounds per cubic foot)

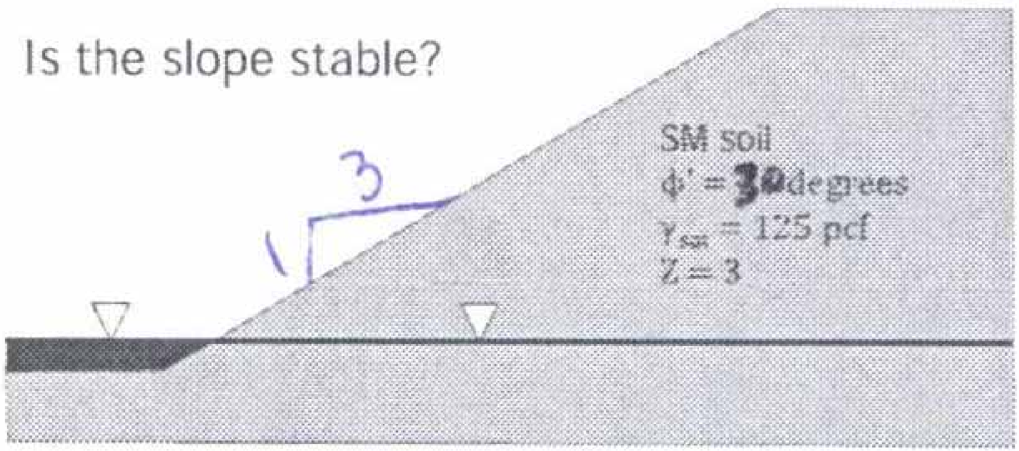
Horizontal Flow

- FS = $(\gamma' - \gamma w \tan^2 \Theta) / \gamma sat \ (\tan \Phi / \tan \Theta)$
  - Where γ' = buoyant unit weight of soil $\gamma sat - \gamma water$
  - Where γsat = saturated unit weight of soil
  - Where $\gamma water$ = unit weight of water = 62.4 pcf (pounds per cubic foot)
  - Where Φ is the effective angle of internal friction of soil
  - Where Θ is the slope angle

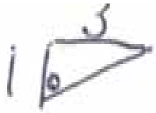
Slope Stability Analysis Methods

Class Problem 1

Is the slope stable?



(Low WT)



$\tan\theta = \frac{3}{1}$

$\theta = 72$

So our angle is $90° - 72° = 18°$

$$FS = \frac{\tan\phi}{\tan\theta} \quad \frac{\tan 30°}{\tan 18°}$$

$$= \frac{.577}{.333}$$

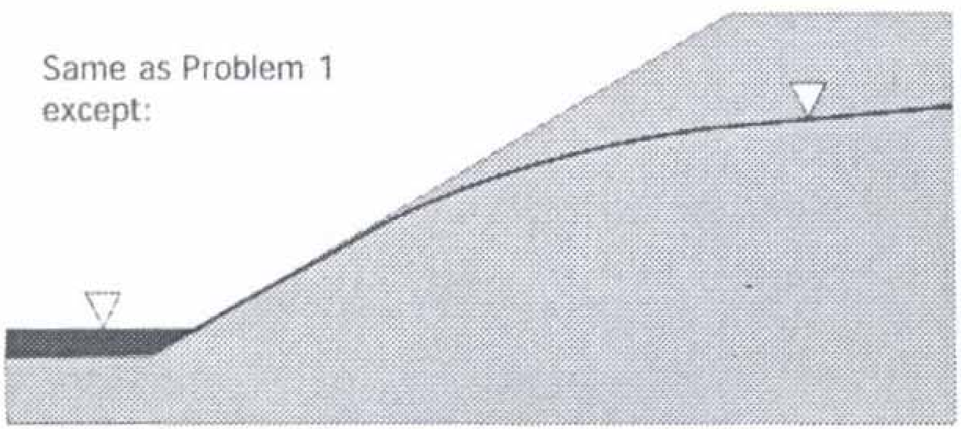
$$= 1.7$$

FS > 1.5 so STABLE!!!

Slope Stability Analysis Methods

Class Problem 2

Same as Problem 1 except:



(High WT)

2. $\dfrac{\gamma'}{\gamma_{sat}} \dfrac{\tan \phi}{\tan \theta} = FS$

$= \dfrac{62.6}{125} \dfrac{\tan 30}{\tan 18}$

$= 0.5008 \left(\dfrac{.577}{.333} \right)$

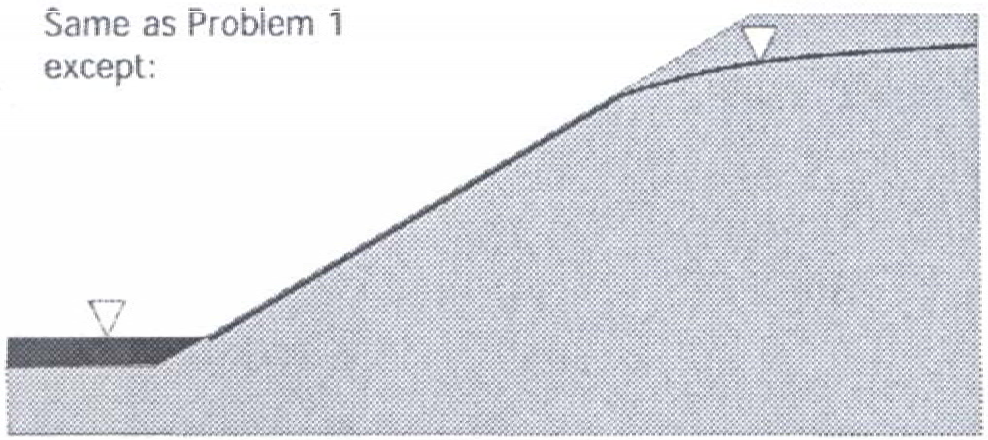
$= 0.86$ Not Stable

FS < 1.4 so NOT STABLE!!!

Slope Stability Analysis Methods

Class Problem 3

Same as Problem 1
except:



(Rapid Drawdown)

3. $$FS = \frac{\gamma' - \gamma_w \tan^2\theta}{\gamma_{sat}} \cdot \frac{\tan\phi}{\tan\theta}$$

$$= \frac{62.6 - 62.4\tan^2(18)}{125}\left(\frac{\tan 30}{\tan 18}\right)$$

$$= \frac{62.6 - 6.59}{125}(1.8)$$

$$= 0.45\,(1.8)$$

$$= 0.81$$ Not Stable

FS < 1.4 so NOT STABLE!!!

Slope Stability Analysis Tools for Streambank Stabilization

Protective treatments shall be installed that result in stable slopes. Design limitations of the bank or shoreline materials and type of measure installed shall determine steepest permissible slopes.

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Slope Stability Analysis Tools for Streambank Stabilization

Contribution of Riprap to Stability

1. Non-cohesive slopes
2. Cohesive slopes

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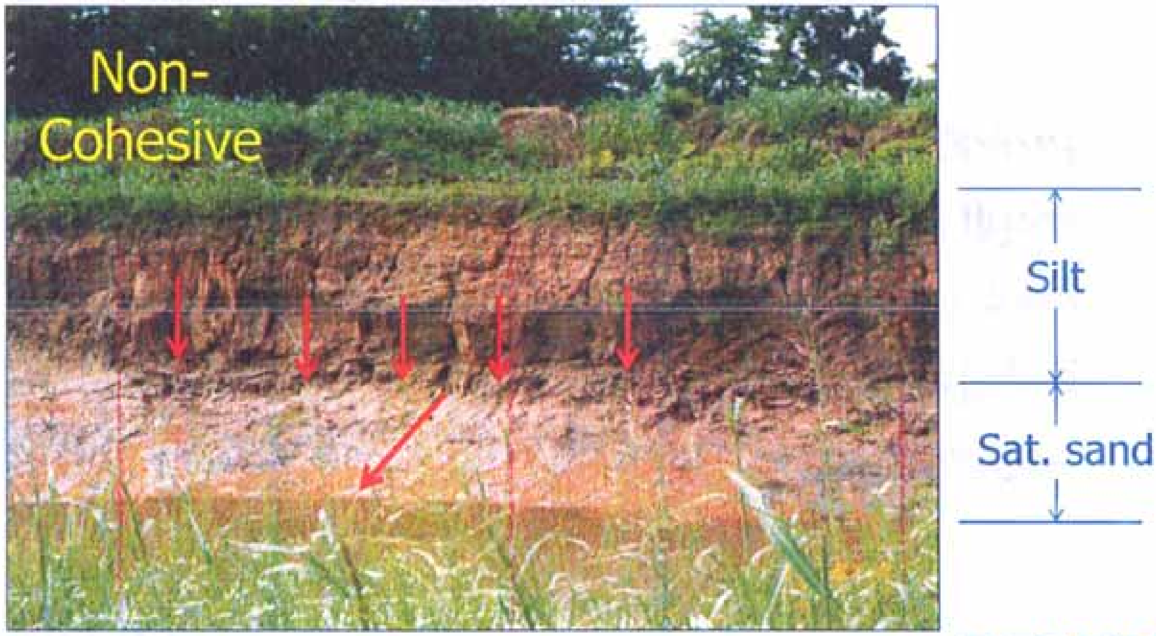
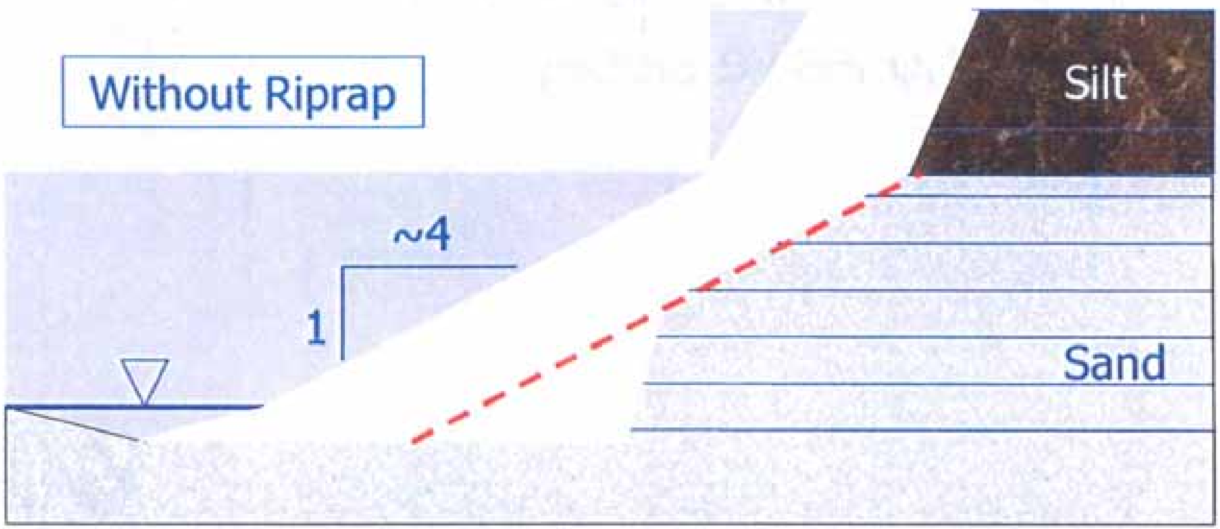
Slope Stability Analysis Tools for Streambank Stabilization



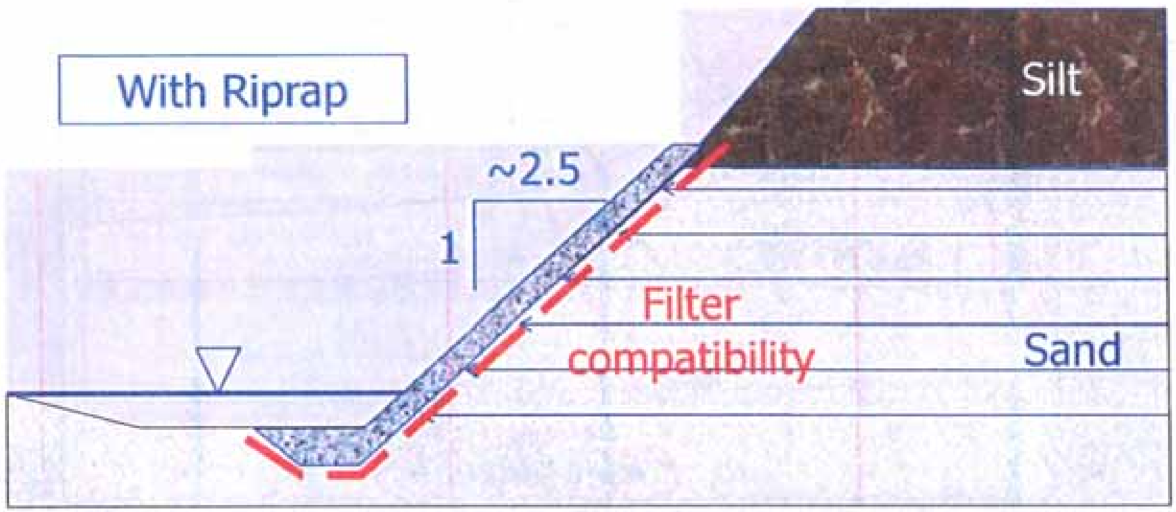
Slope Stability Analysis Tools for Streambank Stabilization

Contribution of Riprap - Non-cohesive



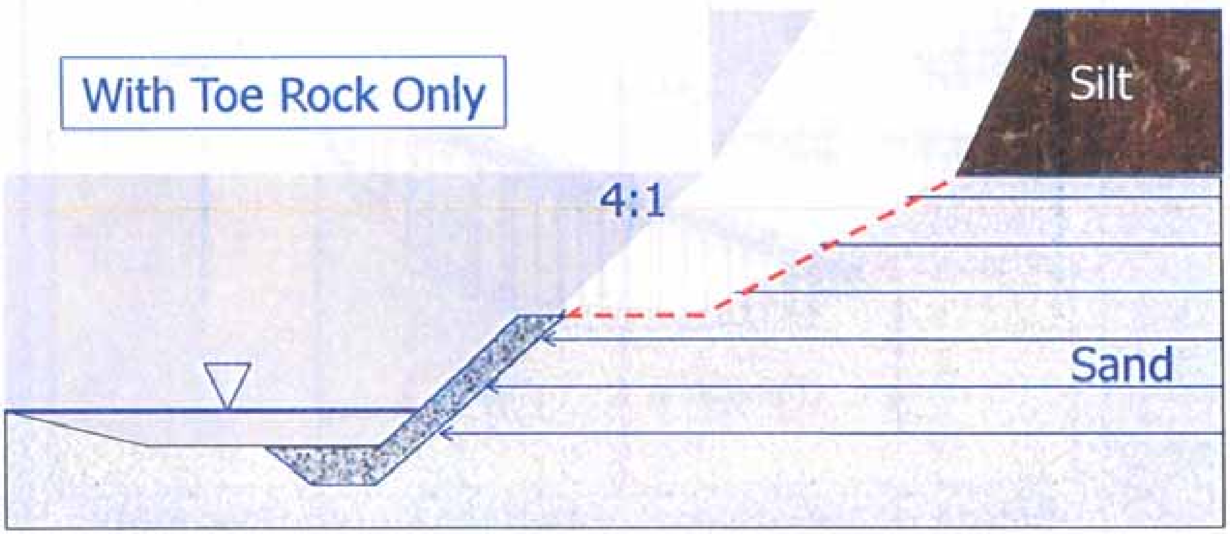
Slope Stability Analysis Tools for Streambank Stabilization

Contribution of Riprap - Non-cohesive

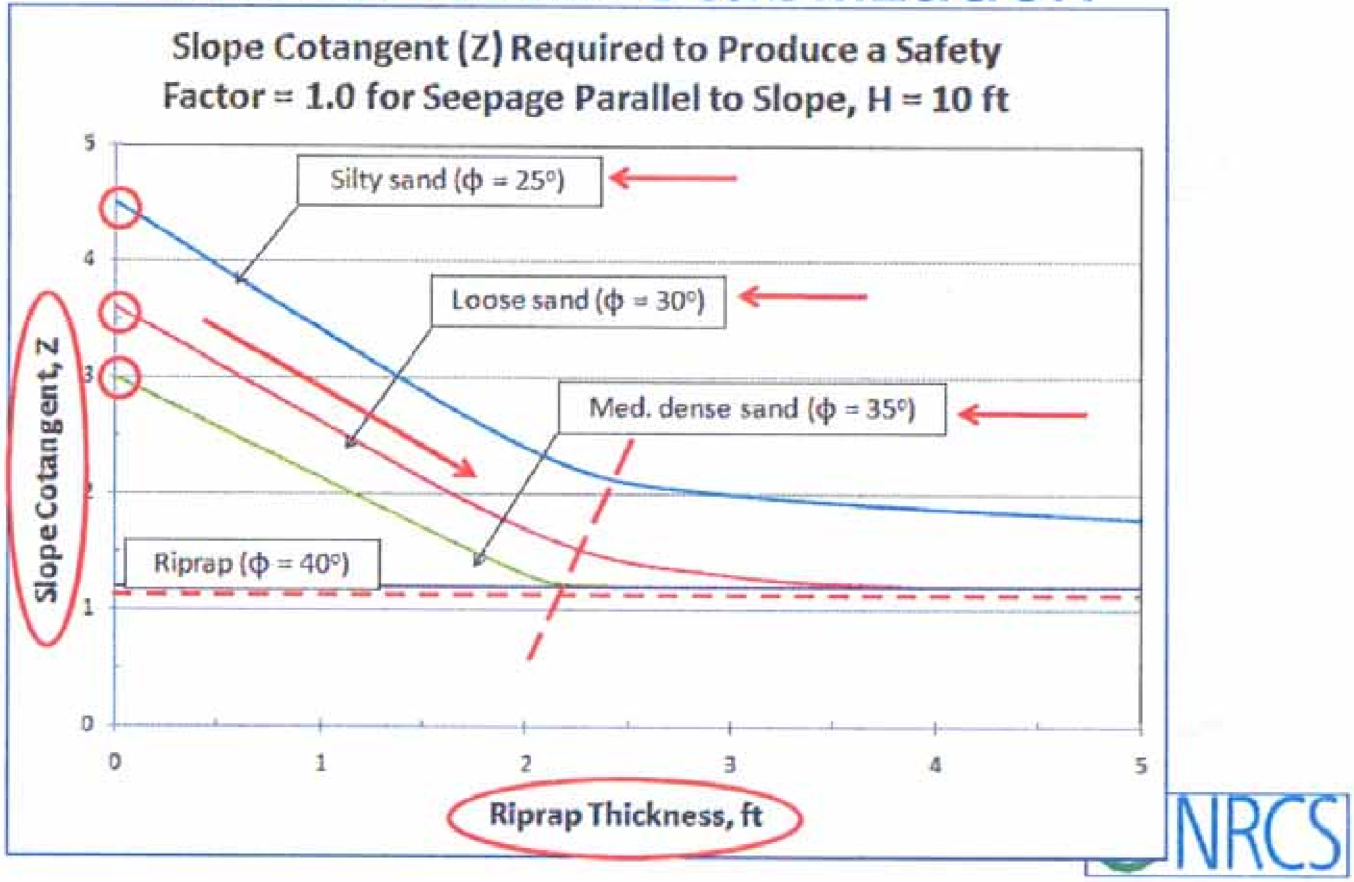


Slope Stability Analysis Tools for Streambank Stabilization

Contribution of Riprap - Non-cohesive



Slope Stability Analysis Tools for Streambank Stabilization



Slope Stability Analysis Tools for Streambank Stabilization

Contribution of Riprap - Cohesive

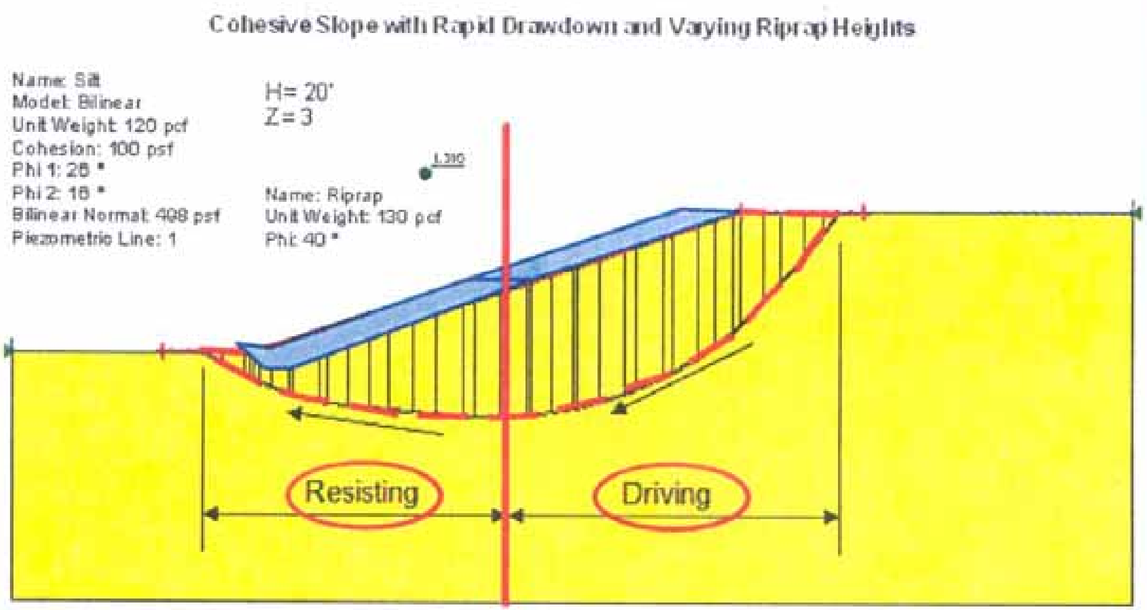


Figure 6. Typical Failure Surface for Cohesive Slope With Varying Riprap Height

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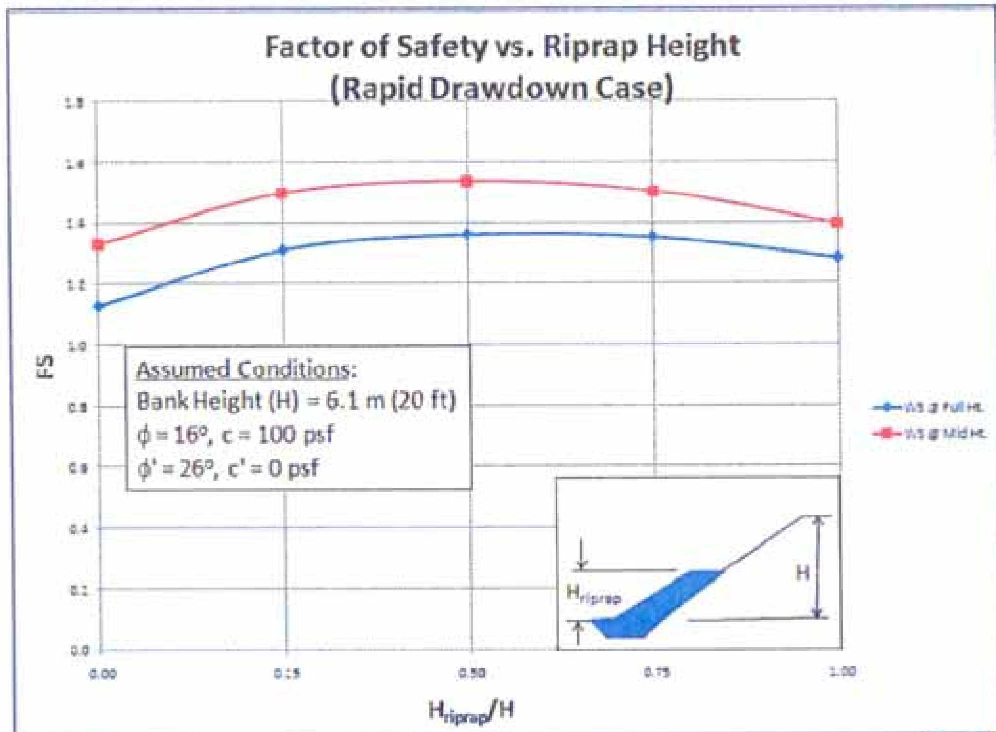
Slope Stability Analysis Tools for Streambank Stabilization



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Slope Stability Analysis Tools for Streambank Stabilization

Conclusions

1. Full height riprap blankets dramatically improve stability on cohesionless slopes with seepage.

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Slope Stability Analysis Tools for Streambank Stabilization

Conclusions

2. For riprap revetments on cohesive slopes, maximum stability is achieved by extending the riprap only to about mid-height.

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Slope Stability Analysis Tools for Streambank Stabilization

Conclusions

3. Streambank stabilization measures should be consistent with the anticipated geotechnical mode of failure.

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Slope Stability Analysis Tools for Streambank Stabilization

Conclusions

4. Limiting riprap to "toe rock only" may be appropriate for cohesive slopes, but it may be inappropriate for non-cohesive slopes with seepage.

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QUESTIONS?!?!