Design of Geosynthetics for Slope Stability

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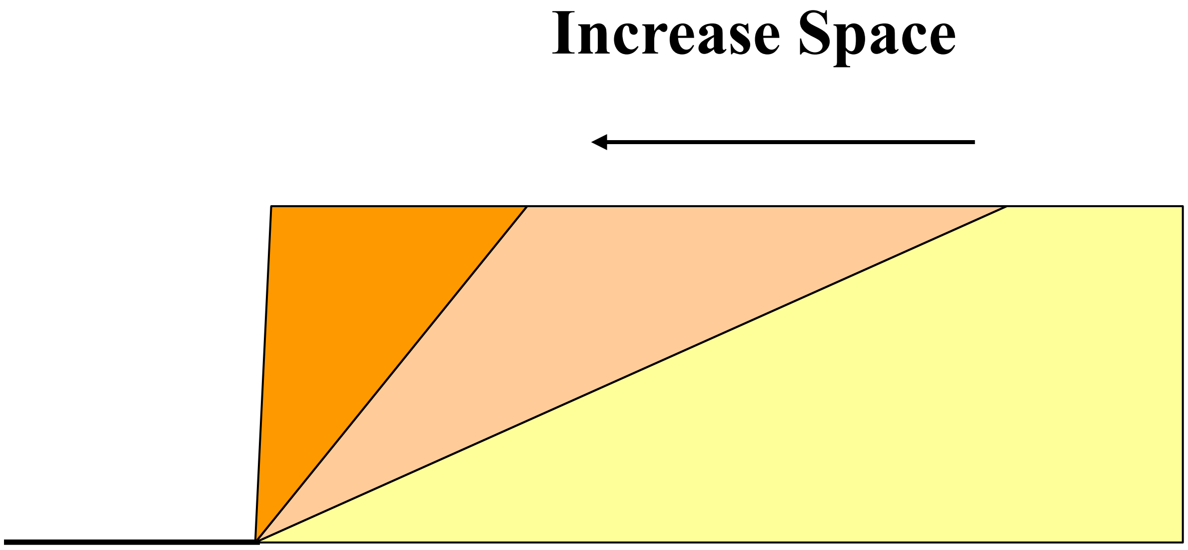
Outline of Presentation

- Introduction
- Advantages and Concerns
- Face Options
- Slope Stability Design
- Case Study of Reinforced Slopes

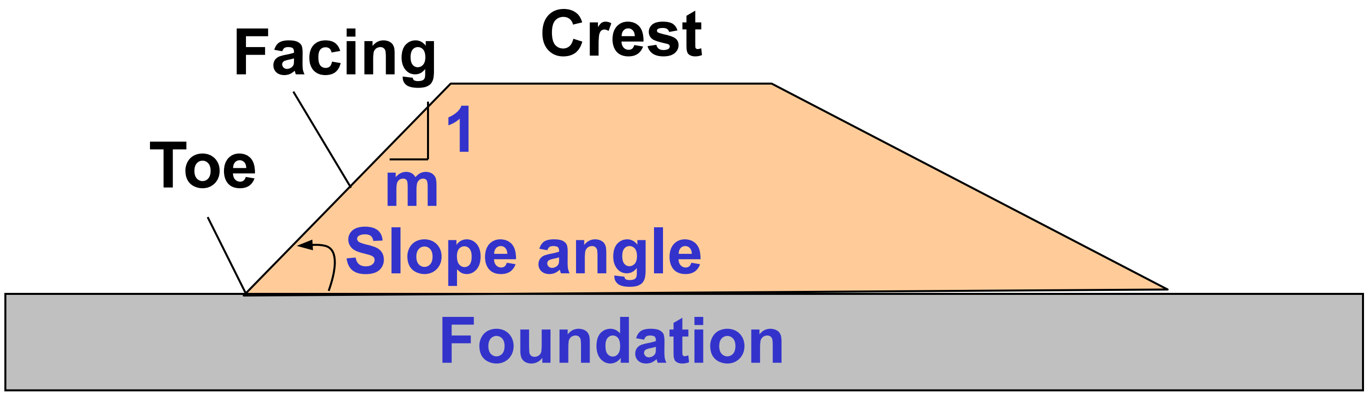
Steepen Slope to Wall

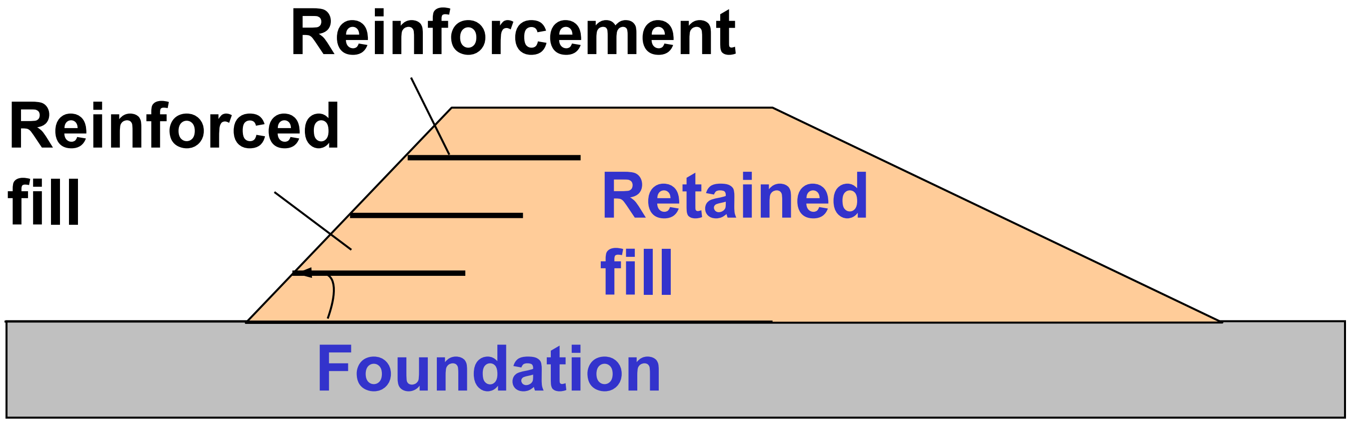


Slope vs. Wall

- Slope: Face inclination $\leq 70^0$
- Solution driven by many factors

Components of Slopes





Advantages and Concerns

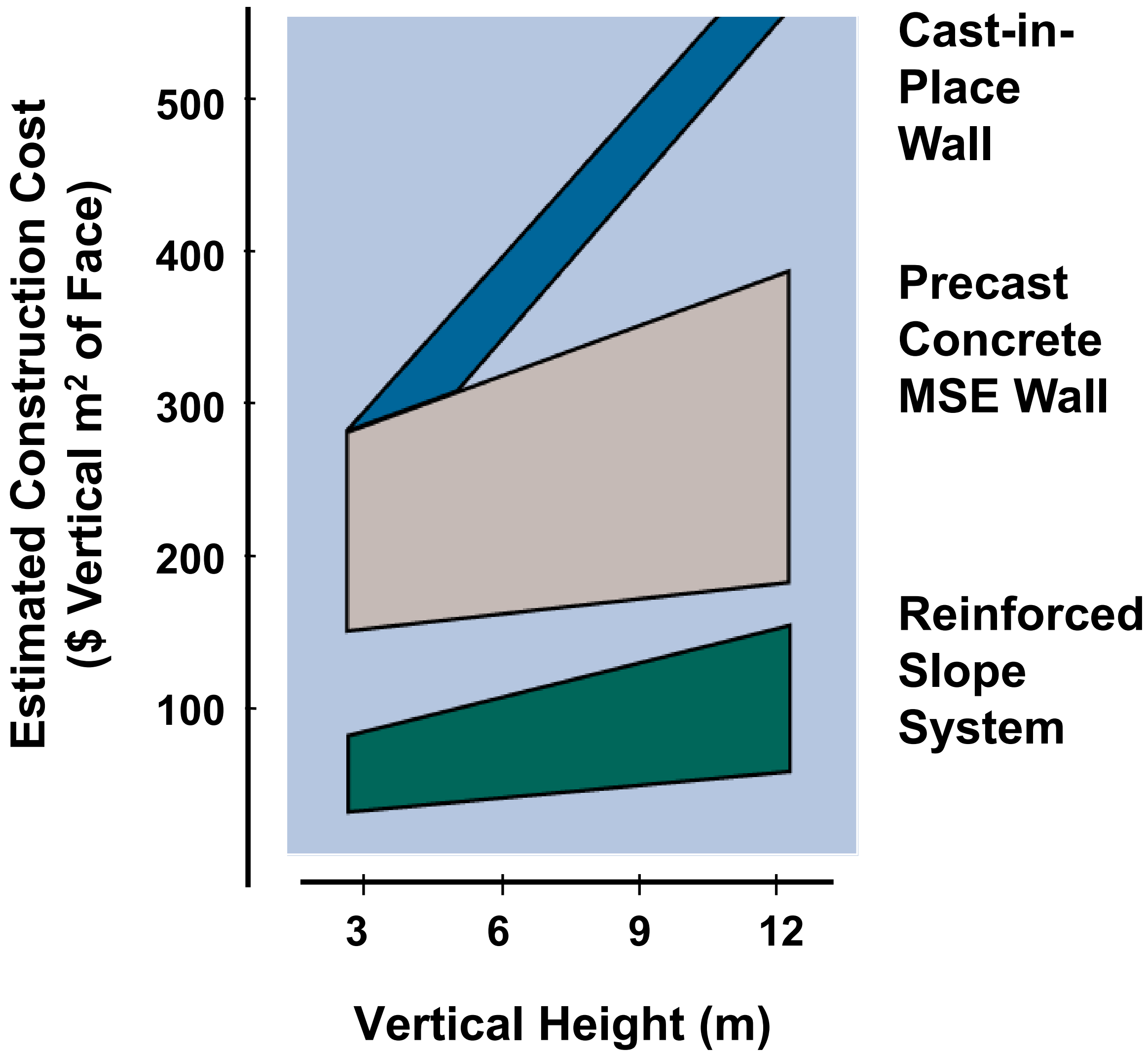
Advantages of Reinforced Slopes

- Space optimization vs. cost
- Optional facings based on:
  - appearance
  - inclination
  - site conditions
  - cost
- Ecology-friendly vegetation

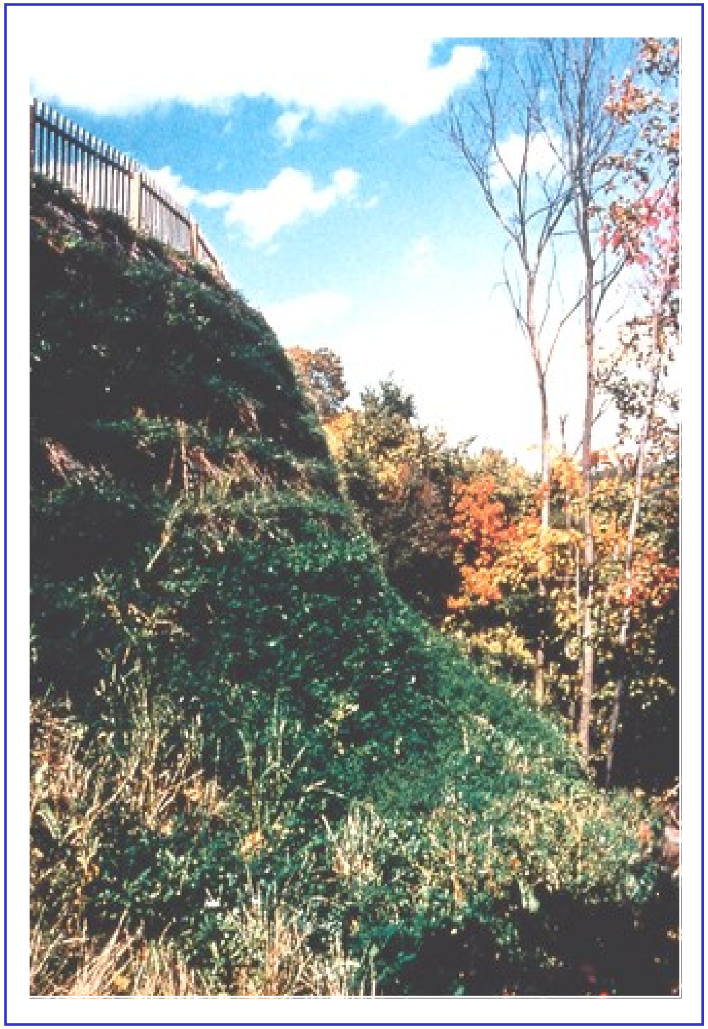
Advantages of Reinforced Slopes

- Ease and speed of construction
- No special labor or equipment is required
- Non-select fills can be used
- High tolerance to differential settlement

Cost Comparisons



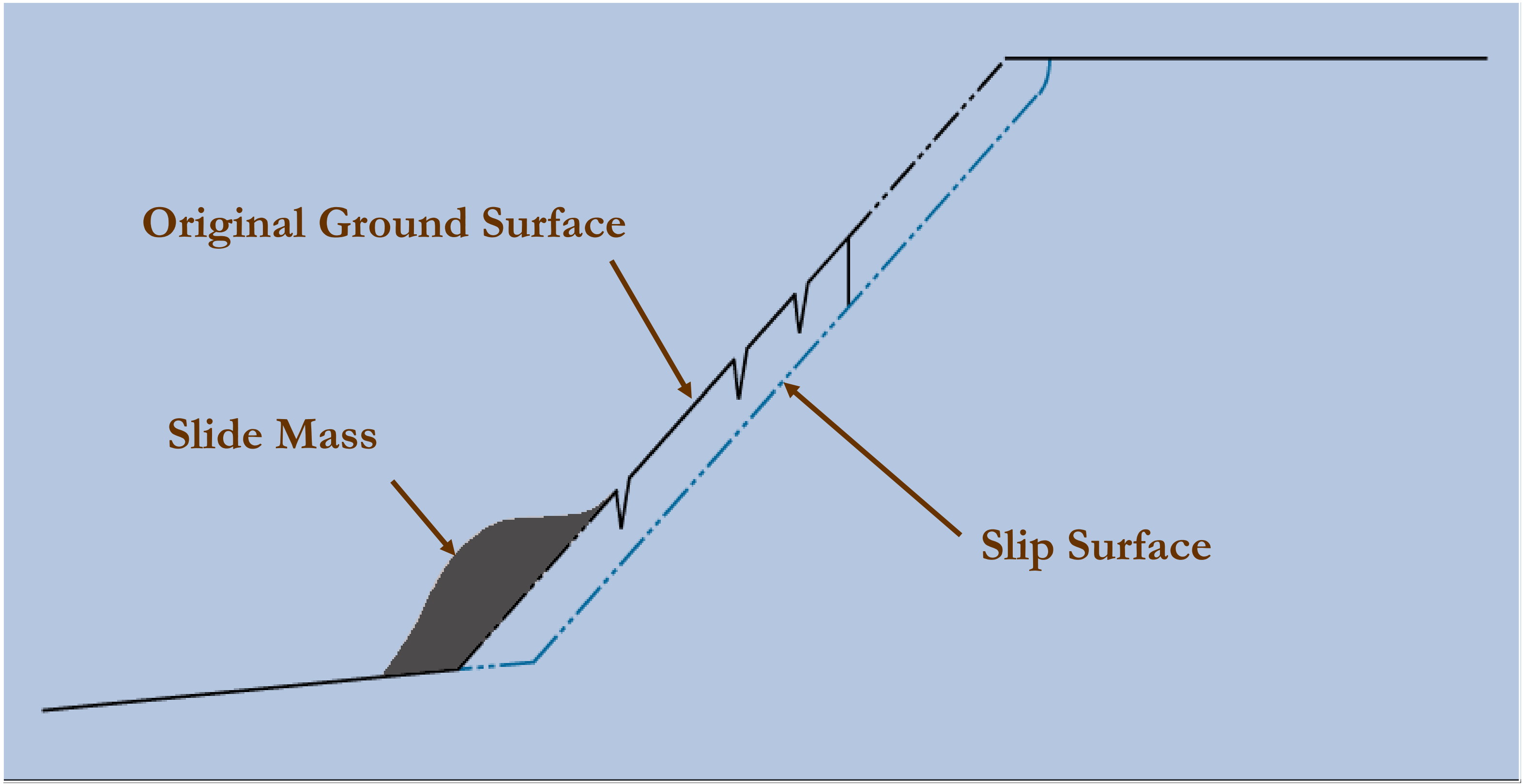
Main Concerns



- Slope stability, especially surficial stability
- Vegetation selection and establishment
- Erosion
- Maintenance/mowing

Private Residence - Pittsburgh, PA

Typical Surfical Failure



Surficial Failure

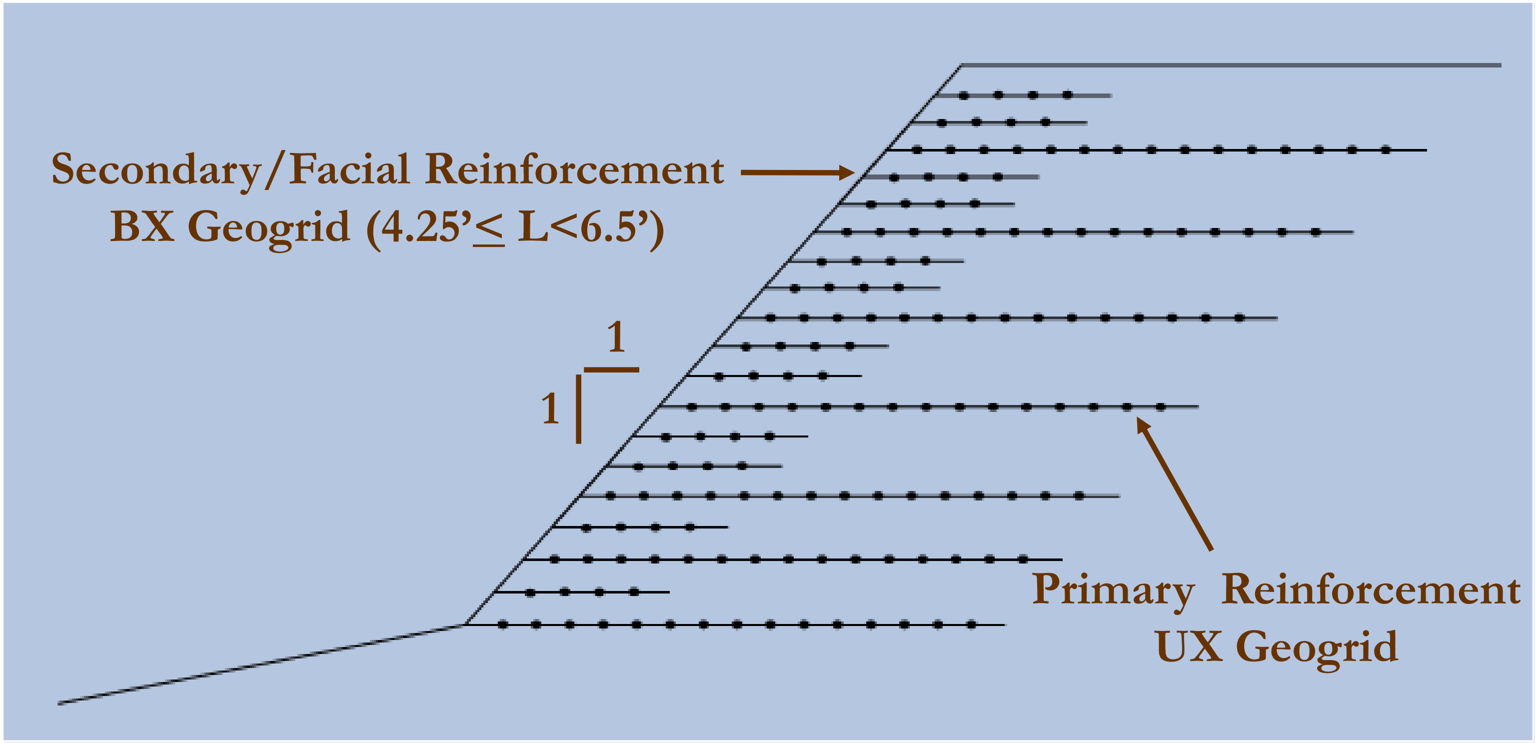
- Shallow failure surface up to 1.2m (4ft)
- Failure mechanisms
  - Poor compaction
  - Low overburden stress
  - Loss of cohesion
  - Saturation
  - Seepage force

Erosion Problem

- Loss of soil mass
- Failure mechanism
  - Loss of vegetation cover
  - Soil washed out by water

Slope Failure

Typical Cross Section
Geosynthetic-Reinforced Slope



Facing Options

Gabion Facing




Courtesy of Leshchinsky

Geogrid-Wrapped Stone Face

AEP Cardinal Plant Slope Repair - Brilliant, OH

- Stone facial fill
- Soil behind facial fill for economy
- Tensar® geogrids protected from UV degradation

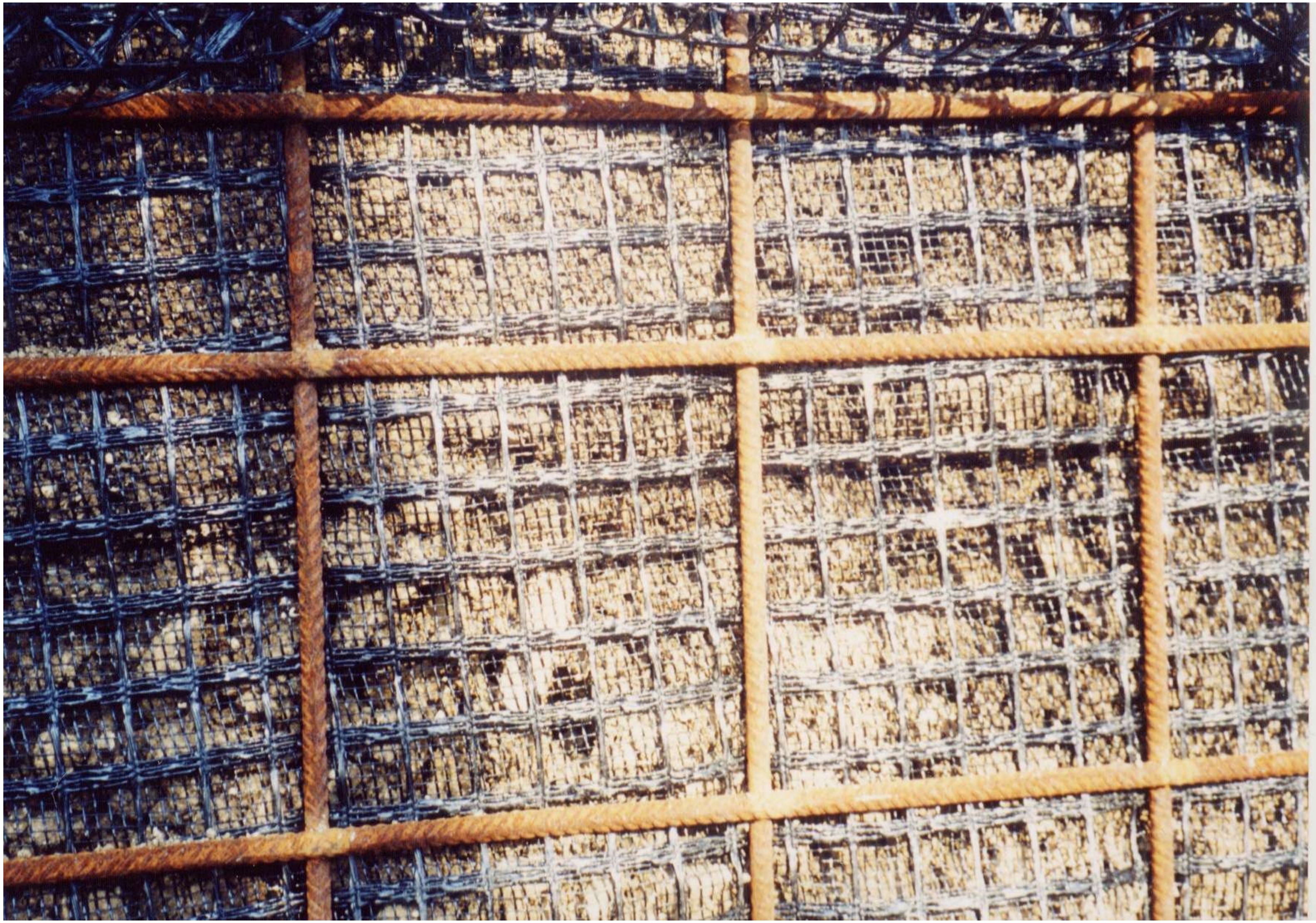
Wrapped Around (Germany)

Courtesy of Leshchinsky

Facia: Wire Baskets

Courtesy of Leshchinsky

Facia: Wire Baskets



Courtesy of Leshchinsky

Vegetated Face (Italy)

Courtesy of Leshchinsky

Geogrid-Wrapped Soil Face

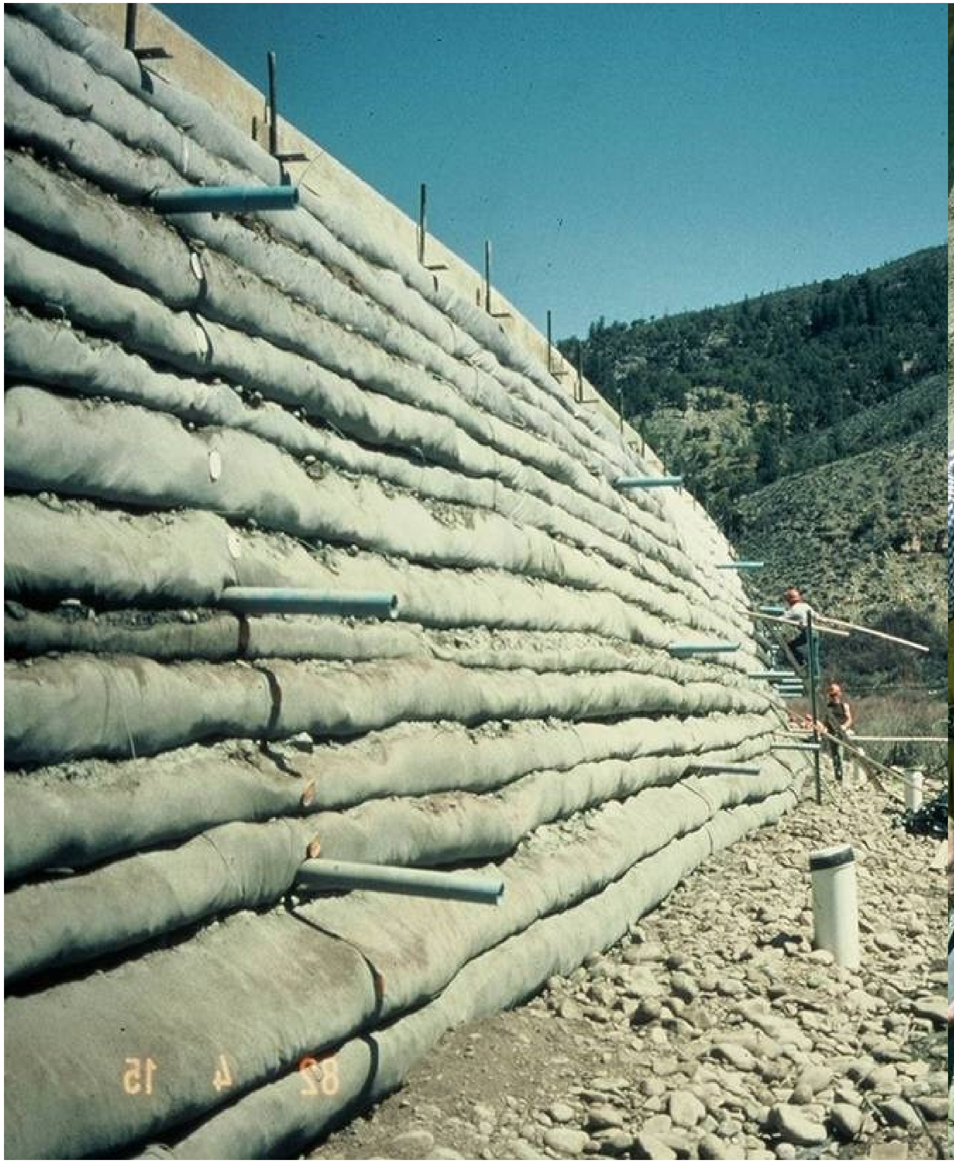
- 35°-70° inclination
- Stair-stepped shape with vegetation
- Welded-wire baskets

R & B Chambers MSW Landfill Banks County, GA

Geogrid-Wrapped Soil Face

Geogrid-Wrapped Soil Face

Geotextile-Wrapped Around & Shotcrete



Courtesy of Leshchinsky

Shotcrete to Protect the Exposed Geosynthetic and the Picky Supervisor…

Courtesy of Leshchinsky

Segmental Block Slope Face

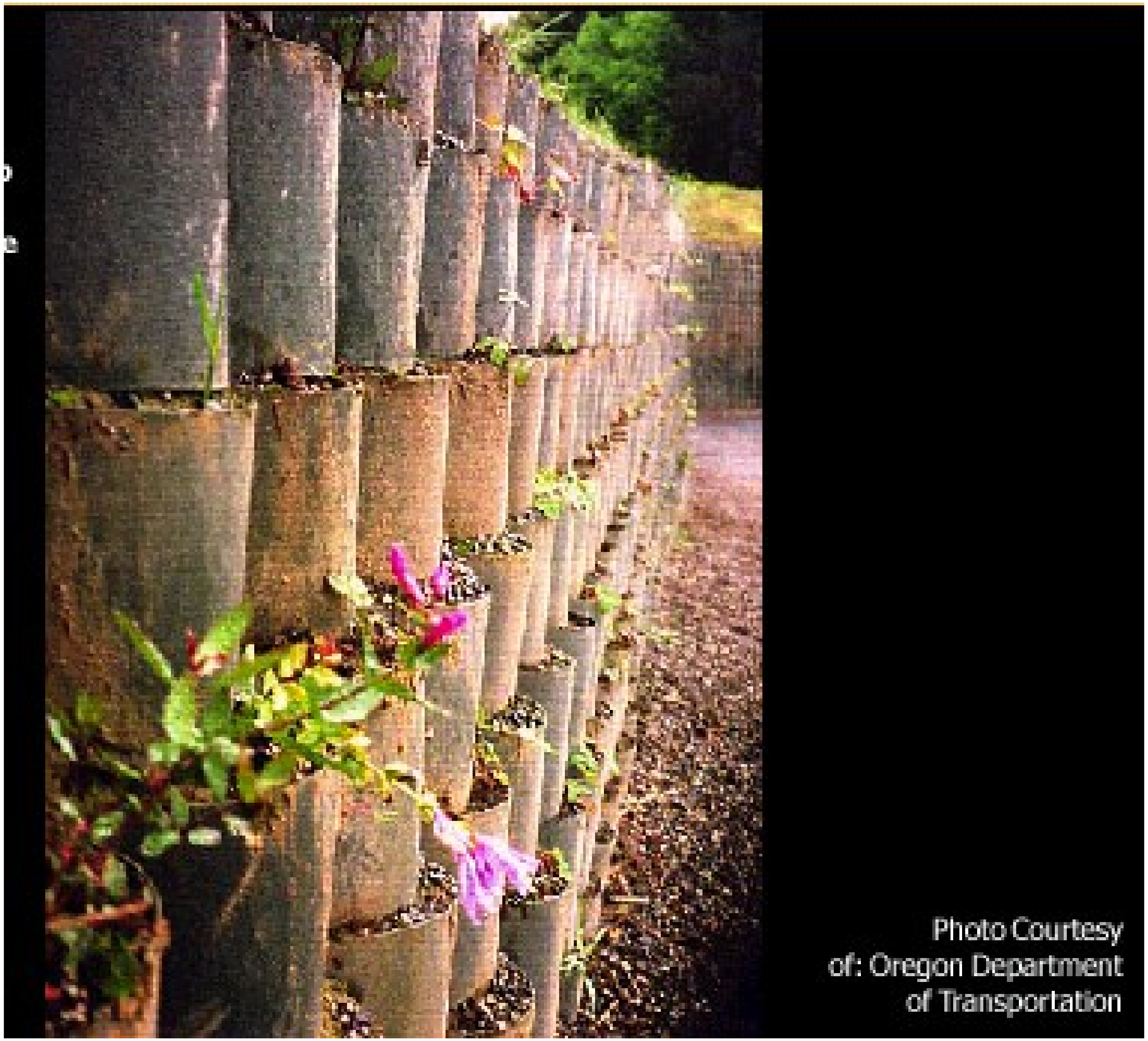
Wood Facing Option

Windy Hill Station - Atlanta, GA

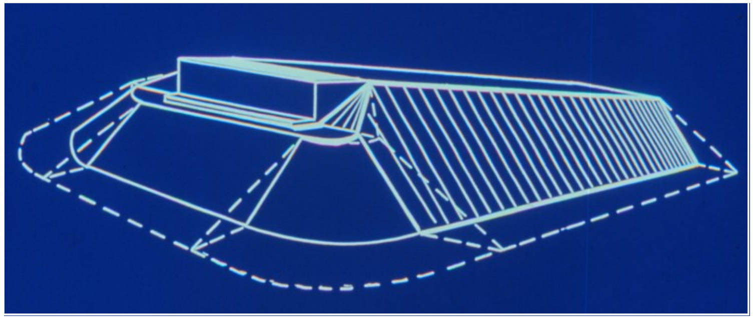
Treated Wood

- Stepped
- Landscaped or natural vegetation for low maintenance
- Slope stability with geogrids

Geocell Facing Option



Other Hard Facing Options



SR 430 Seabreeze Bridge - Daytona, FL

Other Hard Facings

- Concrete articulating revetments
- Gabions/mattresses
- Riprap
- Shotcrete

Erosion Control

Village at Westlake - Austin, TX

- Erosion Mat or Blanket:
- Enhance seed germination and erosion resistance
- UV protected

Slope Stability Design

Select Fill for Reinforced Slope (AASHTO)

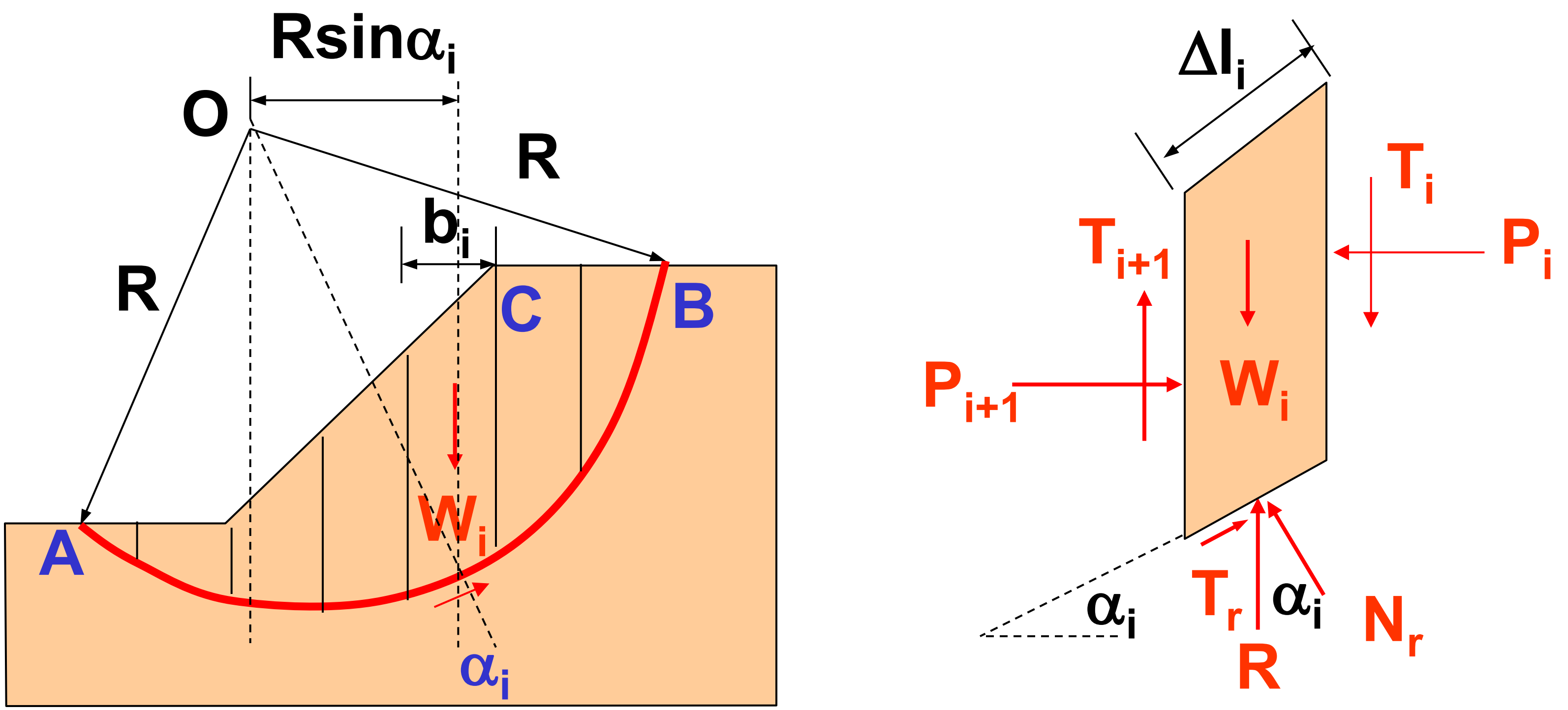
Sieve Size	Percent Passing
3/4 in (20mm)	100-75
No. 4 (4.76 mm)	100-20
No. 40 (0.425 mm)	0-60
No. 200 (0.075 mm)	0-50

- Plasticity Index (PI) should not exceed 20

- To insure survivability, maximum grain size should be limited to 19 mm (experience)

- Free of organic and other deleterious materials

Stability of Slope with Circular Surface – Bishop's Simplified Method



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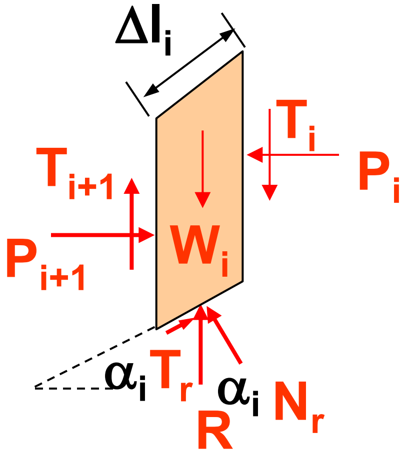


Mobilized shear (strength) resistance

$$T_r = N_r\left(\frac{\tan\phi}{FS}\right) + \frac{c\Delta l_i}{FS}$$

Vertical side force difference

$$\Delta T = T_i - T_{i+1}$$

Force equilibrium in the vertical direction

$$W_i + \Delta T = N_r \cos\alpha_i + \left[\frac{N_r \tan\phi}{FS} + \frac{c\Delta l_i}{FS}\right]\sin\alpha_i$$

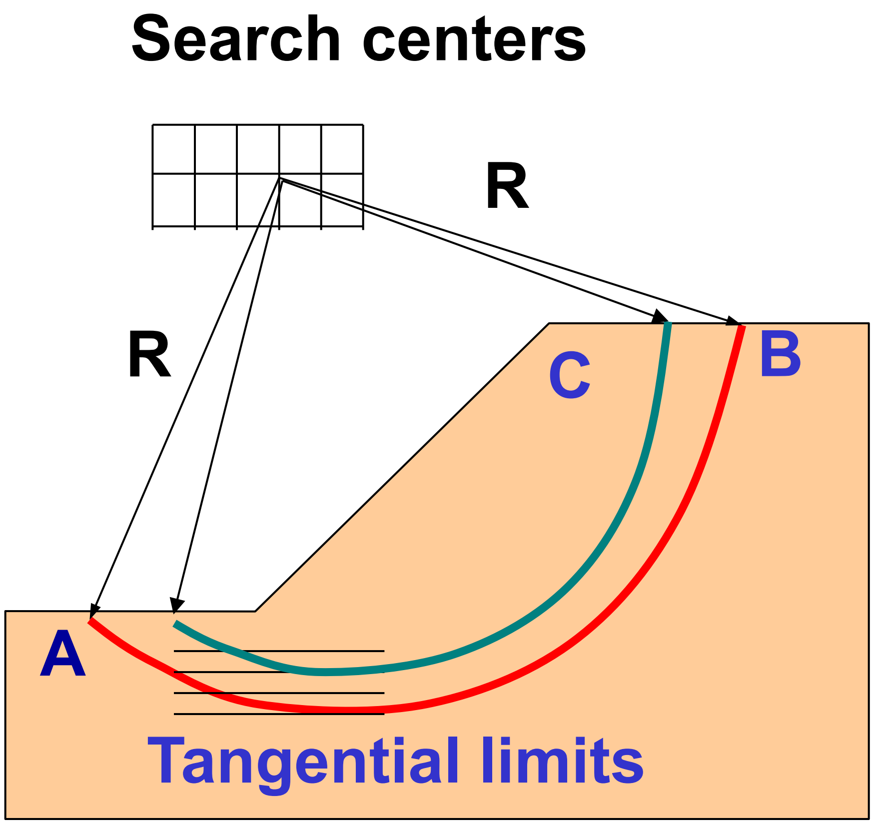
$$N_r = \frac{W_i + \Delta T - \dfrac{c\Delta l_i}{FS}\sin\alpha_i}{\cos\alpha_i + \dfrac{\tan\phi\sin\alpha_i}{FS}}$$

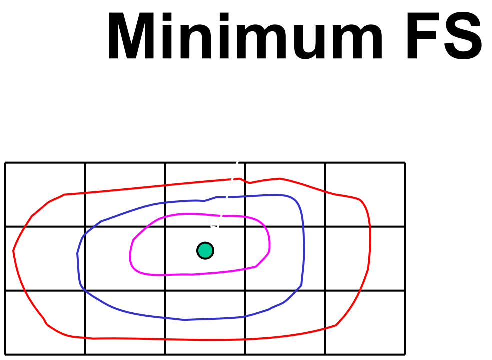
Moment equilibrium about O

$$\sum_{i=1}^{n} W_i R\sin\alpha_i = \sum_{i=1}^{n} T_r R$$

$$FS = \frac{\sum_{i=1}^{n}\left[\left(cb_i + W_i\tan\phi + \Delta T\tan\phi\right)\dfrac{1}{m_{\alpha i}}\right]}{\sum_{i=1}^{n} W_i \sin\alpha_i}$$

Search for Minimum Factor of Safety





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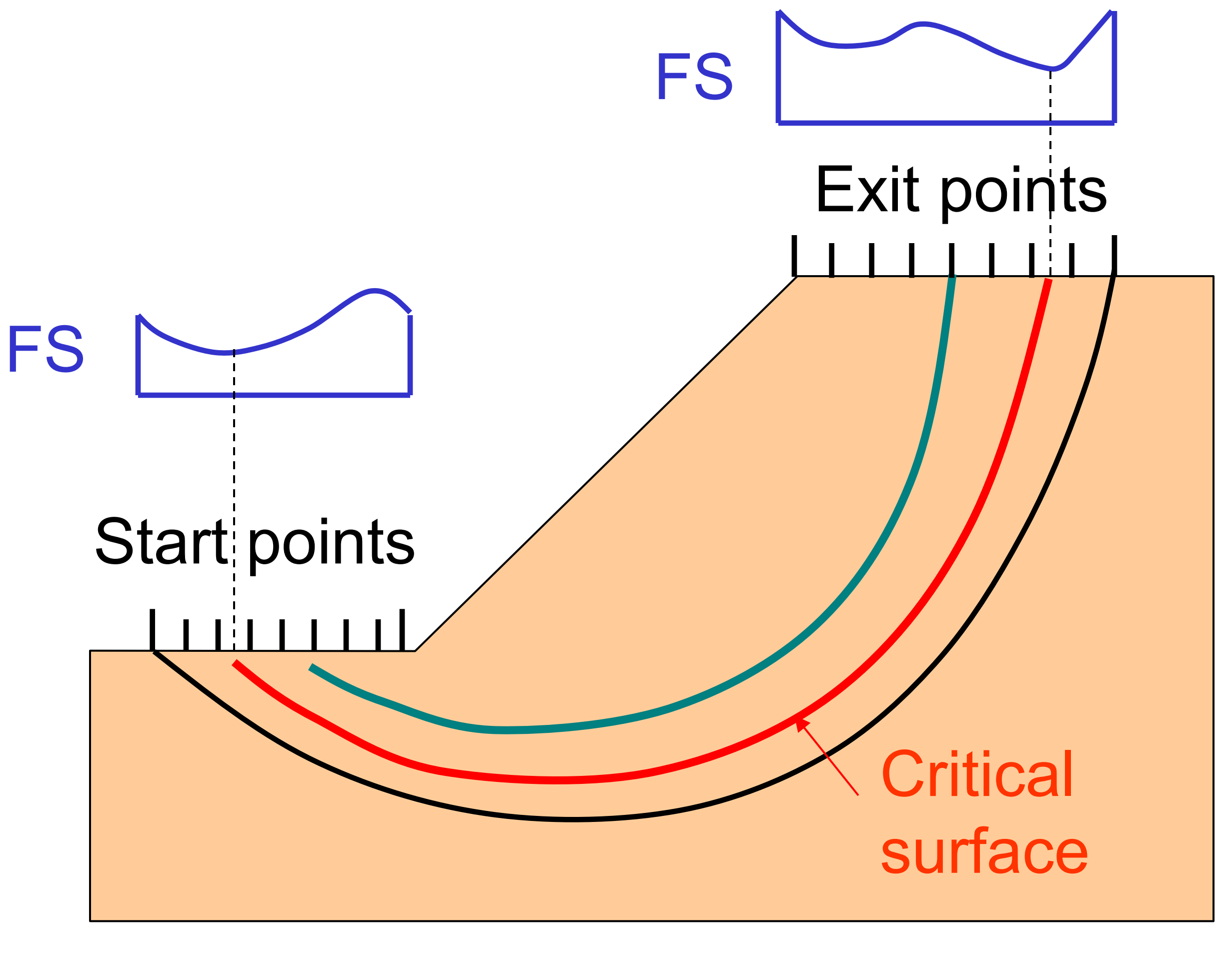
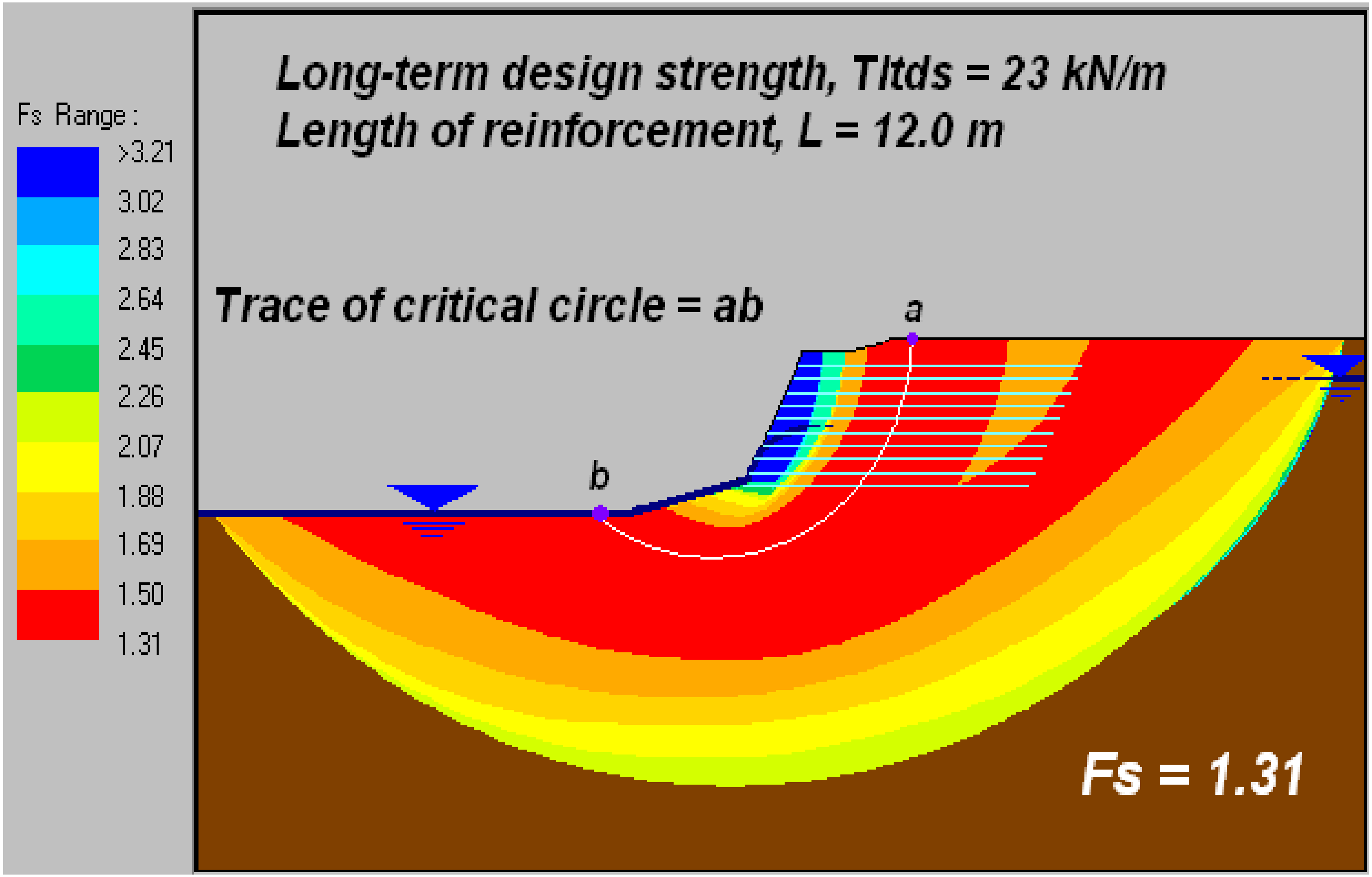
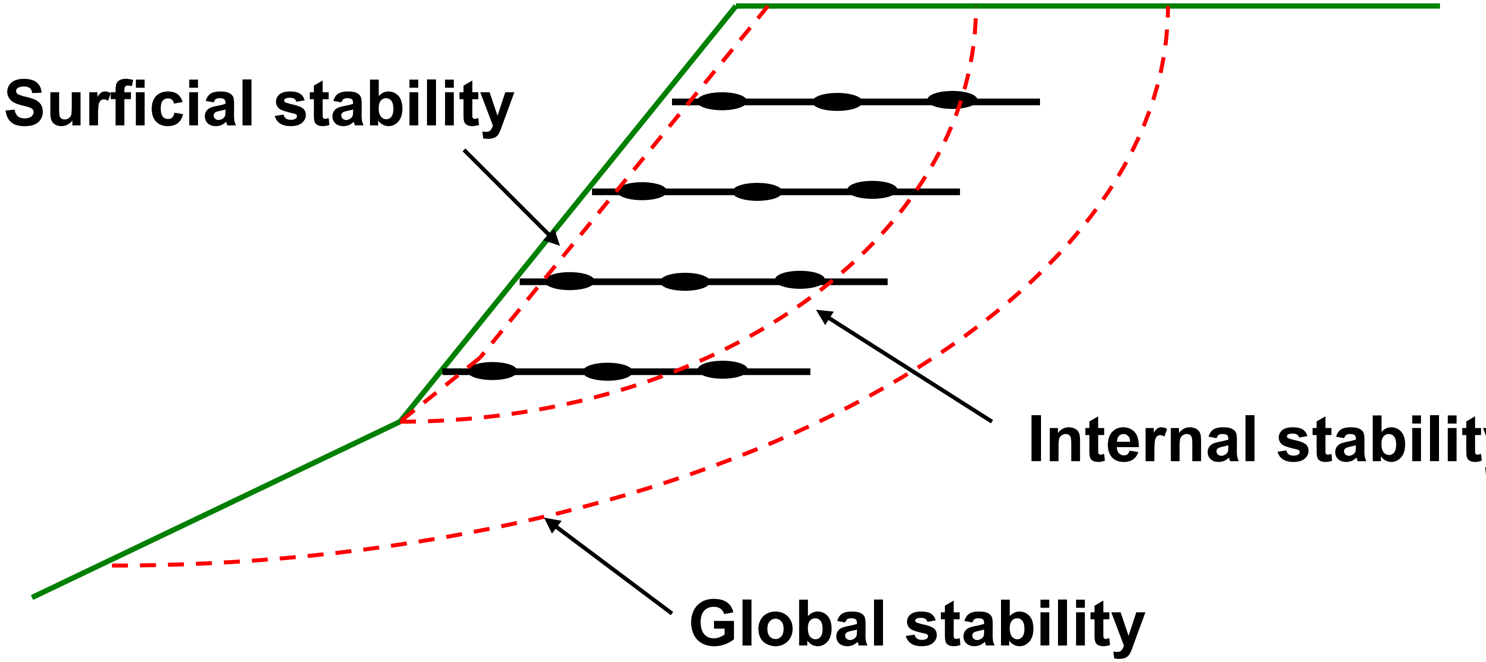


FS Safety Map



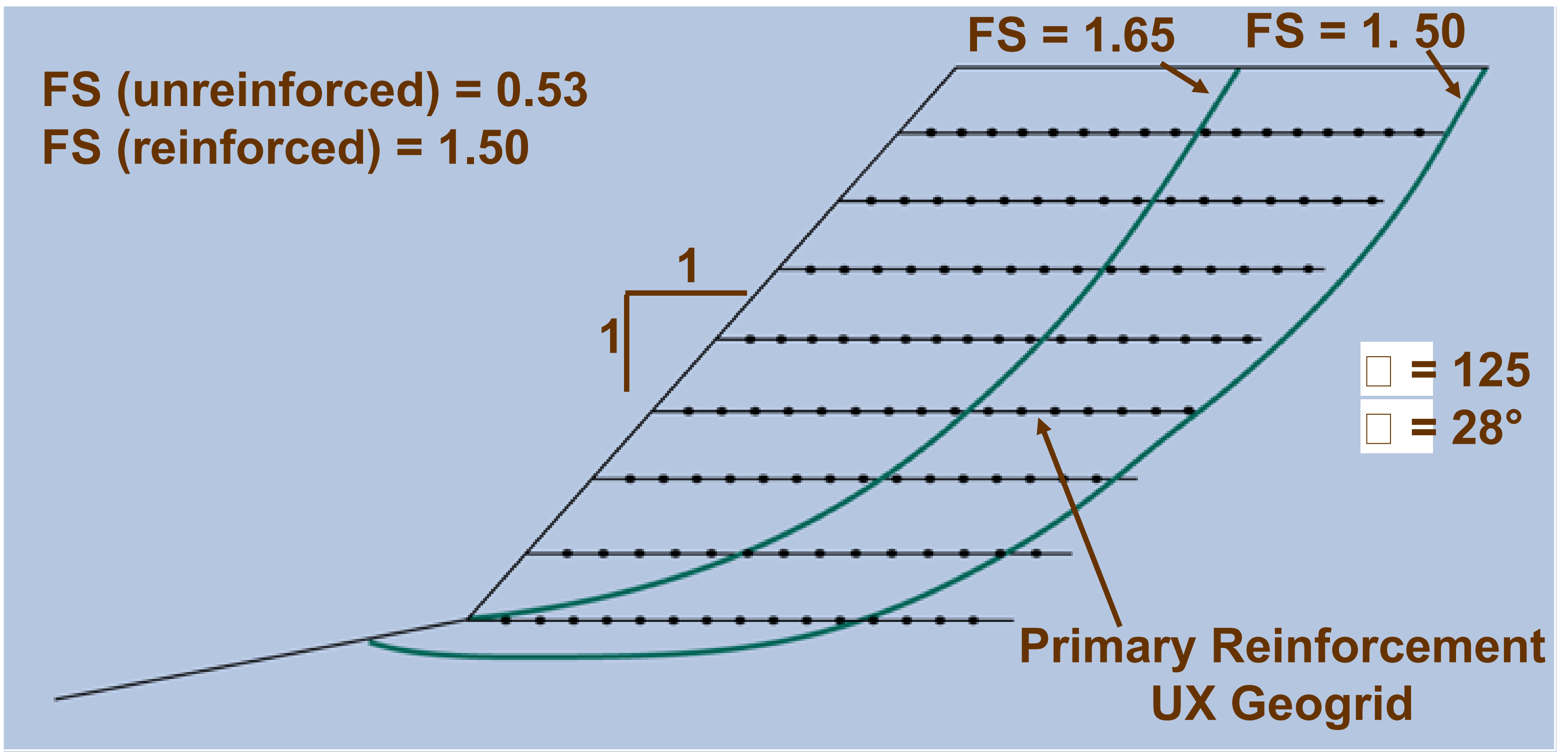
Courtesy of Leshchinsky

Slope Stability Design



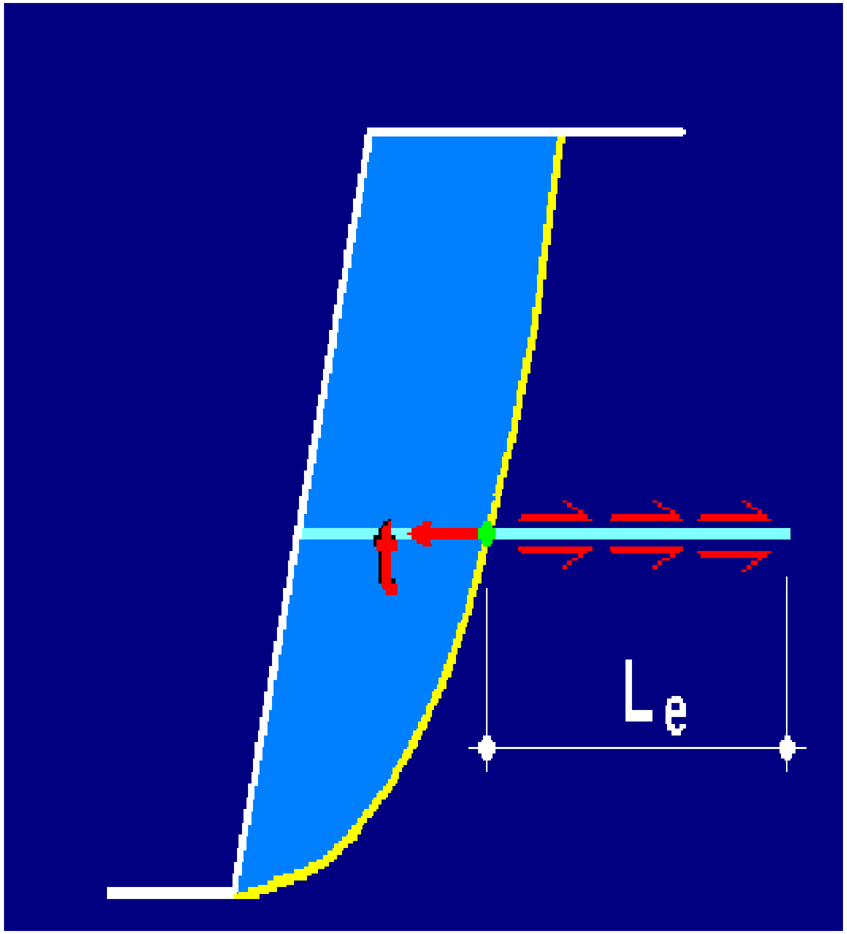
Slope Stability Design

Modified Bishop Method



Limit State Basic Concept

- Active wedge is formed
- Tensioned reinforcement is anchored in stable soil
- If reinforcement is too weak, it will rupture
- If anchorage length is too short, it will be pulled out



Allowable Tensile Force, T_{ai}

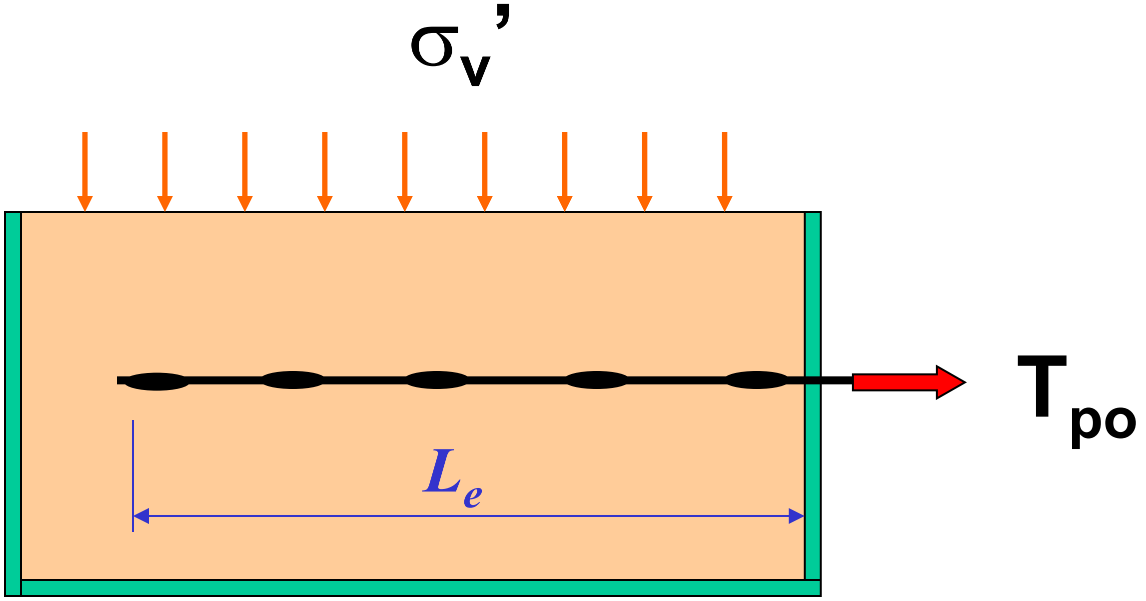
The lesser of allowable tensile strength and pullout capacity

Long-Term Design Strength

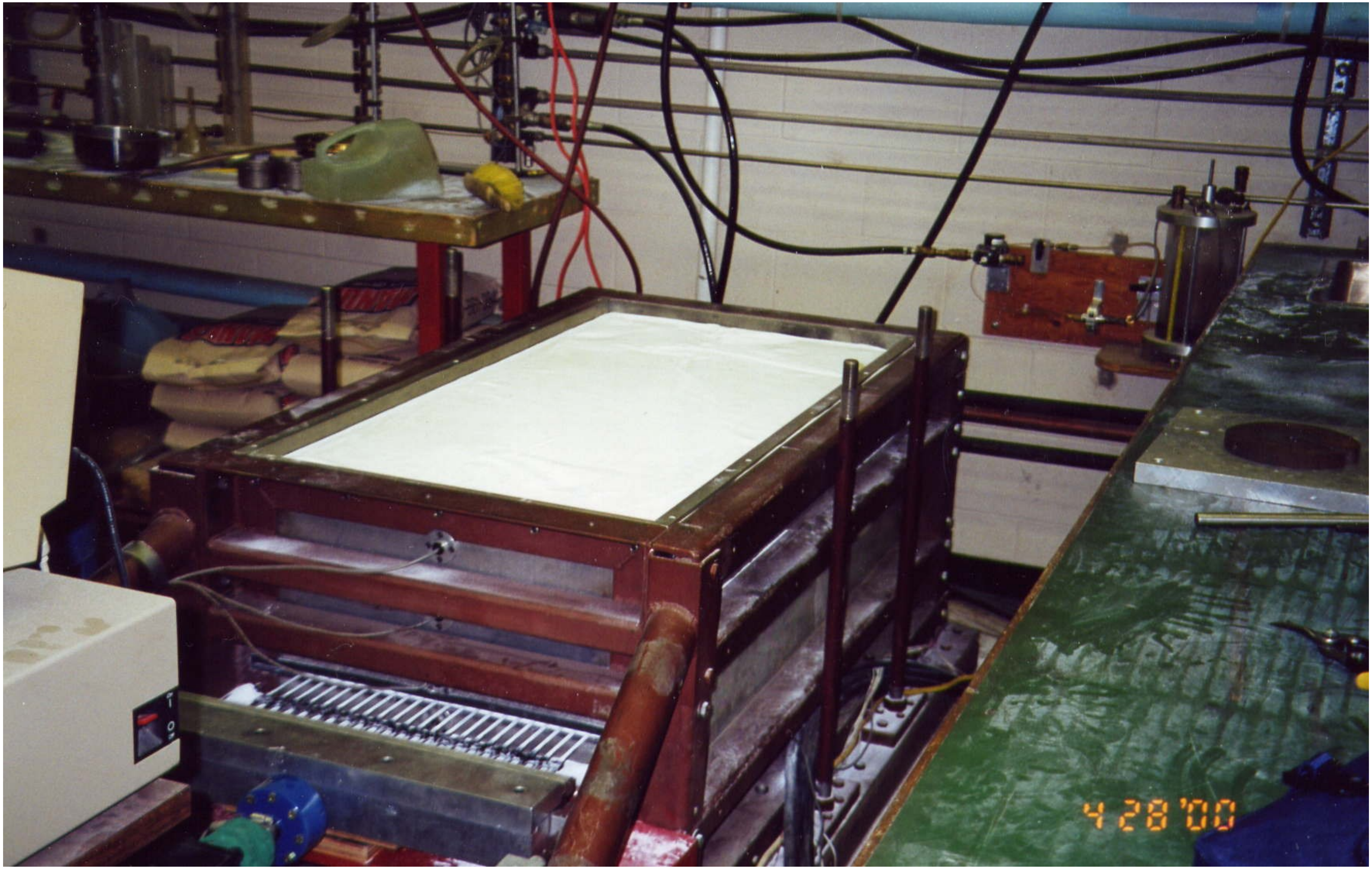
$$T_a = LTDS = \frac{T_{ultimate}}{RF_{Creep} RF_{Durability} RF_{InstallationDamage}}$$

Per AASHTO Bridge 1998 specifications

Geosynthetic Pullout Capacity



Pullout Test



Geosynthetic Pullout Capacity

$$T_{po} = 2F^* \cdot \alpha \cdot \sigma_v' \cdot L_e \cdot R_c$$

$$F^* = F_q \cdot \alpha_\beta + \tan\delta$$

F* = the pullout resistance (or friction-bearing -interaction) factor

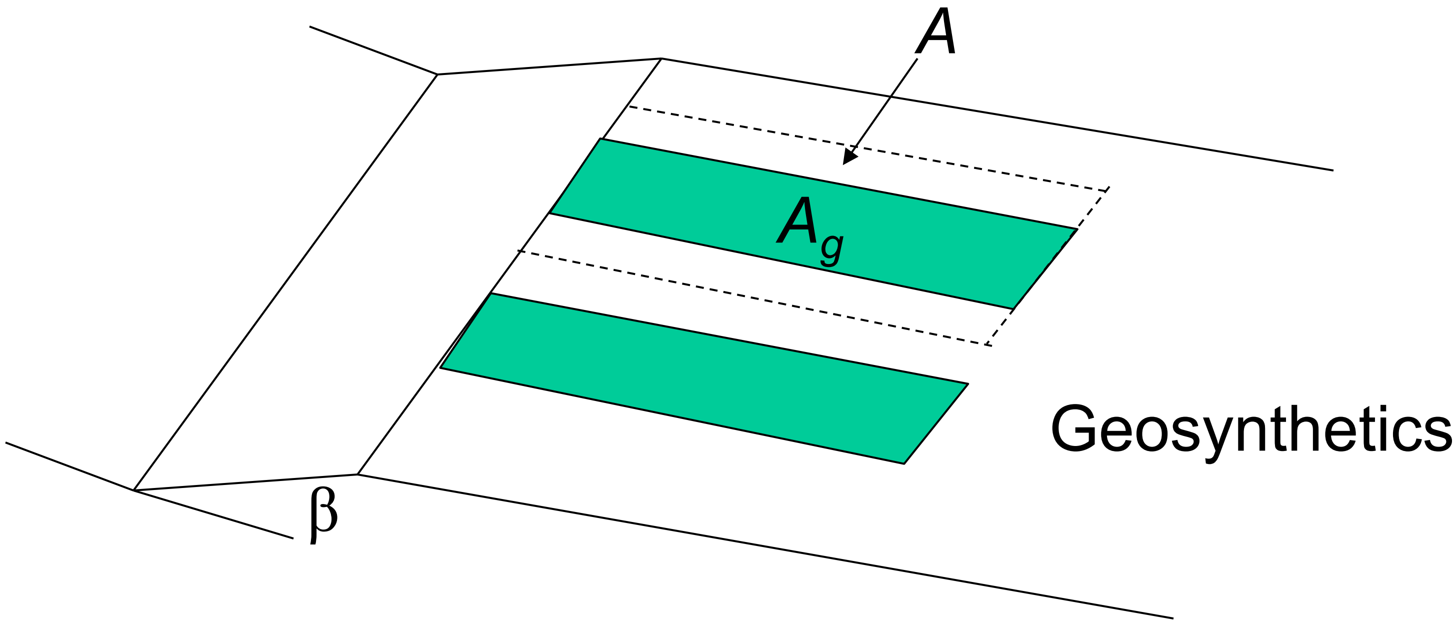
α = a scale effect correction factor to account for a nonlinear stress reduction over the embedded length (0.6 to 1.0 for geosynthetics)

Commonly assume $F^* = \tan\delta = C_i \tan\phi$

$$T_{po} = 2\sigma_v' \cdot L_e \cdot \alpha \cdot C_i \cdot \tan\phi \cdot R_c$$

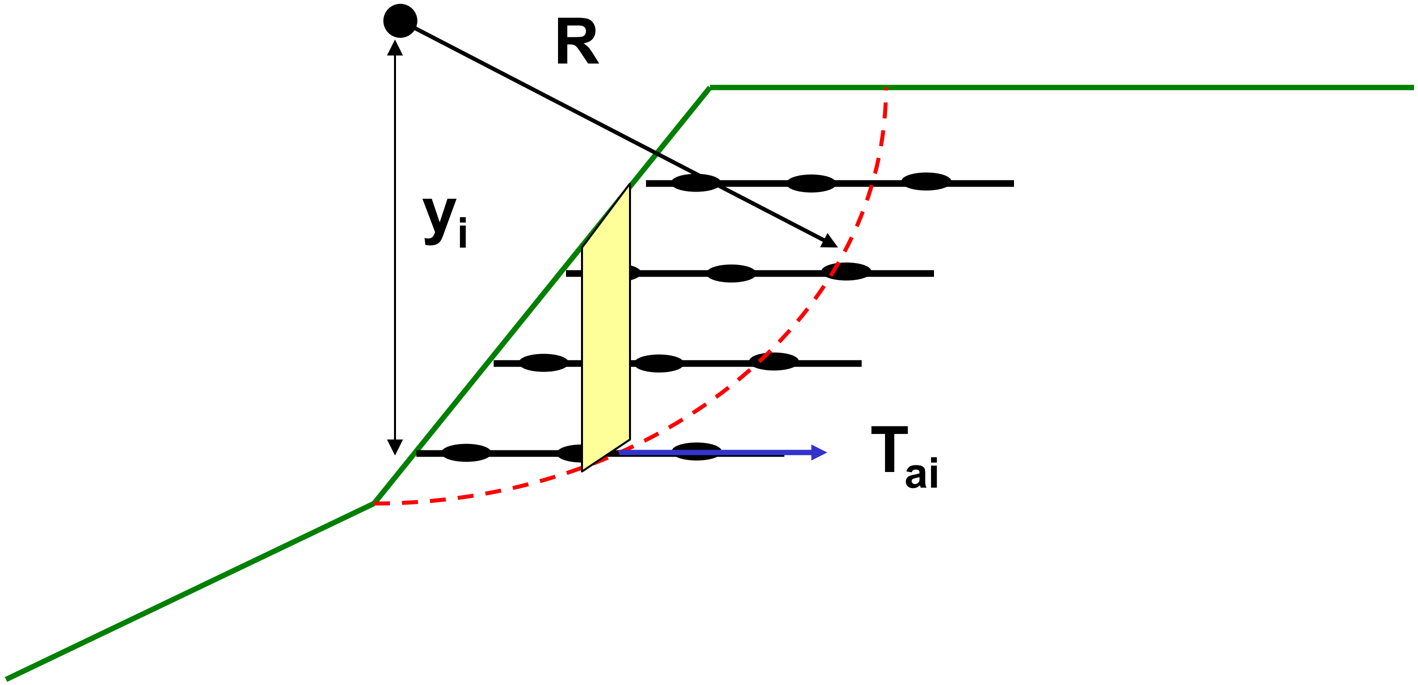
Allowable $T_{po(a)} = 2\sigma_v' \cdot L_e \cdot \alpha \cdot C_i \cdot \tan\phi \cdot R_c / FS_{po}$

Percent Coverage



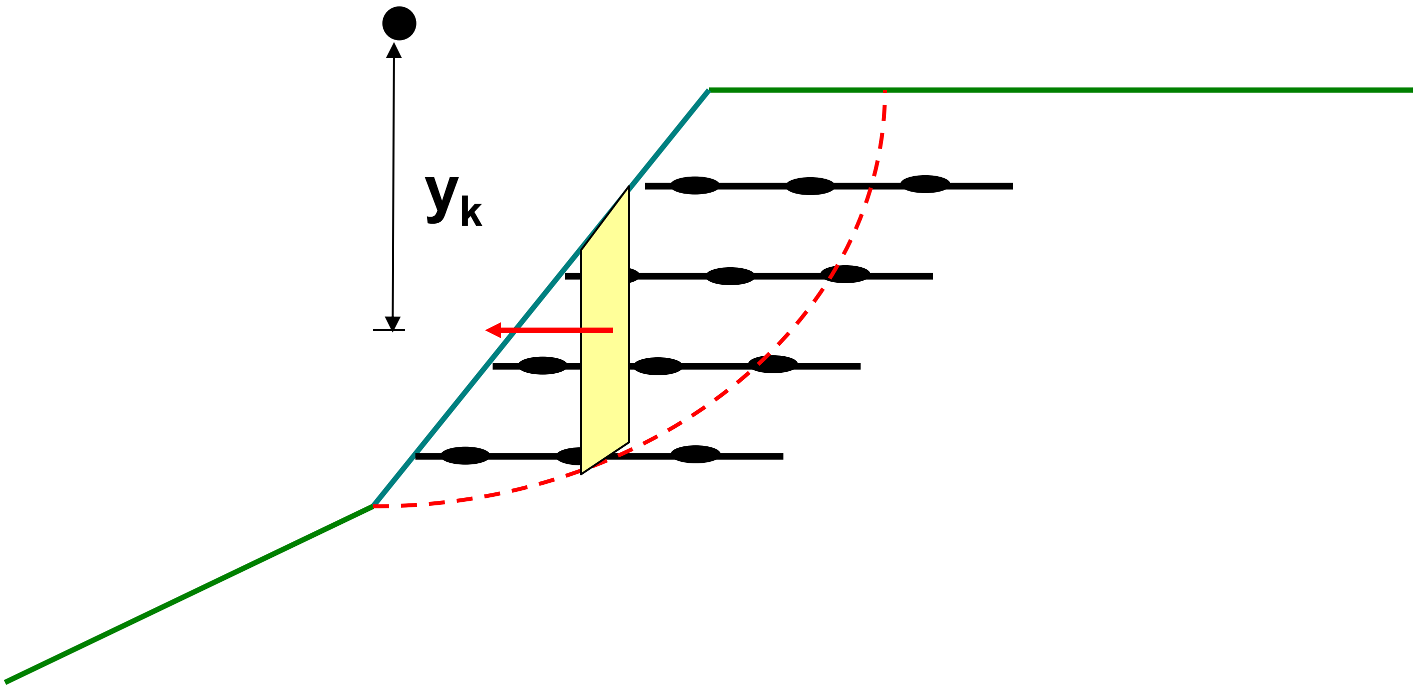
Percent coverage, $R_c = A_g/A \times 100\%$

Static Factor of Safety – Simplified Method (FHWA)



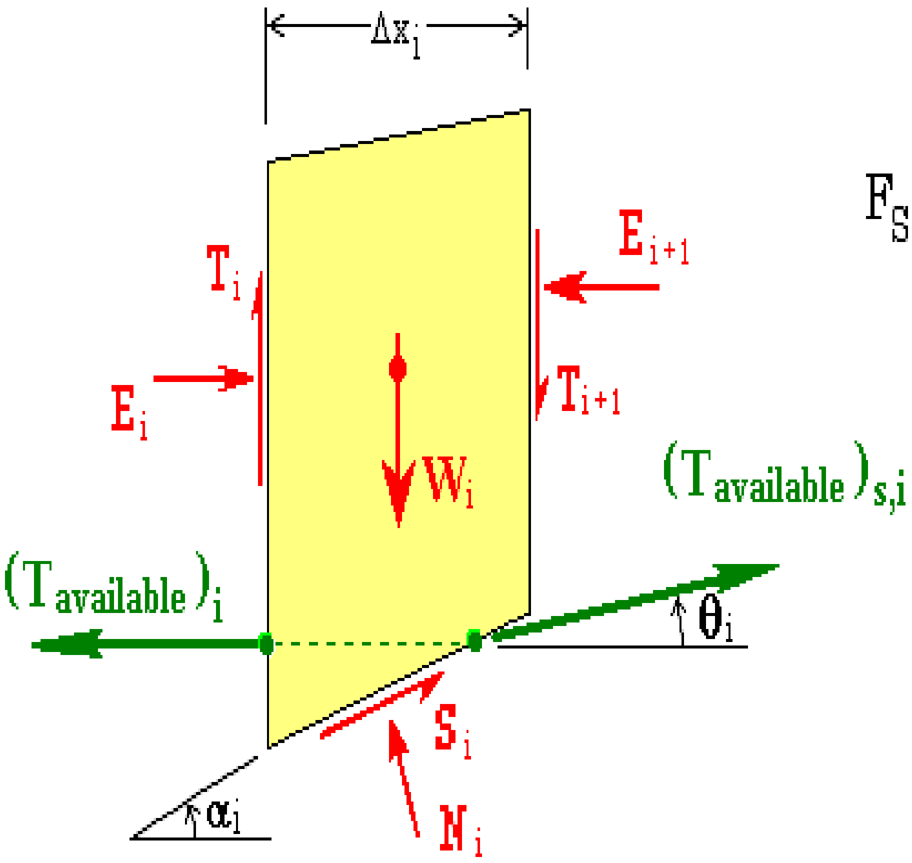
$$FS_r = \frac{M_R + \sum T_{ai} y_i}{M_D} = FS_u + \frac{\sum T_{ai} y_i}{M_D} \geq 1.3$$

Seismic Factor of Safety



$$FS_r = \frac{M_R + \sum T_{ai} y_i}{M_D + \sum m_i (k_{hi} g) y_k} \geq 1.1 \qquad (k_{hi}=A/2)$$

Modified Bishop's Analysis – Rigorous Method



$$F_S = \frac{\sum \left[c_i \Delta x_i + (W_i - t_i \sin\theta_i)\tan\phi_i \right] / m_{\alpha_i}}{\sum \left[W_i \sin\alpha_i - t_i \cos(\alpha_i - \theta_i) \right]}$$

$$t_i = (T_{available})_{s,i}$$

Leshchinsky

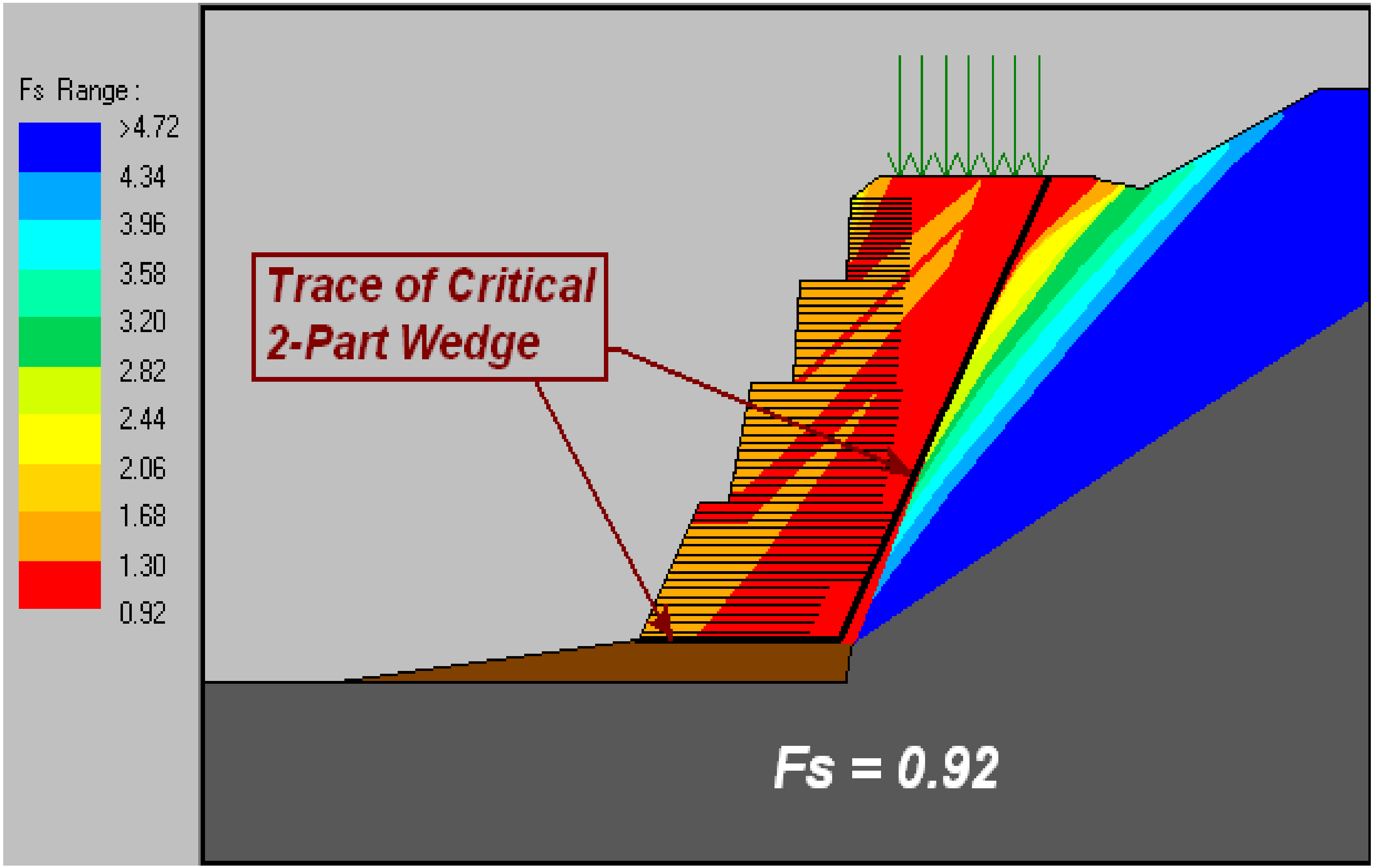
Translational Failure

- Sliding can occur along reinforcement layer or along foundation interface

- Conduct translational stability analysis (including deep-seated) to calculate the required L and T

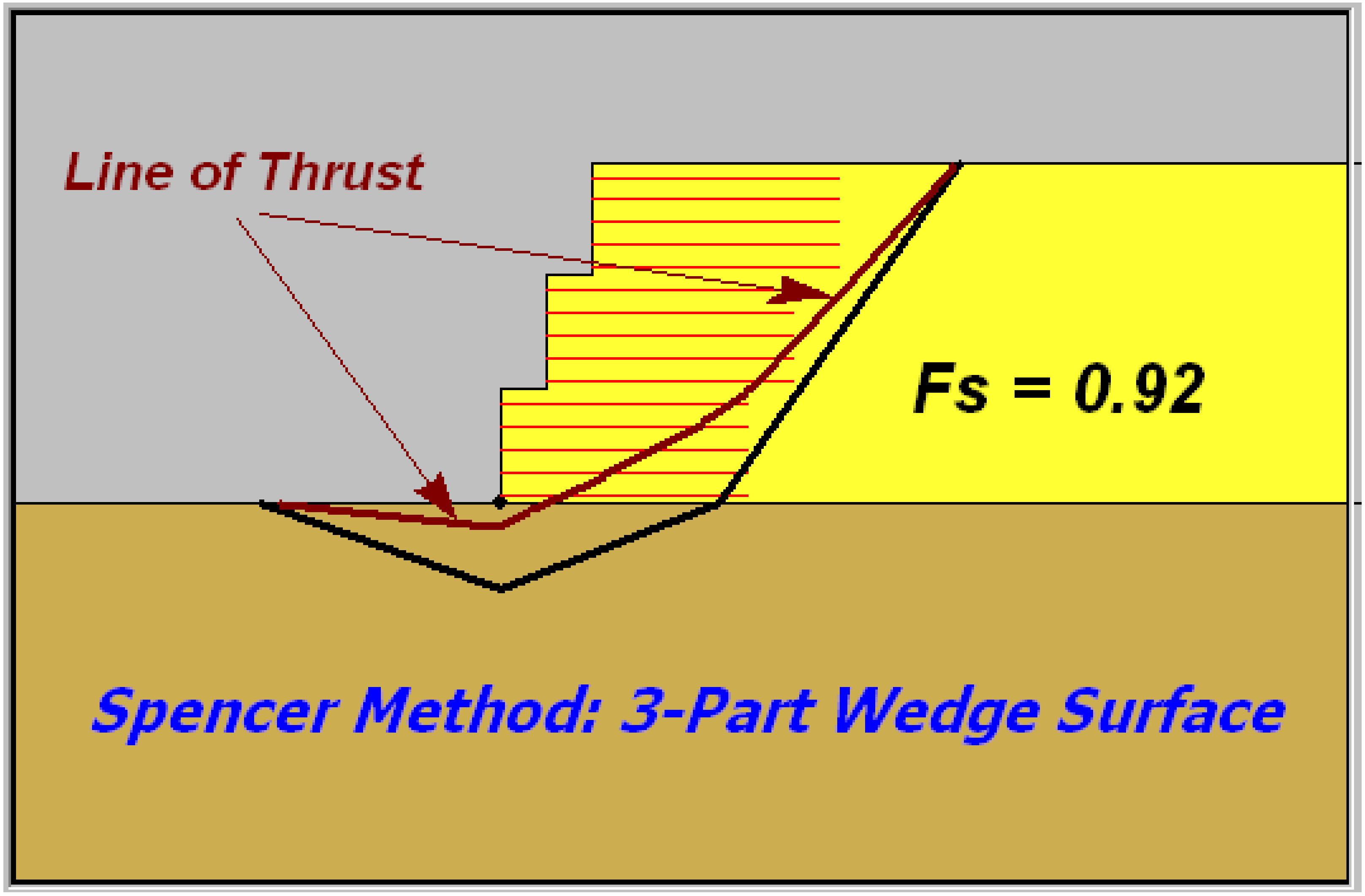
- Translational stability analysis: Can utilize 2-Part and 3-Part Wedge – Spencer Analysis

2-Part Wedge Using Spencer's



From ReSSA Program

Spencer's Method



From ReSSA Program

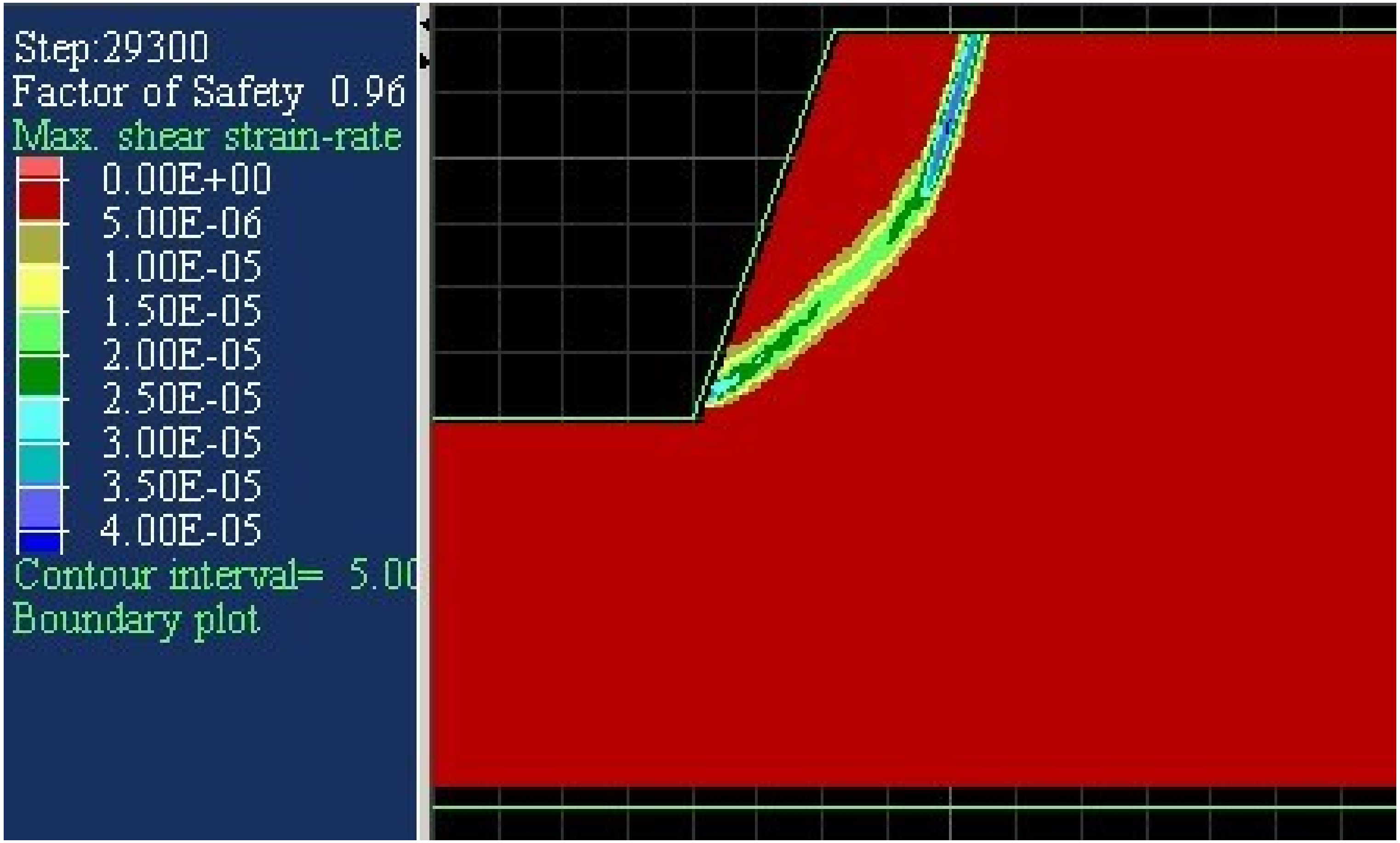
FS using Numerical Method

Shear Strength Reduction Technique

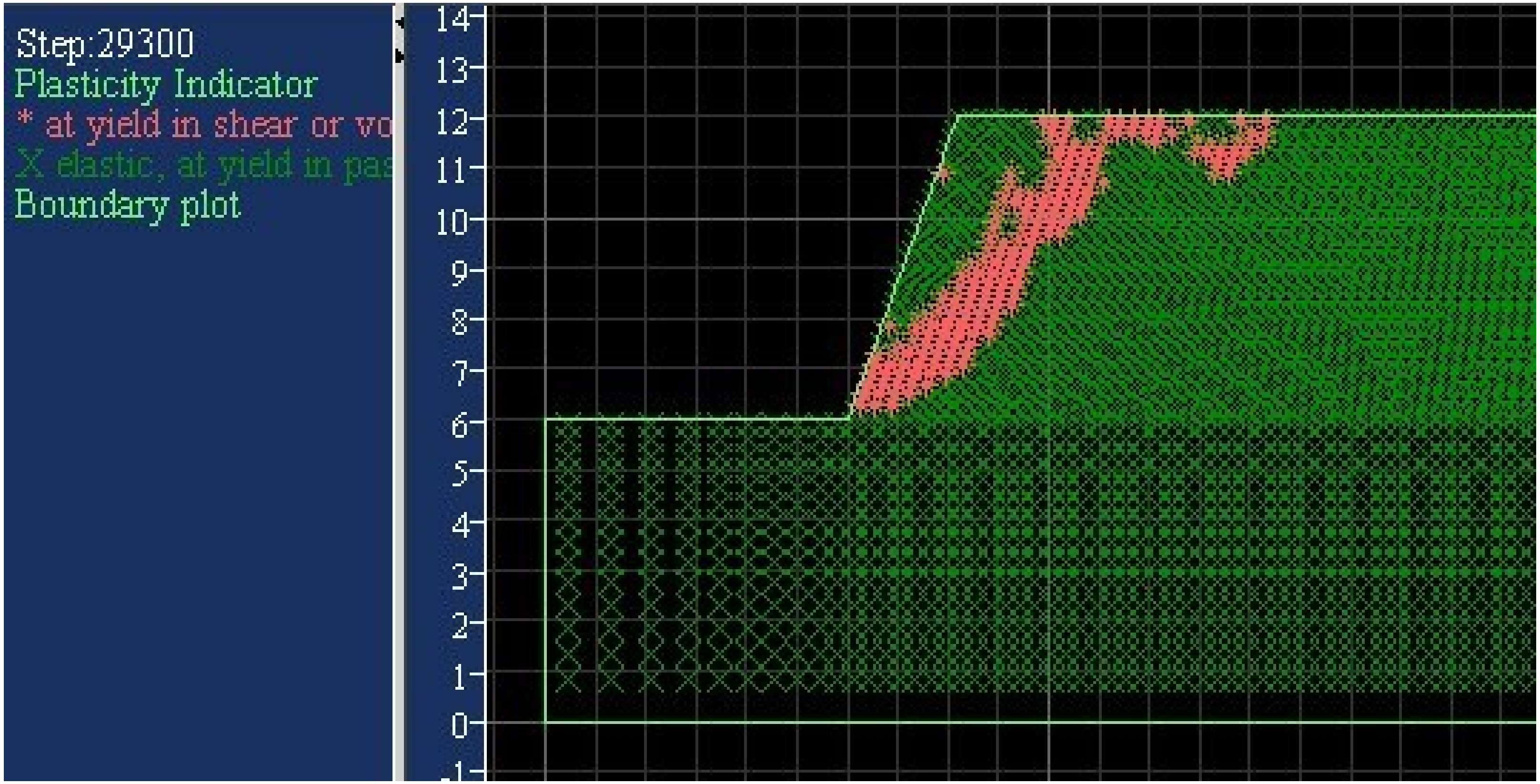
$$C^{\text{trial}} = C / FS^{\text{trial}}$$

$$\phi^{\text{trial}} = \tan^{-1} (\tan \phi / FS^{\text{trial}})$$

Minimal Factor of Safety and Critical Surface from FLAC (4.0)



Plasticity Zone from FLAC (4.0)



Required Factors of Safety

Limit equilibrium $$FS = 1.0$$

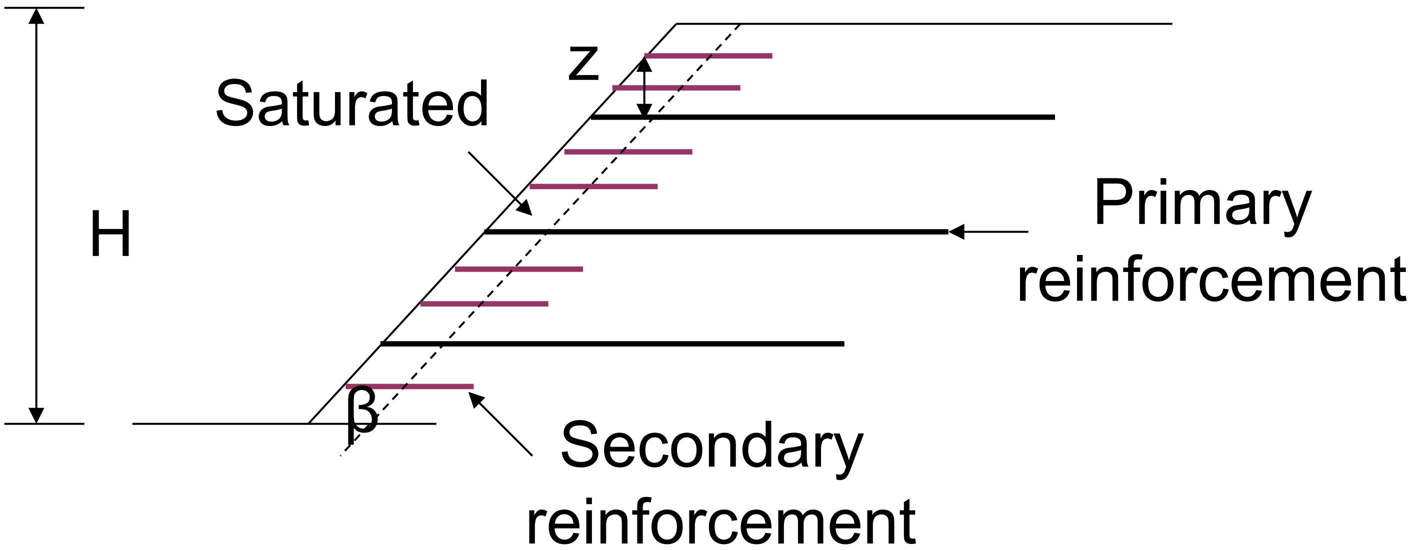
Required FS under static loads

$$FS \geq 1.3 - 1.5$$

Required FS under seismic loads

$$FS \geq 1.1$$

Surficial Slope Stability



$$FS = \frac{c' H + (\gamma_{sat} - \gamma_w) Hz \cos^2 \beta \tan \phi' + T_g (\cos \beta \sin \beta + \sin^2 \beta \tan \phi')}{\gamma_{sat} Hz \cos \beta \sin \beta}$$

T_g = summation of geosynthetic resisting force (controlled by pullout or rupture)

Case Study of Reinforced Slopes

Case History - Recreational Water Park

Orlando, FL

Design Requirements

- Create artificial "mountain" 21m (70 ft) high
- Highly irregular surface shape
- Slopes from 3H:1V to 0.35H:1V
- Compressible foundation soils

Case Study - Recreational Water Park

Orlando, FL

Alternative

- Customized concrete facing

Solutions

- Wire formed geogrid-wrapped face
- Vegetated erosion blanket
- Artificial "rock" concrete

Case Study
- Recreational Water Park

Orlando, FL

<u>Special Details</u>

- 0.5H:1V slopes used to preconsolidate foundation for tunnel
- Drainage composite included to expedite consolidation

Case Study - Recreational Water Park

Orlando, FL

Construction

- Fast track construction
- Achieved finished height in approximately 100 days