Geomembrane Design Issues

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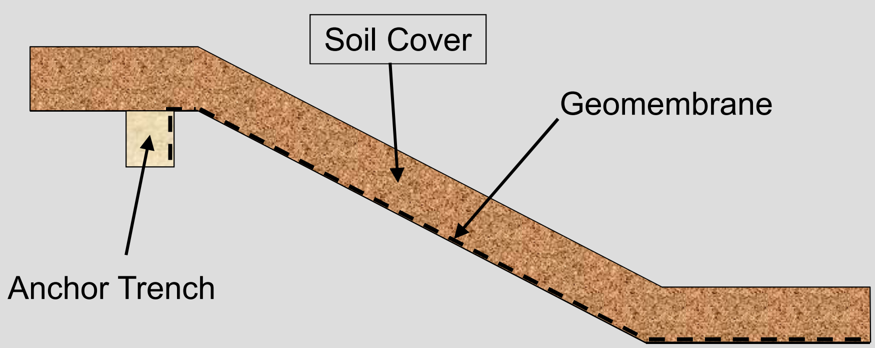
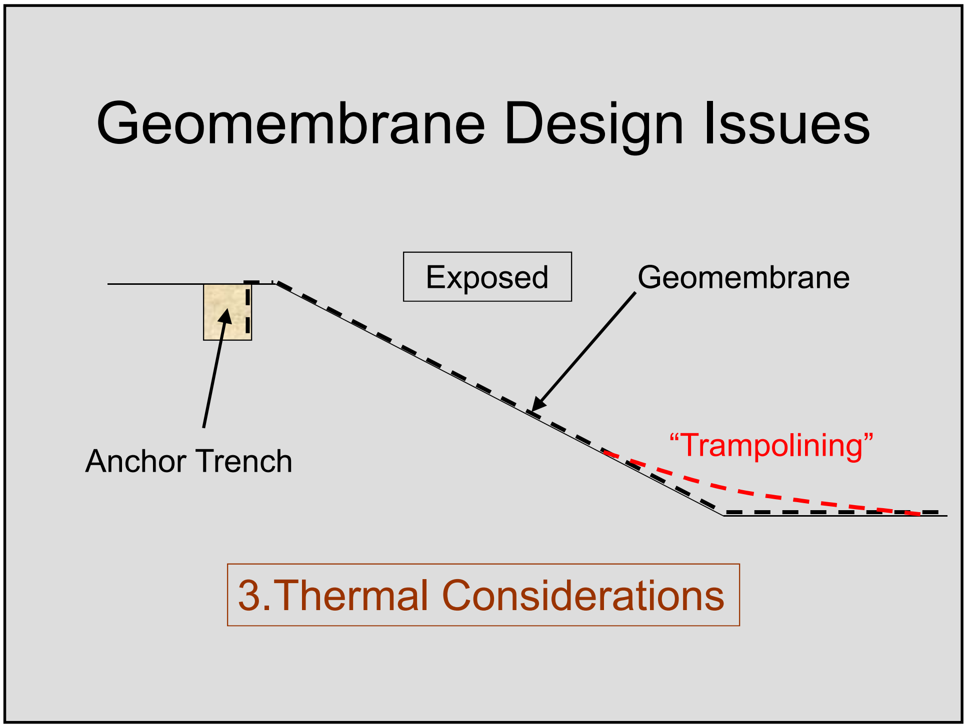
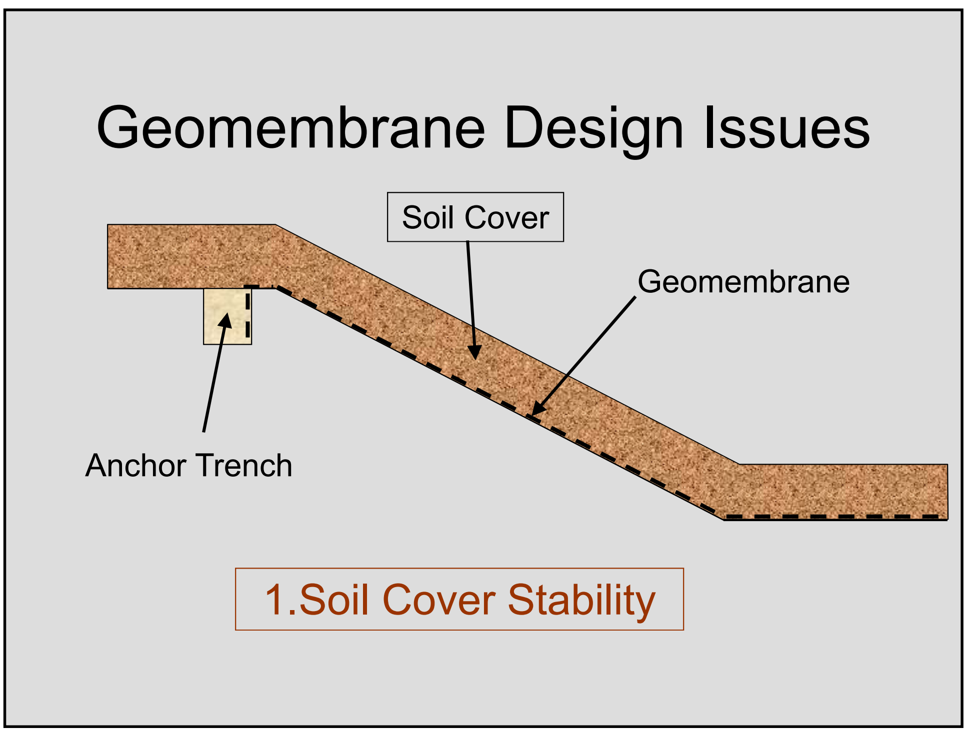
Geomembrane Design Issues

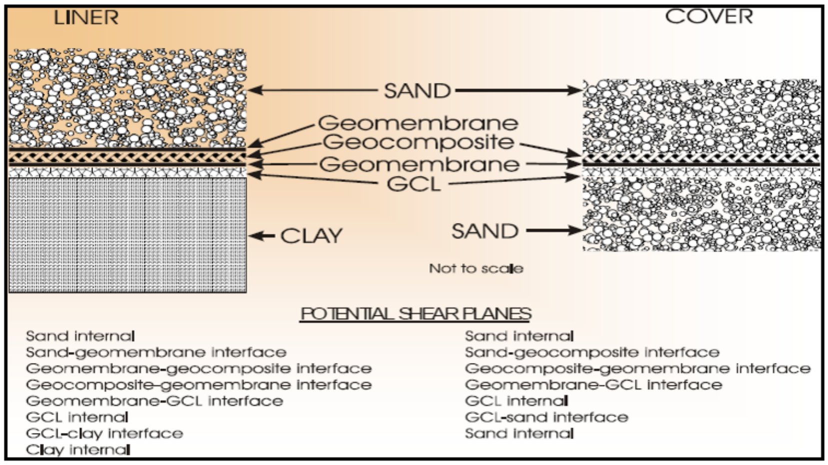


1. Soil Cover Stability
2. Anchor Trench Design


Geomembrane Design Issues
Exposed
Geomembrane
Anchor Trench
"Trampolining"
3.Thermal Considerations

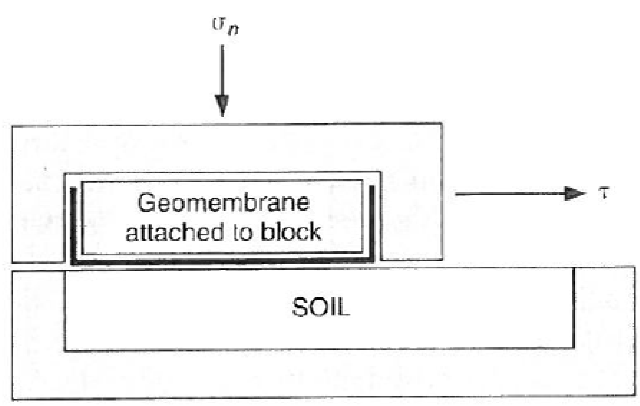

Geomembrane Design Issues
Soil Cover
Geomembrane
Anchor Trench
1.Soil Cover Stability

Interface Shear Strength



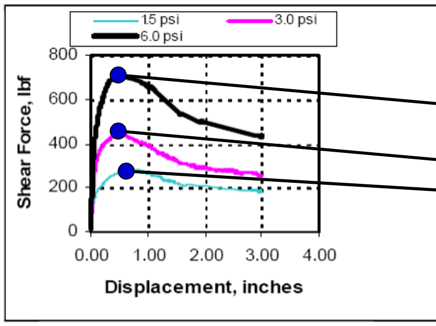
Typical Interfaces in Landfill Liner and Cover Systems

Interface Shear Strength

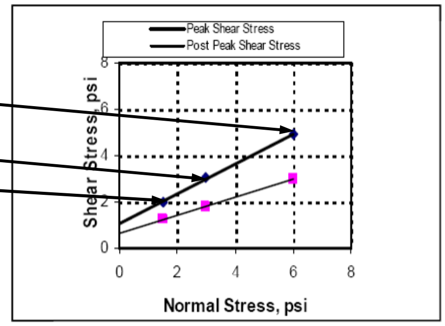


(a) Direct shear test device

Interface Shear Strength

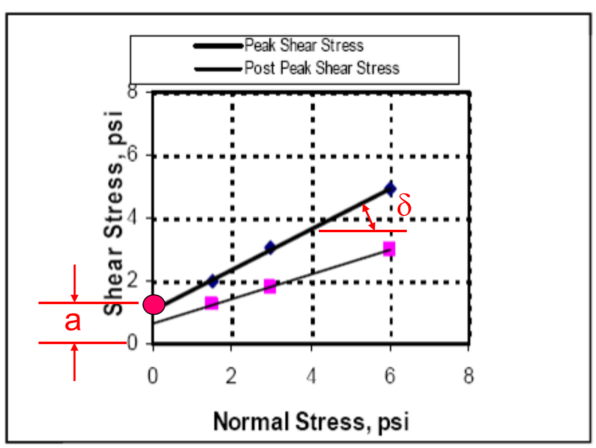


Typical Shear Force vs. Displacement
Curves for Three Normal Stresses



Typical Peak and Post Peak
Stress Envelopes

Interface Shear Strength



Typical Peak and Post Peak
Stress Envelopes

Interface Shear Strength

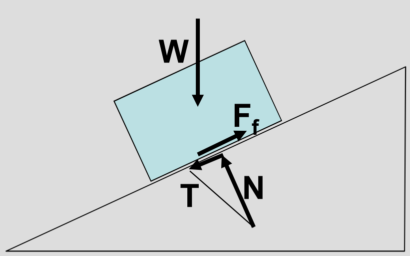
Published, average values of δ - a

	SURFACE 2			
SURFACE 1	Granular Soil	Cohesive Soil	NW-NP GT	Ottowa Sand (ϕ=30^o)
HDPE-S	21^o – 0	22^o - 0	11^o – 0	---
LLDPE-S	27^o – 0	11^o - 260	10^o – 0	---
PVC-S	---	---	20^o – 0	---
PVC-F	---	---	27^o – 4	---
NW-NP GT	33^o – 0	30^o - 104	---	30^o - 0 psf
W-SF GT	32^o – 0	29^o - 0	---	24^o - 0 psf
GCL-top, woven GT	33^o – 130	---	---	---
GCL, bottom, GM	22^o – 55		---	---

Slope Stability

Shear Strength ≈ Resistance to Sliding

Sliding Block Analogy



T = driving force

F_f = available frictional resistance

= c + N * tan ϕ

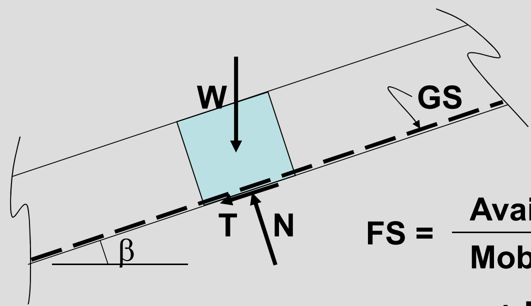
ϕ = "friction angle" of interface

c = "cohesion" of interface

$$FS = \frac{F_f}{T}$$

Slope Stability

Soil Cover on Geosynthetic



$$FS = \frac{\text{Available Shear Strength}}{\text{Mobilized Shear Strength}} = \frac{a + N * \tan \delta}{W * \sin \beta}$$

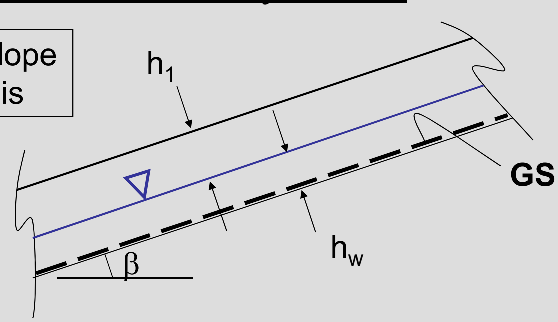
δ = friction angle of GS-soil interface ($\approx \phi$)

a = adhesion of interface ($\approx$ c)

Slope Stability

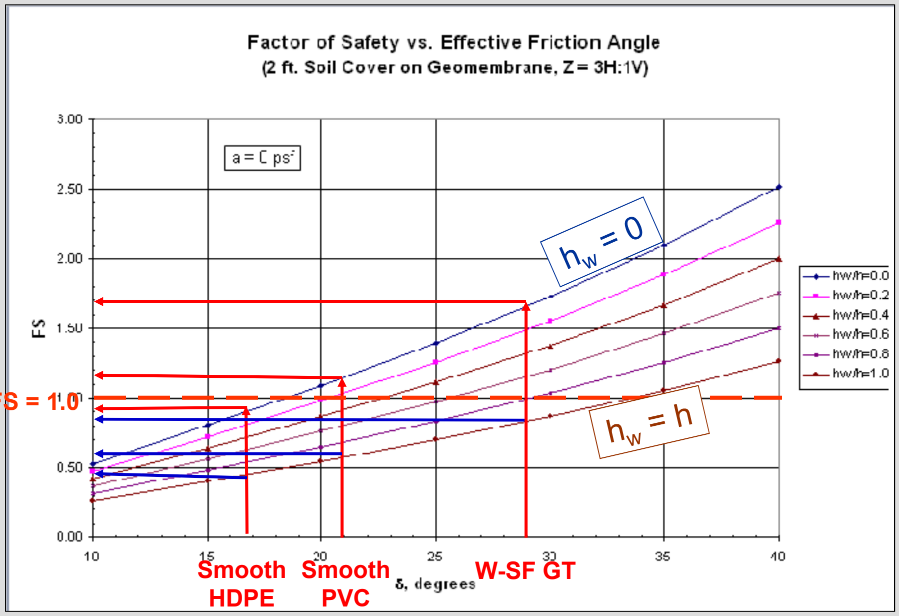
Soil Cover on Geosynthetic

Infinite Slope Analysis



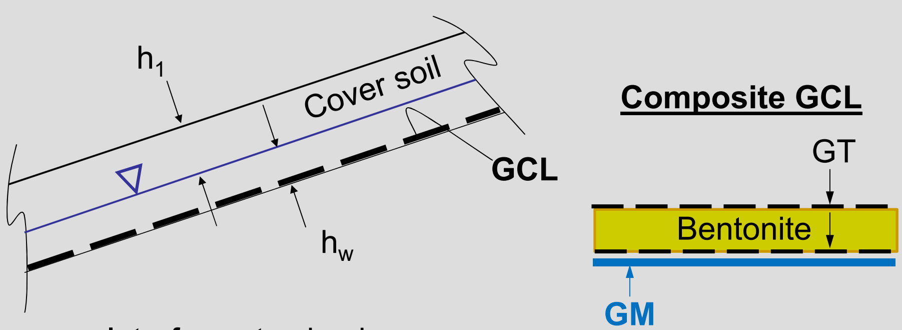
$$FS = \frac{a_{GS\text{-}soil} + [h_1 * \gamma_m + h_w * \gamma_b] * \tan \delta_{GS\text{-}soil} * \cos \beta}{[h_1 * \gamma_m + h_w * \gamma_{sat}] * \sin \beta}$$

FS = 1.0 at failure $\qquad$ FS_{min} = 1.3+ (Koerner, 2005)



Slope Stability

<u>Stability of Composite GCL on Slope:</u>



<u>Interfaces to check</u>:
•Cover soil on top of GCL
•GCL on subgrade

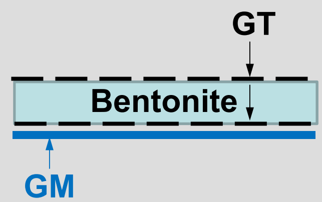
Slope Stability

Stability of GCL on Slope:

Avg. values*

Interfaces to check:	Interface δ and a:
•Cover soil on top of GCL	δ = 33.5° a = 130 psf
•GCL on subgrade	δ = 22° a = 55 psf

Composite GCL



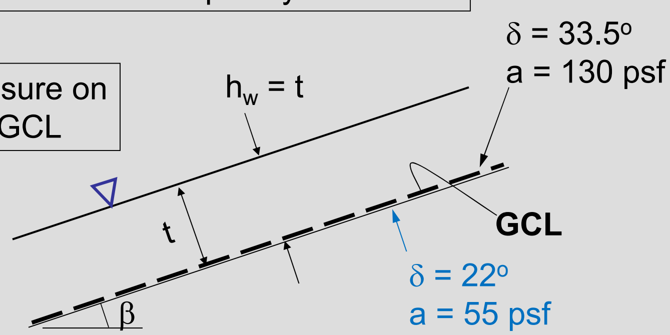
* - From CETCO, Design and Construction of Water Containment Systems Using Bentomat CL, v. 3.0, 2009

Slope Stability

Stability of GCL on Slope:

Assume cover soil completely saturated

Pore pressure on top of GCL



No pore pressure on bottom of GCL

Slope Stability

Stability of GCL on Slope:

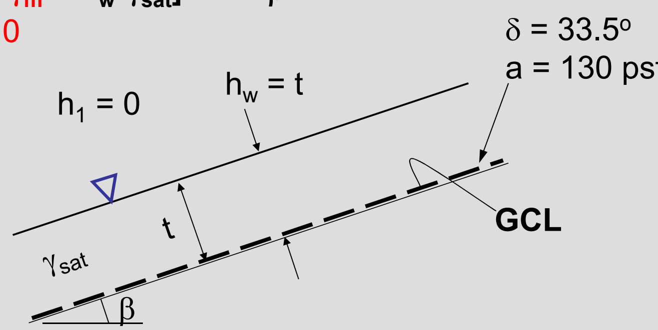
1) Cover soil on GCL

$$FS = \frac{a_{GCL\text{-}soil} + [\underbrace{h_1 * \gamma_m}_{=0} + h_w * \gamma_b] * \tan \delta_{GCL\text{-}soil} * \cos \beta}{[\underbrace{h_1 * \gamma_m}_{=0} + h_w * \gamma_{sat}] * \sin \beta}$$

$h_w = t = 1.5$ ft

$\gamma_{sat} = 128$ pcf

3:1
FS = 3.16
2:1
FS = 2.19



Slope Stability

Stability of GCL on Slope:

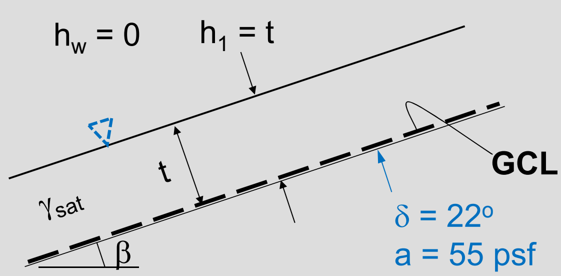
2) GM on subgrade

$$FS = \frac{a_{GCL\text{-}soil} + [h_1 * \gamma_{sat} + \underbrace{h_w * \gamma_b}_{=0}] * \tan \delta_{GCL\text{-}soil} * \cos \beta}{[h_1 * \gamma_{sat} + \underbrace{h_w * \gamma_{sat}}_{=0}] * \sin \beta}$$

$h_w = t = 1.5$ ft

$\gamma_{sat} = 128$ pcf

3:1
FS = 2.17
2:1
FS = 1.48



Slope Stability

Stability of GCL on Slope:

Summary:

1) Saturated cover soil on GCL

δ (deg)	a (psf)	Side Slope 2:1	Side Slope 3:1	Notes
33.5	130	2.19	3.16	Avg. δ & a (CETCO)
32.6	19.5	0.88	1.30	Low a (CETCO)

For a = 0, FS = 1.0

δ (deg)	a (psf)	Side Slope 2:1	Side Slope 3:1
44.2	0	1.00	---
33.0	0	---	1.00

Slope Stability

Stability of GCL on Slope:

Summary:

2) GM on subgrade

δ (deg)	a (psf)	Side Slope 2:1	Side Slope 3:1	Notes
22.5	55	1.48	2.17	Avg. δ & a (CETCO)
16	14	0.74	1.10	Low δ & a (CETCO)

For a = 0, FS = 1.0

δ (deg)	a (psf)	Side Slope 2:1	Side Slope 3:1
26.6	0	1.00	---
18.5	0	---	1.00

Slope Stability

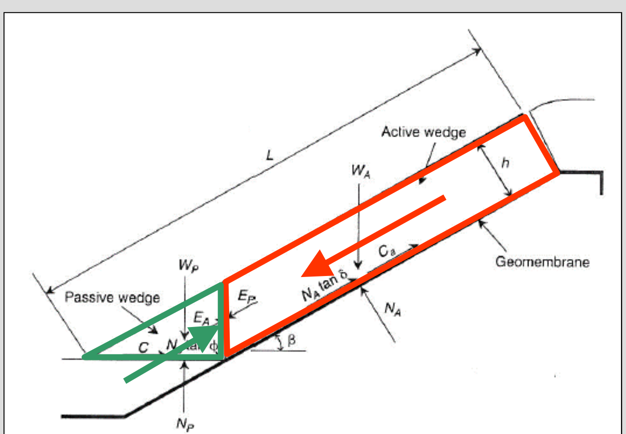
Stability of GCL on Slope:

Take-home messages:

- Never use a GCL on a 2:1 slope.
- 3:1 slope probably ok.
- Don’t use average, generic values for δ and a.
- To be sure, do site-specific testing.
- Adhesion (a) has a huge influence on slope stability.

Slope Stability

Finite Slope Analysis – w/o reinforcement



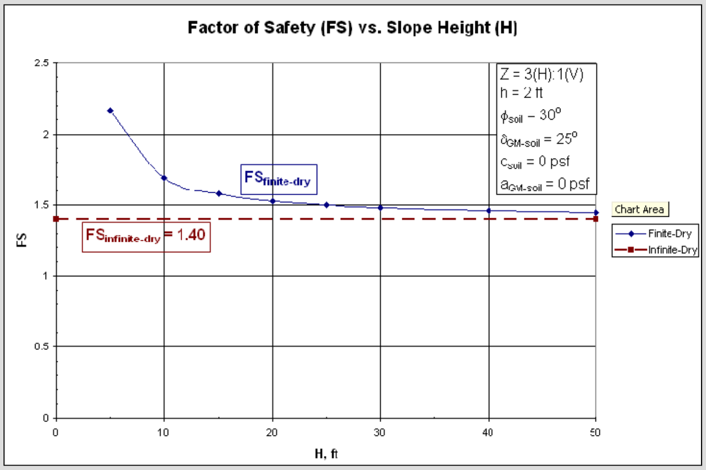
(a) Without reinforcement

Note: Saturation of cover soil not considered.

From: Koerner, R. M., Designing With Geosynthetics, Fifth Edition, 2005.

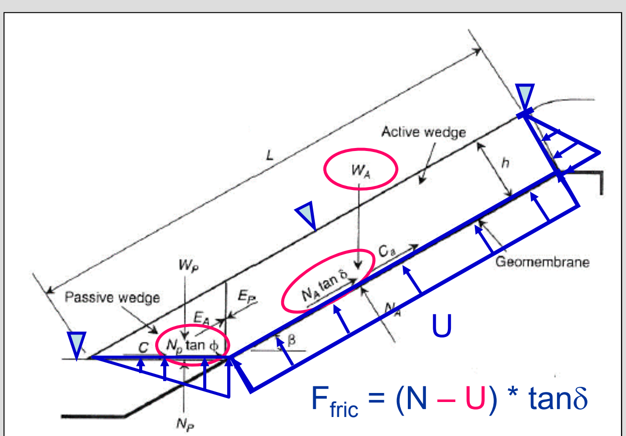
Slope Stability

Finite Slope Analysis – w/o reinforcement



Slope Stability

Finite Slope Analysis – w/o reinforcement

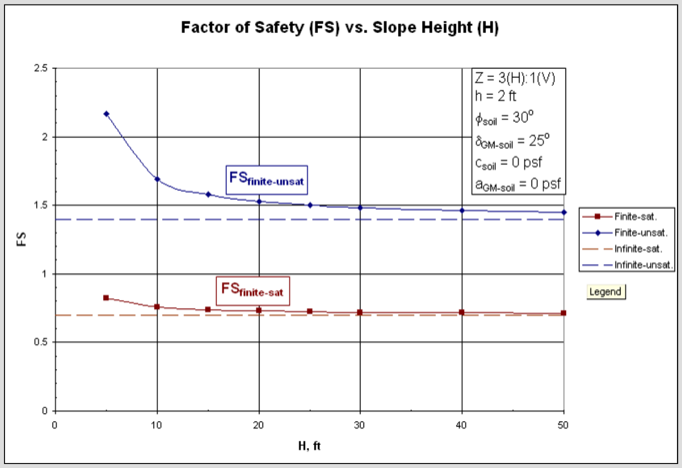


(a) Without reinforcement

Add effects of saturation.

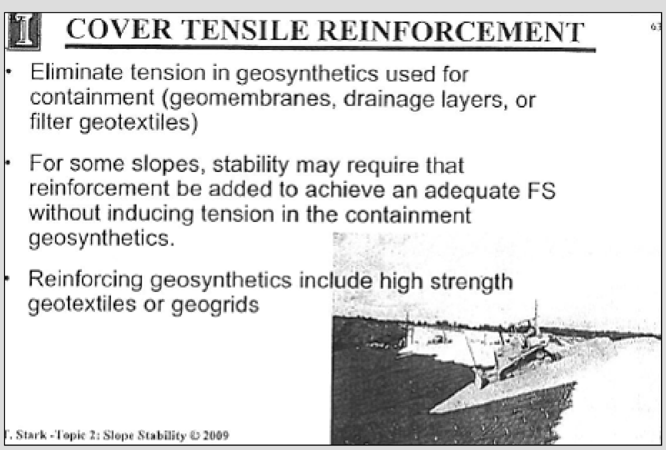
Slope Stability

Finite Slope Analysis – w/o reinforcement



Slope Stability

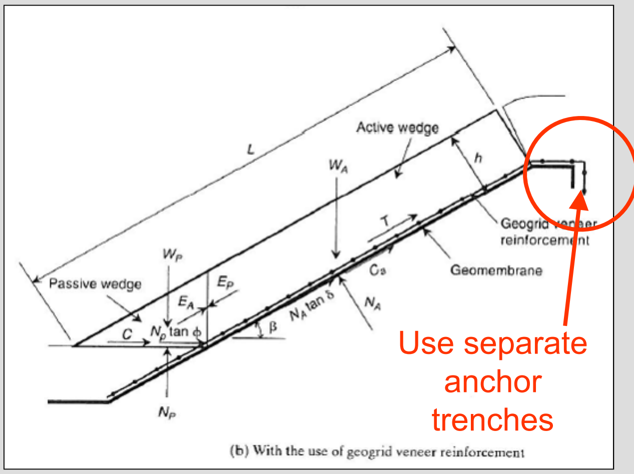
Finite Slope Analysis - w/ reinforcement



From: Stark, T., Advanced Slope Stability and Geosynthetic Interface Testing Short Course, Geosynthetics 2009.

Slope Stability

Finite Slope Analysis – w/ reinforcement

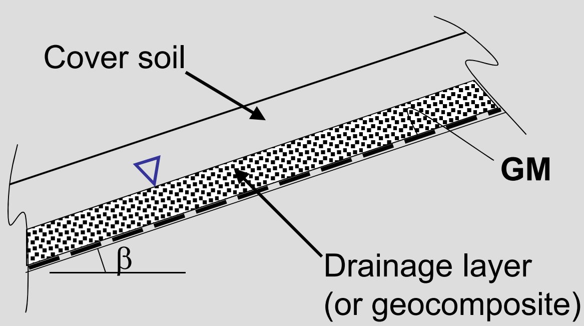


(b) With the use of geogrid veneer reinforcement

From: Koerner, R. M., Designing With Geosynthetics, Fifth Edition.

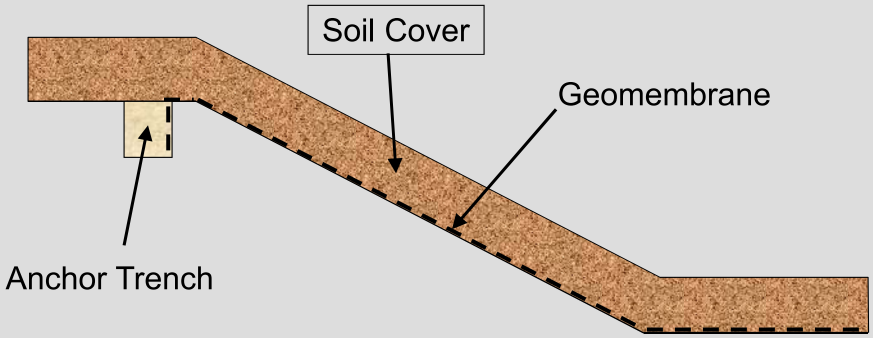
Slope Stability

Finite Slope Analysis – add drainage layer



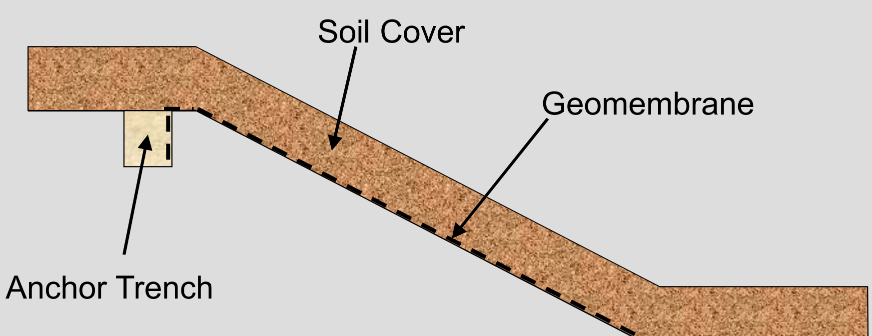
Note: Drainage layer must be filter compatible with cover soil and must have "non-pressurized" flow.

Geomembrane Design Issues



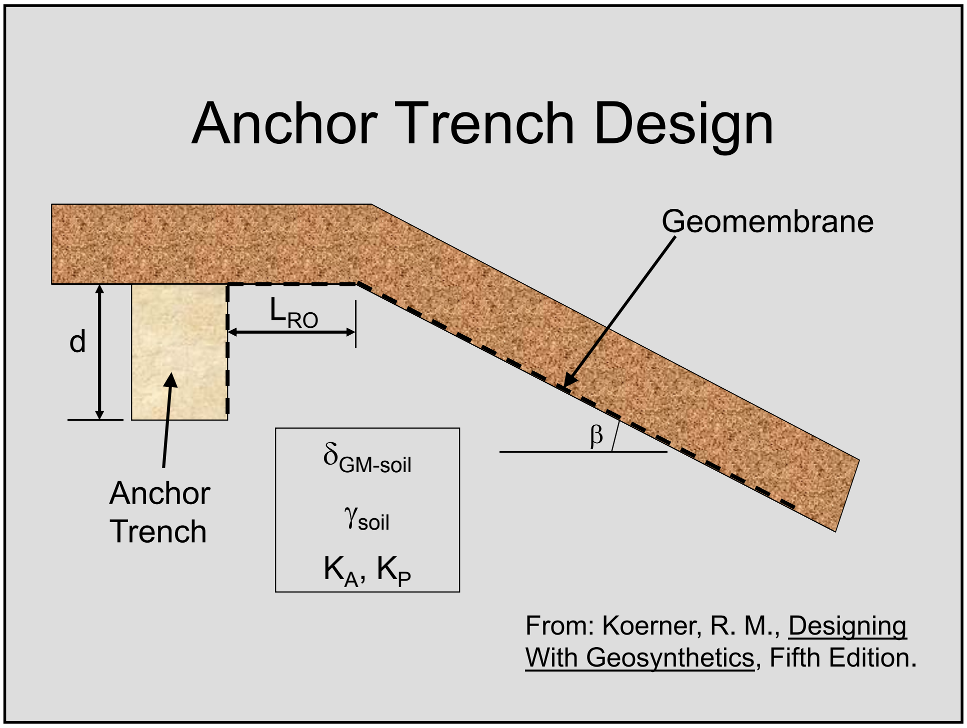
2.Anchor Trench Design

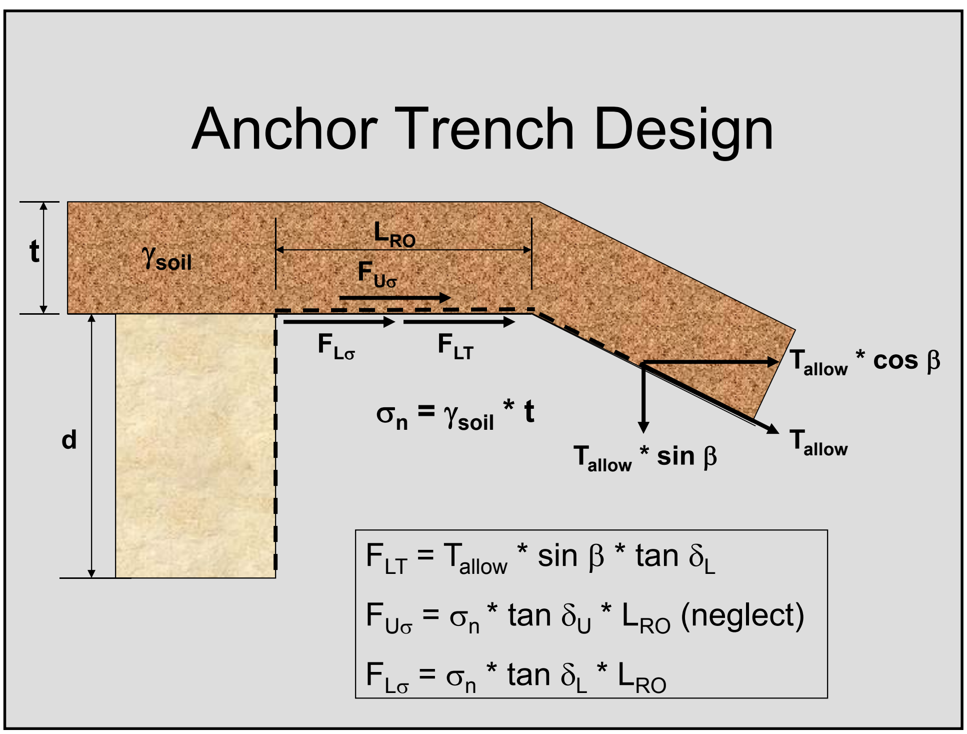
Anchor Trench Design



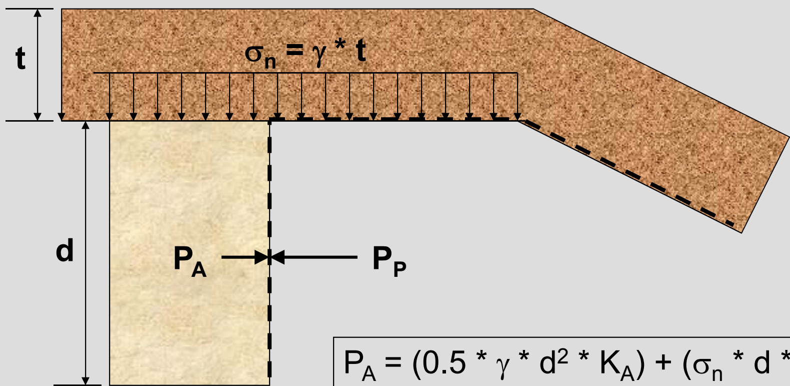
Pullout capacity of anchor trench =?

Design anchor trench so that
GM pulls out before it rips.


Anchor Trench Design
Geomembrane
d
LRO
β
Anchor Trench
δGM-soil
γsoil
KA, KP
From: Koerner, R. M., Designing With Geosynthetics, Fifth Edition.


Anchor Trench Design
t
γsoil
LRO
FUσ
FLσ
FLT
d
σn = γsoil * t
Tallow * cos β
Tallow * sin β
Tallow
FLT = Tallow * sin β * tan δL
FUσ = σn * tan δU * LRO (neglect)
FLσ = σn * tan δL * LRO

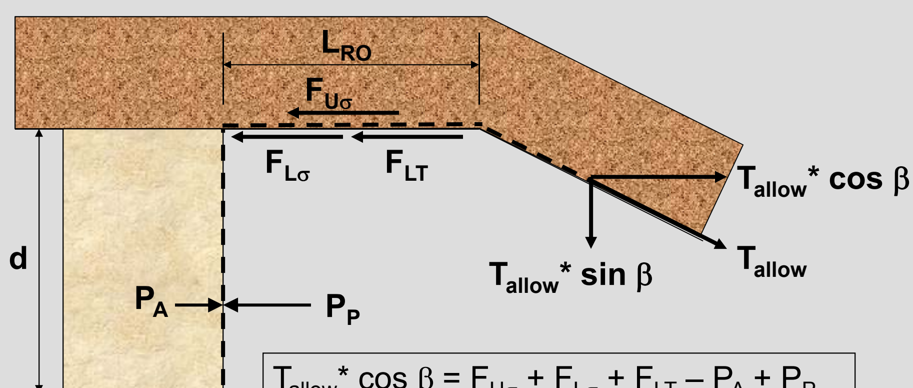
Anchor Trench Design



$P_A = (0.5 * \gamma * d^2 * K_A) + (\sigma_n * d * K_A)$

$P_P = (0.5 * \gamma * d^2 * K_P) + (\sigma_n * d * K_P)$

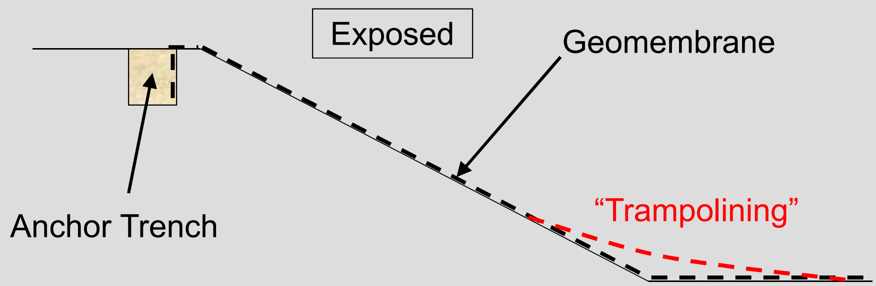
Anchor Trench Design



$T_{allow} * \cos\beta = F_{U\sigma} + F_{L\sigma} + F_{LT} - P_A + P_P$

Solve for d and L_{RO}.

Geomembrane Design Issues



- Thermal Considerations

Thermal Considerations

How much "slack" should be left in uncovered GM to allow for thermal expansion and contraction?

Thermal Considerations

Construction Specification 97
Flexible Membrane Liner

"The liner shall be *loosely laid* over the subgrade *with sufficient slack* to accommodate thermal expansion and contraction. …The methods used to place panels shall *minimize wrinkles*, especially along field seams."

Thermal Considerations

Material	Coeff. Of Thermal Expansion (x $10^{-5}/^{o}C$)
HDPE	11 – 13
LDPE	10 - 12
LLDPE	15 - 25
PP	5 - 9
PVC	7 - 25
EPDM	---

Thermal Considerations

- Δ_{temp} of concern is from placement temperature to minimum temperature (GM shrinks).
- Use typical properties for HDPE (from Koerner, 2005).

Thermal Considerations

- α = 8 to 12 x 10^{-5}/^{o}F. (Use 1 x 10^{-4}/^{o}F)
- Assume Δ_{temp} = 100 ^{o}F
- So $\varepsilon_{thermal} = \alpha * \Delta_{temp}$
  $= (1 \times 10^{-4}/^{o}F) * 100\ ^{o}F$
  $= 1 \times 10^{-2} = 1\%$
- So req'd. slack = 1% or 0.01 ft per ft (theoretical – use 2 to 3%)

Thermal Considerations

If no slack is allowed:

- $\sigma_{thermal} = \varepsilon_{thermal} * E_{HDPE}$
  $= (1 X 10^{-2}) * 65{,}000$ psi
  $= 650$ psi
- $\sigma_{allow\text{-}HDPE} = 2{,}300$ psi
- $\sigma_{thermal} << \sigma_{allow\text{-}HDPE}$ (OK)

Thermal Considerations

Conclusions:

Install exposed GM:

- When cool (backfill anchor trench).
- Loose, but relatively smooth.
- Relatively wrinkle-free (esp. large ones).
- Consider using sand bags.

Thermal Considerations

Conclusions:

Thermal strain would not be a significant issue:

- Except for trampolining.

Geomembrane Design Issues

Closing Thought on GM's:

- Quote from Koerner's book

  "Of all the geosynthetic materials, none are as unforgiving as geomembranes. The smallest leak when placed under hydrostatic pressure can produce alarmingly high flow rates. Thus inspection is clearly warranted."

- Careful design and inspection needed.
- Outside expertise may be needed (for both).

Geomembrane Design Issues

Questions?