ENVIRONMENTAL GEOTECHNICS
MKAJ 1083

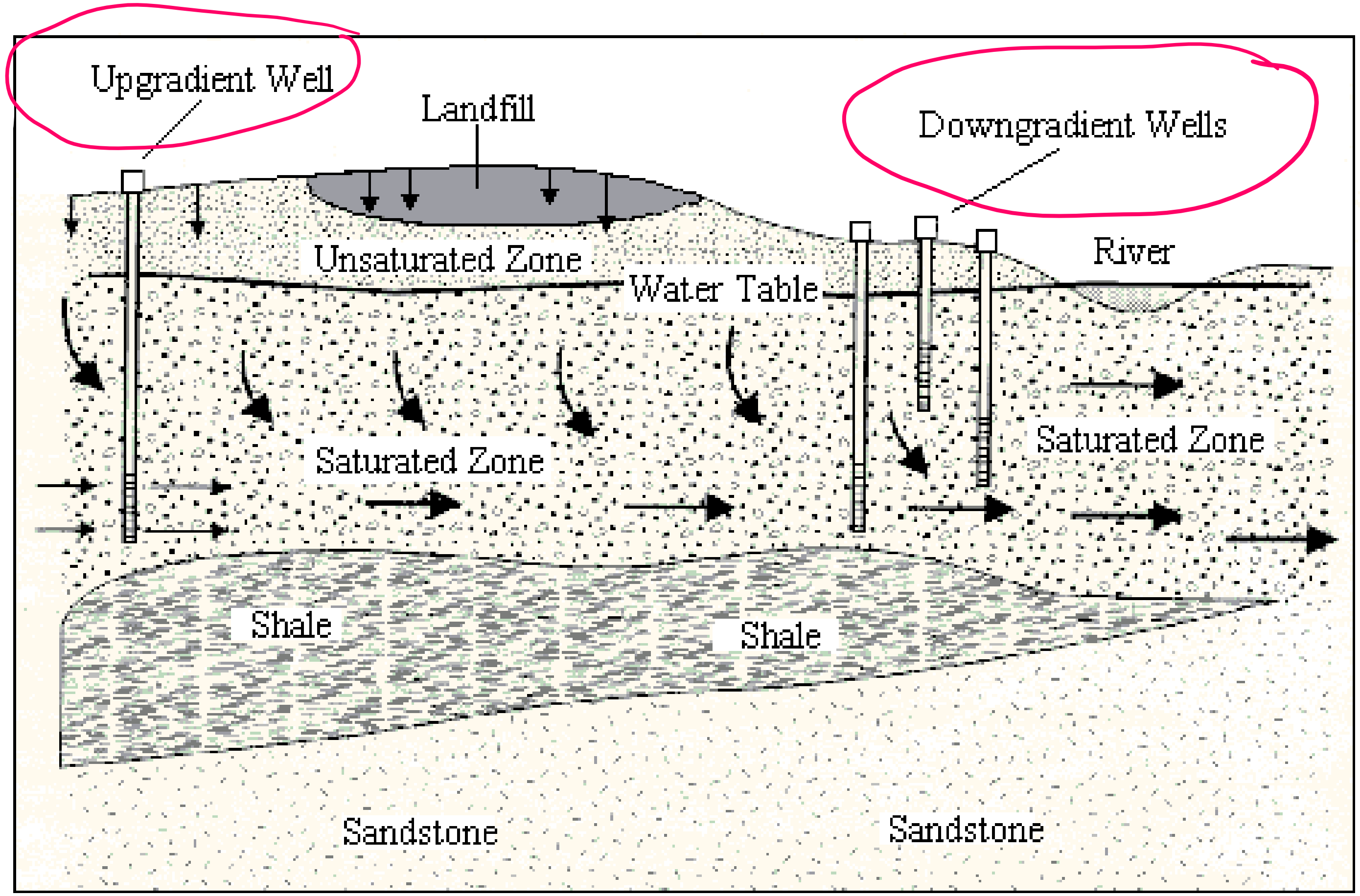
TOPIC 9: LEAKAGE FROM LINERS & COVERS

Dr Nor Zurairahetty Mohd Yunus
School of Civil Engineering, UTM

PURPOSE

- Identifying leaks in landfill liners is an essential part of waste management.
- Several types of leak detection tools can be installed in addition to monitoring wells to identify leaks soon after they occur.
- Federal law requires all landfills to include a leak detection system above the bottom composite liner.
- The system must consist of a layer of granular drainage materials with a slope of at least one percent.
- This system establishes what volume of leachate has leaked through the top liner, but it does not indicate whether or not leachate is leaking through the bottom liner.

CROSS SECTION OF A TRADITIONAL GROUNDWATER MONITORING SYSTEM. (GAO, 1995)



LEAK DETECTION OPTIONS

- Be affordable
- Be durable enough to last through the life of the landfill and the 30 year post-closure period
- Locate leaks and determine their sizes
- Be automated
- Be applicable to all types of landfills and all types of leachate
- Provide full spacial monitoring for the entire area below the landfill

ESTABLISHED SENSOR

Electrical

Diffusion hoses

Capacitance sensors

Tracers

Electro-chemical sensing cables

EMERGING TECHNOLOGIES

Geosynthetic Membrane Monitoring System

SEAtrace

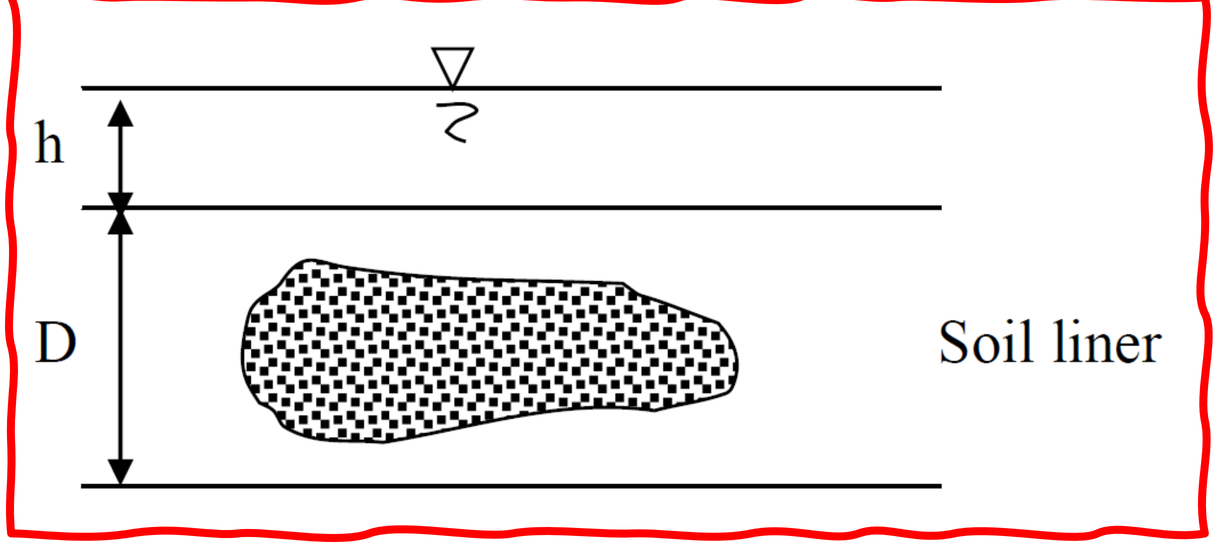
FLUTe ideal system

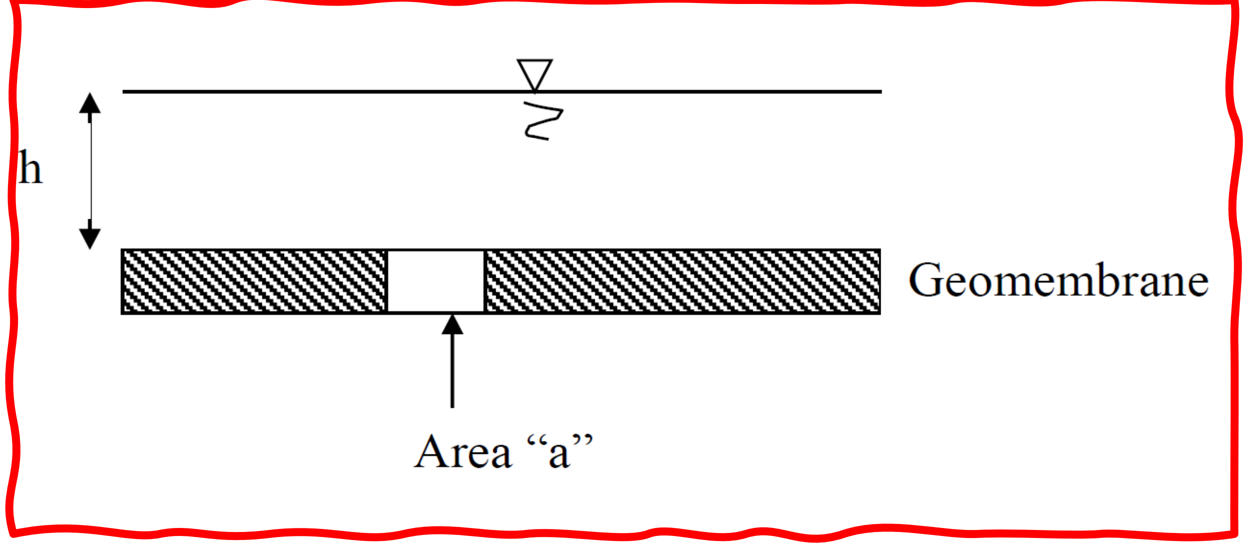
LIDAR

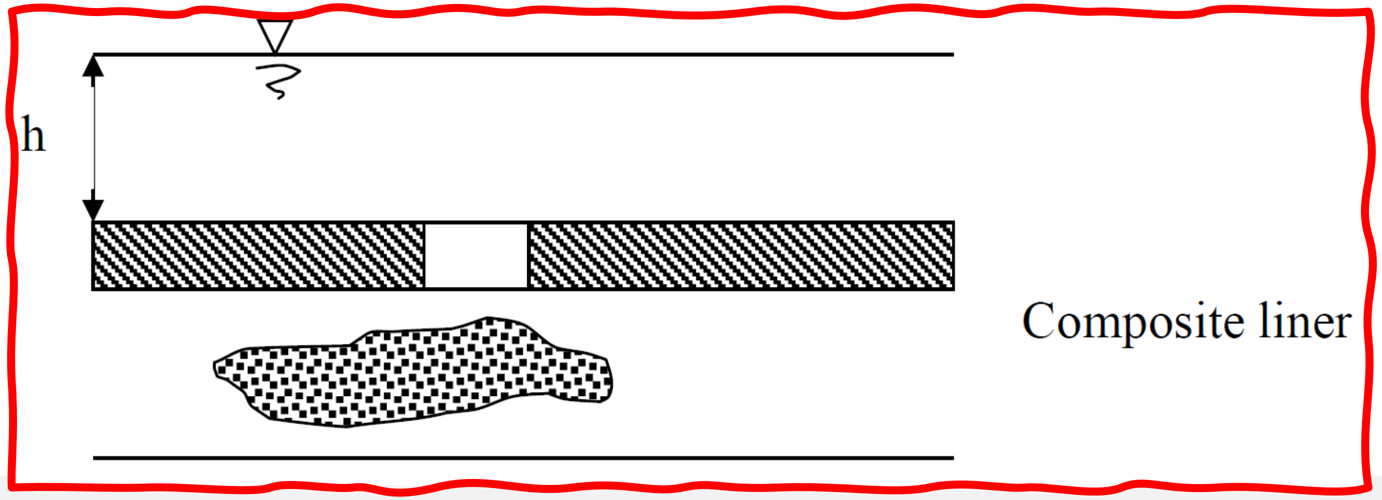
Acoustic monitoring

ACTION LEAKAGE RATE (ALR)

- ‘*the maximum design flow rate that a leak detection system (LDS) can remove without the fluid head on the bottom liner exceeding 1 ft.’*
- To minimize buildup of high heads on the bottom (second) liner and thereby ‘decreases the potential for migration of hazardous constituents out of the unit should a leak develop in the upper liner.’
- FOS > 2.0 is suggested to allow uncertainties in the design, construction, operation and location of LDS due to clogging, creep of geosynthetic, overburden stress etc
- EPA’s empirical formulation for assessing ALR assuming the hole in the liner is large enough to produce the calculated flow.







CASES OF LEAKAGE OF LEACHATE THRU LINERS

FLOW RATE: COMPACTED CLAY LINER

$$\boxed{Q = k_s i A}$$

where

Q = flow rate thru liner, cm^3/sec

k_s = hydraulic conductivity of soil, m/sec

i = hydraulic gradient

A = area over which flow occurs, cm^2

If soil is saturated and no suction,

$$i = \frac{h+D}{D}$$

i = hydraulic gradient

h = leachate head over the liner (Figure poor contact)

D = thickness of liner

FLOW RATE: GEOMEMBRANE LINER

$$\boxed{Q = C_b a (2gh)^{0.5}}$$

where

Q = flow rate thru membrane, cm^3/sec

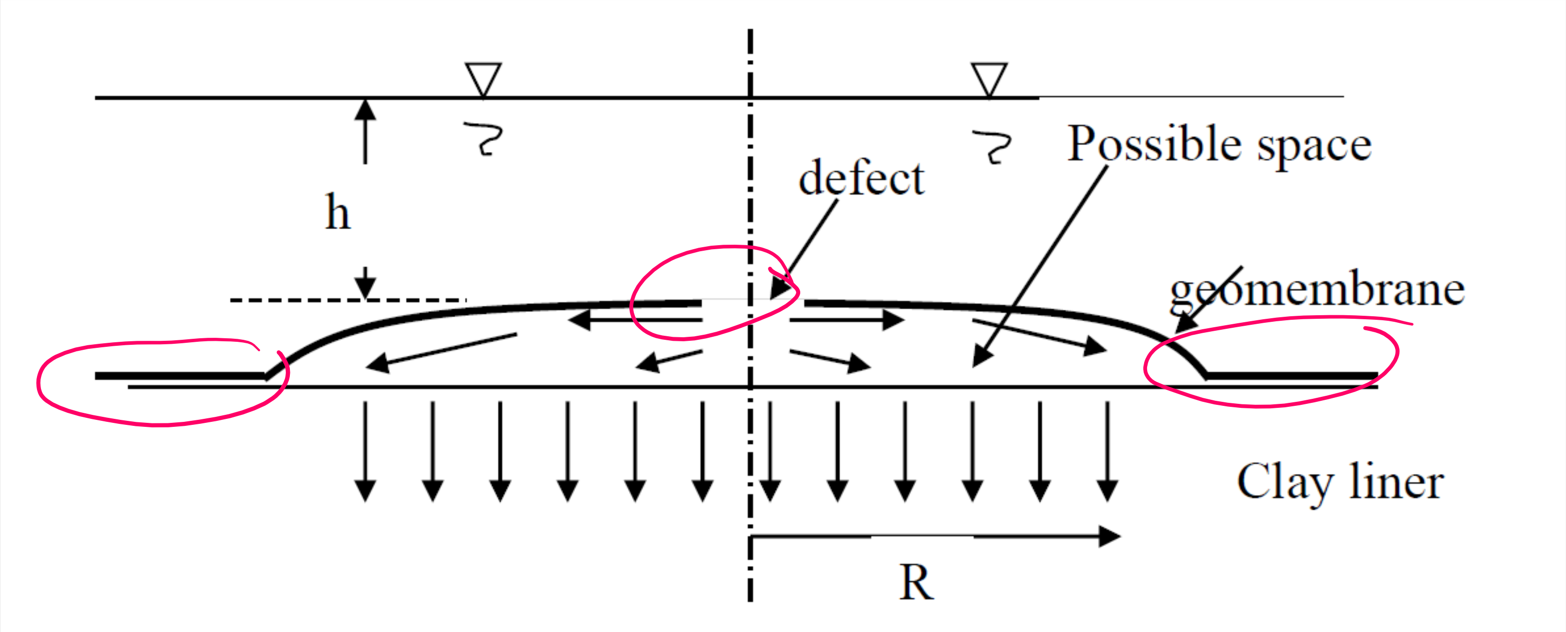
C_b = flow coefficient with a value approx. 0.6 for a circular hole

a = area of circular hole in geomembrane, cm^2

g = acceleration due to gravity, 981 $cm.sec^2$

h = liquid head above the liner, cm

FLOW RATE: COMPOSITE LINER



For "good contact"

$$Q = 0.21 \cdot a^{0.1} \cdot h^{0.9} \cdot k_s^{0.74}$$

For "poor contact"

$$Q = 1.15 \cdot a^{0.1} \cdot h^{0.9} \cdot k_s^{0.74}$$

where

Q = leakage rate thru a hole in geomembrane, m^3/sec

a = area of a circular hole in geomembrane, m^2

h = liquid head on top of geomembrane, m

k_s = hydraulic conductivity of soil liner, m/sec

FLOW RATE: COMPOSITE LINER

For "good contact"

$$Q = 0.21 \cdot a^{0.1} \cdot h^{0.9} \cdot k_s^{0.74}$$

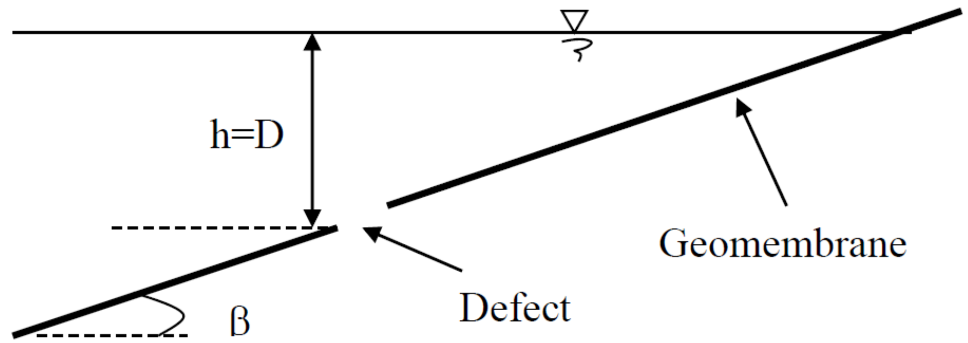
For "poor contact"

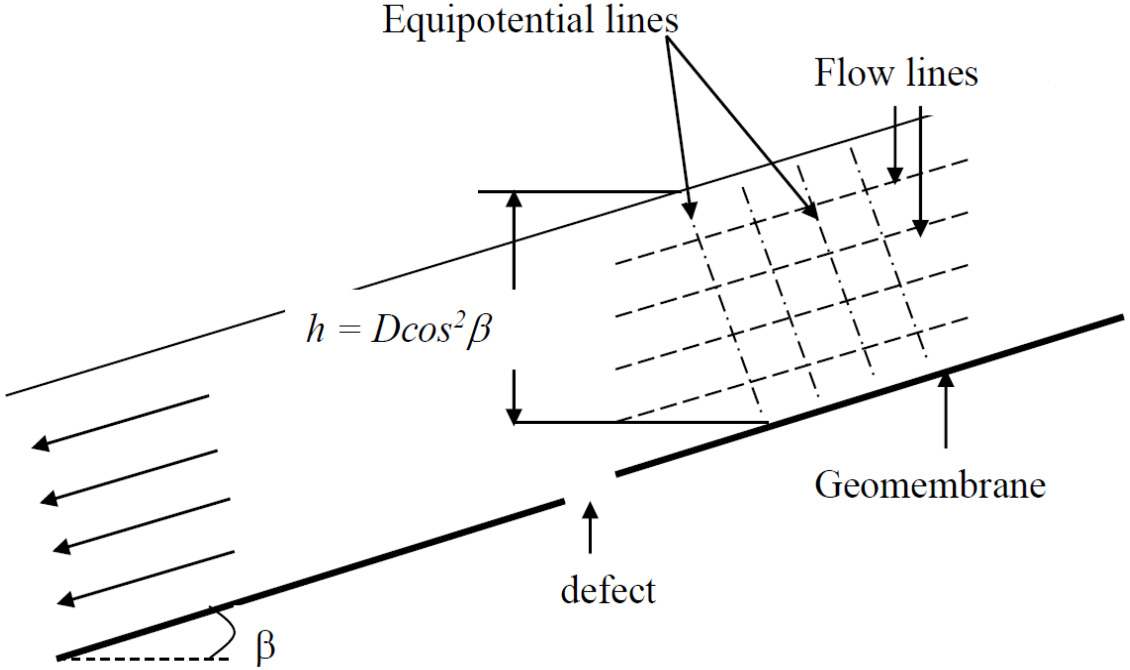
$$Q = 1.15 \cdot a^{0.1} \cdot h^{0.9} \cdot k_s^{0.74}$$

If the liquid is unconfined and flowing along a slope

$$h = D\cos^2 \beta$$

If hydrostatic prevails, $h = D$





ENVIRONMENTAL GEOTECHNICS MKAJ 1083

TOPIC 10: DESIGN OF LEACHATE COLLECTION SYSTEM

Dr Nor Zurairahetty Mohd Yunus

School of Civil Engineering, UTM

OPTIMIZING LEACHATE COLLECTION

- A network of perforated pipes is installed within the drainage layer to facilitate better drainage of landfill leachate
- To optimize leachate drainage and collection, the bottom of the landfill should be gently sloped where it can be effectively removed
- Leachate pipes are typically spaced 45-60 meters apart.
- Leachate drains from the landfill are funneled to a sump, from where it is extracted by a submersible pump.
- Such as side slope landfills, canyon fills, and above-ground mounds that require no excavation, gravity systems may offer a feasible alternative to the sump/pump extraction method.

HEAD (DEPTH) OF LEACHATE ABOVE LINER

1 For flat condition ($S = 0$),

$$y = \left(c\left(L^2 - x^2\right)\right)^{0.5}$$ and

The maximum value of y, y_{max} at x = 0

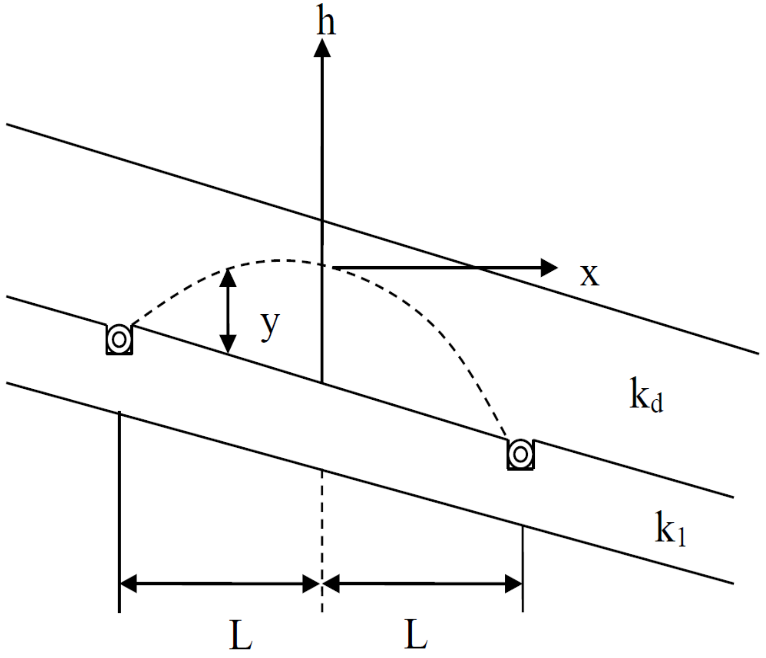
$$y_{\max} = L(c)^{0.5}$$

Where

$$c = \frac{e}{k_d}$$

2 For a liner with s slope

$$y_{\max} = L\left[\left(c + S^2\right)^{0.5} - S\right]$$



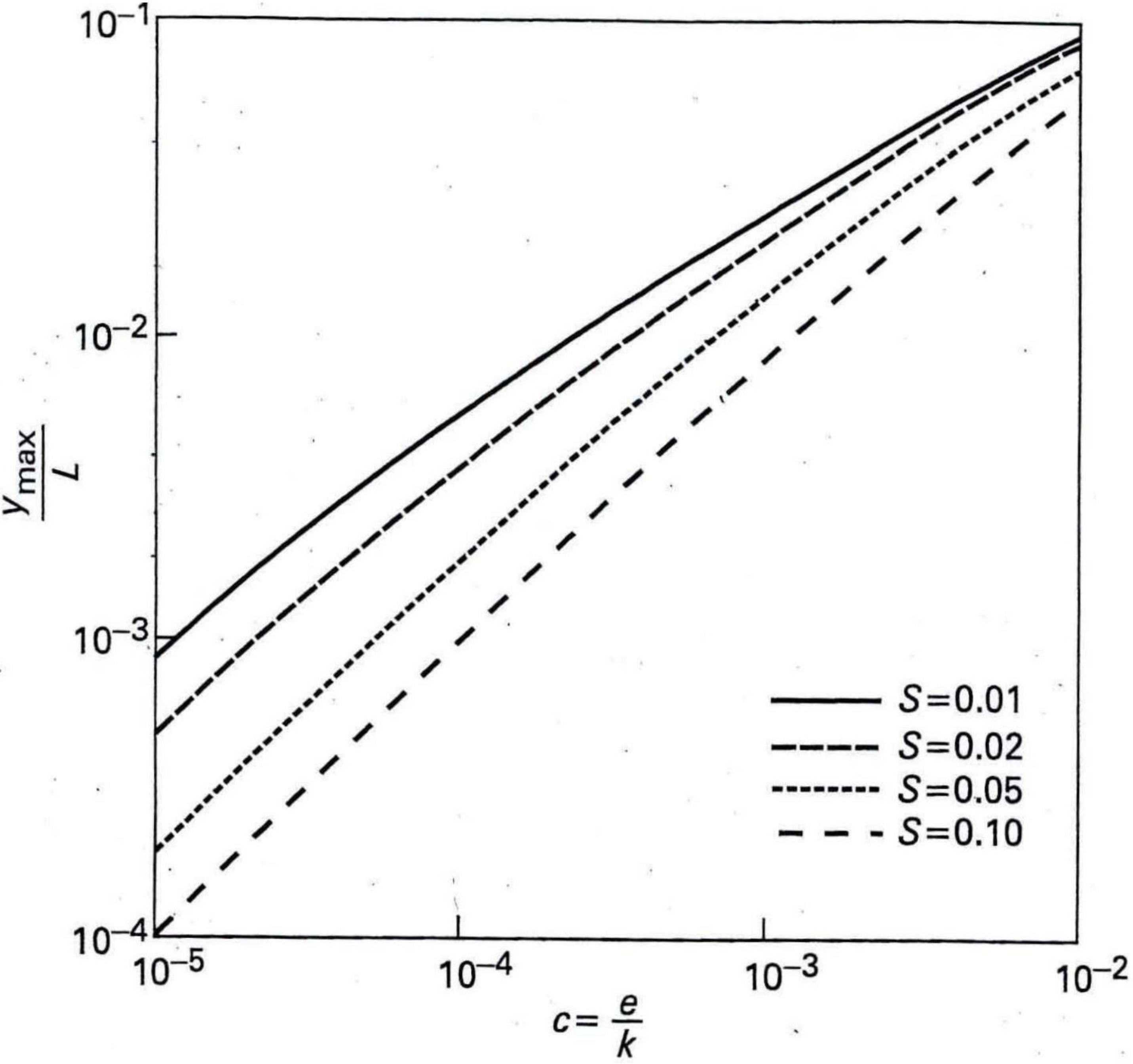


Figure 11.7 (from McEnroe in Oweis and Khera, 1998)

AVERAGE SATURATED DEPTH

$$\boxed{Q_d = 2C_1 k_d y_{av}\left(SL + y_o\right)/L^2}$$

Where

Q_d = lateral drainage rate per unit area of the liner

$y_o = ((y_{av})^{1.16})/(SL)^{0.16}$

= saturated depth above liner at x = 0 (crest of the drainage layer)

$C_1 = 0.51 + 0.00205SL$

y_{av} = average saturated depth

$(y_{max}/L) = 0.75c/SC_1$ (all dimensions in inches)

FLOW RATE OF THE PIPE

$$Q = (AR^{2/3}S^{1/2})/n$$

Where

Q = flow rate

A = cross-sectional area

R = wetted perimeter (hydraulic radius)

S = slope

n = Manning roughness coefficient

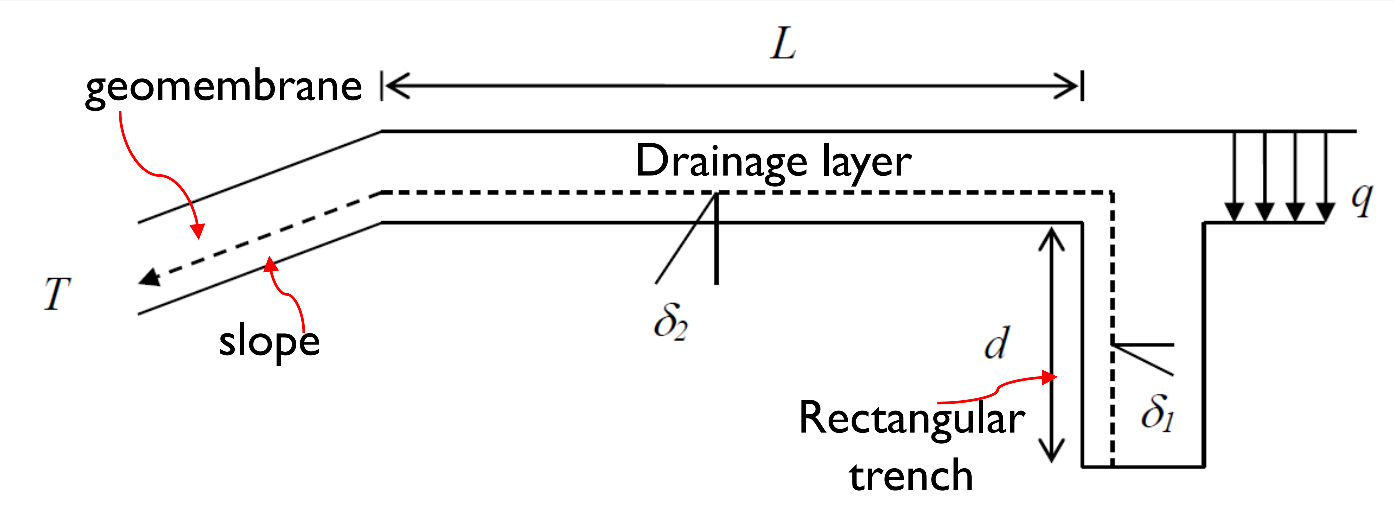
$$D = 0.237\left(Q/S^{0.5}\right)^{0.375}$$

ENVIRONMENTAL GEOTECHNICS
MKAJ 1083

TOPIC 11: DESIGN OF TRENCH

Dr Nor Zurairahetty Mohd Yunus
School of Civil Engineering, UTM

RECTANGULAR TRENCH



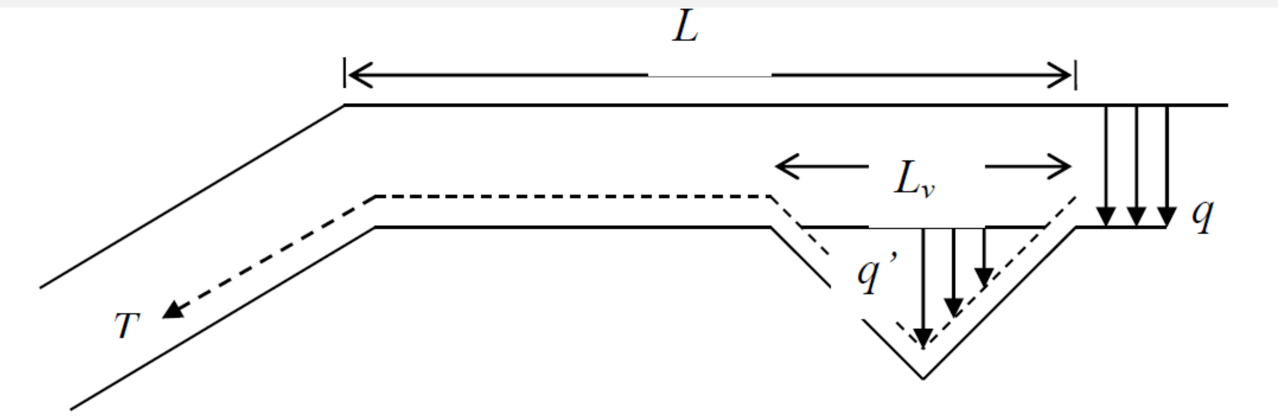
$$\tan\delta_1\left(0.5\gamma d^2+qd\right)\left(k_o+k_a\right)+qL\tan\delta_2+T\sin i\tan\delta_2=TF_s\cos i$$

Where

- F_s = safety factor
- L = runout length
- T = tension in geosynthetics
- δ_1 = friction angle between geosynthetic and soil in trench
- δ_2 = friction angle between geosynthetic and cover soil

- q = effective stress on top of the trench
- d = depth of embedment
- K_o = 1 – sin f
- $K_a = \tan^2 (45^\circ - \phi/2)$
- ϕ = friction angle of the embedment soil

ANCHOR TRENCH



$$\tan\delta_2\left[q\left(L-L_v+\frac{L_v}{\cos i'}\right)+\frac{q'L_v}{2\cos i'}\right]+T\sin i\tan\delta_2=TF_s\cos i$$

Where

i' = slope of the V trench

q' = the max stress at the base of the V trench due to the effective stress of the soil within the V portion

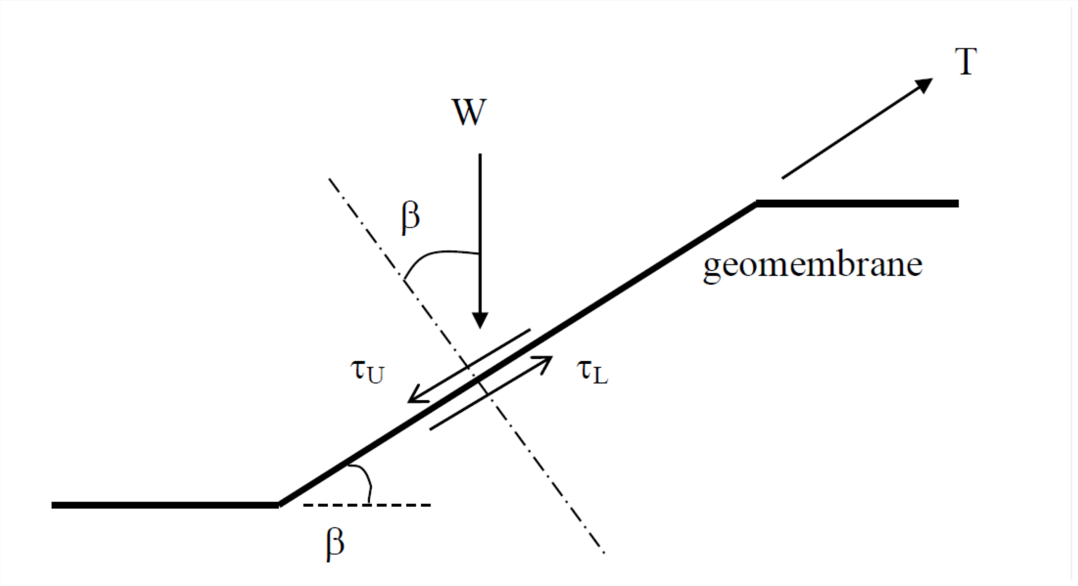
q = the effective stress due to the fill above the top of the V trench

ENVIRONMENTAL GEOTECHNICS MKAJ 1083

TOPIC 12: STRESSES IN GEOMEMBRANE

Dr Nor Zurairahetty Mohd Yunus
School of Civil Engineering, UTM

TENSION STRESS



$$\left(FS\right)_S = \frac{T \cdot w + \tau_L \cdot w \cdot L}{\tau_U \cdot w \cdot L}$$

- The shear stresses from the cover soil act downward on the underlying geomembrane and mobilize upward shear stresses beneath the geomembrane from the underlying soil.

- 3 different scenarios to be considered:

a) $\tau U = \tau L$

b) $\tau U < \tau L$ the balance of $\tau L - \tau U$ is not mobilized

c) $\tau U > \tau L$ the balance of $\tau U - \tau L$ must be carried by the geomembrane in tension.

where
T = tension per unit width in geomembrane, kN/m
w = width of geomembrane
L = length of geomembrane
β = slope angle, degree
τ*U* = shear stress between geomembrane and upper soil, kN/m2
τL = shear stress between geomembrane and lower soil, kN/m2

For case (iii), when $(FS)_s = 1$

$$\tau_U \cdot w \cdot L = T \cdot w + \tau_L \cdot w \cdot L$$

thus

$$T = \left(\tau_U - \tau_L\right) \cdot L = \tau_U \cdot L - \tau_L \cdot L = S_U - S_L$$

where

T = tension per unit width in geomembrane, kN/m

S_U = shear force per unit width between geomembrane and upper soil, kN/m

S_L = shear force per unit width between geomembrane and lower soil, kN/m

SHEAR FORCE

$$\boxed{S = c \cdot L + \gamma_s \cdot H \cdot L \cdot \cos\beta \cdot \tan\delta}$$

c = adhesion between geomembrane and adjacent material, kN/m^2

L = length of geomembrane

γ_s = unit weight of cover soil, kN/m^3

H = thickness of cover soil, m

β = slope angle, degree

δ = friction angle between geomembrane and adjacent material, degree

The mobilized unit shear resistance on the upper and lower surfaces of the membrane

$$S_U = c_{aU} \cdot L + \gamma_s \cdot H \cdot L \cdot \cos\beta \cdot \tan\delta_U$$

$$S_L = c_{aL} \cdot L + \gamma_s \cdot H \cdot L \cdot \cos\beta \cdot \tan\delta_L$$

$$\boxed{T_{reqd} = \left(S_U - S_L\right)}$$

THANK YOU FOR YOUR ATTENTION