PEARCE CREEK CONFINED DISPOSAL FACILITY MODIFICATIONS CECIL COUNTY, MARYLAND

LINER PRESENTATION - 20 MARCH 2015

Richard DePasquale, PE

- Civil Engineer

USACE, Philadelphia District
Engineering Branch,
Geotechnical Section

- Regional Technical Specialist for USACE North Atlantic Division (NE, NY, Phila., Baltimore, Norfolk, & Europe Districts)

- Engineer in Corps for 22 years

- BS & MS In Civil Engineering

US Army Corps of Engineers
BUILDING STRONG®

Site Map – Pearce Creek CDF

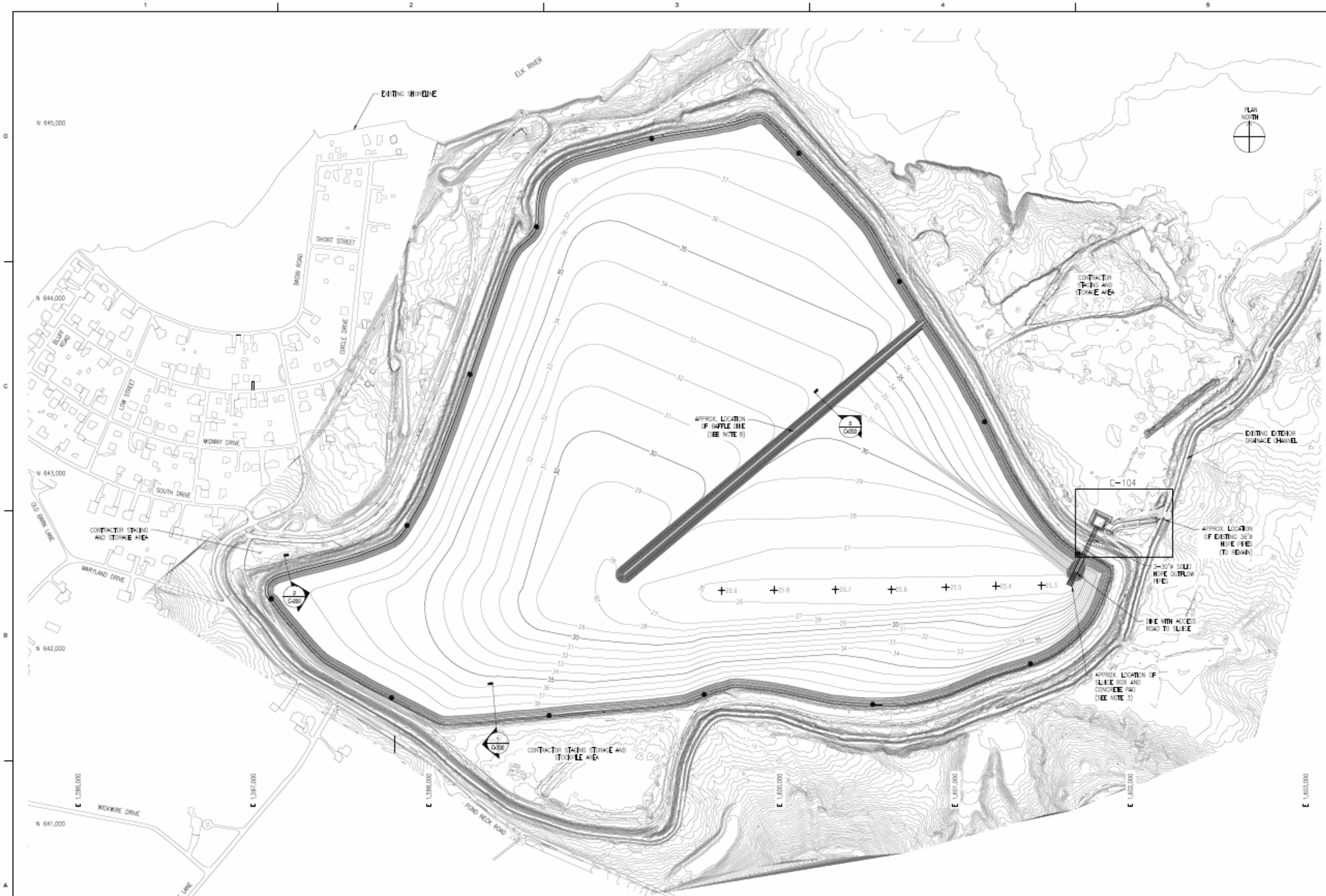
Confined Disposal Facility (CDF) – used to contain soil and water resulting from periodic dredging in the Elk River & Chesapeake Bay to maintain navigable depths.

PLANNED CDF MODIFICATIONS

- Install synthetic (plastic) liner over the CDF to isolate newly placed dredged material from the underlying aquifer.

Summary of Proposed Construction:

- Clear and grub existing vegetation within the CDF.
- Re-grade the existing perimeter dikes to El. 50 ft.
- Flatten interior slopes to 3H:1V to increase dike stability.
- Re-grade/compact the interior floor to better support the liner system.
- Install new steel sluice boxes and associated outlet works.
- Install thick cushioning fabric (a.k.a., geotextile) over the improved subgrade to protect liner from puncture.
- Install impervious polyethylene (plastic) liner.
- Install another thick cushioning fabric over the installed liner.
- Place 12 inches of protective fill over the liner.



1 PLAN - GRADING
SCALE: AS SHOWN

0 100 200 400
SCALE IN FEET

NOTES:

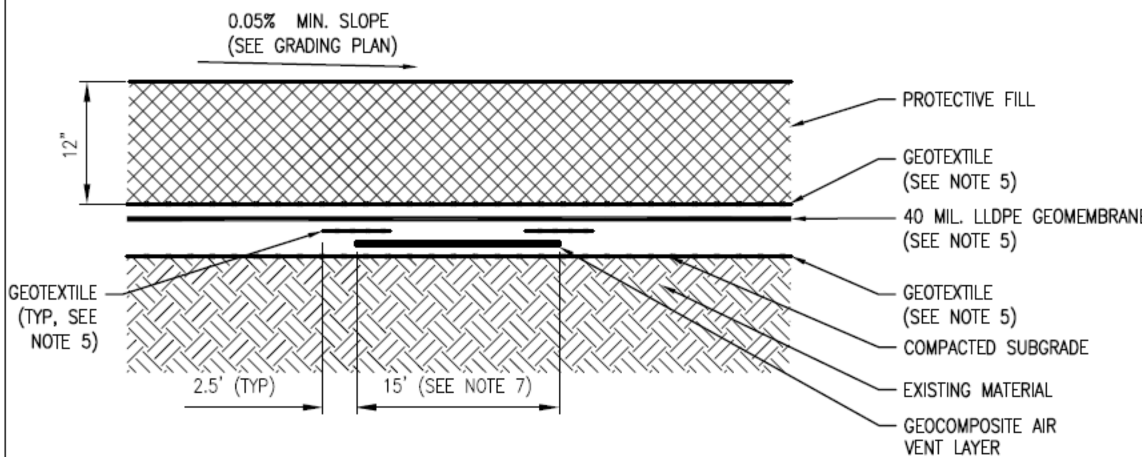
1. FOR GENERAL NOTES AND LEGEND, SEE SHEET C-001.
2. CONTOURS DEPICTED REPRESENT THE FINAL GRADE ELEVATIONS. FOR LOCATION OF LINER WITH RESPECT TO THE FINAL GRADE, SEE DETAILS ON SHEETS C-200 AND C-201.
3. SLUICE STRUCTURE WILL BE GOVERNMENT FURNISHED AND SHALL BE INSTALLED BY THE CONTRACTOR IN THE LOCATION SHOWN. FOR DETAILS OF SLUICE STRUCTURE TO BE INSTALLED, SEE REFERENCE DRAWING. FOR CONCRETE PAD DIMENSIONS AND SLUICE LAYOUT, SEE SHEET C-203.

US Army Corps of Engineers
Philadelphia District

U.S. ARMY CORPS OF ENGINEERS
PHILADELPHIA DISTRICT
PHILADELPHIA, PA

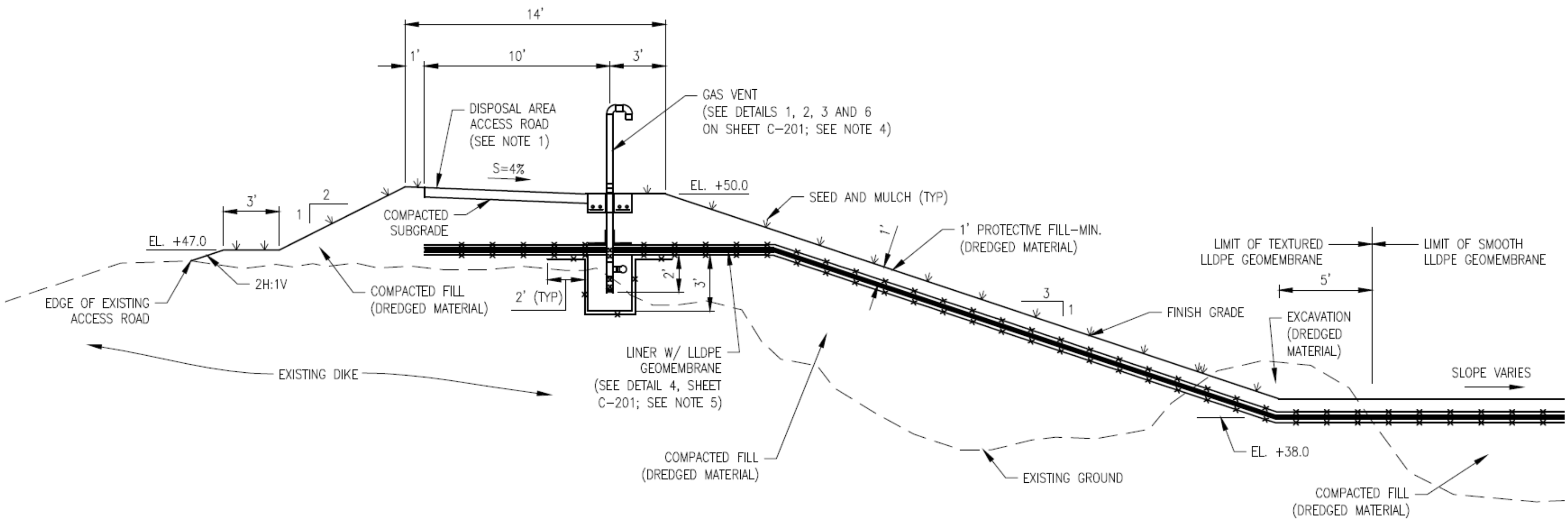
DELAWARE RIVER TO CHESAPEAKE BAY
DELAWARE AND MARYLAND
PEARCE CREEK CONFINED DISPOSAL FACILITY
MODIFICATIONS
GRADING PLAN

SHEET NUMBER
C-103



TYPICAL LINER DETAIL

N.T.S.



1 DETAIL - TYPICAL PERIMETER DIKE SECTION WITH TOP OF EXISTING DIKE BELOW EL. +47.0

SCALE: AS SHOWN

Geosynthetic Materials To Be Used In CDF Liner System

- geotextile (thick felt)
- geomembrane (a.k.a., liner)
- geogrid (thick plastic netting)
- geonet (for air flow)

Do not degrade when covered since they’re plastic


GEOTEXTILES

Geotextile

- a thick felt
- made from polypropylene (plastic) fibers using standard textile manufacturing methods
- nonwoven needle-punched, weighing 10 oz./sy
- will protect/cushion the geomembrane
- allows any air trapped under the liner to flow to the perimeter dikes


GEOMEMBRANES

Geomembrane

- thick impermeable plastic barrier to liquids and gases
- many types: HDPE, LLDPE, fPP, PVC, EPDM, etc.
- we've selected LLDPE (linear low density polyethylene) type since it is very durable and can handle excessive stretching resulting from any settling of the CDF subgrade floor.
- 40 mil (0.040 inch) thick = 1.0 mm thick
- manufactured rolls are field seamed in 22'-wide panels
- same material used to line landfills and surface impoundments (e.g., reservoirs and ponds)

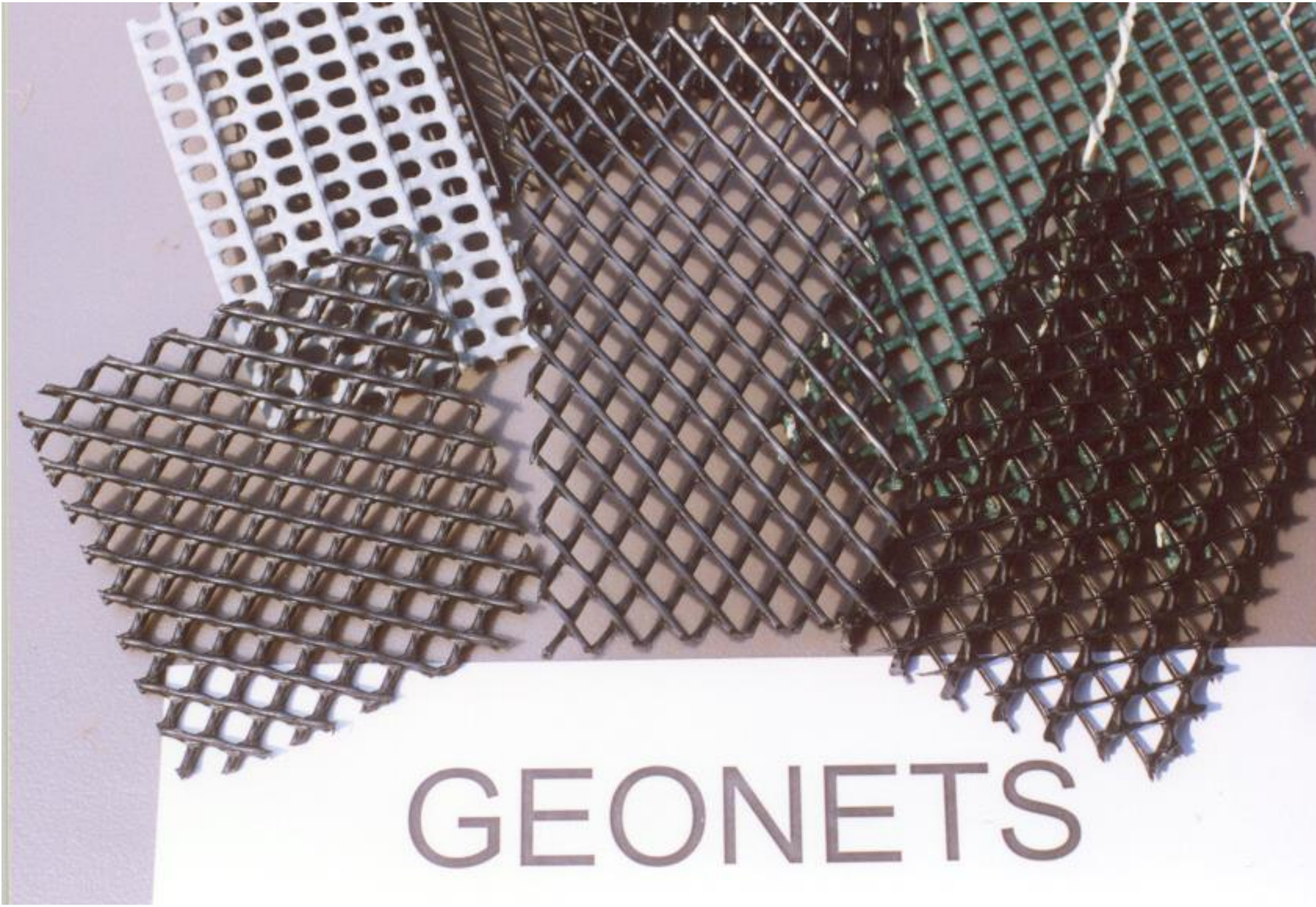
Seaming Geomembrane

Dual track thermal fusion weld.


GEOGRIDS

Geogrid

- made of polypropylene (plastic) manufactured in a grid pattern
- bidirectional – equal strength in both directions
- spreads load out like a snow shoe
- will reinforce ground under the new sluice boxes and outlet pipes


GEONETS

Geonet

- made from high density polyethylene (plastic)
- allows any air trapped under the liner to flow to the perimeter dikes
- function is to increase in-plane air flow under liner
- geonet has geotextile attached to top and bottom

Summary of Geosynthetics

- Geosynthetics are engineering materials that have been in use for decades in similar applications.
- Field performance has been excellent.
- Products must be accompanied by rigorous CQC/CQA – only as good as the installation.
- Stringent project installation specifications will ensure a high quality installation.
- Extensive field and laboratory testing will also be performed during construction to ensure all quality requirements are met (e.g., geomembrane strength and thickness, seam strength and integrity) .
- Extensive engineering calculations were performed to ensure that the appropriate materials were selected considering site conditions and future use.

Overview of Calculations

1. Determine Geomembrane Thickness

Problem: Determine the required thickness of a smooth, linear low density polyethylene (LLDPE) geomembrane (a.k.a., liner) beneath the final (closure) thickness of dredged material in the Pearce Creek confined disposal facility (CDF).

Procedure: Follow the procedure in Koerner's *Designing with Geosynthetics*, 6th edition, Vol. 2, Section 5.6.6, pp. 643-644, except where otherwise noted. The main equation is listed below:

$$t = \frac{\sigma_n x(\tan\delta_U + \tan\delta_L)}{\sigma_{allow}(\cos\beta - \sin\beta\tan\delta_L)}, \qquad \textit{Equation } 5.18$$

Equation 5.18[1]

where

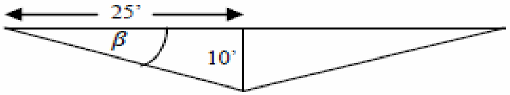
t	= thickness of the geomembrane,
σ_n	= applied stress from the dredged materials,
x	= distance of mobilized geomembrane deformation,
δ_U	= angle of shearing resistance between geomembrane and upper material,
δ_L	= angle of shearing resistance between geomembrane and lower material,
σ_{allow}	= allowable geomembrane stress, and
β	= settlement angle mobilizing the geomembrane tension.

To compute the maximum loading that will act on the liner at the closure of the CDF, subtract the liner's low point elevation at the sluice from the proposed final CDF elevation:

El. +68' (highest future elev.) - El. +28' (liner low point at sluice) = 40' thickness. Therefore,

$$\sigma_n = 100\,pcf * 40' = 4{,}000\,psf \approx 192\,kPa$$

To estimate β, consider a worst case scenario of maximum settlement over a small area, i.e., a 10' localized depression (more conservative than estimated in settlement analyses) over a 50' diameter area (radius = 25'):



$$tan\beta = \frac{10}{25};\ \beta = 22°$$

To estimate $\delta_U = \delta_L$, assume a non-woven needle punched geotextile is over and under the LLDPE geomembrane:

$$\delta_U = \delta_L = 8°, \qquad \textit{Table 5.6b}^{2}$$

To estimate x, use σ_n calculated above ($192\ kPa$) and refer to Figure 5.10a from the cited reference. Interpolate between the two curves to estimate x for a 1.0 mm (40 mil) HDPE geomembrane. It was assumed that the HDPE graph is most applicable to the proposed LLDPE.

$$x \approx 150\ mm, \qquad \textit{Figure 5.10a}^{3}$$

$$\sigma_{allow} = 10{,}000\ kPa, \qquad \textit{Figure 5.5}^{4}$$

Thus,

$$t_{req} = \frac{(192\ kPa)(0.150\ m)(\tan(8) + \tan(8))}{(10{,}000\ kPa)(\cos(22) - \sin(22)\tan(8))} = 0.00092m = \mathbf{0.92\ mm}$$

<u>Results</u>:

Since the actual thickness of the proposed 40 mil LLDPE geomembrane is greater than the required thickness (i.e., t_{act} = 1.0 mm > t_{req} = 0.9mm), the proposed geomembrane thickness is ***ACCEPTABLE***.

2. Check Geomembrane Strain

$$\varepsilon(\%) = \left\{ \frac{\tan^{-1}\left[\left(\frac{4L\delta}{L^2 - 4\delta^2}\right)\right]\left(\frac{L^2 + 4\delta^2}{4\delta}\right) - L}{L} \right\} \times 100, \qquad Equation\ 5.5^5$$

where

L	= diameter of interest (mm), and
δ	= centerpoint deflection (mm).

For maximum loading, assume:

$$L = 50\,ft = 15{,}240\,mm$$
$$\delta = 10\,ft = 3{,}048\,mm$$

This is the same worst case scenario of maximum settlement that was assumed in Geomembrane Calculation #1. Note that the true calculated settlement is about 6.5 feet, so $\delta = 10\,ft$ assumed above overestimates settlement by about 35%.

Thus,

$$\varepsilon(\%) = \left\{ \frac{\tan^{-1}\left[\left(\frac{4(15{,}240\,mm)(3{,}048\,mm)}{(15{,}240\,mm)^2 - 4(3{,}048\,mm)^2}\right)\right]\left(\frac{(15{,}240\,mm)^2 + 4(3{,}048\,mm)^2}{4(3{,}048\,mm)}\right) - 15{,}240\,mm}{15{,}240\,mm} \right\} \times 100$$

$$= \mathbf{10.3\%} < 70\%\ \ for\ LLDPE, thus\ \boldsymbol{ACCEPTABLE}$$

Note: Allowable strain, $\varepsilon_{allow}(\%)$ for 40 mil LLDPE is from Figure 5.5[6]

3. Determine Runout/Anchor Trench Length

Calculate length of geomembrane runout needed with no anchor trench used.

$$L_{RO} = \frac{T_{allow}(\cos\beta - \sin\beta\tan\delta_L)}{\sigma_n(\tan\delta_U + \tan\delta_L)}, \qquad \textit{Equation } 5.26^7$$

where

T_{allow} = allowable force in geomembrane = $\sigma_{allow}t$, where
σ_{allow} = allowable stress in geomembrane, and
t = thickness of the geomembrane;
δ_U = angle of shearing resistance between geomembrane and upper material,
δ_L = angle of shearing resistance between geomembrane and lower material,
σ_n = applied normal stress from cover soil, and
β = side slope angle.

Under maximum loading conditions:

$$t = 1.0\ mm$$
$$\beta = 3{:}1 = 18.43°$$
$$\delta_U = 0$$
$$\delta_L = 32°, \qquad \textit{From Table } 5.6b^8$$
$$\sigma_{allow} = 5{,}000\ kPa, \qquad \textit{Example } 5.13^9$$
$$\sigma_n = (115\ pcf)(3\ ft) \approx 16.5\ kPa$$
$$T_{allow} = \sigma_{allow} * t = 5{,}000(0.001\ m) = 5.0\ kN/m$$

Thus,

$$L_{RO} = \frac{(5.0)(\cos(18.4) - \sin(18.4)\tan(32))}{(16.5\ kPa)(\tan(0) + \tan(32))} = 0.36\ m = 1.2\ ft$$

$$\approx \mathbf{1.2\ ft} < 10\ ft\ actual\ runout, \boldsymbol{ACCEPTABLE}$$

4. Check Side Slope Cover Stability – Finite Slope

$$W_A = \gamma h^2 \left(\frac{L}{h} - \frac{1}{\sin\beta} - \frac{\tan\beta}{2}\right), \qquad \textit{Equation } 3.15^{10}$$

$$N_A = W_A \cos\beta, \qquad \textit{Equation } 3.16^{11}$$

$$W_P = \frac{\gamma h^2}{\sin 2\beta}, \qquad \textit{Equation } 3.18^{12}$$

$$a = (W_A - N_A \cos\beta)\cos\beta, \qquad \textit{Equation } 3.22^{13}$$

$$b = -[(W_A - N_A \cos\beta)\sin\beta \tan\Phi$$
$$+(N_A \tan\delta + C_A)\sin\beta\cos\beta + \sin\beta\,(C + W_P \tan\Phi)], \qquad \textit{Equation } 3.23^{14}$$

$$c = (N_A \tan\delta + C_A)\sin^2\beta \tan\Phi\,, \qquad \textit{Equation } 3.24^{15}$$

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \qquad \textit{Equation } 3.25^{16}$$

where,

γ = unit weight of cover soil,
h = thickness of cover soil,
β = soil slope angle beneath geomembrane,
Φ = friction angle of cover soil,
C_A = adhesion force between cover soil of the active wedge and geomembrane

For:

$$\gamma = 100\ pcf$$
$$h = 1\ foot$$
$$\beta = 3{:}1\ slope \approx 18.4^\circ$$
$$\Phi = 25^\circ$$
$$C_A \approx 0$$

Consider L = 38 ft

$$W_A = (100\ pcf)(1\ ft)^2\left(\frac{38\ ft}{1\ ft} - \frac{1}{\sin(18.4)} - \frac{\tan(18.4)}{2}\right) = 3{,}466\ \frac{lbs}{ft}$$

$$N_A = \left(3{,}466\frac{lbs}{ft}\right)\cos 18.4 = 3{,}289\frac{lbs}{ft}$$

$$W_P = \frac{(100\ pcf)(1\ ft)^2}{\sin 2(18.4)} = 167\frac{lbs}{ft}$$

$$a = \left(\left(3{,}466\frac{lbs}{ft}\right) - \left(3{,}289\frac{lbs}{ft}\right)\cos 18.4\right)\cos 18.4 = 327\frac{lbs}{ft}$$

$$b = -\left[\left(\left(3{,}466\frac{lbs}{ft}\right) - \left(3{,}289\frac{lbs}{ft}\right)\cos 18.4\right)\sin(18.4)\tan(25) + \left(\left(3{,}289\frac{lbs}{ft}\right)\tan 25 + 0\right)\sin(18.4)\cos(18.4) + \sin(18.4)\left(0 + \left(167\frac{lbs}{ft}\right)\tan 25\right)\right] = -535\frac{lbs}{ft}$$

$$c = \left(\left(3{,}289\frac{lbs}{ft}\right)\tan 25 + 0\right)\sin^2(18.4)\tan(25) = 71\frac{lbs}{ft}$$

$$FS = \frac{-\left(-535\frac{lbs}{ft}\right) + \sqrt{\left(-535\frac{lbs}{ft}\right)^2 - 4\left(327\frac{lbs}{ft}\right)\left(71\frac{lbs}{ft}\right)}}{2\left(327\frac{lbs}{ft}\right)} = \mathbf{1.49}$$

Check L = 90 ft (Note: longest design slope length is about 60', so this calculation is conservative.)

$$W_A = (100\ pcf)(1\ ft)^2\left(\frac{90\ ft}{1\ ft} - \frac{1}{\sin(18.4)} - \frac{\tan(18.4)}{2}\right) = 8{,}667\ \frac{lbs}{ft}$$

$$N_A = \left(8{,}667\frac{lbs}{ft}\right)\cos 18.4 = 8{,}223\frac{lbs}{ft}$$

$$W_P = \frac{(100\ pcf)(1\ ft)^2}{\sin 2(18.4)} = 167\frac{lbs}{ft}$$

$$a = \left(\left(8{,}667\frac{lbs}{ft}\right) - \left(8{,}223\frac{lbs}{ft}\right)\cos 18.4\right)\cos 18.4 = 820\frac{lbs}{ft}$$

$$b = -\left[\left(\left(8{,}667\frac{lbs}{ft}\right) - \left(8{,}223\frac{lbs}{ft}\right)\cos 18.4\right)\sin(18.4)\tan(25) + \left(\left(8{,}223\frac{lbs}{ft}\right)\tan 25 + 0\right)\sin(18.4)\cos(18.4) + \sin(18.4)\left(0 + \left(167\frac{lbs}{ft}\right)\tan 25\right)\right] = -1{,}300\frac{lbs}{ft}$$

$$c = \left(\left(8{,}223\frac{lbs}{ft}\right)\tan 25 + 0\right)\sin^2(18.4)\tan(25) = 382\frac{lbs}{ft}$$

$$FS = \frac{-\left(-1{,}300\frac{lbs}{ft}\right) + \sqrt{\left(-1{,}300\frac{lbs}{ft}\right)^2 - 4\left(820\frac{lbs}{ft}\right)\left(382\frac{lbs}{ft}\right)}}{2\left(820\frac{lbs}{ft}\right)} = \mathbf{1.19}$$

6. Check Geomembrane Puncture Resistance

Problem: Determine the required geotextile mass per unit area to protect the proposed linear low density polyethylene (LLDPE) geomembrane (a.k.a., liner) from puncture from aggregate in either the subgrade below the liner or cover soil above the liner. Analysis assumes the final height of dredged material at closure.

Procedure: Follow the procedure in Koerner's *Designing with Geosynthetics*, 6th edition, Vol. 2, Section 5.6.7, pp. 645-648. The main equations are listed below:

Equation 5.33:

$FS = \frac{p_{allow}}{p_{act}}$, where:

FS= factor of safety (against geomembrane puncture); FS = 3 is required per Koerner,
p_{act} = required pressure due to the landfill (dredged material) contents, and
p_{allow} = allowable pressure using different types of geotextiles and site-specific conditions.

Equation 5.34:

$$p_{allow} = \left(50 + 0.00045\frac{M}{H^2}\right)\left[\frac{1}{MF_S \times MF_{PD} \times MF_A}\right]\left[\frac{1}{RF_{CR} \times RF_{CBD}}\right]$$

p_{allow} = allowable pressure (kPa),
M = geotextile mass per unit area (g/m2),
H = protrusion height (m),
MF_S = modification factor for protrusion shape,
MF_{PD} = modification factor for packing density,
MF_A = modification factor for arching in soils,
RF_{CR} = reduction factor for long-term creep, and
RF_{CBD} = reduction factor for long-term chemical/biological degradation.

Assumptions:

- Subgrade/cover soil: trace to little rounded coarse aggregate in a clayey silt matrix (conservative, as aggregate content will likely be no to trace since specifications require that borrow to be used for the 12"-thick protective cover layer be obtained from the lower half of the CDF, which is predominately fine-grained, i.e., all coarse aggregate dropped out of suspension near the dredge pipe discharging into the CDF).
- Coarse aggregate: rounded to sub-rounded with max. size aggregate = d_{100} = 1.5" = 38 mm.
- Final CDF thickness at closure: El. +68' (highest future elev.) - El. +28' (liner low point at sluice) = 40' thickness = 12.2 m.
- Geomembrane is a 40 mil (1.0 mm) smooth LLDPE on the CDF floor.
- Dredged material total unit weight = 100 pcf = 100*0.1572 = 15.72 kN/m^3.

Solution:

- Use H = protrusion height (m) = 25 mm = 0.025m, which is an estimate since the gravel particles will not be isolated, but adjacent to one another. Also, the project specifications will require that the subgrade be smooth drum rolled and will restrict the maximum protrusion height to ½-inch. Additionally, GSE's *Geomembrane Protection Design Manual*, 2002, pg. 2-1 recommends that "for the case of grouped particles, the effective protrusion height, H', is approximated as half of the maximum particle size." The USACE conservatively assumed H was equal to 2/3 the maximum particle size (i.e., 2/3 x 38mm = 25mm).
- MF_S = 0.5 for shape (sub-rounded); 0.25 could have been used as gravel is typically rounded.
- MF_{PD} = 0.67 for dense, 25mm.
- MF_A = 0.50 for arching.
- RF_{CR} = 1.5 for creep.
- RF_{CBD} = 1.0 for long-term degradation – no leachate issue as CDF water is essentially clean.

Now calculate the value of p_{allow} using equation 5.33.

$FS = p_{allow}/p_{act}$
$3.0 = p_{allow}/(12.2\text{m}*15.72\text{kN/m}^3)$; $3.0 = p_{allow}/(192\ \text{kN/m}^2)$
$p_{allow} = 576\ \text{kN/m}^2$

Then calculate the required mass per unit area of the geotextile using equation 5.34.
All modification and reduction values are taken from Table 5.16, pg. 646.
Note that the isolated value of 50kPa in the equation below represents the puncture resistance of a 1.5mm (60 mil) HDPE geomembrane by itself. For a 40 mil LLDPE, the puncture resistance is proportionally less. Estimate proportional reduction as 250N/480N ~= 50% using ASTM D 4833 puncture values for 40 mil LLDPE / 60 mil HDPE, respectively.

$$p_{allow} = \left((0.50 * 50) + 0.00045 \frac{M \frac{g}{m^2}}{(0.025\ m)^2}\right)\left[\frac{1}{0.50 \times 0.67 \times 0.50}\right]\left[\frac{1}{1.5 \times 1.0}\right]$$

$p_{allow} = 576\ \text{kN/m}^2$ from solved equation 5.33, above. Now solve for M.

$576 = (25+0.72M)(5.97)(0.67)$;
$144 = (25+0.72M)$;
$119 = 0.72M$.

$M_{req} = 165\ \text{g/m}^2$; $165\ \text{g/m}^2 \times 0.0294935$ oz./sy = 5 oz./sy.

Results:

The project's proposed geotextile is specified as a 10 ounce/square yard nonwoven needle-punched, which is greater than the calculated M_{req} of 5 oz./sy. Therefore, the geotextile/geomembrane design is ***ACCEPTABLE*** considering puncture criteria.

7. Check Geotextile Venting Capacity

Problem: Determine the factor-of-safety (FS) provided by a 10 oz/sy nonwoven geotextile to vent any gases trapped below the geomembrane via the geotextile's transmissivity (lateral flow capacity).

Procedure: Follow the procedure in Koerner's *Designing with Geosynthetics*, 6th edition, Vol. 2, Section 5.3.2, pp. 570-573.

Assumptions:

$$Gas\ Generation = 0.10\ m^3/m^2 day\ \ at\ a\ pressure\ of\ 7.0\ kPa$$

(from Example 5.7; conservative, not likely to be this high)

$$Density\ of\ moist\ air = \gamma_{moist\ air} = 0.0118\frac{kN}{m^3}$$

Procedure:

(a) Gas flow rate:

$$q = 0.10\left(\frac{1000}{2} x\ 1\right) = 50\frac{m^3}{day} = 3.47 \times 10^{-2}\ \frac{m^3}{min}$$

(b) Air gradient, assuming a uniform distribution is 7.0 kPa acting at the center to zero at the edge is:

$$i = \frac{\Delta P/\gamma_{air}}{L/2}$$

$$i = \frac{7.0/0.0118}{1000/2} = 1.19$$

(c) Determine the required transmissivity in the geotextile, θ_{req}

$$q = kiA$$

$$q = ki(t \times W)$$

$$kt = \theta_{req} = \frac{q}{i \times W}$$

$$\theta_{req} = \frac{3.47 \times 10^{-2}}{(1.19)(1.0)}$$

$$\theta_{req} = 2.92 \times 10^{-2}\ m^3/m - m$$

(d) Determine the transmissivity, θ_{allow}, of a 10 oz/sy (339 g/m^2) nonwoven geotextile with 50 feet of soil cover at the end of the CDF use. Note that 50-foot total fill thickness is conservative, as the final fill height will be about 35 feet.

$$Normal\ stress = \gamma_T = 50' \times 100pcf = 5{,}000\ psf$$

$$5{,}000\ psf \times \frac{0.04788kPa}{psf} = \sim 240\ kPa.$$

The transmissivity of a 16 oz/sy (550 g/m^2) geotextile can be estimated from Koerner 6th Ed. Vol. 1, Fig. 2.17a, pg. 154 by extrapolating to a normal stress of 240 kPa.

$$\theta_{allow-16\ oz} = 0.14\ m^3/m - m$$

This value is then factored for a 10 oz/sy geotextile as follows:

$$\theta_{allow-10\ oz} = 0.14\ m^3/m - m\ \times 10/16$$

$$\theta_{allow-10\ oz} = 0.088\ m^3/m - m$$

(e) The actual factor of safety (FS) is as follows:

$$FS = \frac{\theta_{allow}}{\theta_{reqd}}$$

$$FS = \frac{0.088}{2.92 \times 10^{-2}}$$

$$FS = 3$$

<u>Results:</u>

The proposed 10 oz/sy nonwoven geotextile has 3 times the required capacity to vent any trapped gases under the geomembrane, which is *ACCEPTABLE*.

To increase this FS even more, a geocomposite sheet drain will be used to augment the geotextile flow. A geocomposite is a plastic geonet with geotextile attached to the upper and lower surfaces. Two panels of geocomposite will be installed down the middle of the CDF, and will be perpendicular to each other (partitioning the CDF into quarters). By doing this, the FS increases to 19, which is a significant increase for a nominal cost.

Thank You

Questions?