Closure Design and Construction of Contaminated Soft Sludge Lagoons:
A Tale of Innovation, Poor Field Execution and Final Redemption

PURDUE GEOTECHNICAL SOCIETY

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Located in the Shenandoah valley (62 miles west of DC)
A LITTLE HISTORY...

America's first rayon plant
established in 1910 and still going strong!

American Viscose Corporation
America's largest producer of rayon
Marcus Hook, PA.
ONCE UPON A TIME…

Plant built in 1937
AVTEX FIBERS

Manufacturing Era (1940 - 1989)

Age of Rayon - Manufacturing Process & History

Manufacturing Lifestyle

Rayon's Many Uses - Defense Industry and Everyday Objects

Plant Construction and Periods of Ownership

Norfolk and Western Railroad

www.avtextfibers.com
Ingredients:
• Caustic soda
• Sulfuric acid
• Carbon disulfide
PRODUCE SOME MORE…
ET VOILÀ (1990’s)…
Fly ash was recommended to close the lagoon (260,000 m³)
• Leave in place and cap 5 sulfate sludge basins (~50 acres)

• Capping implied: 4 ft – 10 ft surcharge
• Perm $10^{-7}$ to $10^{-8}$ cm/s
• Unit Weight: 10 pcf to 50 pcf
• Moisture Content: 90% to 800%
• Shear Strength: 10 psf to 100 psf
An average person weighs 180 lb
Average shoe size: 10 (~ 0.75 ft$^2$)
Use fly ash as grading fill
Place soil-geomembrane cap on the top

Surplus of fly ash available on site (240,000 m³)
THE $1M QUESTION IS:

How to over build a 10 PSF soft sludge lagoon?
**LAGOON TO BE STABILIZED**
*(SOFT SLUDGE)*

A. Lagoon Filled with Soft Sludge
<table>
<thead>
<tr>
<th>A. Lagoon Filled with Soft Sludge</th>
<th>B. Install Geotextile over Lagoon and Place Stabilizing Berms</th>
</tr>
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</table>

**Construction Sequence**

- **A.** Lagoon Filled with Soft Sludge
- **B.** Install Geotextile over Lagoon and Place Stabilizing Berms
A. Lagoon Filled with Soft Sludge

B. Install Geotextile over Lagoon and Place Stabilizing Berm

C. Construct Intermediate Berms
Construction involves a step-wise procedure to be followed in the field.

A. Lagoon Filled with Soft Sludge

B. Install Geotextile over Lagoon and Place Stabilizing Berm

C. Construct Intermediate Berms

D. Widen Intermediate Berms
CLOSURE METHOD

- STABILIZING BERM
- HIGH STRENGTH GEOTEXTILE
- LOCKING BERM
- INTERMEDIATE BERM

SOFT SLUDGE
Excerpts from Page 23:

For the tensile forces $F_1$ and $F_2$ in the fabric to be equal then $\epsilon_1 = \epsilon_2$ and $\Delta h_1/l_1 = \Delta h_2/l_2$. Thus the axial strain in the fabric will depend only on the ratio $\Delta h_1/l_1$ and $\Delta h_2/l_2$. If, for example, $l_2 = 5l_1$ then $\Delta h_2 = 5\Delta h_1$ so that $F_1 = F_2$. The heave will in this case be five times larger than the settlement within the loaded area for the force in the fabric to be constant ($F_1 = F_2$).

Hypothesis:

\[
\frac{\Delta h_1}{l_1} = \frac{\Delta h_2}{l_2}
\]

For example:

\[
l_2 = 5l_1
\]
\[
\Delta h_2 = 5\Delta h_1
\]

\[
l_1 = 10\text{ft}; \quad l_2 = 5(10\text{ft}) = 50\text{ft}
\]
\[
\Delta h_1 = 1\text{ft}; \quad \Delta h_2 = 5(1\text{ft}) = 5\text{ft}
\]
NEW APPROACH (2000)!

CE68901

CE48300

MA161000

Whoa.
Bearin Capacity Analysis
Ultimate Reinforced Bearing Capacity of Soil, $q_{ur}$
(Membrane Effect from High Strength Geotextile)

$$q_{ur} = cN_c + q_{gb} + q_{gh}$$
\[ q_{ur} = c \ N_c + q_{gb} + q_{gh} \]

\[ q_{gb} = \frac{J}{L_b} \int_{-L_b/2}^{L_b/2} \varepsilon(x) \left[ 1 + f'(x)^2 \right]^{-1/2} f''(x) \, dx \]

\[ q_{gh} = \frac{2J}{L_c} \int_{L_b/2}^{L_b/2+L_h/2} \varepsilon(x) \left[ 1 + f'(x)^2 \right]^{-1/2} f''(x) \, dx \]

Data required: Modulus \( J \) and shape of deformation \( f(x) \)

Reference: Espinoza and Sabatini (2008), Geosynthetics International
Deformed shape approximated by parabolas (Giroud and Noirey, 1981)

\[
\lambda_q = \frac{q_{\text{avg}}}{(2J/L_b)} = \varepsilon_{\text{avg}} \left[ \ln(\tan \beta_b + \sec \beta_b) + \frac{1}{\rho} \ln(\tan \beta_h + \sec \beta_h) \right]
\]

\[
q_{\text{avg}} = q_{gb} + q_{gh}
\]

\[
\varepsilon_{\text{avg}} = \frac{\varepsilon_{gb} + \rho \varepsilon_{gh}}{1 + \rho}
\]

\[
\rho = \frac{L_h}{L_b}
\]
Using this chart, the effect of geotextile contribution can be quantified.
Sludge Thickness = 0.3m
Undrained shear strength = 0.5 kPa
Equipment CAT D3C-LGP-5IIL = 29.6 kPa

\[ q_u = c N_c = 0.5 \times 5.14 = 2.5 \text{kPa} \]

\[ FS = \frac{q_u}{q_{equipment}} = \frac{2.5}{29.6} = 0.08 \ll 1.0 \]

For Berm Deflection
- \( r_b = 0.45 \text{m} \)
- \( L_h = 8.0 \text{ m} \)
- \( L_b = 2.7 \text{ m} \)

\[ \frac{L_h}{L_b} = 3.0, \frac{r_b}{L_b} = 0.17 \]
Calculating factors using the proposed chart

Membrane Contribution \( \lambda = \frac{q_r}{2J/L_b} \)

Rutting Factor \( r_b/L_b \)

Geosynthetic Contribution

With \( \varepsilon = 1.9\% \) and \( q_r = 27.1 \text{ kN/m} \) then \( J = 2540 \text{ kN/m} \)

Working tensile strength = \( (2,540 \text{ kN/m}) \times 1.9\% = 48.25 \text{ kN/m} \)

For FS =2, \( \varepsilon_u = 3.8\% \), \( T_u = 96.5 \text{ kN/m} \)
• Develop construction details

• Specifications
  • High strength geotextile \( (T_u = 96.5 \text{ kN/m and } \varepsilon_u = 3.8\%)\)
  • Sequence of construction
  • Equipment (D5G-LGP)
Fill Placement to slow and time consuming

Specified Equipment (e.g., D5H-LGP) too small for production
Use large equipment to push fly ash over sludge to “save” the cost of geotextile and construction time.

(2002-2008)
After all it is just a dirt job...

Crust Displacement

Mixing lots of fill with sludge
9 Years later (2009)…

- **Fly Ash Stockpile (500,000 m³)**
- **Remaining 100,000 m³**
- **Used 400,000 m³**
- **Sludge Basins (21 hectares)**
- **Remaining 9 hectares**
- **Closed 12 hectares**

Slow rate of closure and fly ash deficit for remaining work
Maybe the consultant is not as dumb as he looks
Field panels seamed in accordion manner in the field.
FIELD CONSTRUCTION

Geotextile installed rapidly in the field

Minimal slack following deployment of the seamed geotextiles
Fly ash layer placement perpendicular to geotextile seams

Ease of placement of fly ash material over sludge using equipment on site
Parallel berms provided confinement to the sludge.

Increased bearing capacity due to membrane effect of geotextile.
Series of parallel berms were constructed

Reduced construction time to one month to cover one hectare of basin
Problems occurred when the contractor tried to use oversized equipment.

Geotextile was torn and patched in place.
FIELD CONSTRUCTION

Intermediate space between berms was filled

Fill thickness of 1-3 m was achieved with remaining fly ash
LESSONS LEARNED

Above: Jack Shea, who scored brilliant victories in the 1500 meter Olympic events. He says: "Any one who goes in for speed skating needs an abundant supply of stamina and energy. Naturally, I feel pretty well when I have a bit of tobacco after the last hard sprint to the tape. Cigarettes restore my 'pug.' The 'lifting' effect is noticeable in a very few minutes. And they taste so good. For short pleasure, there is nothing like a Camel."

DRAFTSMAN: Franklin Roosevelt: "Camel brings back the mental alertness that a draftsman needs!"

STORE MANAGER: W. F. Stafford: "When I am tired, I smoke a Camel and my energy revives."

TREE SURGEON: H. C. Vough says: "Camel relieves tiredness and they never jangle my nerves."

Printed ≠ correct
• Developing good engineering solutions is not always sufficient
• Convey the risks associated with potential alternatives
We CANNOT focus in our mouse traps…

Remember, our clients don’t care about our mouse traps…

They care about having less mice
Questions?

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