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Closure Design and Construction of Contaminated Soft Sludge Lagoons:

A Tale of Innovation, Poor Field Execution and Final Redemption

PURDUE GEOTECHNICAL SOCIETY

David Espinoza
Washington DC, USA

Geosyntec consultants

engineers | scientists | innovators

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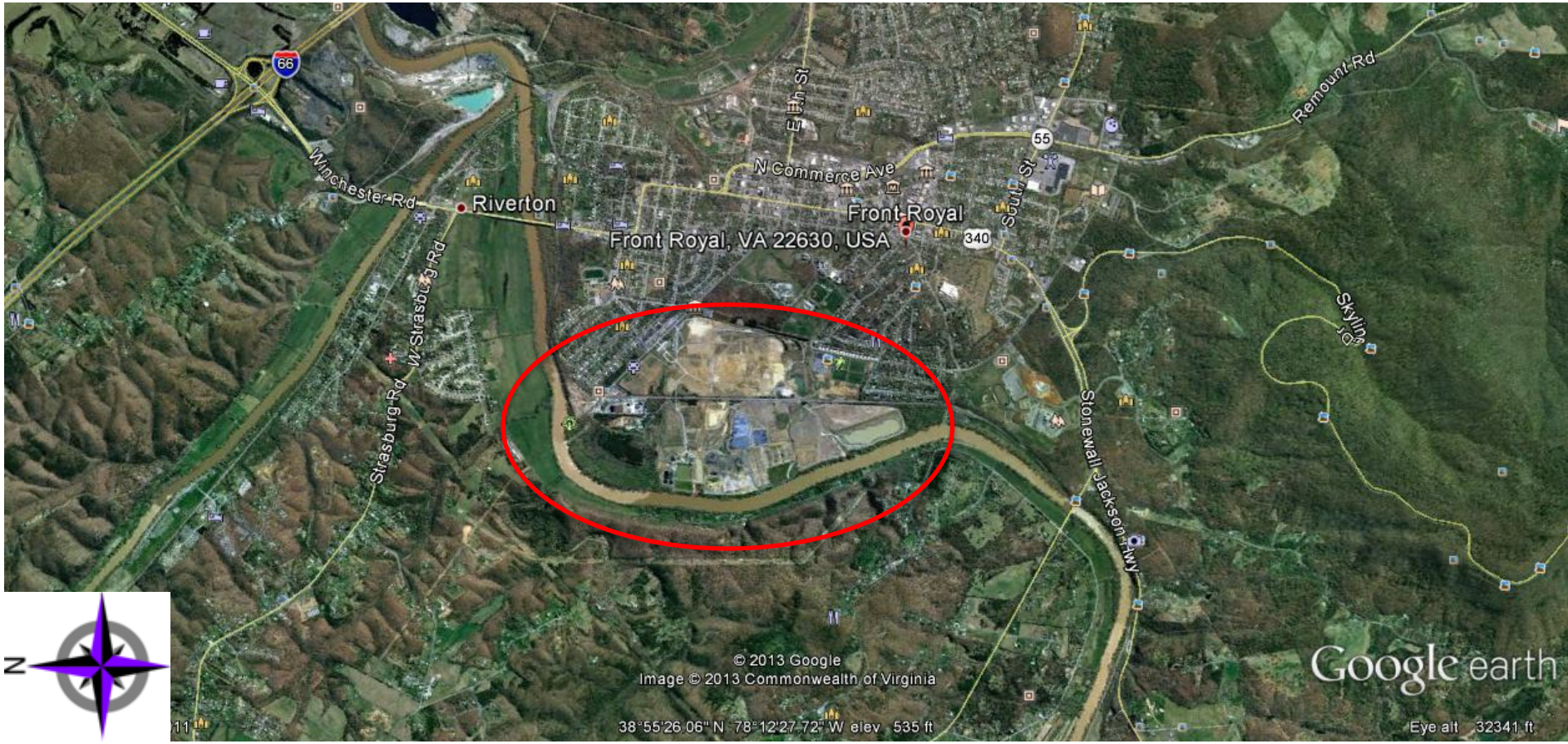
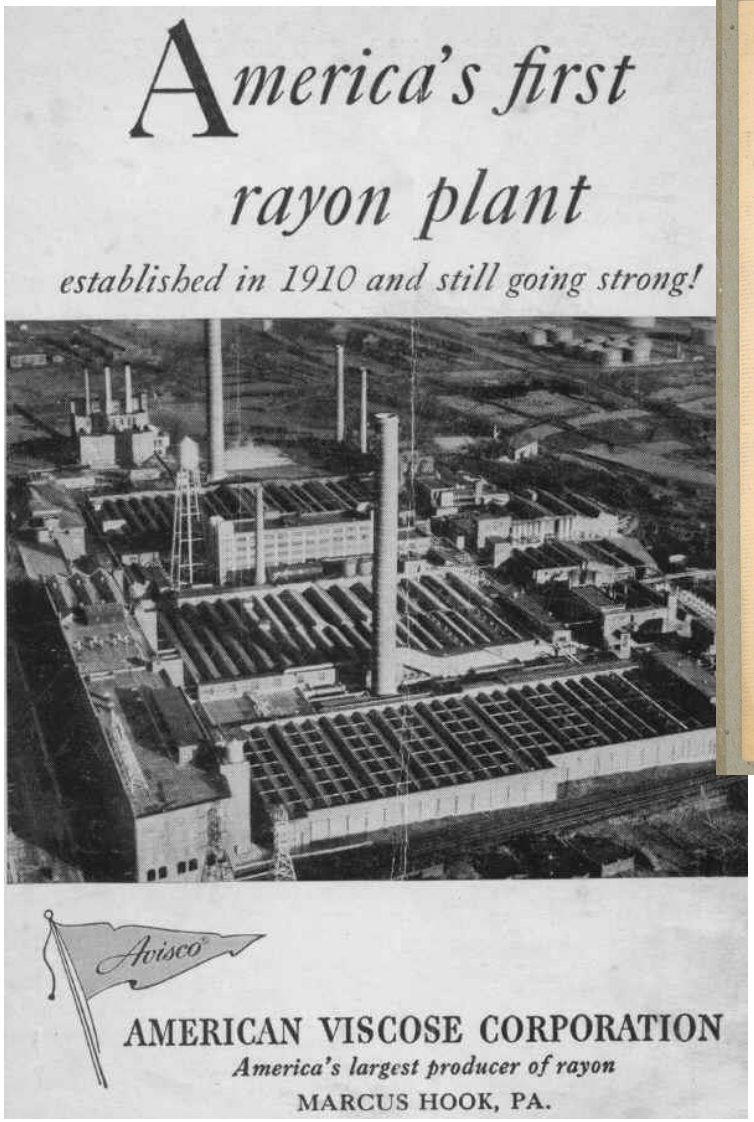
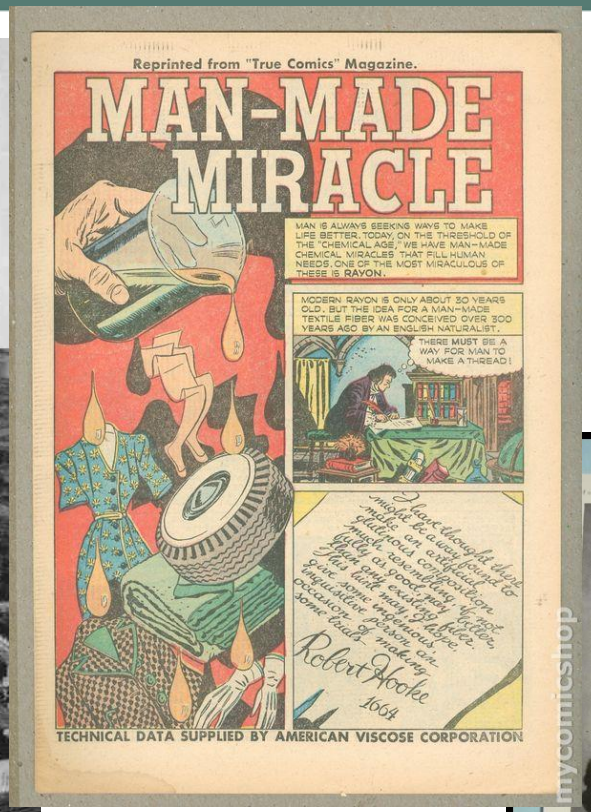
AVTEX SUPERFUND SITE

Located in the Shenandoah valley (62 miles west of DC)

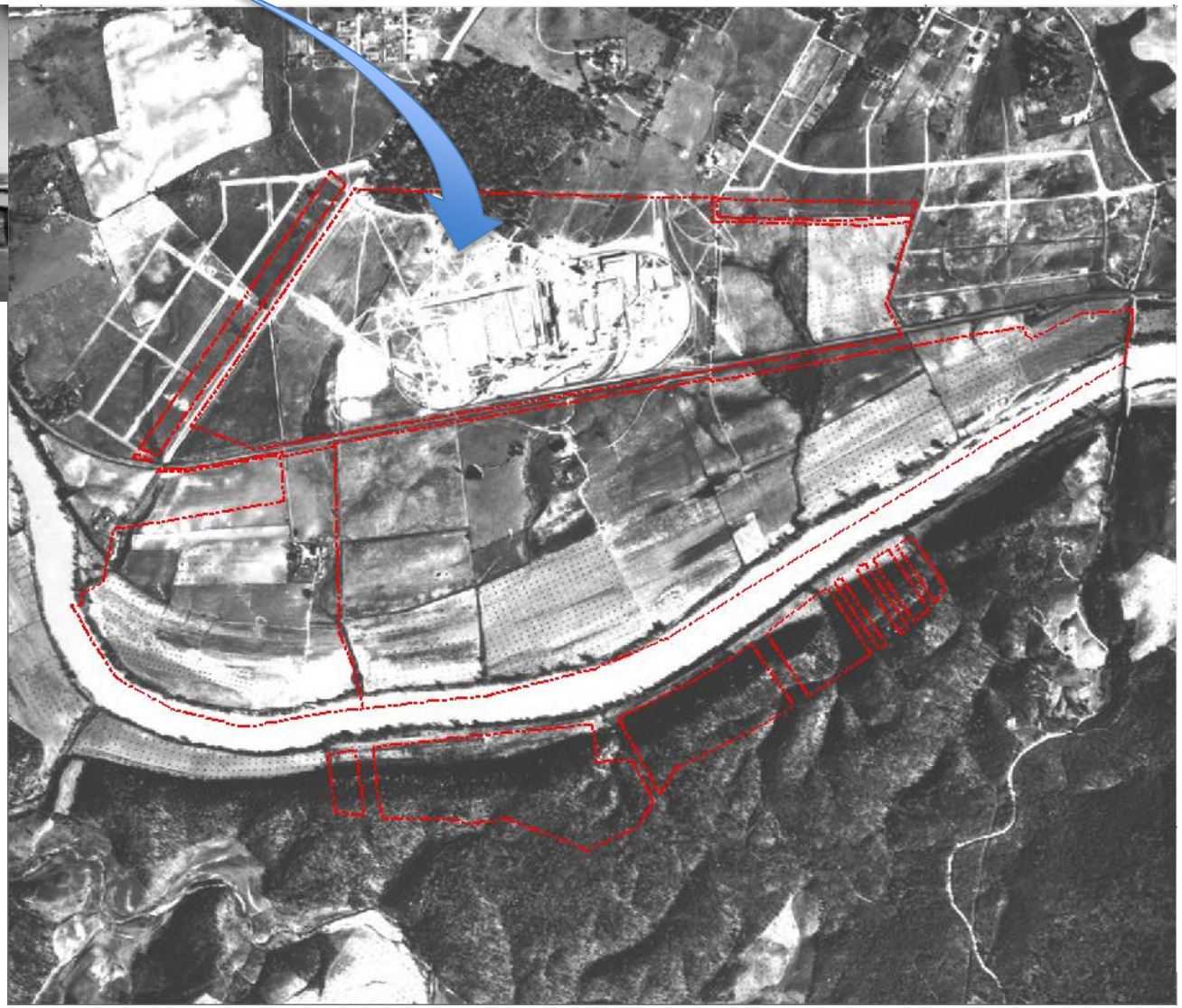


A LITTLE HISTORY…





ONCE UPON A TIME…



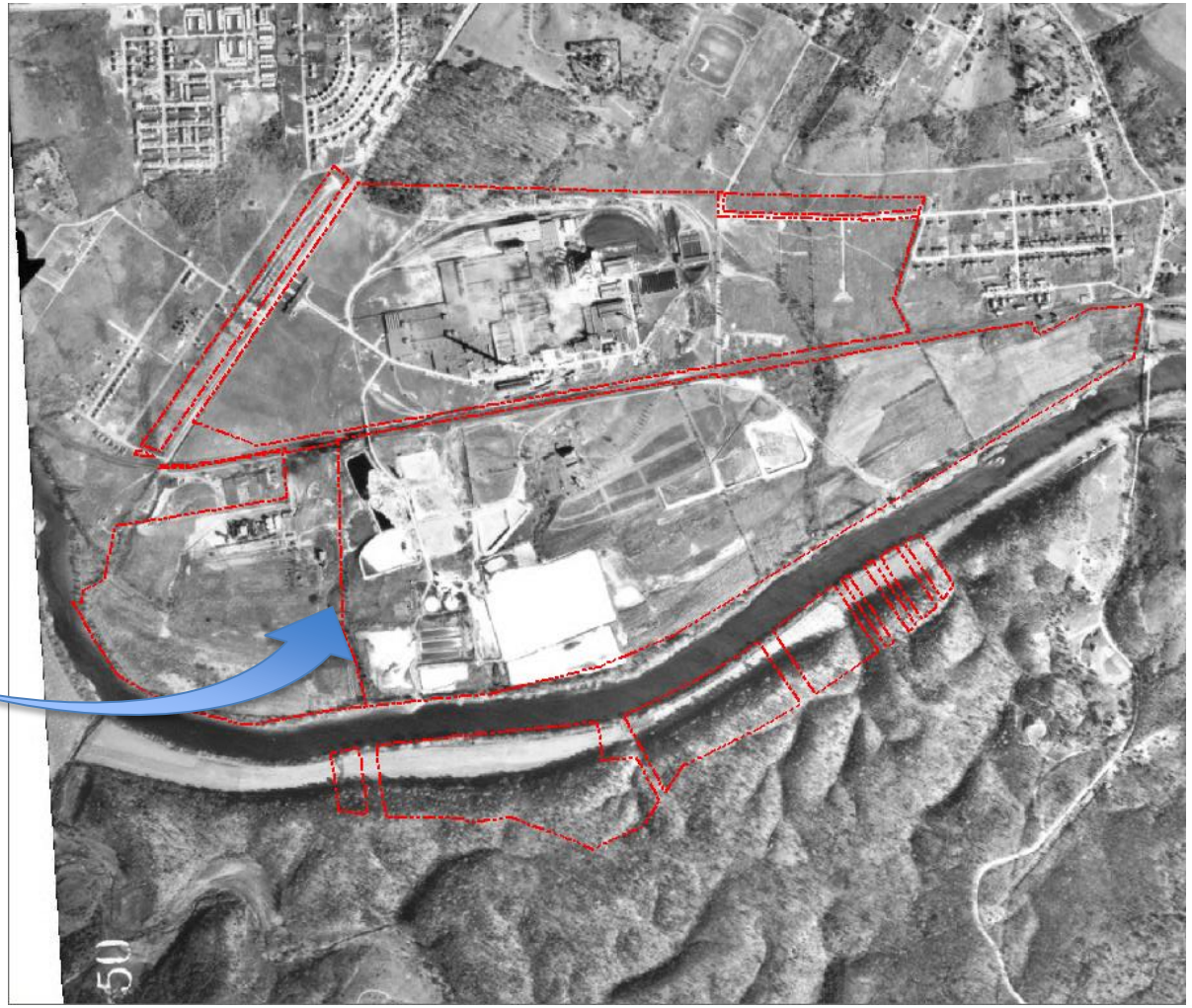
Plant built in 1937

AVTEX FIBERS

SUPERFUND RECIPE

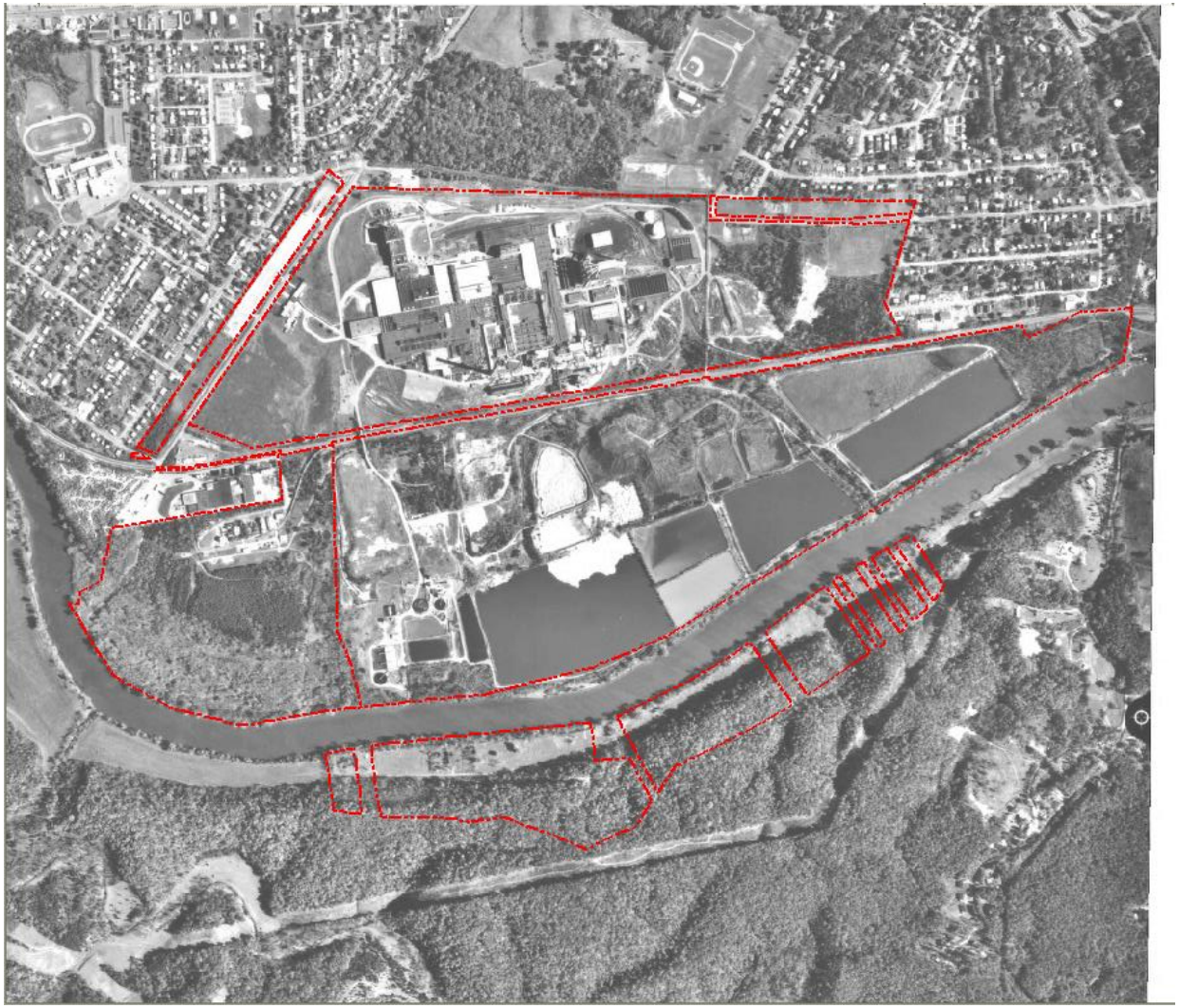
Ingredients:

- **Caustic soda**
- **Sulfuric acid**
- **Carbon disulfide**



1950s

PRODUCE SOME MORE…



1970s

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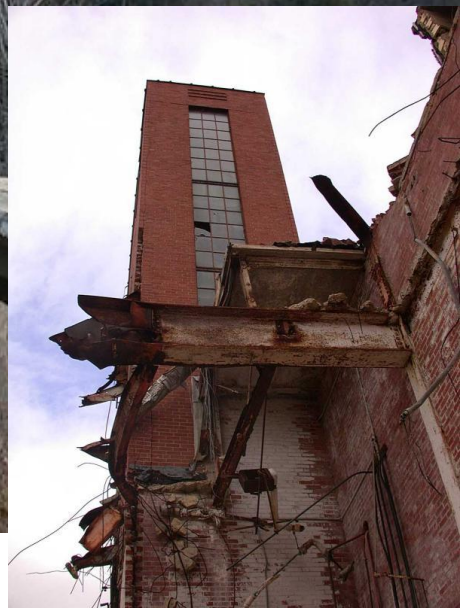
ET VOILÀ (1990's)…



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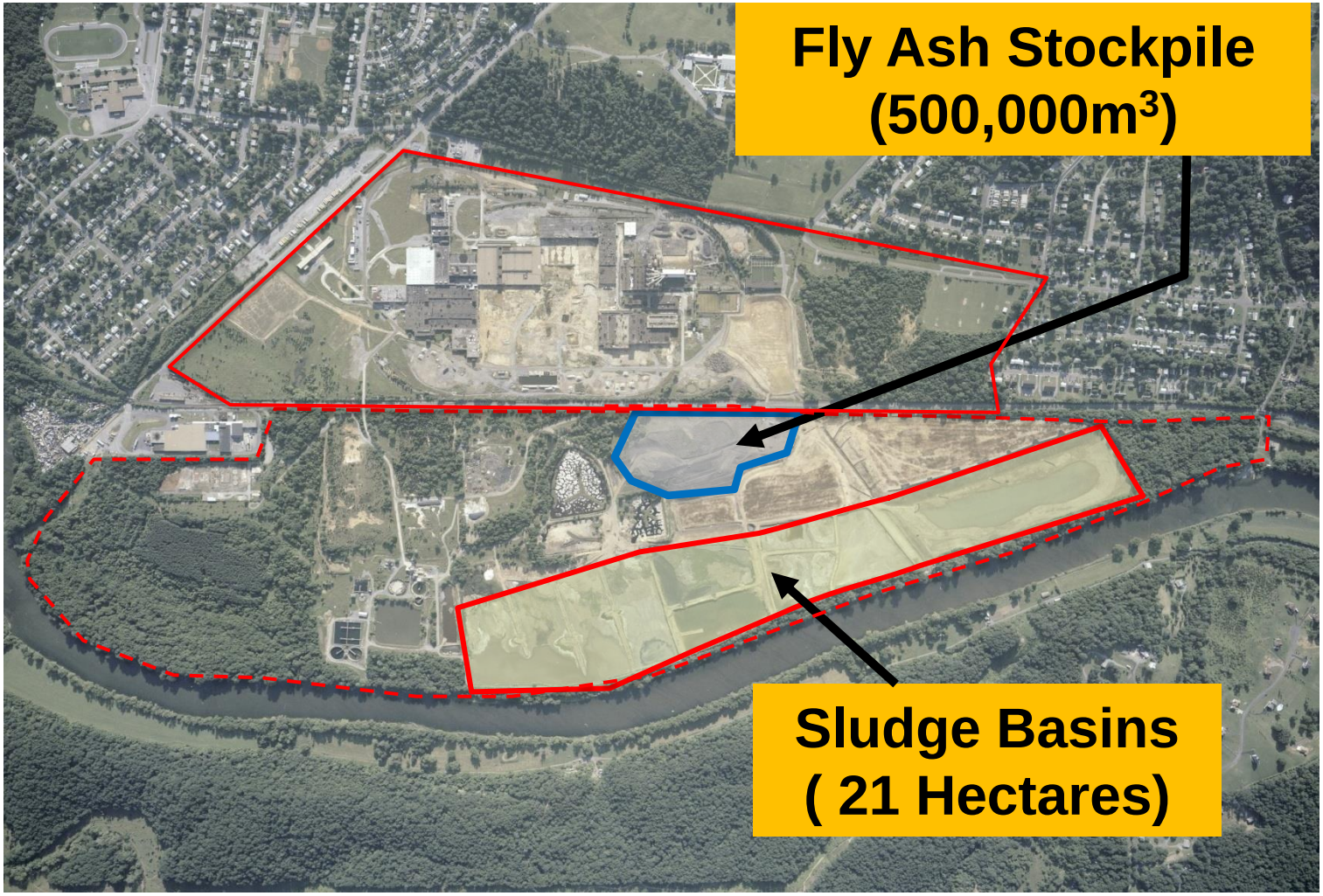
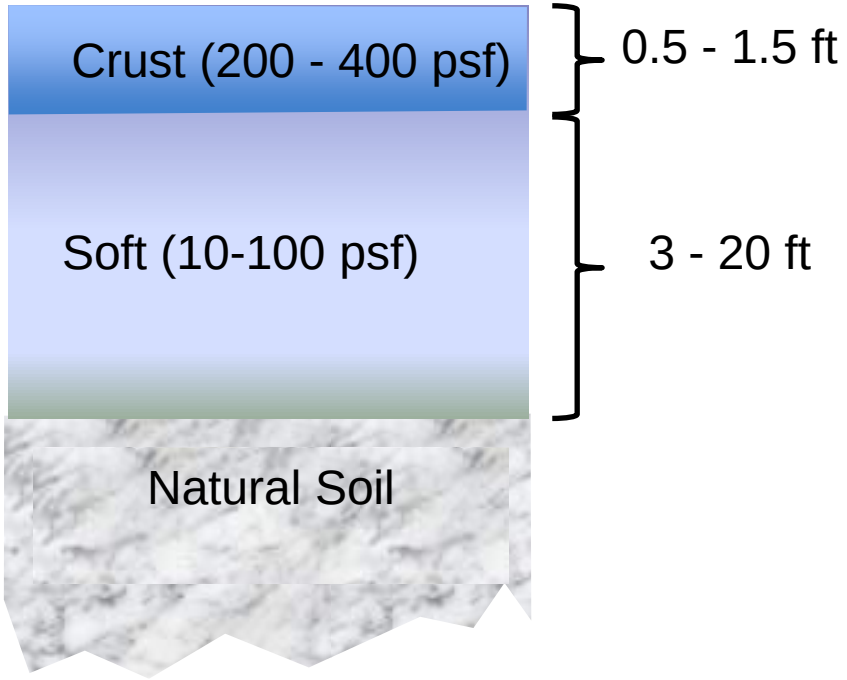
PROJECT BACKGROUND



Fly ash was recommended to close the lagoon (260,000 m³)

REMEDIATION

- **Leave in place and cap 5 sulfate sludge basins (~50 acres)**
- **Capping implied: 4 ft – 10 ft surcharge**



CHARACTERIZATION

- **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**

HOW SOFT IT IS 10-100 PSF?

An average person weighs 180 lb

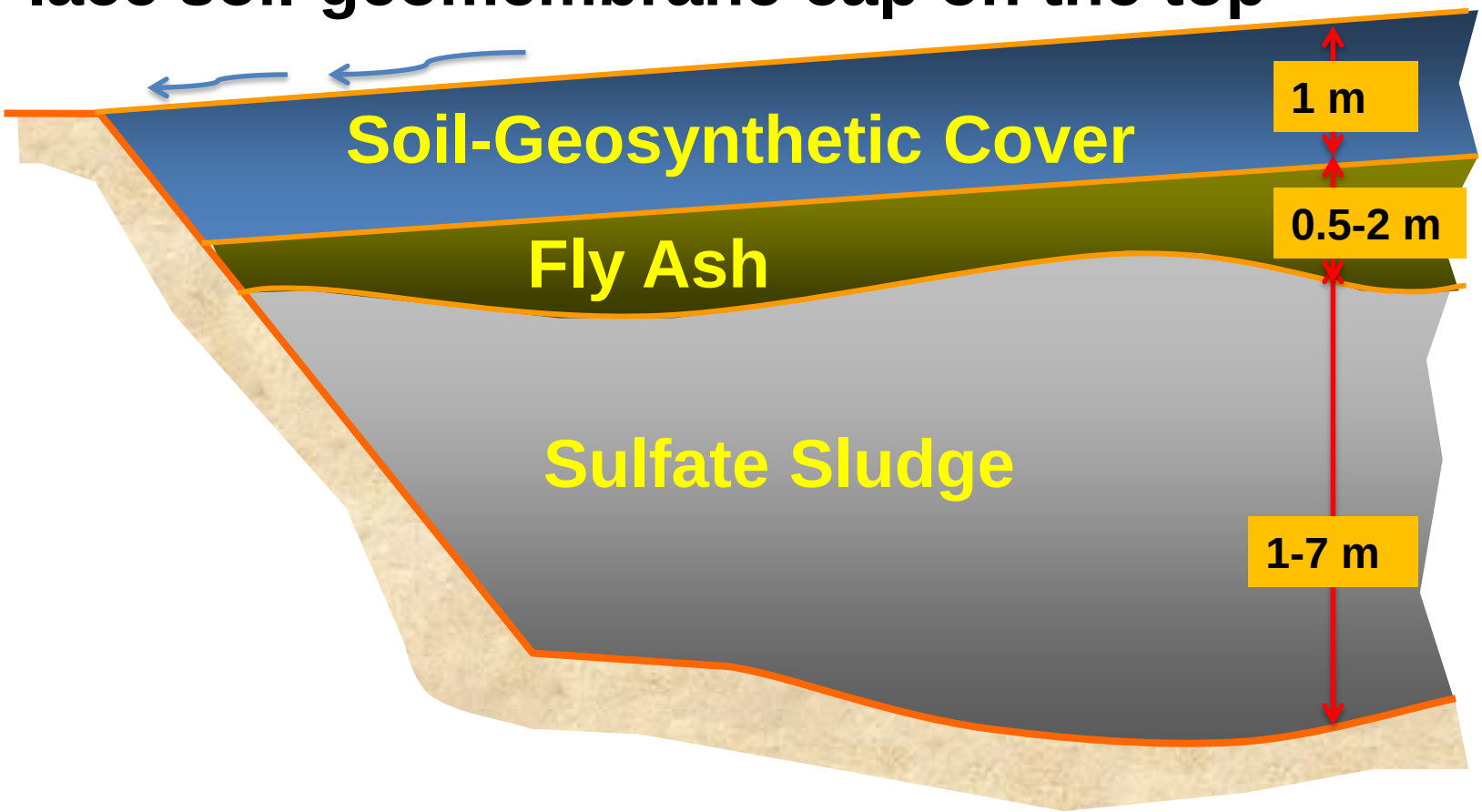
Average shoe size: 10 (~ 0.75 ft^2)

} **240 psf**

CLOSURE APPROACH

Use fly ash as grading fill

Place soil-geomembrane cap on the top



Surplus of fly ash available on site (240,000 m^3)

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THE $1M QUESTION IS:

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How to over build a 10 PSF soft sludge lagoon?

ANSWER: BROMS (1987)

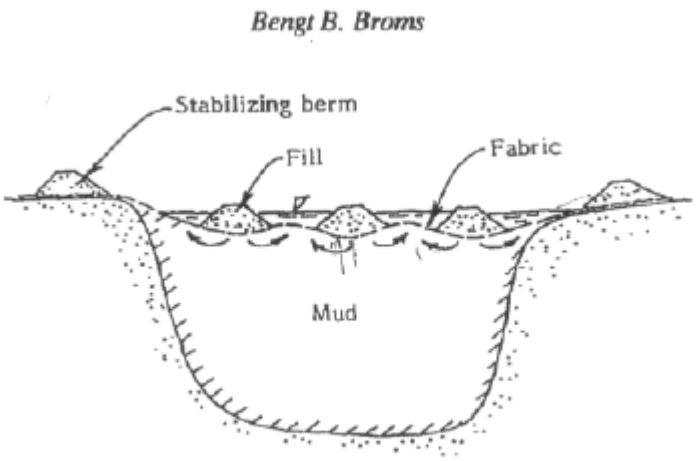


Fig. 2. Stabilization of very soft clay (mud) with geofabric.

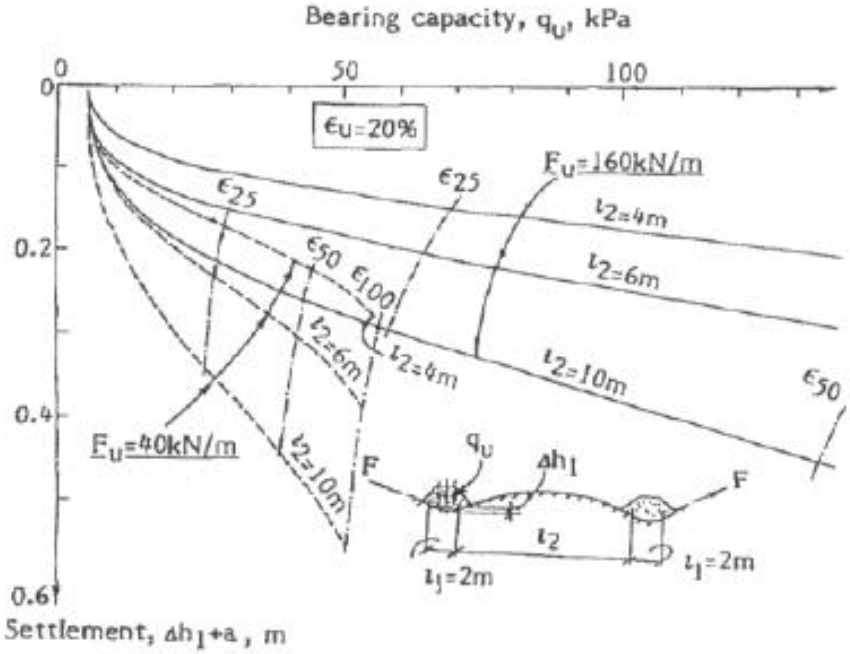
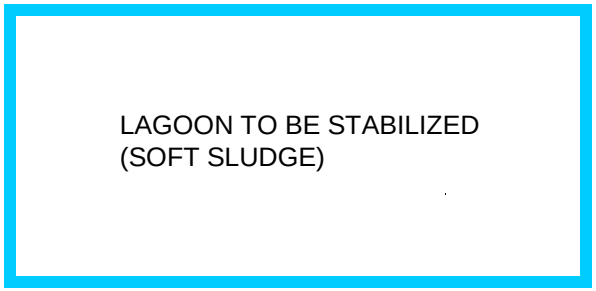


Fig. 6. Bearing capacity of fabric (l_1 = 2 m).

Stabilization of Very Soft Clay using Geofabric Geotextiles and Geomembranes Vol. 5, pp 17-28

HOW DOES IT WORK?



A. Lagoon Filled with Soft Sludge

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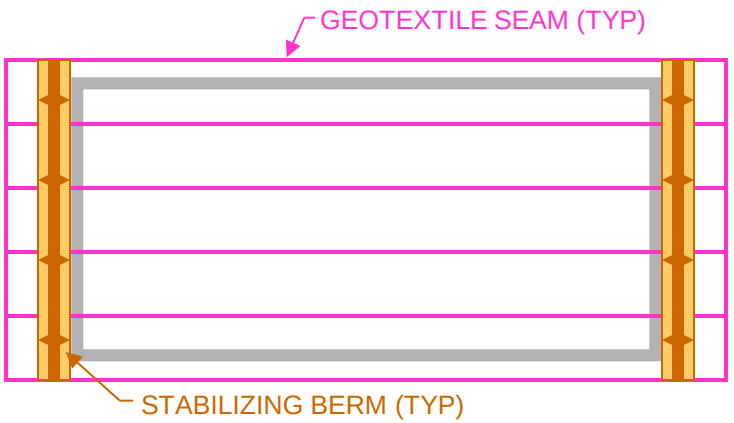
CONSTRUCTION SEQUENCE

A. Lagoon Filled with Soft Sludge



B. Install Geotextile over Lagoon and Place Stabilizing Berms

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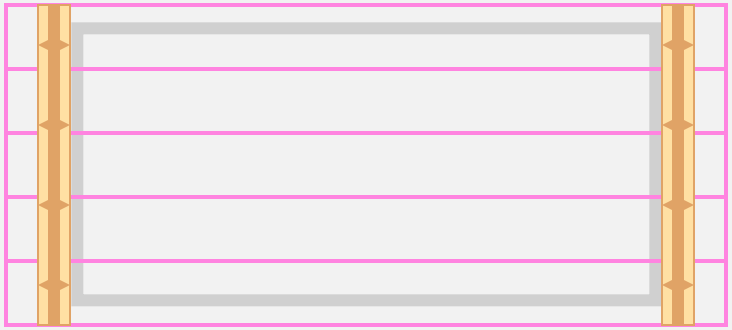
CONSTRUCTION SEQUENCE

A. Lagoon Filled with Soft Sludge



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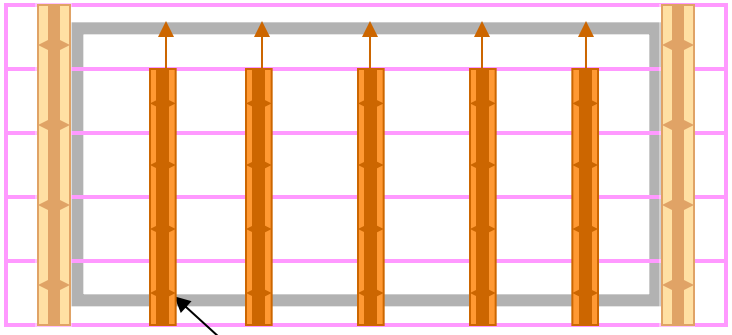

C. Construct Intermediate Berms

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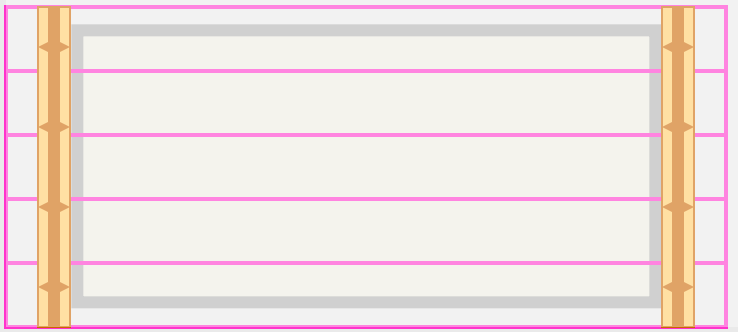
CONSTRUCTION SEQUENCE

A. Lagoon Filled with Soft Sludge



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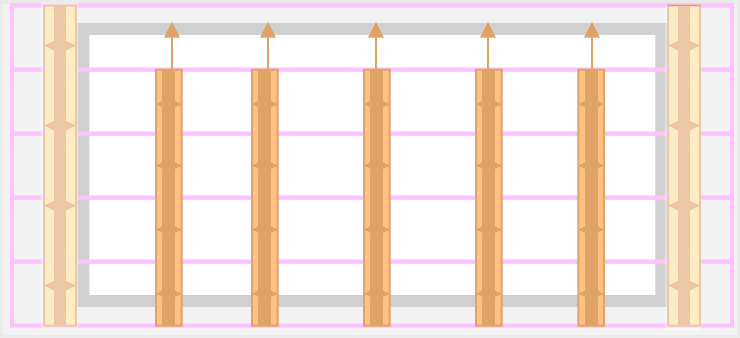

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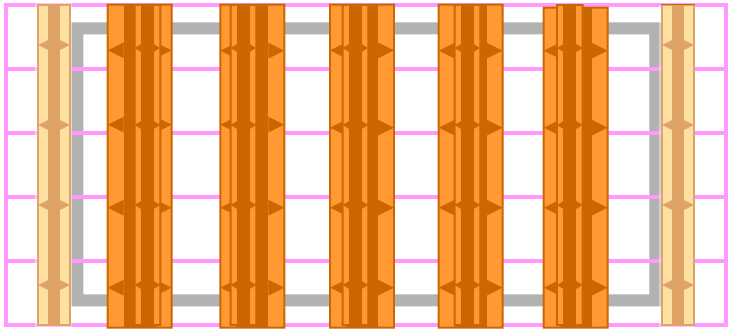

D. Widen Intermediate Berms

Construction involves a step-wise procedure to be followed in the field

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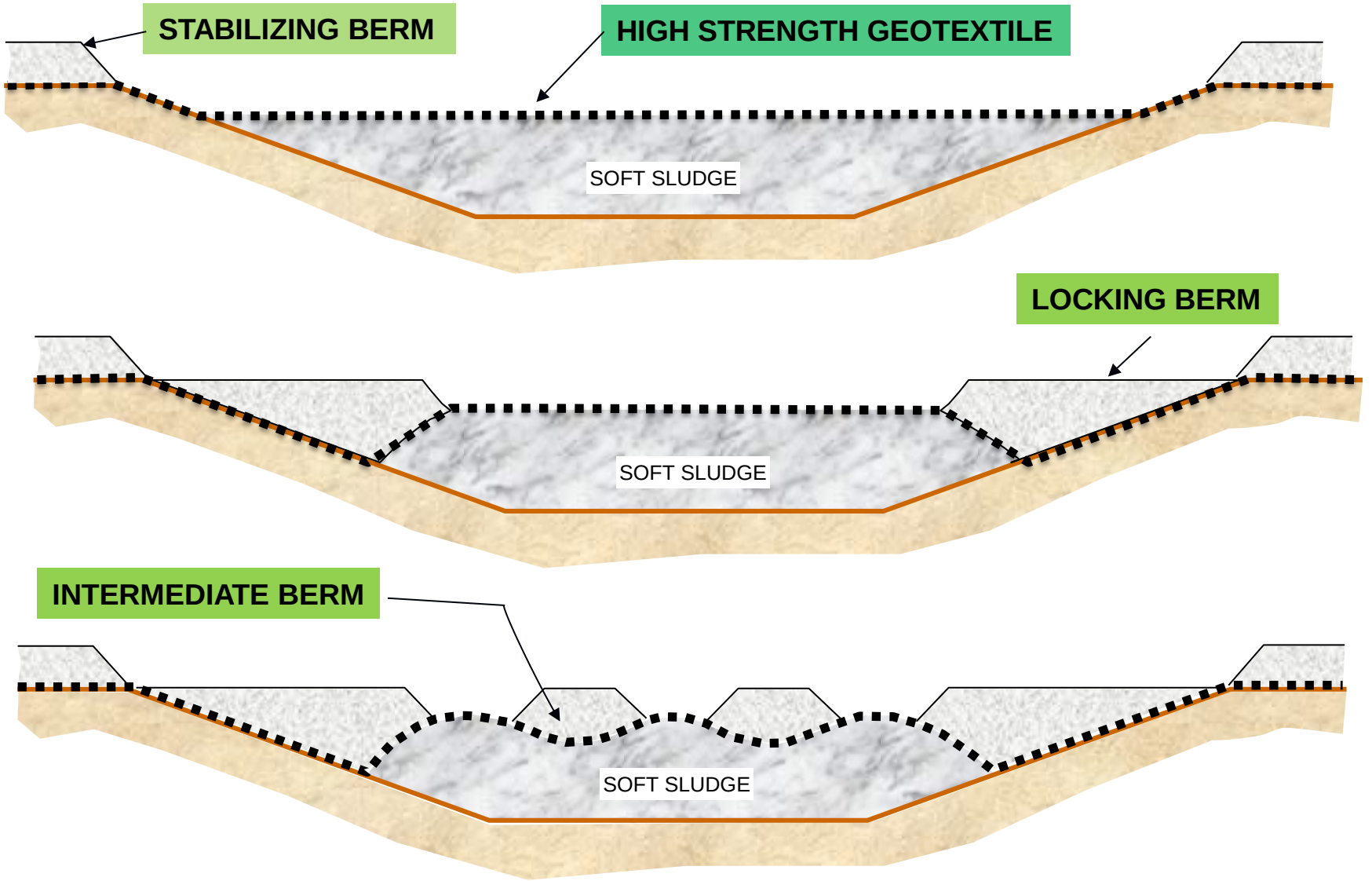
CLOSURE METHOD



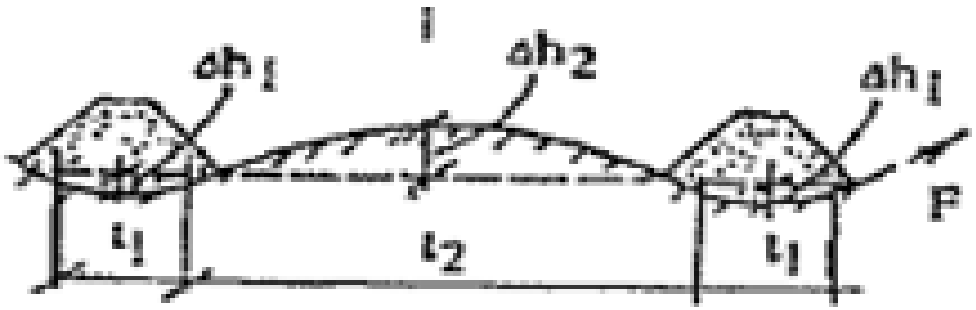
BROMS (1987)

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:

$$l_2 = 5l_1$$

$$\Delta h_2 = 5\Delta h_1$$

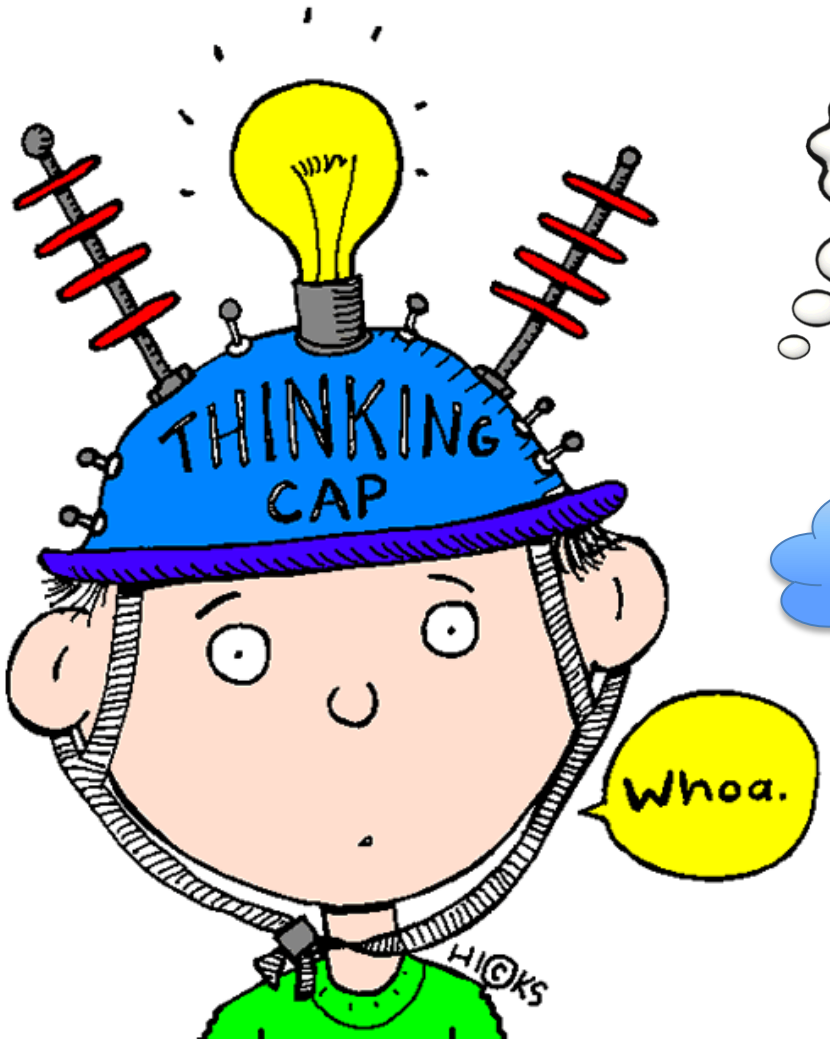
$$l_1 = 10\text{ft};\quad l_2 = 5(10\text{ft}) = 50\text{ft}$$

$$\Delta h_1 = 1\text{ft};\quad \Delta h_2 = 5(1\text{ft}) = 5\text{ft}$$

NEW APPROACH (2000)!

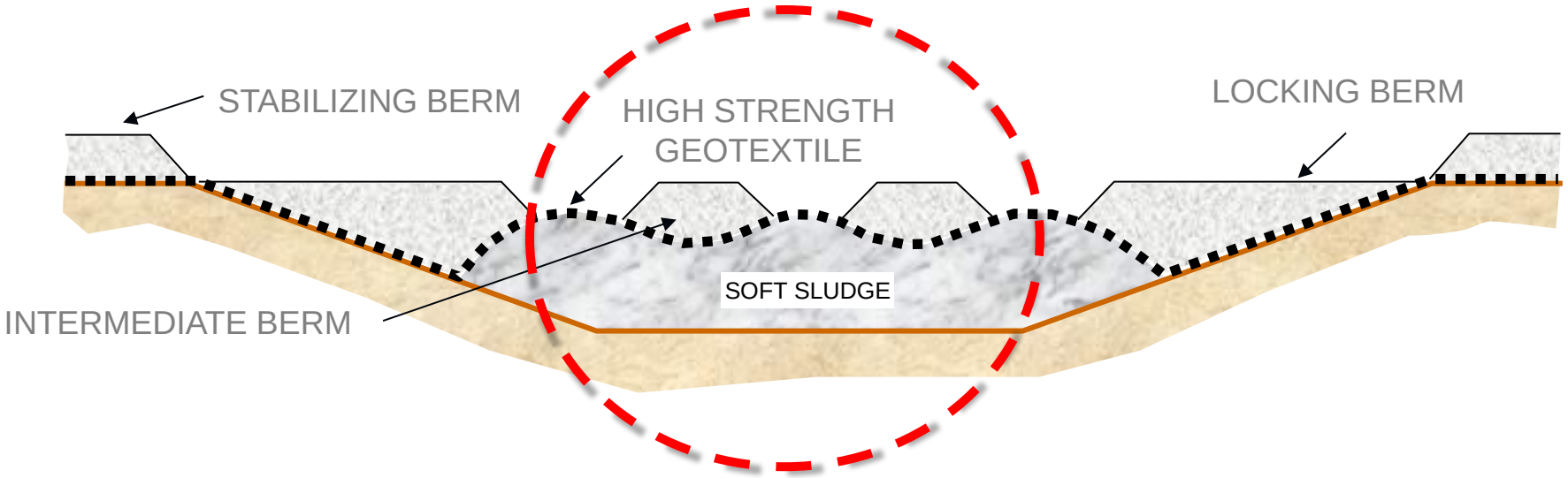
CE68901

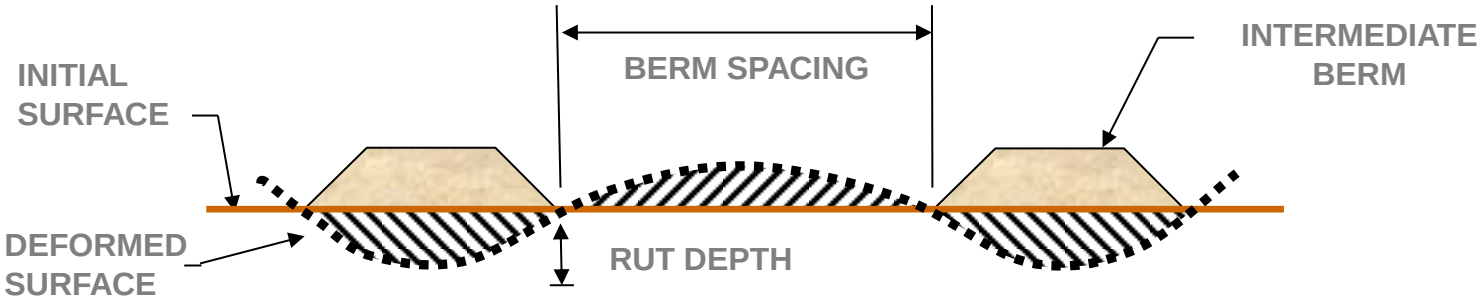
CE48300



MA161000

DESIGN ANALYSIS



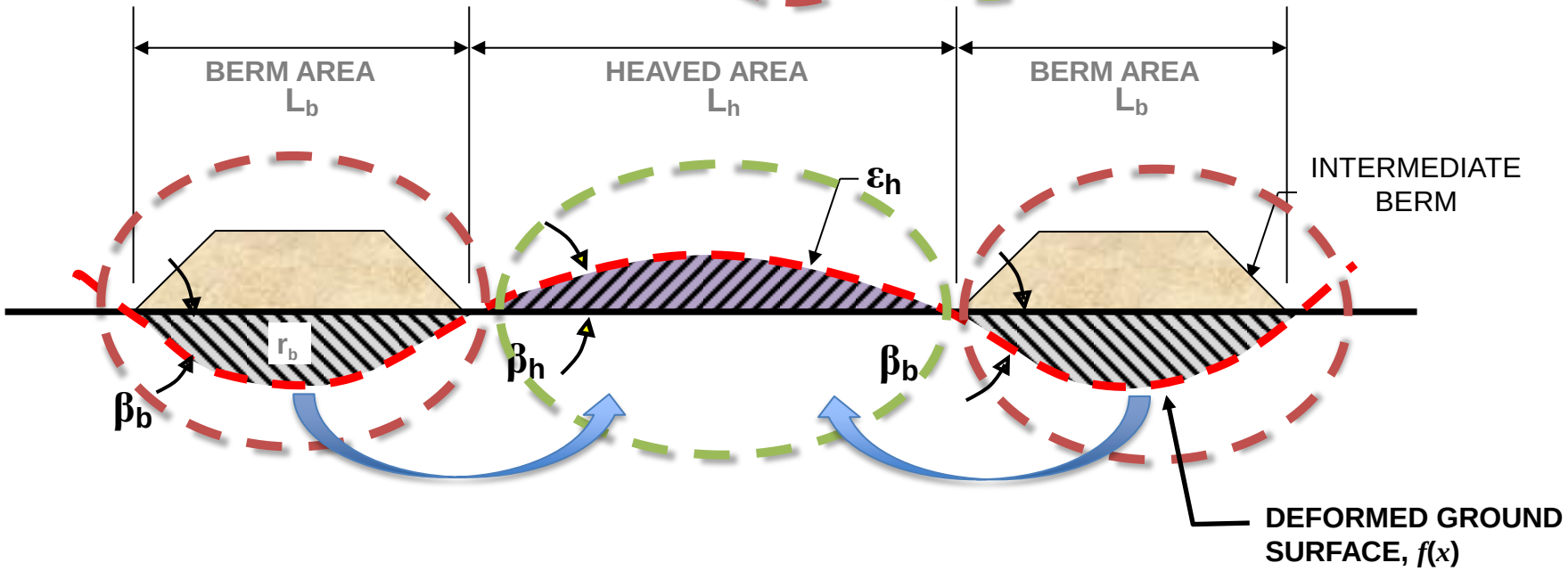


Bearing Capacity Analysis

DESIGN ANALYSIS

Ultimate Reinforced Bearing Capacity of Soil, q_{ur} (Membrane Effect from High Strength Geotextile)

$$q_{ur} = cN_c + q_{gb} + q_{gh}$$



A_b = Volume of soft sludge displaced under an intermediate berm

A_h = Volume occupied by soft Sludge heave between intermediate berms

DESIGN ANALYSIS

$$q_{ur} = c\,N_c + q_{gb} + q_{gh}$$

$$q_{avg} \begin{cases} q_{gb} = \dfrac{J}{L_b} \displaystyle\int_{-L_b/2}^{L_b/2} \varepsilon(x)\left[1 + f'(x)^2\right]^{-1/2} f''(x)\,dx \\ q_{gh} = \dfrac{2J}{L_c} \displaystyle\int_{L_b/2}^{L_b/2+L_h/2} \varepsilon(x)\left[1 + f'(x)^2\right]^{-1/2} f''(x)\,dx \end{cases}$$

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

Reference: Espinoza and Sabatini (2008), Geosynthetics International

DESIGN ANALYSIS

Deformed shape approximated by parabolas (Giroud and Noirey, 1981)

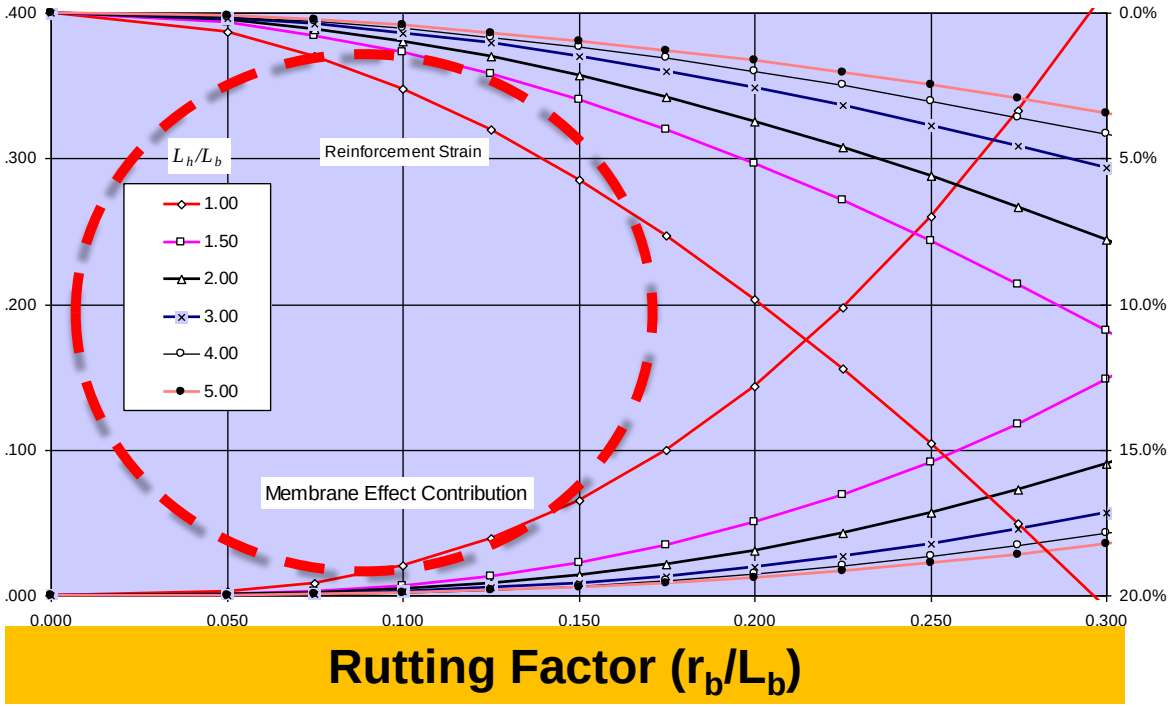
$$\lambda_q = \frac{q_{avg}}{(2J/L_b)} = \varepsilon_{avg}\left[\ln(\tan\beta_b + \sec\beta_b) + \frac{1}{\rho}\ln(\tan\beta_h + \sec\beta_h)\right]$$

$$q_{avg} = q_{gb} + q_{gh} \qquad \varepsilon_{avg} = \frac{\varepsilon_{gb} + \rho\varepsilon_{gh}}{1+\rho} \qquad \rho = \frac{L_h}{L_b}$$

GEOTEXTILE CONTRIBUTION

Additional Bearing Capacity Provided by Reinforcement

Membrane Contribution $\lambda = q_{ur}/(2J/L_b)$



Average Strain (%)

Using this chart, the effect of geotextile contribution can be quantified

CALCULATION

Unreinforced Case

Sludge Thickness = 0.3m
Undrained shear strength= 0.5 kPa
Equipment CAT D3C-LGP-5II = 29.6 kPa

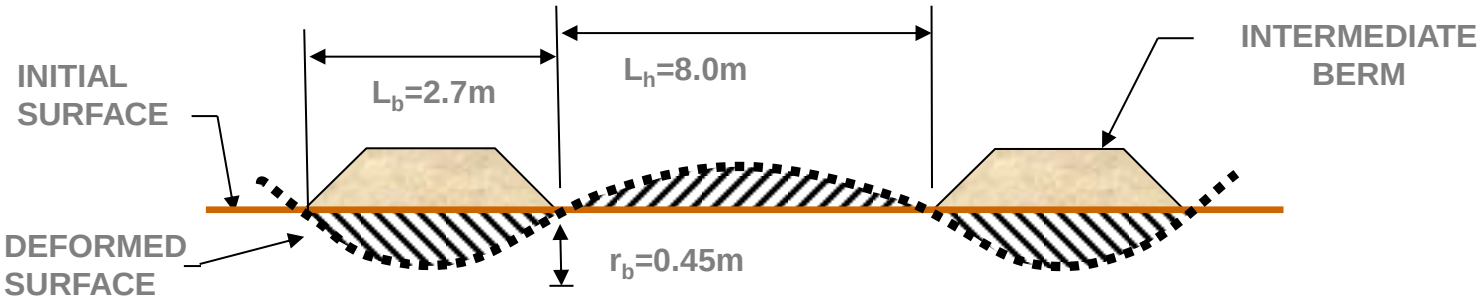
$$q_u = c\,N_c = 0.5 \times 5.14 = 2.5 kPa$$

$$FS = \frac{q_u}{q_{equipment}} = \frac{2.5}{29.6} = 0.08 <<< 1.0$$

Reinforced Case with Berms

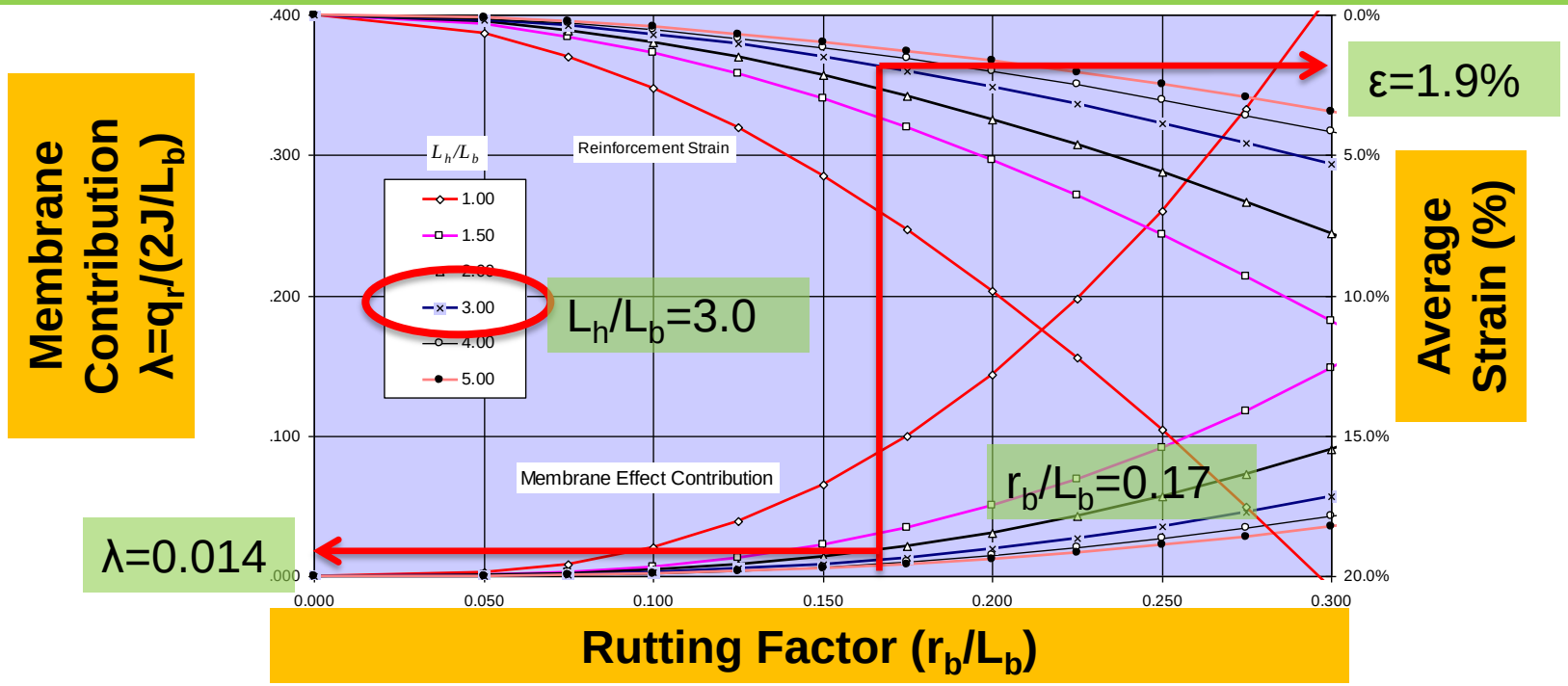
For Berm Deflection r_b**= 0.45m**
Berm spacing L_h**= 8.0 m**
Berm width L_b**= 2.7 m**

$$\frac{L_h}{L_b} = 3.0, \frac{r_b}{L_b} = 0.17$$



GEOTEXTILE CONTRIBUTION

Calculating factors using the proposed chart



Geosynthetic Contribution

With ε = 1.9% and q_r = 27.1 kN/m then J= 2540 kN/m

Working tensile strength = (2,540 kN/m)×1.9% = 48.25 kN/m
For FS =2, ε_u = 3.8%, T_u = 96.5 kN/m

SPECIFICATIONS

- **Develop construction details**
- **Specifications**
  - **High strength geotextile (T_u = 96.5 kN/m and ε_u = 3.8%)**
  - **Sequence of construction**
  - **Equipment (D5G-LGP)**

CLOSURE IMPLEMENTATION

Fill Placement to slow and time consuming

Specified Equipment (e.g., D5H-LGP) too small for production

Interesting but no, thanks

Use large equipment to push fly ash over sludge to "save" the cost of geotextile and construction time

(2002-2008)

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After all it is just a dirt job…

Crust Displacement

Mixing lots of fill with sludge

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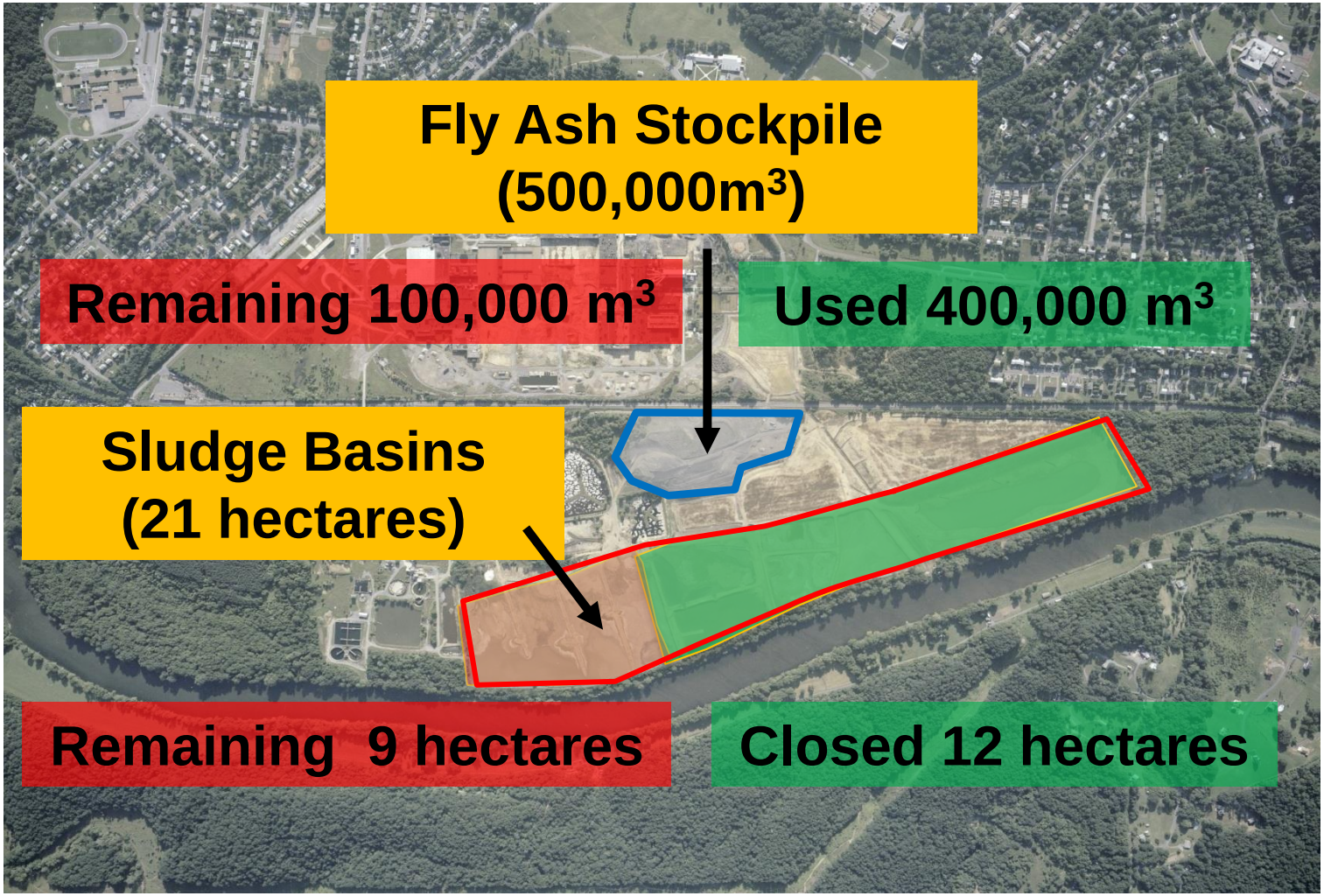
9 Years later (2009)…



Slow rate of closure and fly ash deficit for remaining work

FINAL REDEMPTION

Maybe the consultant is not as dumb as he looks

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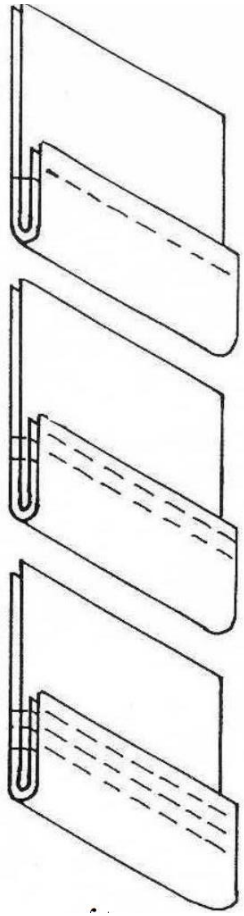
SEAMS FOR GEOTEXTILES

HAND SEAMING

J SEAM



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

FIELD CONSTRUCTION

Fly ash layer placement perpendicular to geotextile seams

Ease of placement of fly ash material over sludge using equipment on site

FIELD CONSTRUCTION

Parallel berms provided confinement to the sludge

Increased bearing capacity due to membrane effect of geotextile

FIELD CONSTRUCTION

Series of parallel berms were constructed

Reduced construction time to one month to cover one hectare of basin

FIELD CONSTRUCTION

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

Printed ≠ correct

LESSONS LEARNED

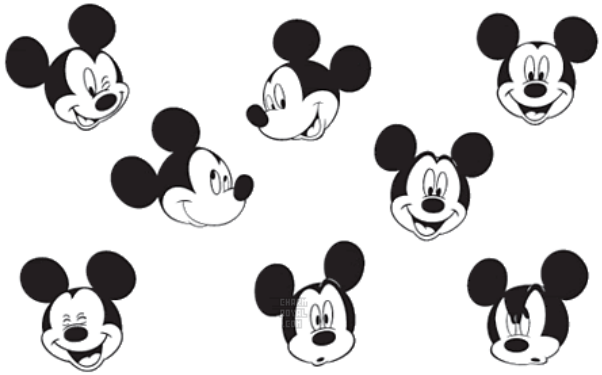
- **Developing good engineering solutions is not always sufficient**
- **Convey the risks associated with potential alternatives**

TO BE A GOOD CONSULTANT…

We CANNOT focus in our mouse traps…

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

They care about having less mice



THANKS

Questions?

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