USEPA BIOREACTOR WORKSHOP FEBRUARY 27, 2003

LANDFILL & WASTE GEOTECHNICAL STABILITY

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PRESENTATION OVERVIEW

- Traditional Waste Geotechnics
- Geotechnics for Bioreactor Landfills
- Final Thoughts & Recommendations


DRY TO MOIST WASTE (~1 m)

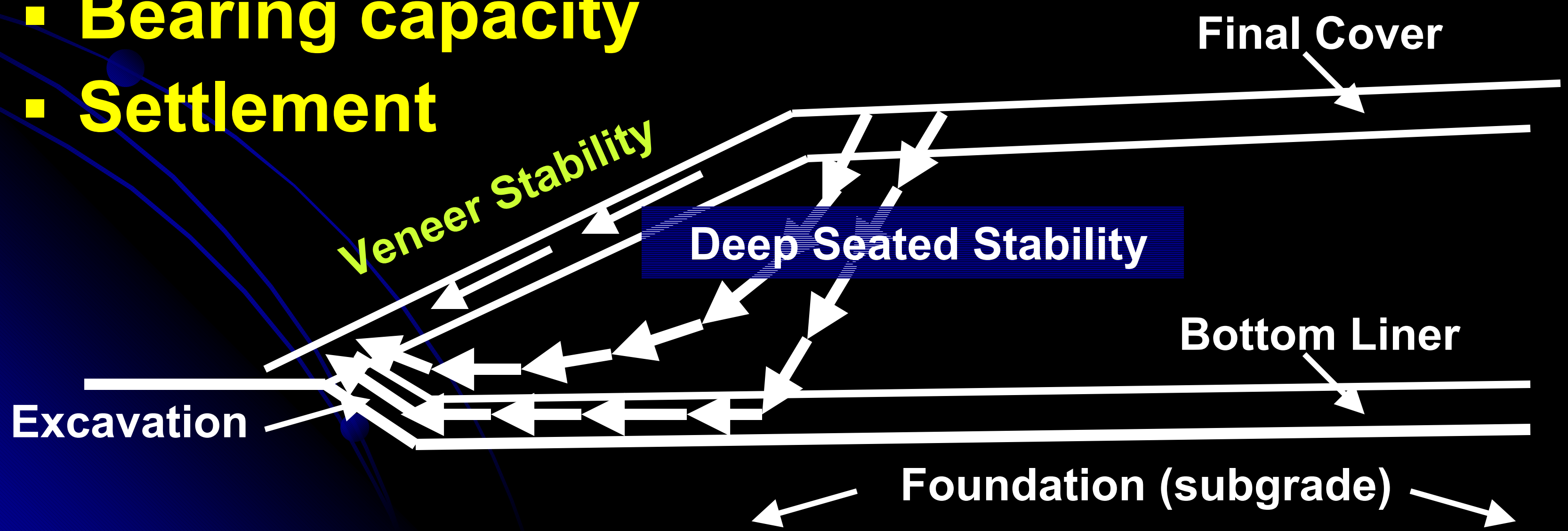
WET WASTE (~5 m)

WET TO SATURATED WASTE
(NEAR LEACHATE LEVELS)

Traditional Geotechnical Approach

Principal Stability Considerations:

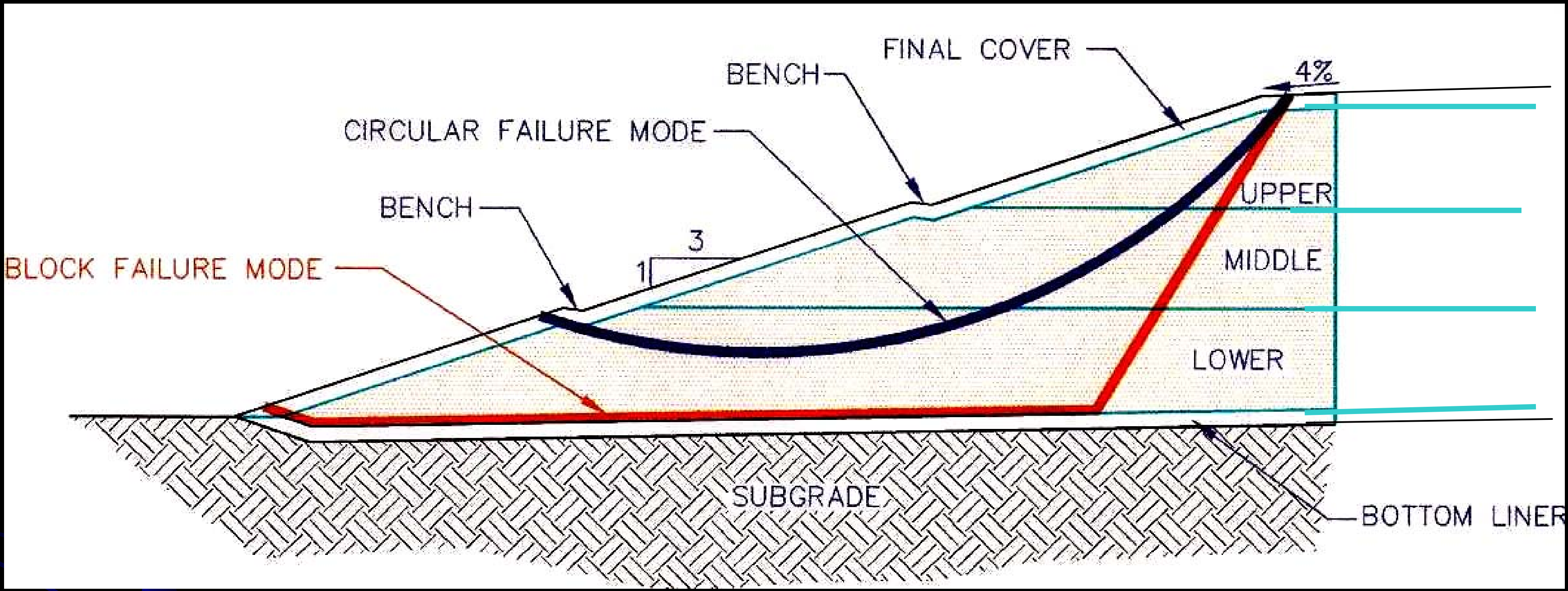
- Excavation slopes
- Interim waste slopes
- Final covered slopes
- Foundation
  - Bearing capacity
  - Settlement



Waste Geotechnics

- Critical sideslopes
  - Construction, operations and final
- 2-D Limit equilibrium models
  - Spencer, Bishop, Janbu, et al
  - Minimum Factor of Safety (FS)
  - Static and pseudo-static
- Material properties
  - Waste: shear strength & density → waste & operation specific
  - Soil: shear strengths & density → site specific
  - Soil/Geosynthetic: interface strength → material specific

Typical Shear Surfaces



FACTORS OF SAFETY:

FS > 1.5 for Static final (peak)

FS > 1.3 for Static interim

FS > 1.0 for Pseudo static (peak)

Or, deformation analysis (e.g., Newmark's)

STABILITY MODELING:

Computer models: PCSTABL, UTEXAS3, XSTABL, and others

Drained and Undrained conditions (pore pressures)

Other Loadings (equipment)

A Word about FS

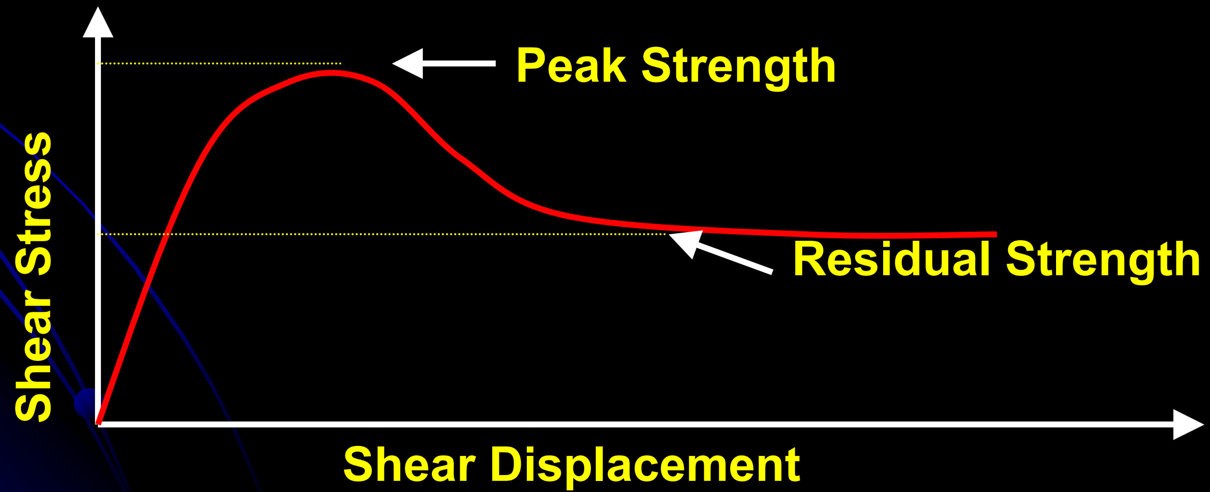
$$FS = \left[\frac{\text{Peak Shear Strength (or, residual)}}{\text{Shear Strength for Equilibrium}} \right]$$

$$= \frac{[C_{ult} + (N-\mu) \bullet [\tan(\varnothing_{ult})]}{[C_{equil} + (N-\mu) \bullet [\tan(\varnothing_{equil})]}$$

Ø=friction angle and C=cohesion (equivalent)

N=normal stress and μ=pore pressure

FS=1.5 means 50% more strength than required for equilibrium



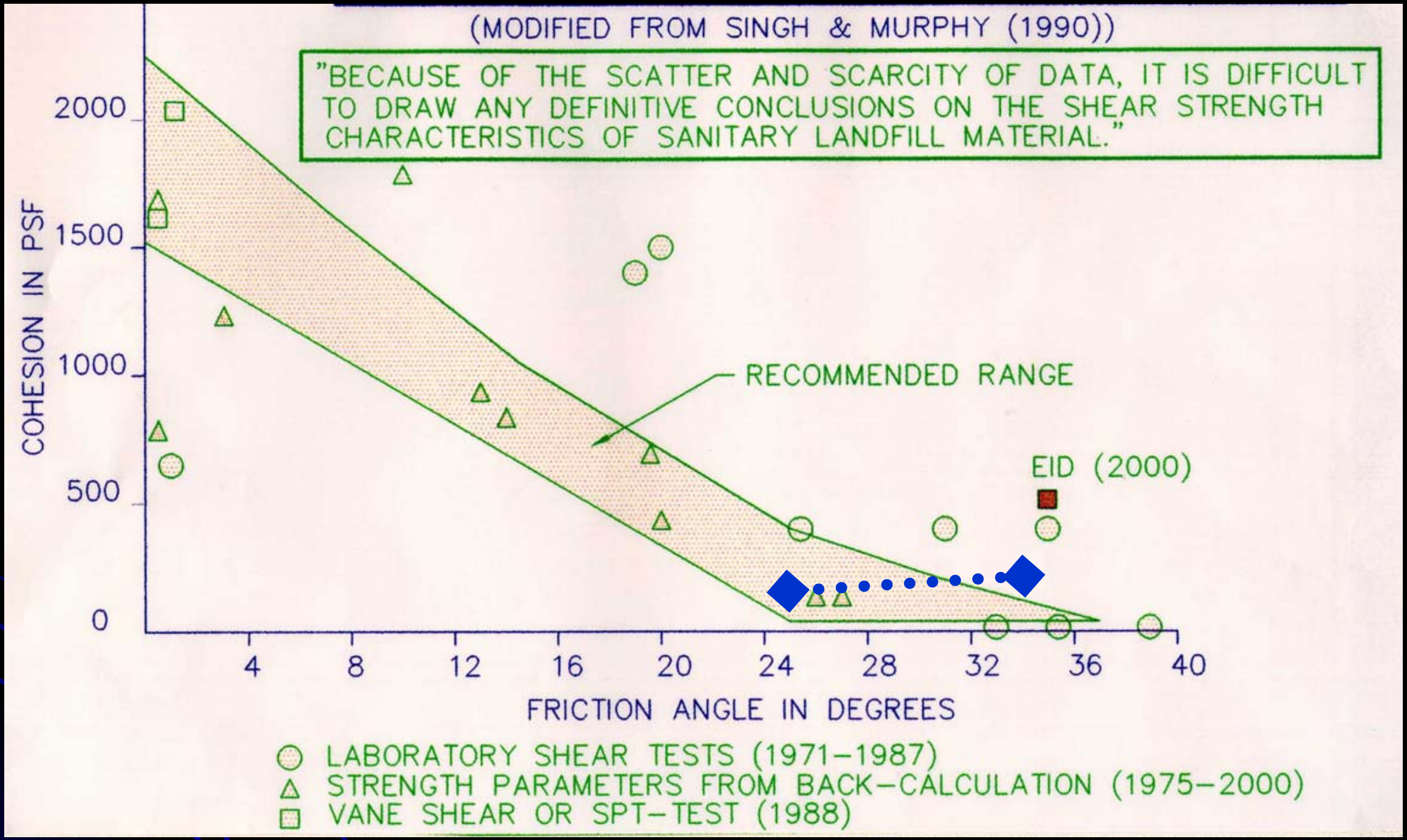
Waste Properties Ranges

- In-place (field) density: ~800 to ~1600 pcy
- Peak shear strength – *Mohr-Coulomb* behavior
  - Friction (Ǿ): ~20° to ~35°
  - Cohesion (C) : 0 to ~1000 psf
  - Residual strength undetermined
- Moisture content (wet weight)
  - Range: ~10% to ~60%
  - Average ~20% to 30%
  - Field Capacity (Fc): ~35% to 55%
- Permeability: ~10^{-2} to ~10^{-6} cm/sec

* All variable & function of waste type, composition, compaction, daily cover, moisture conditions, age, overburden pressure, etc

MSW Strength- Method 1

(Based on Published Lab and Field Testing)



Example:

Assume MSW peak shear strength
Ǿ=34° and C=200 psf
Design for FS=1.5

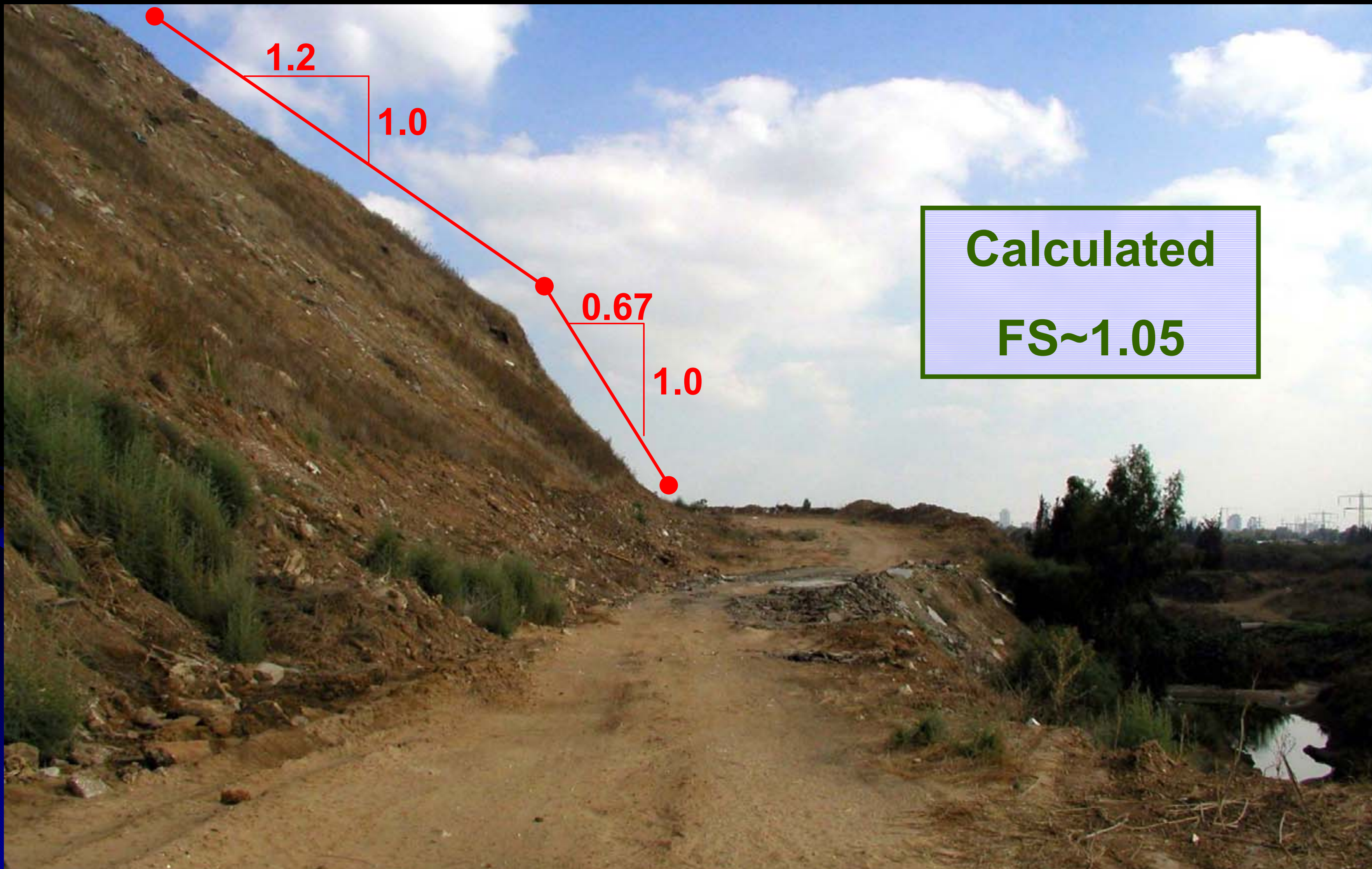
Equilibrium ("stability"):
Ǿ= atan[(tan34°)/(1.5)])= 24.2°
C= 200/1.5 =133 psf

MSW Strength – Method 2

Based on Observations

(Hiriya Landfill, Tel Aviv, 2002)

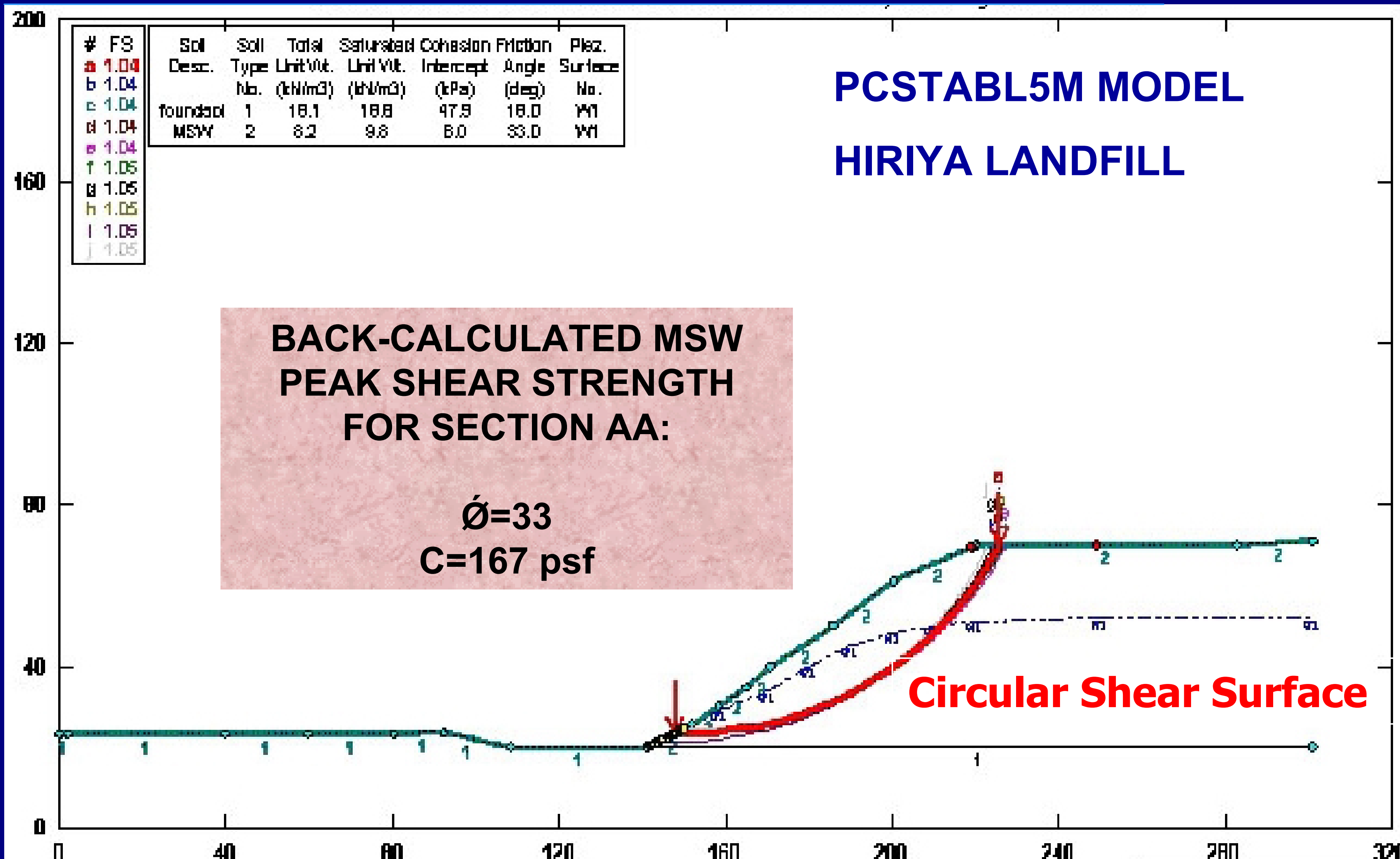
Waste Can Stand on Steep Slopes…



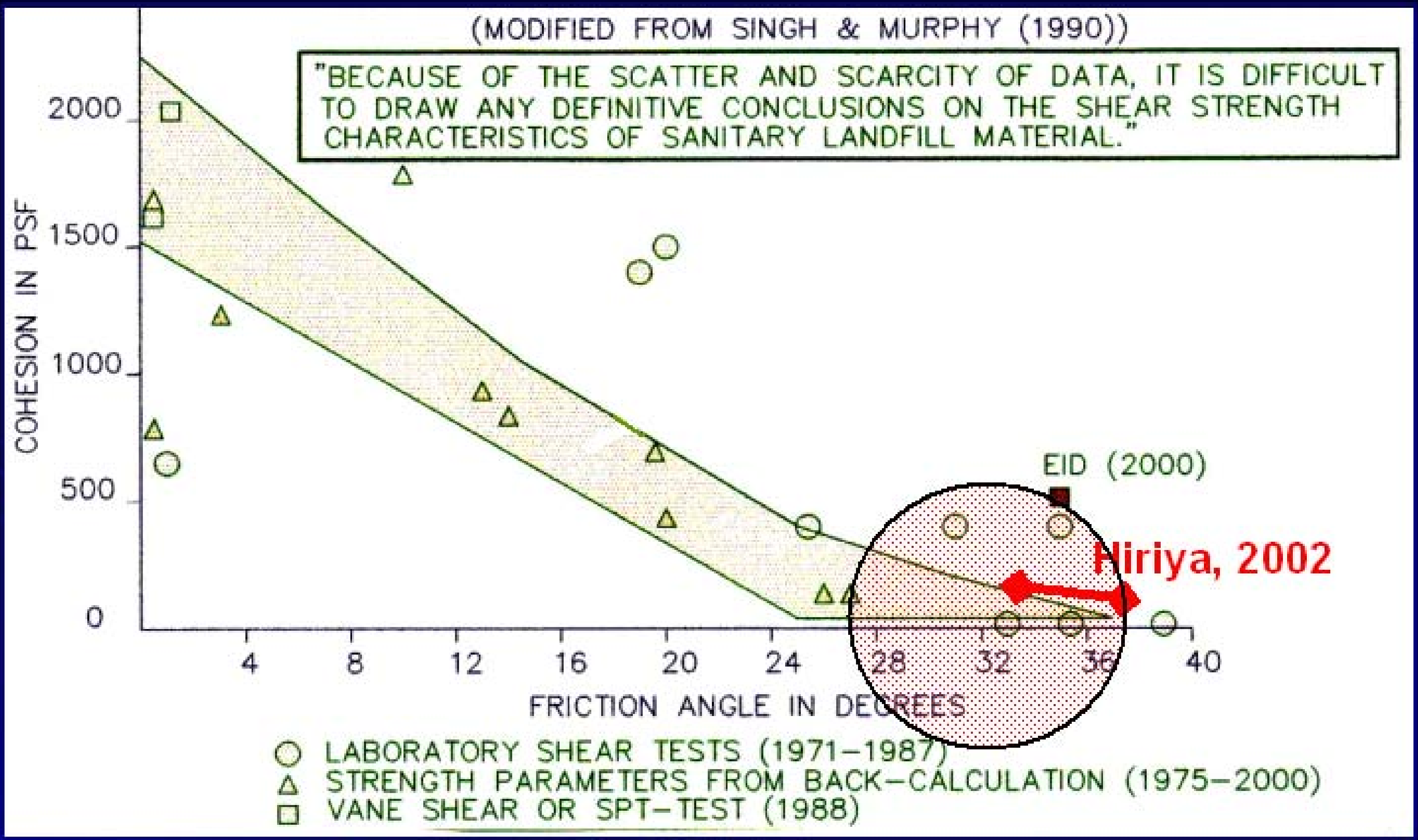
Temporarily.

Hiriya Landfill Slope Failure (1997)

MSW Strength - Method 3
Based on Back-calculation



Back Calculated Shear Strength Hiriya LF- wet, decomposed MSW



LANDFILL BIOREACTORS

***Modified Traditional Approach*:**

"What is the Goal of Your Bioreactor?"

- **1. Increased waste density - (measurable ±15%)**
  - **Increased moisture content**
  - **Compression, settlement**
  - **Ravelling (particle re-orientation)**
  - **Decomposition of organics**
- **2. Change in waste shear strength - ?**
  - **Density increase vs. decomposition**
  - **Pore pressures (liquid build-up)**
  - **Preferential shear surfaces**

In-Place Density Factors

- γ_{wet} = actual in place density

Increases with overburden pressure

" with compactive effort

" with soil daily cover

" with time and settlement

" with moisture content addition

Cumulative effects significant

~40% to >70%

1000 pcy waste will increase to 1400 - 1700 pcy

Example calculation

Initial Condition:

γ_{wet} = 1000 pcy @ w=25% (250# water/cy)

Alternative Daily Cover (intermediate cover soil only)

Moisture Addition:

To achieve w=40%=> 250# water/cy (30 gal)

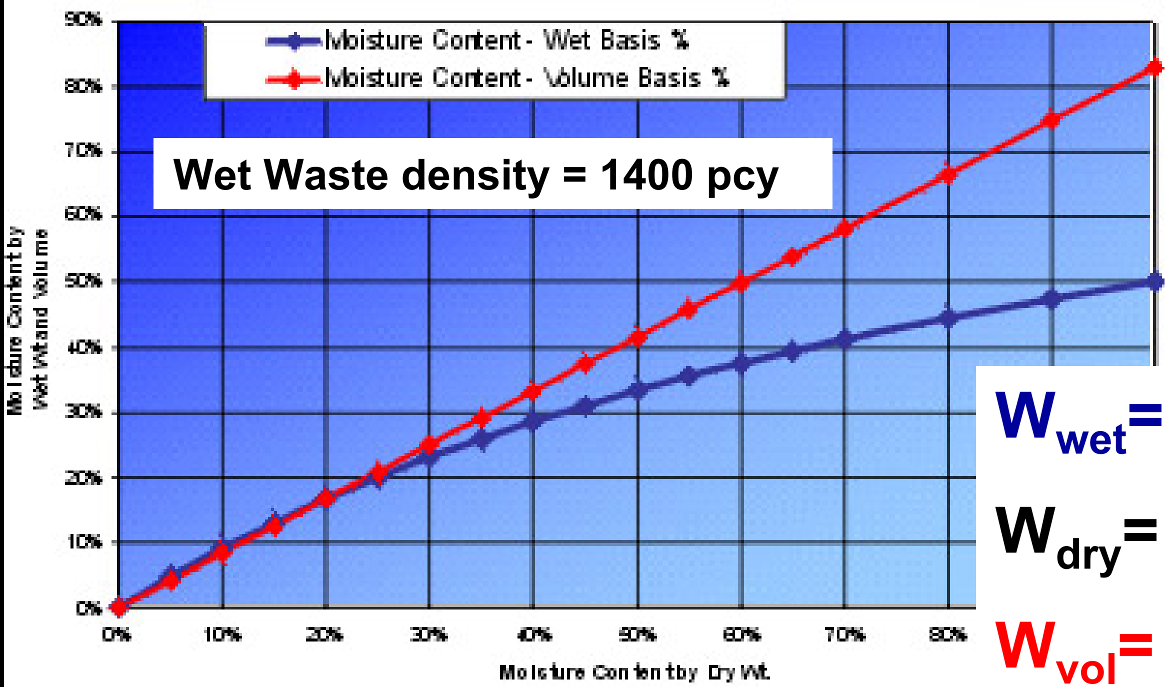
New γ_{wet} = 1250 pcy (assumes no by-pass)

Settlement (compression) + Decomposition = 20%

New γ_{wet} = (1250 pcy)/(0.80) = 1562 pcy

Net Density Increase = (1562-1000)/(1000) => **56.2%**

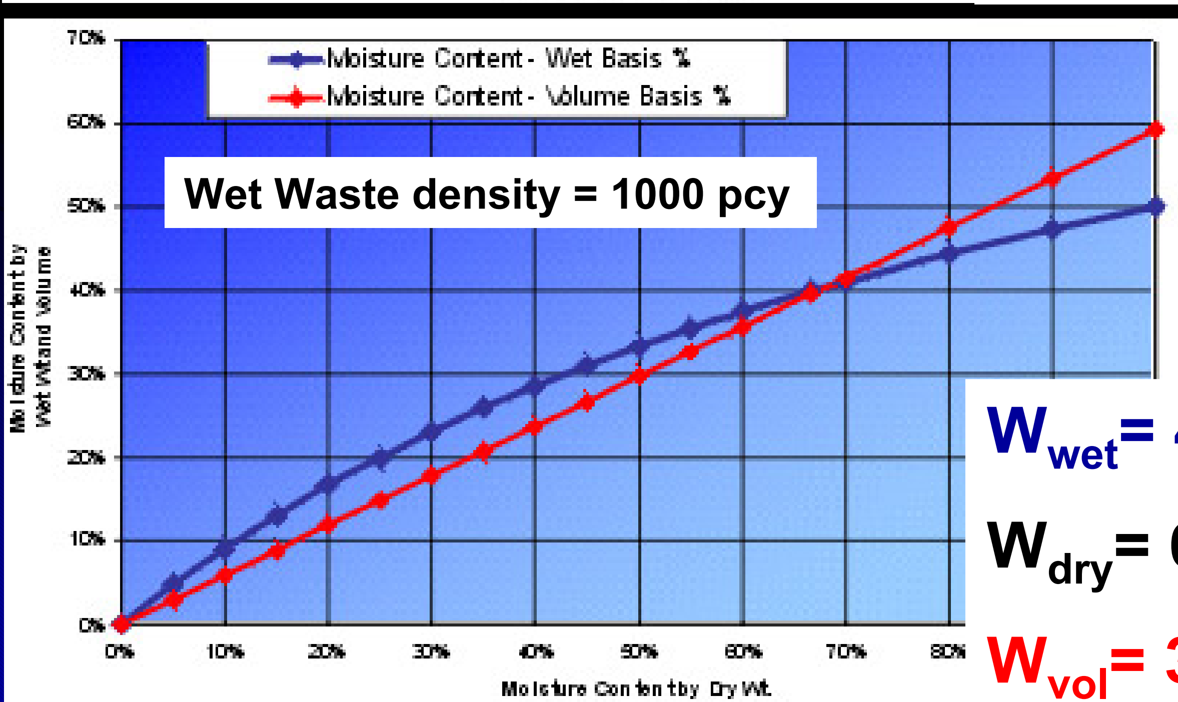
Moisture Contents Are Not Created Equal



W_{wet}= 40%

W_{dry}= 66.6%

W_{vol}= 55.3%



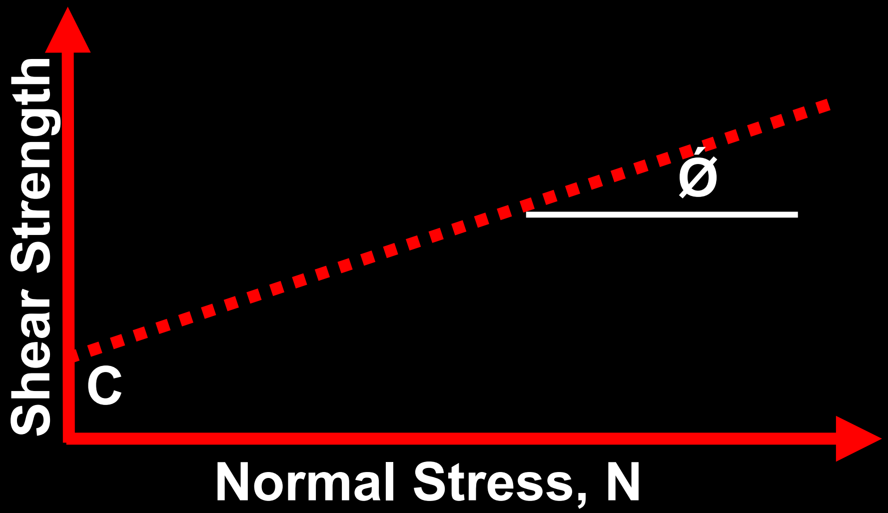
W_{wet}= 40%

W_{dry}= 66.6%

W_{vol}= 39.5%

More on Waste Shear Strength

- Assume *Mohr – Coulomb* Behavior
  - Friction equivalent, Ǿ
  - Cohesion equivalent, C
  - Varies with
    - ⇨ Waste type
    - ⇨ Compaction
    - ⇨ Liquids additions
    - ⇨ Daily cover
    - ⇨ Density
    - ⇨ Moisture content
    - ⇨ Age, time-dependent
- Heterogeneous, anisotropic



And more….

Bioreacted Waste: Limited testing

- Laboratory remolded samples
  - Large Triaxial cells
  - Field shear tests – none reported?
  - Direct simple shear – recent tests→→

DIRECT SIMPLE SHEARS ON DECOMPOSED WASTE*

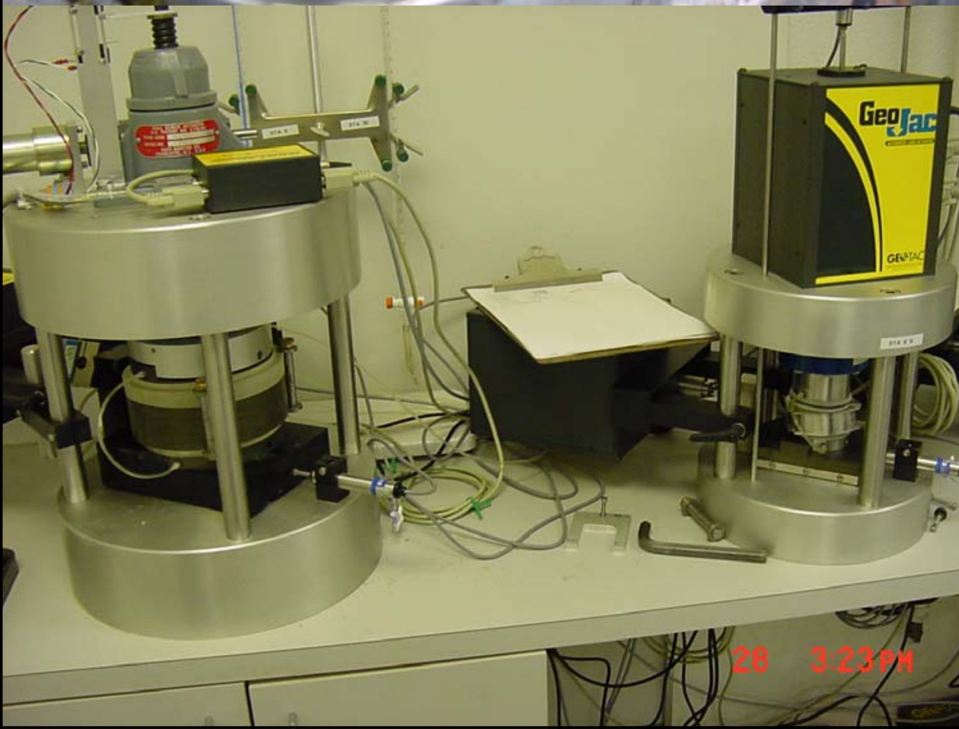
6”x6”x2” Simple Shear Box

Y=103 pcf @ w = 28% to 52% (Sat.)

Ø (drained) = 27.8º to 32.4º

Ø (undrained) = 29.6º to 36.2º

*Testing for Waste Management, Inc. by Applied Land Sciences, JQH Engineering, and Fugro South



Sensitivity Analysis
Bioreactor “Types”

TYPE 0: Baseline; non-bioreactor Subtitle D without recirculation
-“normal” waste density

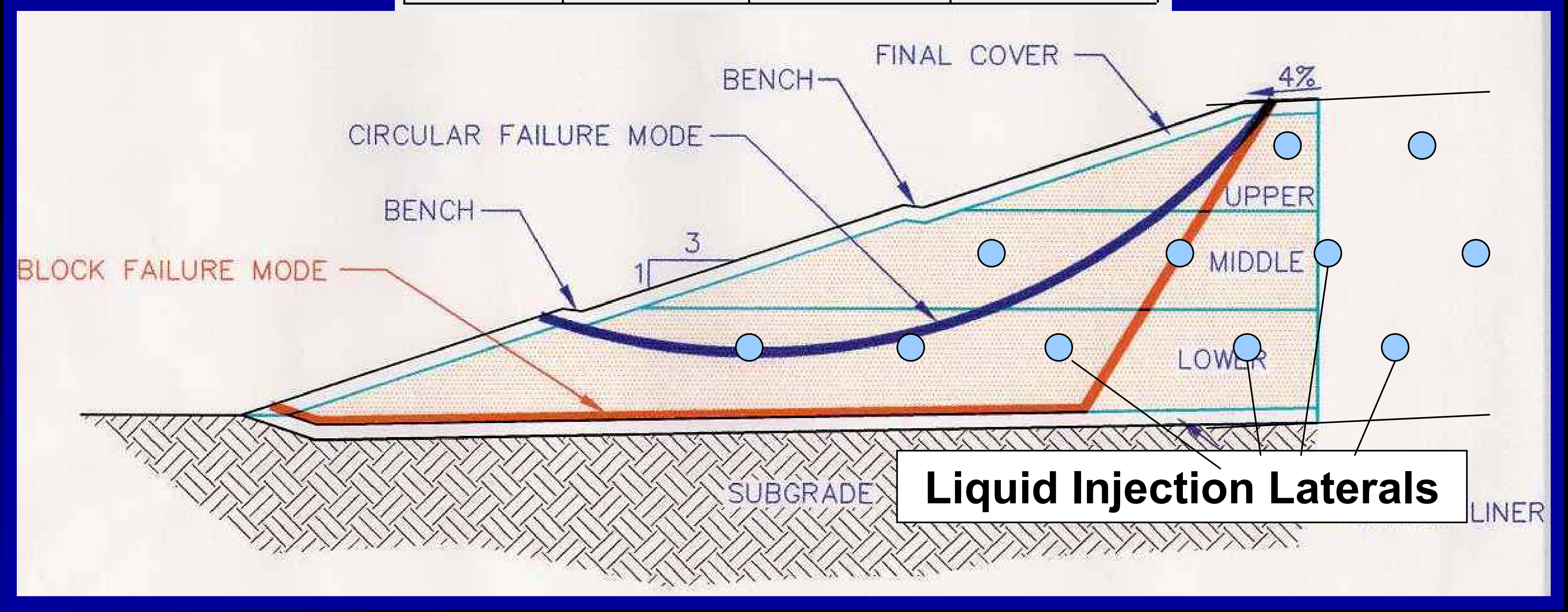
TYPE I: Limited or intermittent recirculation
>25% waste density increase

TYPE II: Moderate, controlled recirculation (below field capacity)
>50% waste density increase

TYPE III: Heavy recirculation; at field capacity
~75% waste density increase

Sensitivity Modeling Parameters

LAYER BioType:	DENSITY (pcf) O →III	FRICTION (degrees) O →III	COHESION (psf) O →III
Upper	45 →78.8	26 → 18	200 → 40
Middle	55 →96.3	30 → 22	250 → 50
Lower	65 →113.8	34 → 26	300 → 60



Geotechnical Design Considerations

- What is the goal?
  - Capacity, leachate control and treatment, gas
  - What type of bioreactor?
- Shear strength and density will change
- Prevent excess pore pressures
- Revise filling sequences
- Set risk based FS values

What Geotechs Need To Do

- Testing and standards for waste shear strength and compressibility
- Database
- Improved monitoring methods

What Operations Should Consider

- Monitor liquids additions continuously
- Maintain moisture below waste field capacity
- Keep liquids away from slopes
- Develop an operations plan
- Monitor performance and resolve


FINAL COMMENTS . . .
Pipe