Lateral and Vertical Expansions Over Old Landfills

1. Needs and Objectives
2. General Concept
3. Lateral Expansions
4. Vertical Expansions
5. Accelerated Degradation
6. Post-Closure Site Usage
7. Summary

1. Needs and Objectives

- over 10,000 abandoned dumps in USA
- many more worldwide
- linings are nonexistent or nominal
- connectedness to ecological pathways are common (surface water, groundwater, air, and contaminated soil)
- need exists for engineered final cover

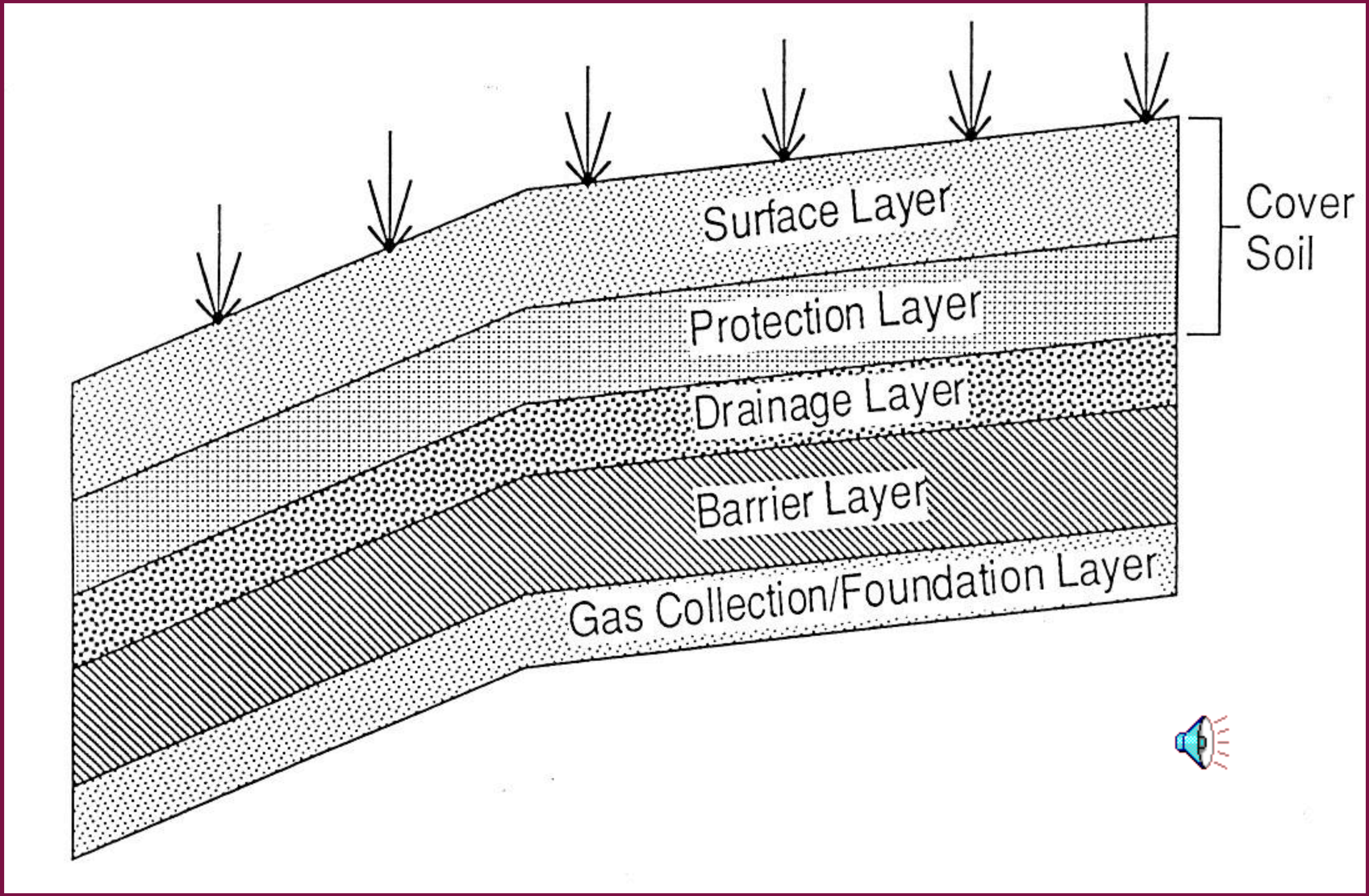
Example: Commonwealth of Virginia

- closure bill for old landfills in 1993
- HB 1205 identified 39 sites to be closed by 2020
- prioritized into high, medium, low rank
- model considered groundwater, surface water, air emissions, soil contamination
- ≃ 10 by 2005; ≃ 15 by 2010; 14 by 2020
- bill is silent on funding, i.e., funding is left to the local communities (more later)

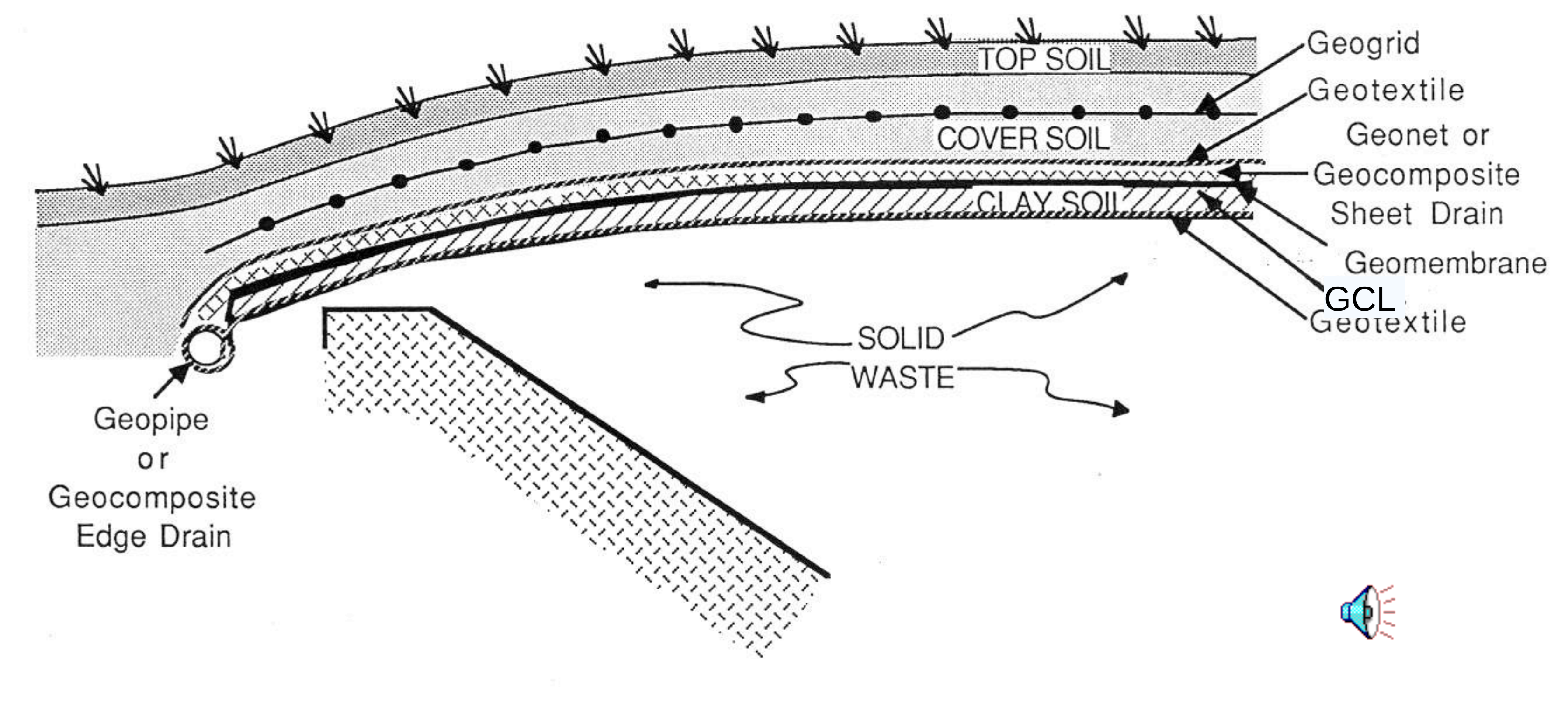
Elements of Final Cover (top-to-bottom)

- properly vegetated topsoil over the entire ground surface
- protection layer, i.e., thick soil layer
- drainage layer to peripheral outlets
- suitable barrier layer
- gas collection layer to proper vents
- foundation layer over underlying densified waste

The Essential Layers



Geosynthetic Design for Landfill Covers



Estimated Costs of Engineered Final Cover:

Item	Description	Cost/acre	Cost/ha
exploration	soundings/test pits	15,000	31,000
design	plans/specifications/permits	25,000	62,000
construction	earthwork/geosynthetics	70,000	172,000
inspection	MQA/CQA	10,000	25,000
guarantees	insurance/bonding	20,000	50,000
maintenance	vegetation/fencing/signage	10,000	25,000
TOTAL		$150,000	$365,000

*these are approximate 2001 costs; they are extremely site specific and can vary by as much as 50%

Cost Payment Methods

Method	Advantage	Disadvantage
superfund	locals don't pay	program being starved
federal grant	locals get relief	not very likely
state grant	locals get relief	even less likely
local bond	locals have control	locals pay directly
waste surcharge	locals have control	can be almost invisible*

*make it a local business!

2.0 General Concept

(a) Compact and grade old landfill

(b) develop and line lateral expansion

(c) place new waste in expansion

(d) develop and line another lateral expansion(s)

(e) place new waste in expansion

(f) place waste in vertical expansion

(g) provide final cover and use site!

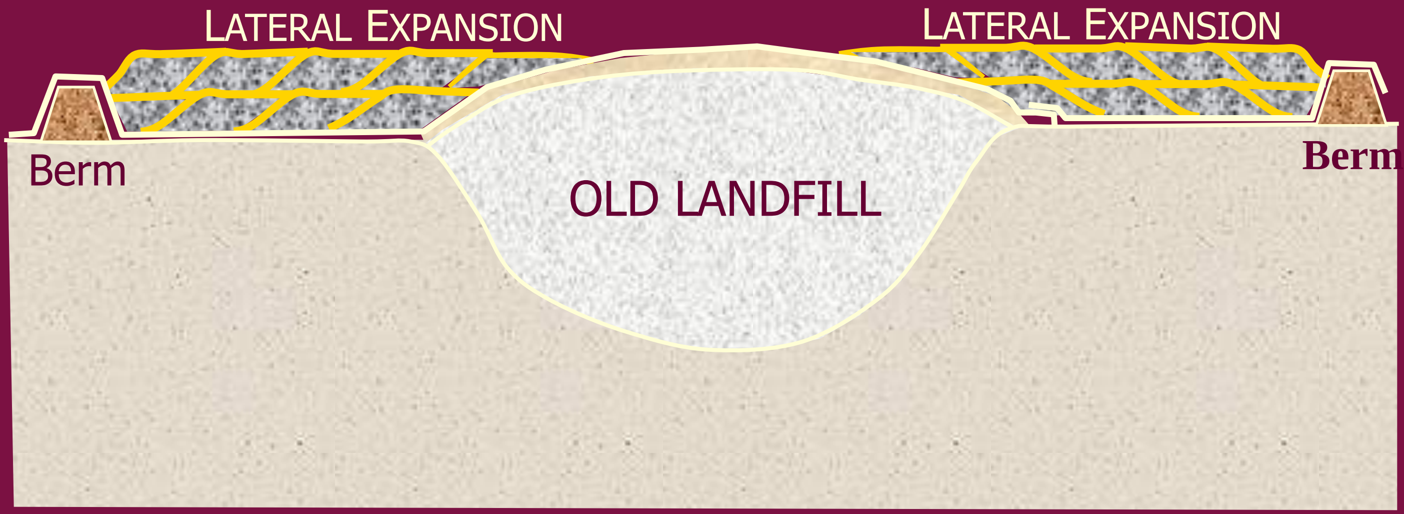
(a) Compact and grade old landfill

(b) Develop and line a lateral expansion to one side of old landfill

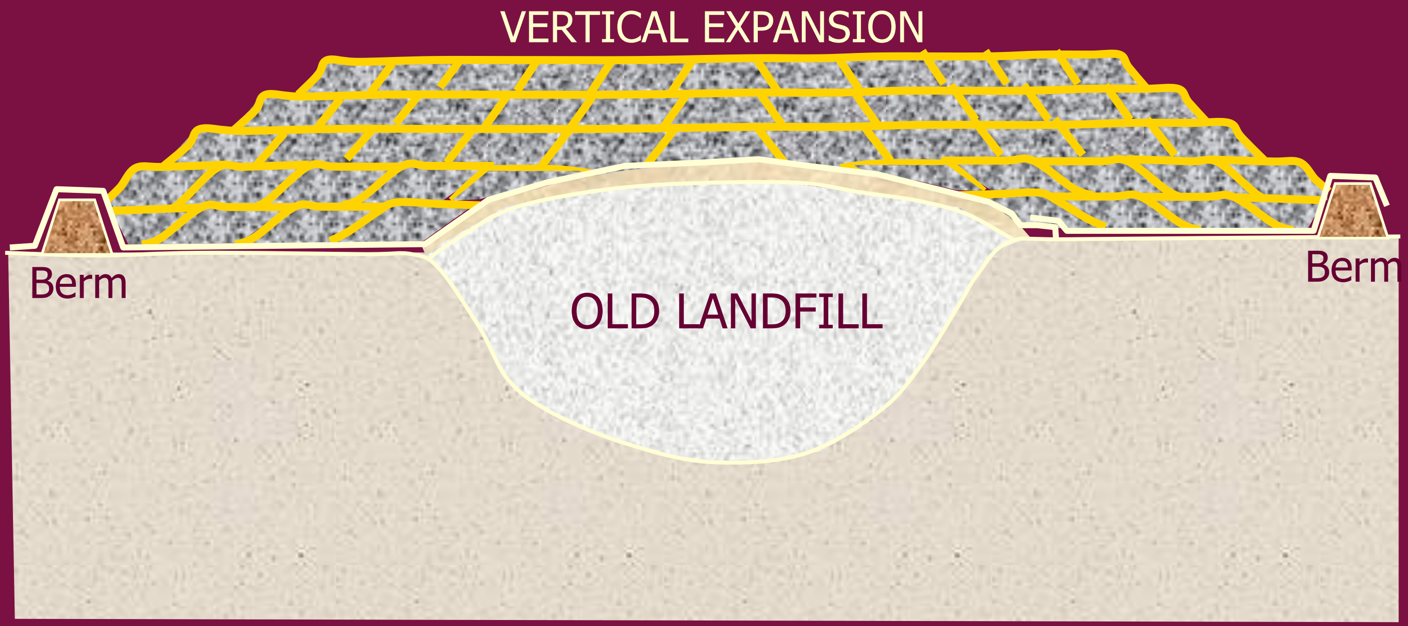
(c) Place new waste in this expansion and provide temporary cover

(d) Develop and line a lateral expansion to another side as site allows

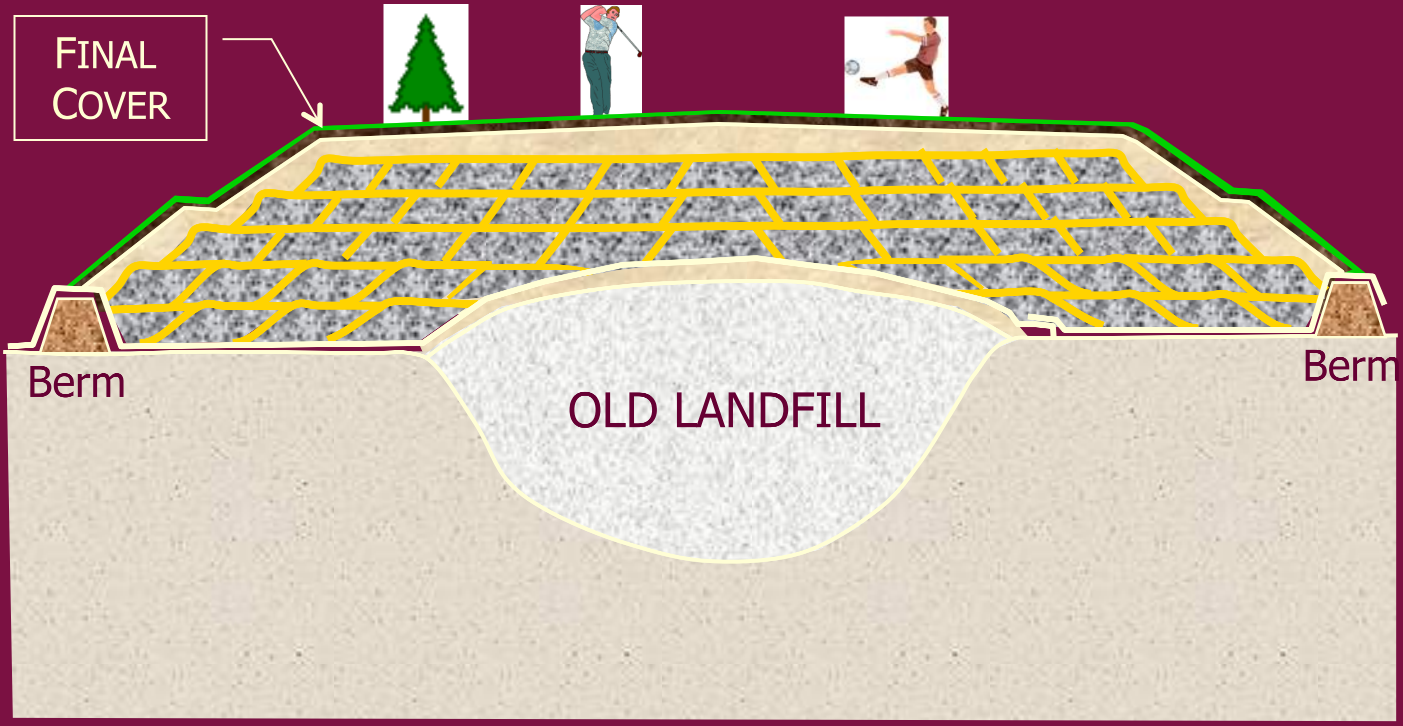
(e) Place new waste in this expansion(s) and provide temporary cover



(f) Place new waste above these expansions in the form of a vertical expansion



(g) When permitted height is reached, provide final cover and use site for beneficial use



3. Lateral Expansions

3.1 Decide on Concept and Orientation
3.2 Select Tentative Cross Section
3.3 Estimate Old Landfill Settlement
3.4 Assess Liner System Behavior
3.5 Select/Specify Appropriate Geosynthetics
3.6 Provide Design Details, Plans, Specifications and QA Document

3.1 Decide on Concept and Orientation

- issue is completely site specific
- consider limitations on adjacent land
    - surface water and groundwater
    - wetlands
    - roads and utilities
    - buildings and infrastructure
- assemble concept plan including footprint, elevations and liquids management program, i.e. dry cell or wet cell

3.2 Select Tentative Cross Section

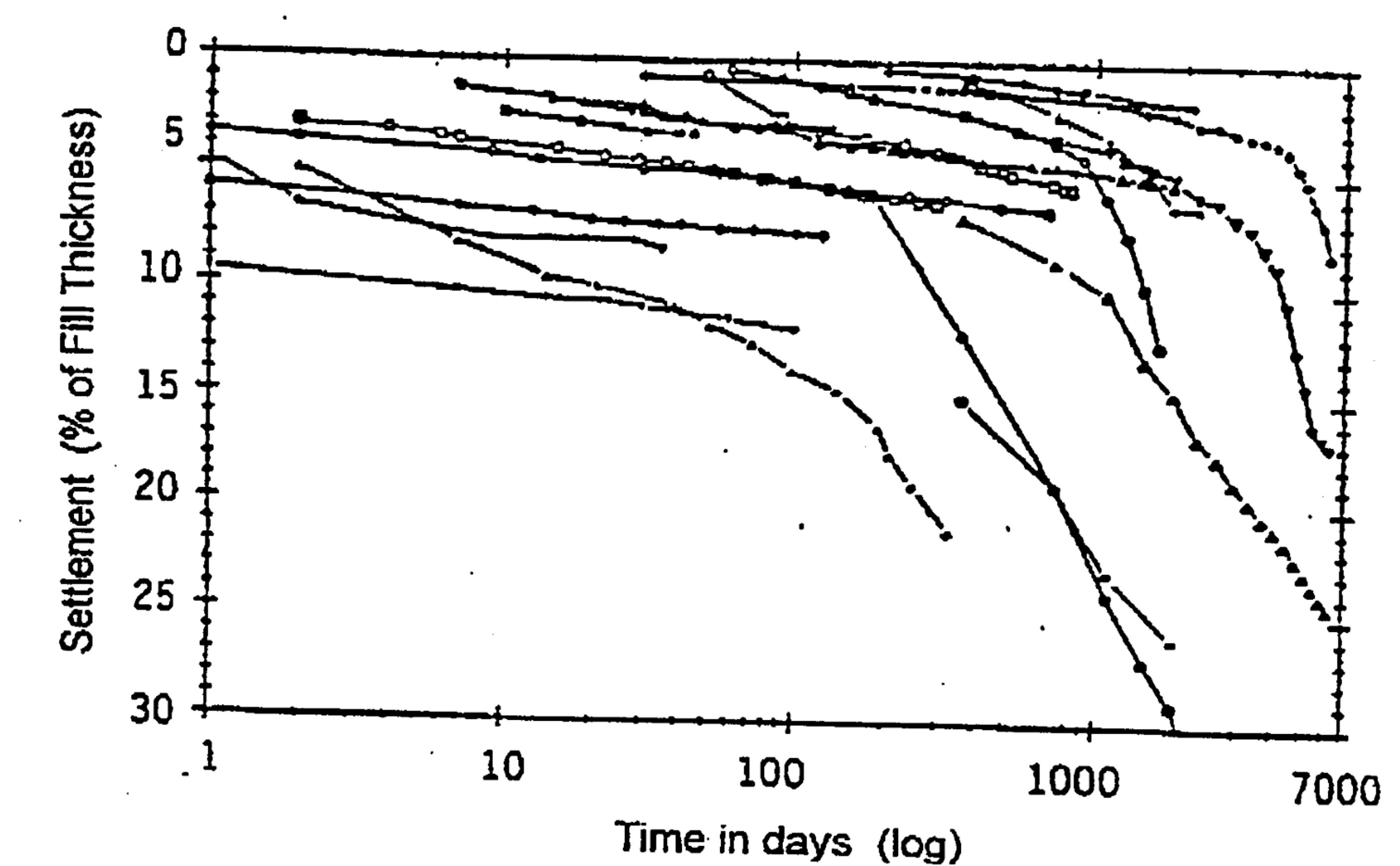
- strong tendency to use geosynthetics
  - ease of placement and maneuverability
  - low weight – hence minimize settlement
  - thin – hence maximize air space
  - cost effective and proven
- single barrier system: GM or GM/GCL
- double barrier system: GM-GC-GM or GM-GC-GM/GCL or GM/GCL-GC-GM/GCL
- drainage system: GC or Sand/GC
- gas collection system: site specific

Compaction of the Old Landfill

- concern is both total and differential settlement
- depends on age, composition, thickness, placement and original site subgrade
- heavy proofrolling is generally adequate
- deep dynamic compaction may be advisable or necessary
- finish by appropriate contouring with native soil (this is foundation for new liner)
- place new liner system accordingly

3.3 Estimate Old Landfill Settlement

(a) based on past experience (Bjarngard & Edgers, 1990)



(b) empirical methods for waste settlement

b1. logarithmic function (Yen and Scanlon, 1975)

$$S = m + n \cdot \log t$$

where

S = settlement between time interval, i.e., $S = S_i - S_o$ (m);
t = difference between time of interest and time of the start of measurement, i.e., $t = t_i - t_o$ (days);
m = empirical constant
n = empirical constant

b2. power function (Edil, et al., 1990)

$$S = p \cdot t^q$$

where

S = settlement between time interval, i.e., $S = S_i - S_o$ (m);
t = difference between time of interest and time of the start of measurement, i.e., $t = t_i - t_o$ (days);
p = empirical constant, $p = p'/q$;
q = empirical constant, $q = 1 - q'$.

b3. hyperbolic function (Ling, et al., 1998)

$$S = \frac{t}{1/\rho_o + t/S_{ult}}$$

where

S = difference between settlement at time t_1 and that measured at time t_o, i.e., $S = S_i - S_o$ (m);

t = difference between time of interest and time of the start of measurement, i.e., $t = t_i - t_o$ (days);

ρ_o = initial rate of settlement at $t = t_o$;

S_{ult} = ultimate settlement, i.e., $t \rightarrow \infty$

(c) geotechnical modeling for waste settlement

Total = Primary (Waste) + Secondary (Waste) + Foundation Settlement

$$H = \Delta H_c + \Delta H_\alpha + z$$

c1. primary settlement of waste

$$f H_c = C_c \frac{H_o}{1 + e_o} \log \frac{\hat{U}_o + f\hat{U}}{\hat{U}_o}$$

where

$$f H_c = C'_c \cdot H_o \cdot \log \frac{\hat{U}_o + f\hat{U}}{\hat{U}_o}$$

ΔH_c = primary settlement;
e_o = initial void ratio of the waste;
H_o = initial thickness of the waste;
C_c = primary compression index;
C'_c = modified primary compression index, $C'_c = 0.17 \sim 0.36$;
σ_o = existing overburden pressure acting at the mid level of the waste;
$\Delta\sigma$ = overburden pressure due to expansion or other extra load.

c2. secondary settlement of waste

$$\Delta H_{\alpha} = C_{\alpha} \frac{H_o}{1 + e_o} \log \frac{t_2}{t_1}$$

$$\Delta H_{\alpha} = C'_{\alpha} \cdot H_o \cdot \log \frac{t_2}{t_1}$$

where

ΔH_{α} = secondary settlement;
e_o = initial void ratio of the waste before starting secondary settlement;
H_o = initial thickness of waste before starting secondary settlement;
C_{α} = secondary compression index;
C'_{α} = modified secondary compression index, $C'_{\alpha} = 0.03 \sim 0.1$;
t_1 = starting time of the secondary settlement;
t_2 = ending time of the secondary settlement.

c3. foundation settlement

$$Z = Z_e + Z_c + Z_\alpha$$

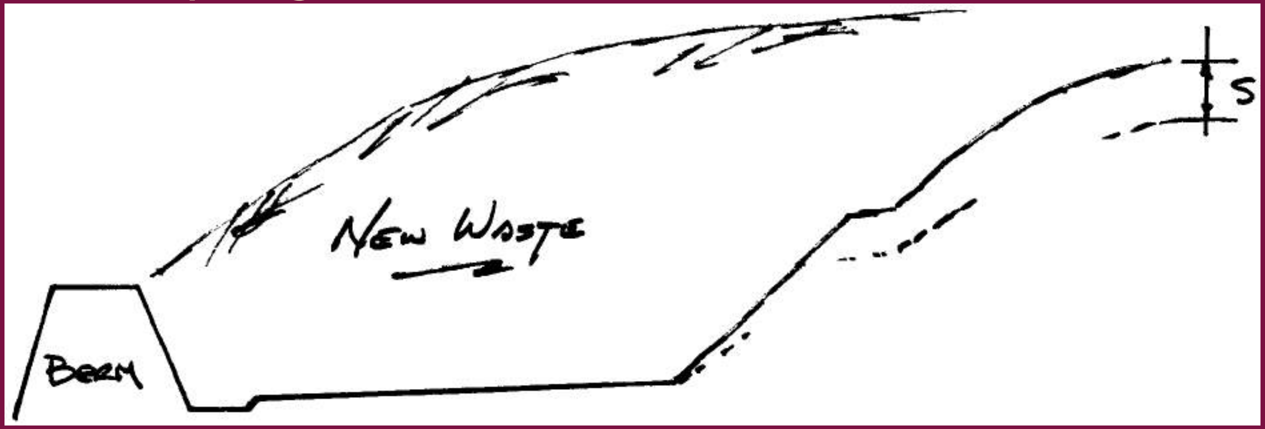
where

Z = total settlement
Z_e = elastic settlement
Z_c = primary consolidation settlement
Z_α = secondary consolidation settlement

[formulas are in Qian, Koerner and Gray, 2001]

3.4 Assess Liner System Behavior

- Barrier materials (GMs & GCLs) can accommodate relatively large total settlements



- Drainage layers (GCs) should grade away from old landfill
- Sump to be located at edge of site or against a berm
- If graded backwards, leachate collection at toe of old landfill will require piping (great concern)

3.5 Select/Specify Appropriate Geosynthetics

- geosynthetic clay liner
  - anticipate high internal shear stresses on steep slopes
  - probably results in a reinforced GCL with needle punched nonwoven GTs on both sides
- geocomposite drainage material
  - flow rate controlled by flat runout of new cell
  - may require sand or gravel to augment biplanar GN
  - triplanar may be good by itself if no orientation can be properly accommodated
  - thermally bond the GTs to GN
- geomembrane
  - Consider using a benefit/cost matrix

Benefit/Cost Procedure

(a) select relevant site-specific properties

(b) weight properties from 10 (highest) to 1 (lowest)

(c) select candidate GM types

(d) weight types from 5 (high) to 1 (low)

(e) multiply properties and types

(f) add resulting numbers

(g) divide by estimated costs

(h) select GM with the highest benefit/cost ratio and specific accordingly

Typical B/C Matrix Layout

Property	Weighting	HDPE		LLDPE		fPP-R		PVC		CSPE-R	
chem. resist.											
durability											
UV stab.											
shear strength											
stress crack											
seameability											
seam behavior											
strength											
elongation											
tear											
puncture											
impact											
exp./cont.											
constructability											
benefit	n/a										
cost/m^2	n/a										
B/C ratio	n//a										

Example B/C Matrix for MSW-LF Expansion

Property	Weighting
chem. resist.	10
durability	10
UV stab.	3
shear strength	6
stress. Crack	10
seamability	8
seam behavior	8
strength	5
elongation	7
tear	5
puncture	5
impact	5
exp./cont.	5
constructability	8
benefit	n/a
cost/m^2	n/a
B/C ratio	n/a

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE	
chem. resist.	10	5	
durability	10	5	
UV stab.	3	5	
shear strength	6	5	
stress. Crack	10	1	
seamability	8	4	
seam behavior	8	4	
strength	5	5	
elongation	7	5	
tear	5	5	
puncture	5	5	
impact	5	5	
exp./cont.	5	2	
constructability	8	3	
benefit	n/a	-	
cost/m^2	n/a	-	
B/C ratio	n/a	-	

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE	
chem. resist.	10	5	50
durability	10	5	50
UV stab.	3	5	15
shear strength	6	5	30
stress. Crack	10	1	10
seamability	8	4	32
seam behavior	8	4	32
strength	5	5	25
elongation	7	5	35
tear	5	5	25
puncture	5	5	25
impact	5	5	25
exp./cont.	5	2	10
constructability	8	3	24
benefit	n/a	-	388
cost/m^2	n/a	-	10.00
B/C ratio	n/a	-	38.8

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE	
chem. resist.	10	5	50	3	
durability	10	5	50	3	
UV stab.	3	5	15	3	
shear strength	6	5	30	5	
stress. Crack	10	1	10	4	
seamability	8	4	32	3	
seam behavior	8	4	32	3	
strength	5	5	25	4	
elongation	7	5	35	5	
tear	5	5	25	4	
puncture	5	5	25	4	
impact	5	5	25	4	
exp./cont.	5	2	10	3	
constructability	8	3	24	4	
benefit	n/a	-	388	-	
cost/m^2	n/a	-	10.00	-	
B/C ratio	n/a	-	38.8	-	

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE	
chem. resist.	10	5	50	3	30
durability	10	5	50	3	30
UV stab.	3	5	15	3	9
shear strength	6	5	30	5	30
stress. Crack	10	1	10	4	40
seamability	8	4	32	3	24
seam behavior	8	4	32	3	24
strength	5	5	25	4	20
elongation	7	5	35	5	35
tear	5	5	25	4	20
puncture	5	5	25	4	20
impact	5	5	25	4	20
exp./cont.	5	2	10	3	15
constructability	8	3	24	4	32
benefit	n/a	-	388	-	349
cost/m^2	n/a	-	10.00	-	10.50
B/C ratio	n/a	-	38.8	-	33.2

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R	
chem. resist.	10	5	50	3	30	3	
durability	10	5	50	3	30	3	
UV stab.	3	5	15	3	9	3	
shear strength	6	5	30	5	30	3	
stress. Crack	10	1	10	4	40	5	
seamability	8	4	32	3	24	3	
seam behavior	8	4	32	3	24	3	
strength	5	5	25	4	20	5	
elongation	7	5	35	5	35	1	
tear	5	5	25	4	20	4	
puncture	5	5	25	4	20	4	
impact	5	5	25	4	20	4	
exp./cont.	5	2	10	3	15	5	
constructability	8	3	24	4	32	4	
benefit	n/a	-	388	-	349	-	
cost/m^2	n/a	-	10.00	-	10.50	-	
B/C ratio	n/a	-	38.8	-	33.2	-	

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R	
chem. resist.	10	5	50	3	30	3	30
durability	10	5	50	3	30	3	30
UV stab.	3	5	15	3	9	3	9
shear strength	6	5	30	5	30	3	18
stress. Crack	10	1	10	4	40	5	50
seamability	8	4	32	3	24	3	24
seam behavior	8	4	32	3	24	3	24
strength	5	5	25	4	20	5	25
elongation	7	5	35	5	35	1	7
tear	5	5	25	4	20	4	20
puncture	5	5	25	4	20	4	20
impact	5	5	25	4	20	4	20
exp./cont.	5	2	10	3	15	5	25
constructability	8	3	24	4	32	4	32
benefit	n/a	-	388	-	349	-	334
cost/m^2	n/a	-	10.00	-	10.50	-	11.25
B/C ratio	n/a	-	38.8	-	33.2	-	29.7

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R		PVC	
chem. resist.	10	5	50	3	30	3	30	2	
durability	10	5	50	3	30	3	30	2	
UV stab.	3	5	15	3	9	3	9	1	
shear strength	6	5	30	5	30	3	18	3	
stress. Crack	10	1	10	4	40	5	50	5	
seamability	8	4	32	3	24	3	24	3	
seam behavior	8	4	32	3	24	3	24	3	
strength	5	5	25	4	20	5	25	3	
elongation	7	5	35	5	35	1	7	5	
tear	5	5	25	4	20	4	20	3	
puncture	5	5	25	4	20	4	20	3	
impact	5	5	25	4	20	4	20	3	
exp./cont.	5	2	10	3	15	5	25	4	
constructability	8	3	24	4	32	4	32	4	
benefit	n/a	-	388	-	349	-	334	-	
cost/m^2	n/a	-	10.00	-	10.50	-	11.25	-	
B/C ratio	n/a	-	38.8	-	33.2	-	29.7	-	

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R		PVC	
chem. resist.	10	5	50	3	30	3	30	2	20
durability	10	5	50	3	30	3	30	2	20
UV stab.	3	5	15	3	9	3	9	1	3
shear strength	6	5	30	5	30	3	18	3	18
stress. Crack	10	1	10	4	40	5	50	5	50
seamability	8	4	32	3	24	3	24	3	24
seam behavior	8	4	32	3	24	3	24	3	24
strength	5	5	25	4	20	5	25	3	15
elongation	7	5	35	5	35	1	7	5	35
tear	5	5	25	4	20	4	20	3	15
puncture	5	5	25	4	20	4	20	3	15
impact	5	5	25	4	20	4	20	3	15
exp./cont.	5	2	10	3	15	5	25	4	20
constructability	8	3	24	4	32	4	32	4	32
benefit	n/a	-	388	-	349	-	334	-	306
cost/m^2	n/a	-	10.00	-	10.50	-	11.25	-	9.00
B/C ratio	n/a	-	38.8	-	33.2	-	29.7	-	34.0

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R		PVC		CSPE-R	
chem. resist.	10	5	50	3	30	3	30	2	20	4	
durability	10	5	50	3	30	3	30	2	20	4	
UV stab.	3	5	15	3	9	3	9	1	3	5	
shear strength	6	5	30	5	30	3	18	3	18	3	
stress. Crack	10	1	10	4	40	5	50	5	50	5	
seamability	8	4	32	3	24	3	24	3	24	3	
seam behavior	8	4	32	3	24	3	24	3	24	3	
strength	5	5	25	4	20	5	25	3	15	5	
elongation	7	5	35	5	35	1	7	5	35	1	
tear	5	5	25	4	20	4	20	3	15	4	
puncture	5	5	25	4	20	4	20	3	15	4	
impact	5	5	25	4	20	4	20	3	15	4	
exp./cont.	5	2	10	3	15	5	25	4	20	5	
constructability	8	3	24	4	32	4	32	4	32	4	
benefit	n/a	-	388	-	349	-	334	-	306	-	
cost/m^2	n/a	-	10.00	-	10.50	-	11.25	-	9.00	-	
B/C ratio	n/a	-	38.8	-	33.2	-	29.7	-	34.0	-	

Example B/C Matrix for MSW-LF Expansion

Property	Weighting	HDPE		LLDPE		fPP-R		PVC		CSPE-R	
chem. resist.	10	5	50	3	30	3	30	2	20	4	40
durability	10	5	50	3	30	3	30	2	20	4	40
UV stab.	3	5	15	3	9	3	9	1	3	5	15
shear strength	6	5	30	5	30	3	18	3	18	3	18
stress. Crack	10	1	10	4	40	5	50	5	50	5	50
seamability	8	4	32	3	24	3	24	3	24	3	24
seam behavior	8	4	32	3	24	3	24	3	24	3	24
strength	5	5	25	4	20	5	25	3	15	5	25
elongation	7	5	35	5	35	1	7	5	35	1	7
tear	5	5	25	4	20	4	20	3	15	4	20
puncture	5	5	25	4	20	4	20	3	15	4	20
impact	5	5	25	4	20	4	20	3	15	4	20
exp./cont.	5	2	10	3	15	5	25	4	20	5	25
constructability	8	3	24	4	32	4	32	4	32	4	32
benefit	n/a	-	388	-	349	-	334	-	306	-	360
cost/m^2	n/a	-	10.00	-	10.50	-	11.25	-	9.00	-	12.50
B/C ratio	n/a	-	38.8	-	33.2	-	29.7	-	34.0	-	28.8

Upon GM Selection – Spec It!

- HPDE use GRI-GM13
- LLDPE use GRI-GM17
- fPP-R use GRI-GM18
- EPDM use GRI-GM21
- CSPE-R use NSF 54 (dep.)
- PVC use PVC-GM Inst.

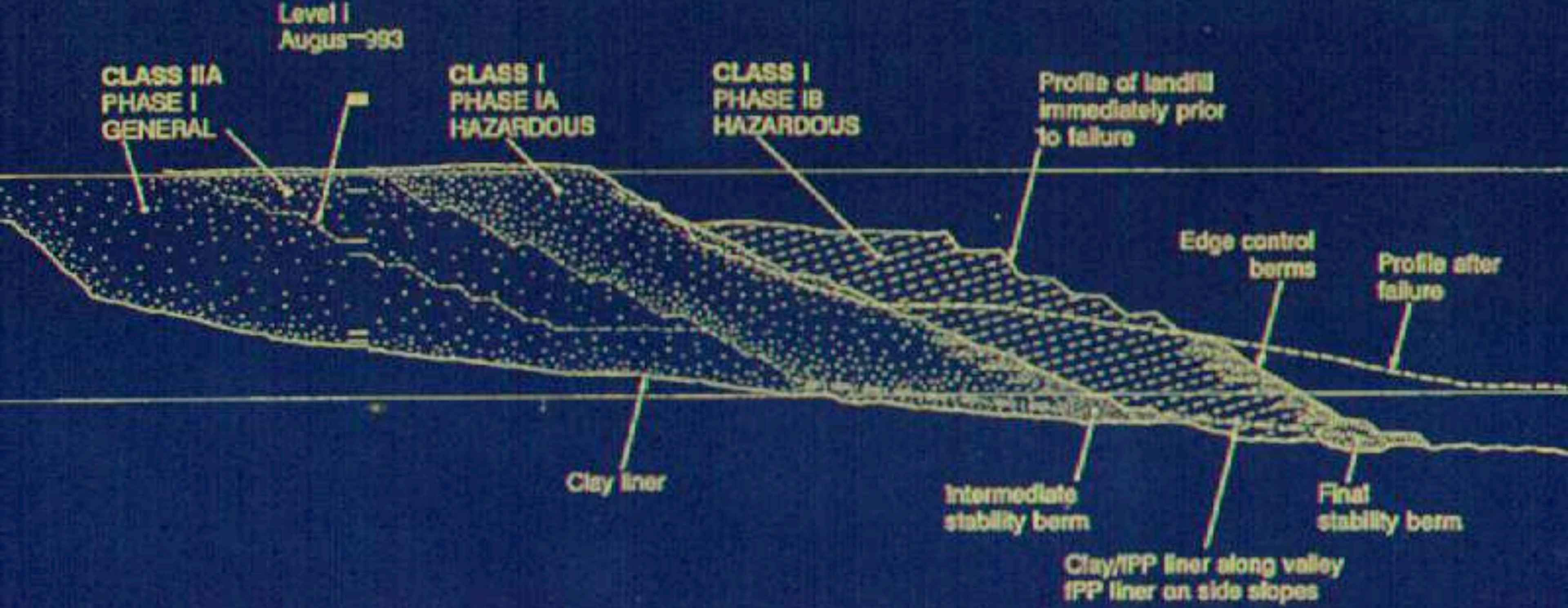
3.6 Provide Design Details, Plans & Specifications and QA Document

(a) Liquids Collection

- sump details (leachate & leakage)
- exit toward edge of expansion
- consider use of a cell termination berm
- provides boundary and stability
- if space limited, berm can be MSE reinforced with GGs or GTs

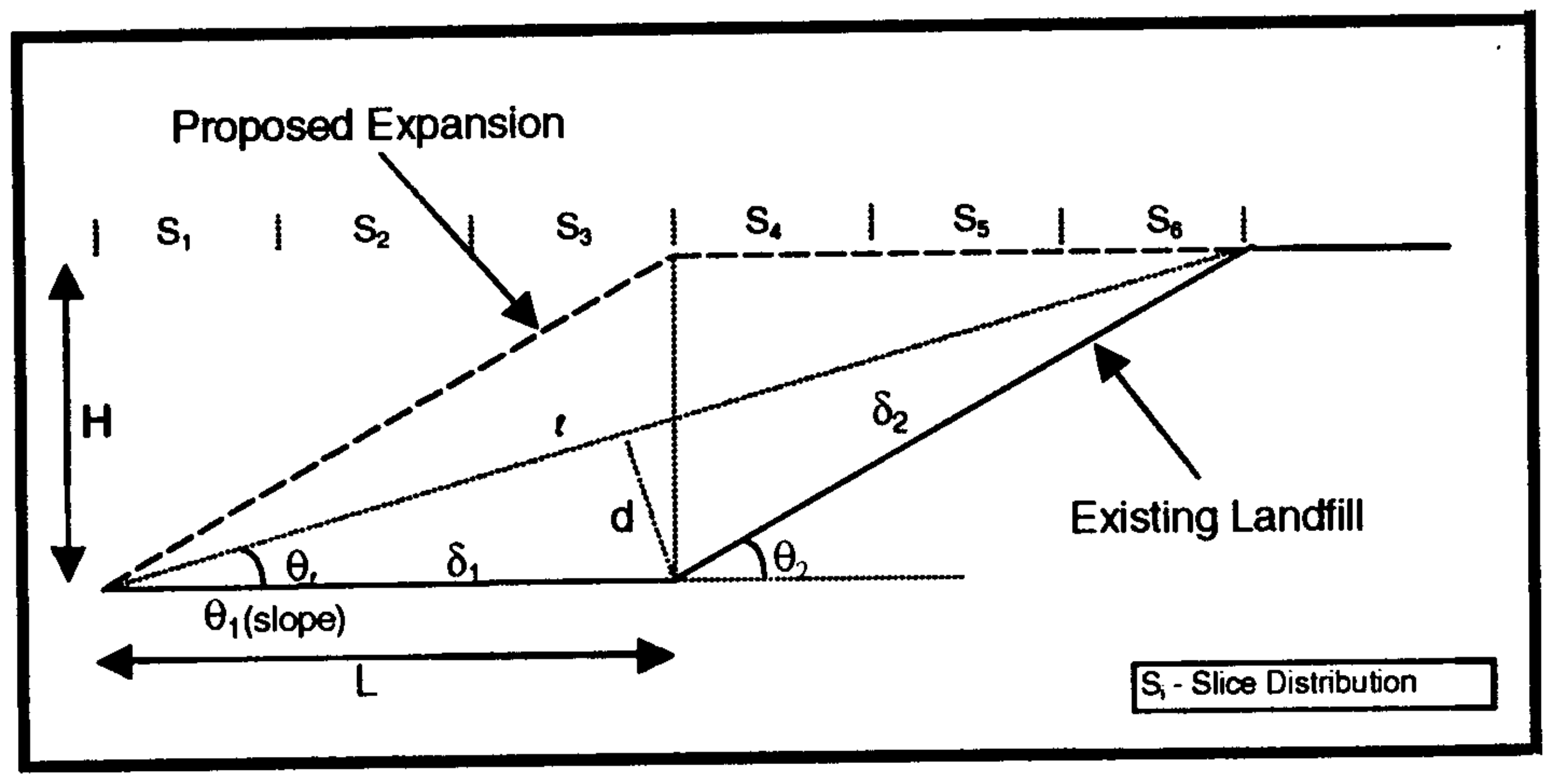
(b) Check Overall Stability

- interfaces and slopes are oriented for a translational type-failure
- if base slope is high be very cautious
- downstream berm is a resisting force
- If massive enough ($) – it resists great
- see Koerner and Soong (2000) for waste stability analysis
- large waste movements are not unknown



SECTION THROUGH LANDFILL

Landfill Lateral Expansion

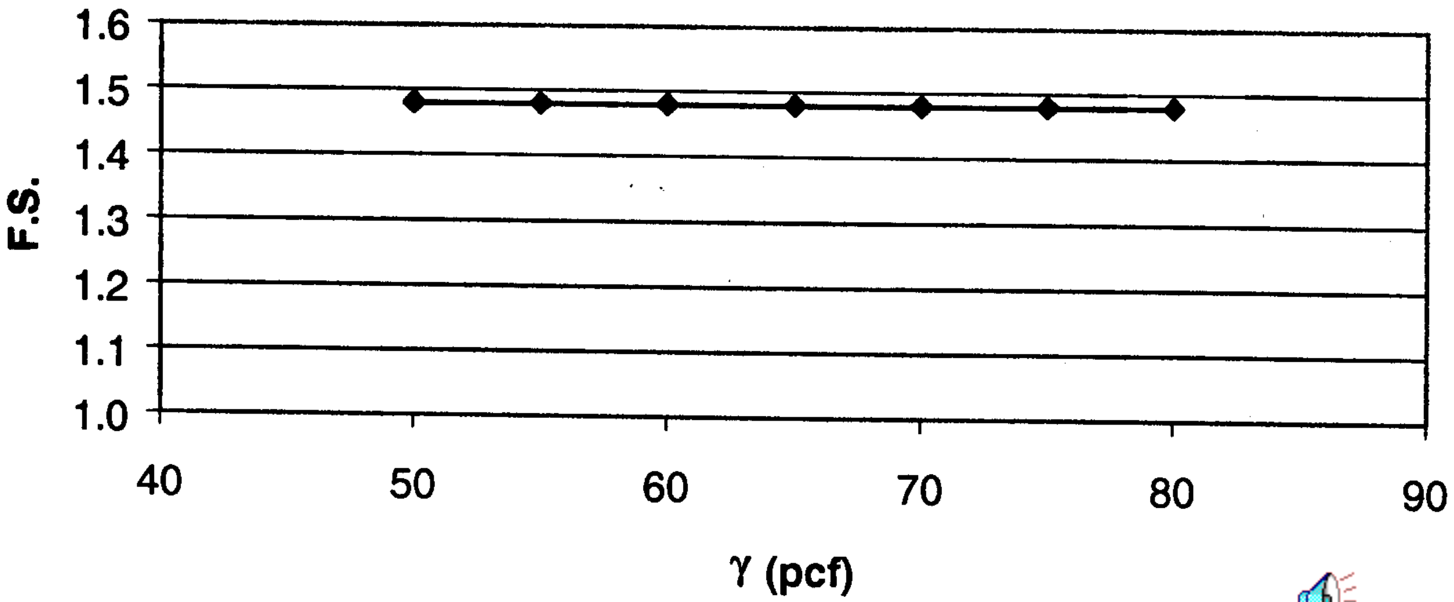


Example: What is the FS for the lateral expansion shown using the following input data:

L = 67 m (220 ft.) θ_1 = 10° δ_1 = 8°
H = 48 m (157 ft.) θ_2 = 23° δ_2 = 14°

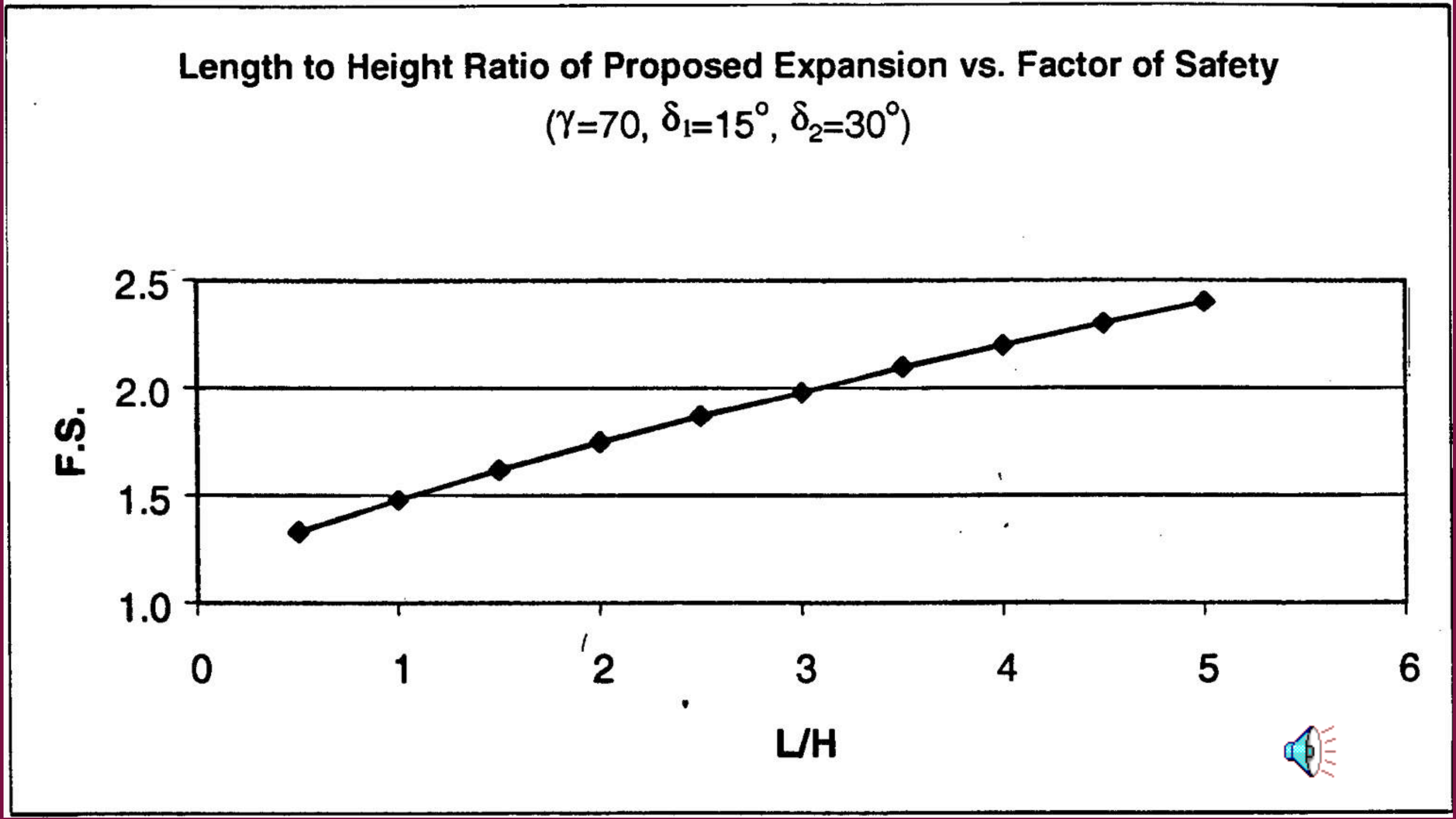
Solution: Uses spread sheet analysis

FS = 0.92 $\therefore$ failure!



Unit Weight of Municipal Sodid Waste vs. Factor of Safety

(L/H=1, δ_1=15°, δ_2=30°)

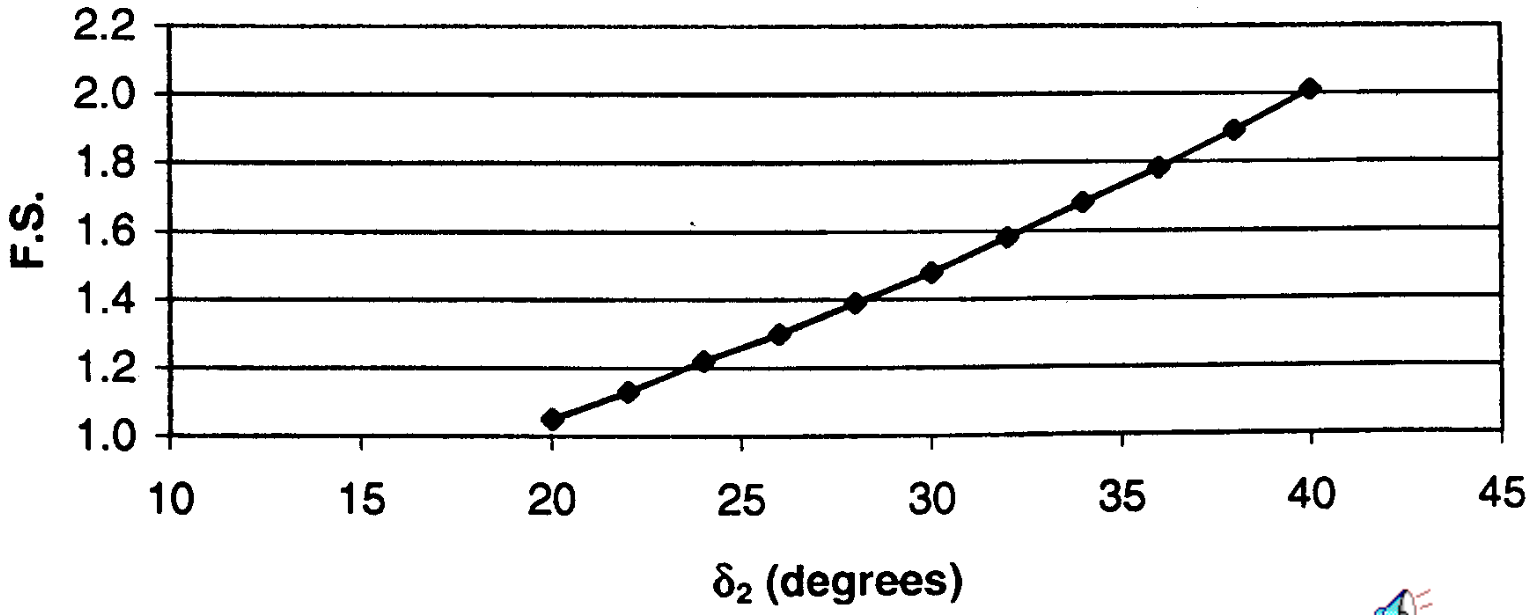


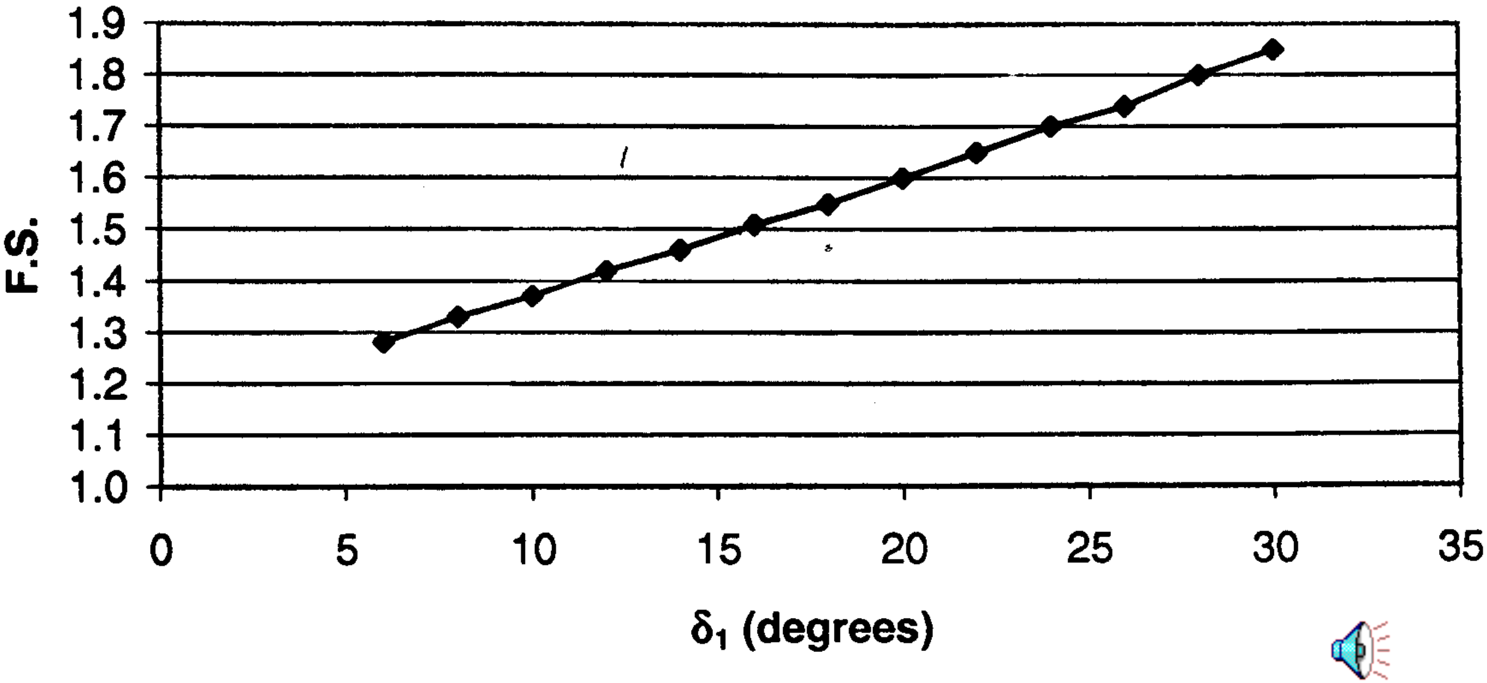
Length to Height Ratio of Proposed Expansion vs. Factor of Safety

(γ=70, δ_1=15°, δ_2=30°)

Existing Landfill Interface Friction Angle vs. Factor of Safety

(γ=70, δ_1=15°, L/H=1)





GS Interface Friction Angle vs. Factor of Safety

(γ=70, δ_2=30°, L/H=1)

(c) Liquids from “Old” Landfill

- remove from opposite side of lateral expansion
- may require directional drilling if no existing leachate collection system
- may require downstream cutoff wall
- very site specific situation

(d) Gas from “Old” Landfill

- hopefully gas generation is beyond its peak
- if so, do nothing since pressures and amounts become minimal over time
- if not, use thick GT beneath barrier layer
- exit on opposite side of the lateral expansion

(e) Provide Temporary Cover

- concern is over air pollution
- if vertical expansion is planned, use temporary cover on top of new lateral expansion
- major considerations: UV durability, temperature stability, anchorage against wind, aesthetics (?)
- consider using benefit/cost ratio matrix for EGMC as previously illustrated

EGMC over Cells 1 and 2 of the DSWA's southern facility.

A 16-acre EGMC placed over MSW landfill in Louisiana.

Exposed Geomembrane Covers (ref. Gleason, et al. 2001, NAGS)

Location	Area (ha)	GM	Thickness (mm)	Color	Fixity
Delaware	17	fPP-R	0.9	green	RB, An, DS
Maine	2	HDPE	1.0	black	DS, Ba
Florida	9	HDPE	1.5	black	AT, Ba
Louisiana	6	HDPE-T	1.5	green	AT, DS

Note: AT = anchor trenches; RB = roadway benches; An = anchors;
DS = drainage swales; Ba = ballast

Exposed GM Cover Design

- concern is over wind uplift
- mainly on leeward side…if known
- tires are insufficient….for hold-down use anchor trenches, swales and road berms
- nice series of 3 articles in GFR by Richardson, et al. (2000-01)
- other strategies are also possible

4. Vertical Expansions

4.1 Define General Conditions and Parameters

4.2 Select Tentative Cross-Section

4.3 Estimate Old Landfill Settlement

4.4 Analyze and Design for Differential Settlement

4.5 Provide Design Details, Plans & Spec

4.1 Define General Conditions and Parameters

- issue is completely site-specific
- consider footprint and height
- consider access for both construction and operations
- decide on liquids management strategy
- wet landfills to be discussed later

4.2 Select Tentative Cross Section

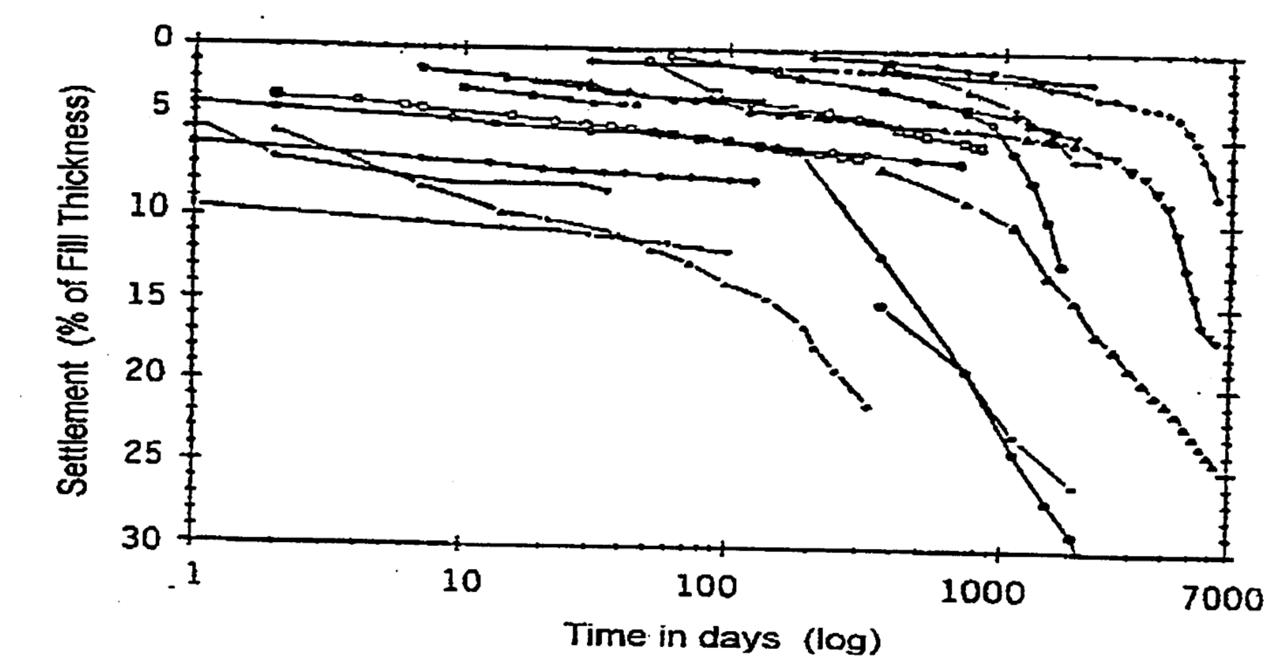
- strong tendency to use geosynthetics
  - ease of placement and maneuverability
  - low weight – hence minimize settlement
  - thin – hence maximize air space
  - cost effective and proven
- single barrier system: GM or GM/GCL
- double barrier system: GM-GC-GM or GM-GC-GM/GCL or GM/GCL-GC-GM/GCL
- drainage system: GC or Sand/GC
- gas collection system: generally omit

Compaction of the “Old” Landfill

- depends on age, composition, thickness, placement and original site subgrade
- heavy proofrolling is generally adequate
- deep dynamic compaction may be advisable or necessary
- finish by uniform contouring with native soil
- place new liner system accordingly
- concern is both total and differential settlement

4.3 Estimate Old Landfill Settlement

(a) based on past experience (Bjarngard & Edgers, 1990)



(b) empirical methods: e.g., logarithmic, power function and hyperbolic
(c) geotechnical modelling

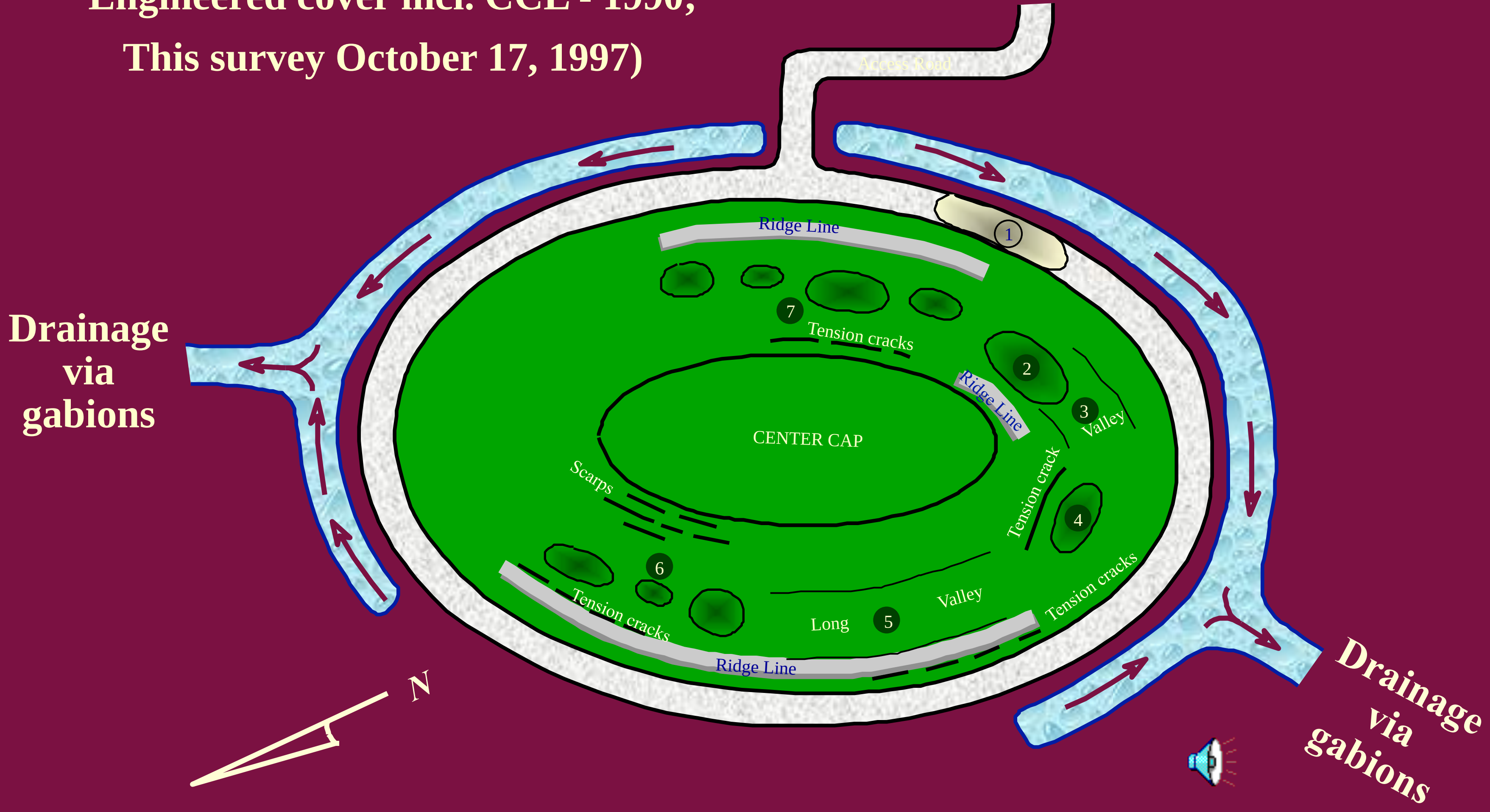
How About the Possibility of Differential Settlement ?

Differential Settlement of Final Cover

40 hectare MSW landfill (1969-1978)

Engineered cover incl. CCL - 1990;

This survey October 17, 1997)



4.4 Analyze and Design for Differential Settlement

Methods to Estimate Localized Subsidence*

- mine subsidence method
- numerical method
- displacement method
- elastic solution

Alternatively, use past experience

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*see Qian, Koerner & Gray, 2001

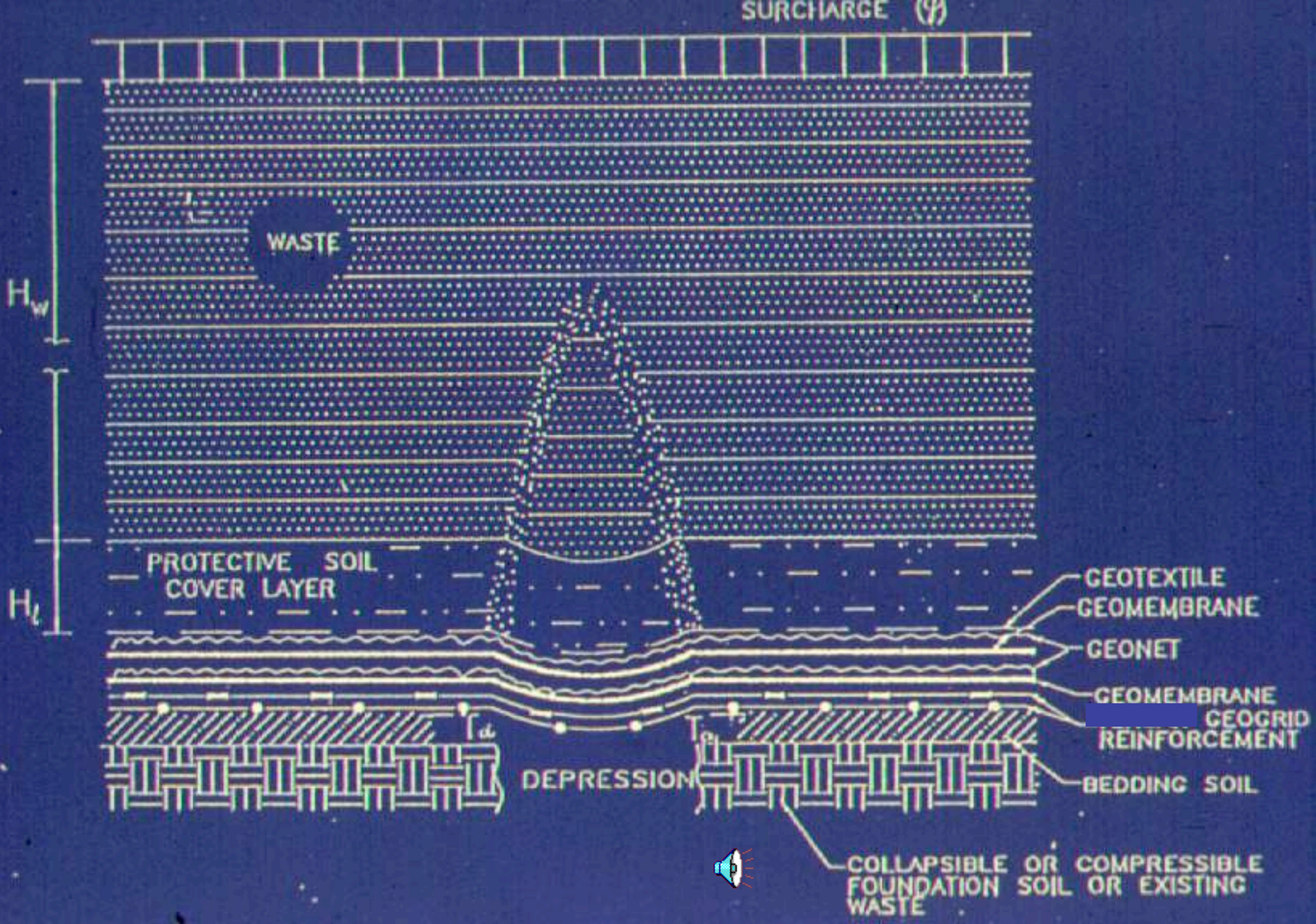
GG or GT Support of Liner System

- greatly depends on size of depression
- theory based on arching in soils
- developed independently by Terzaghi and Marston in 1930's

$$\hat{U}_z = 2\gamma_{avg}R\left[1 - e^{-0.5H/R}\right] + qe^{-0.5H/R}$$

- becomes constant for H ≥ 6R

$$\hat{U}_z = 2\gamma_{avg}R$$


SURCHARGE (q)
WASTE
H_w
H_l
PROTECTIVE SOIL COVER LAYER
GEOTEXTILE
GEOMEMBRANE
GEONET
GEOMEMBRANE
[redacted] GEOGRID REINFORCEMENT
BEDDING SOIL
T_a
T_a
DEPRESSION
COLLAPSIBLE OR COMPRESSIBLE FOUNDATION SOIL OR EXISTING WASTE

Now use strain of the GS to get T_{reqd}

$$T_{reqd} = \hat{U}_z R \ddot{Y}$$

where

$\Omega = 0.25 [(2y)/B + B/(2y)]$, where
B = width of settlement void, and
Y = depth of settlement void

then

$$FS = T_{allow}/T_{reqd}$$

Regarding the T_{allow} Value

- uses T_{ult} of candidate GS via D4595
- testing is reasonably well established
- must now consider reduction factors
- common are ID, CR, CBD (together ΠRF)
- values are site-specific and product-specific

$$T_{allow} = T_{ult} / \Pi RF$$

Example: Determine the FS of a GG support of liner system for 30 m vertical expansion ($\gamma = 12$ kN/m^3), using $T_{ult} = 125$ kN/m and ΠRF = 4.5. Assume R = 1.0 m and $\varepsilon = 10\%$.

Solution:

$$\hat{U}_z = 2\gamma R$$
$$= 2(12)(1.0)$$
$$= 24 \text{kN/m}^2$$
$$\ddot{Y} = 0.73 \text{ at } 10\% \text{ strain}$$

$$\ddot{Y} = 0.73 \ @\ 10\% \text{ str.}$$

so

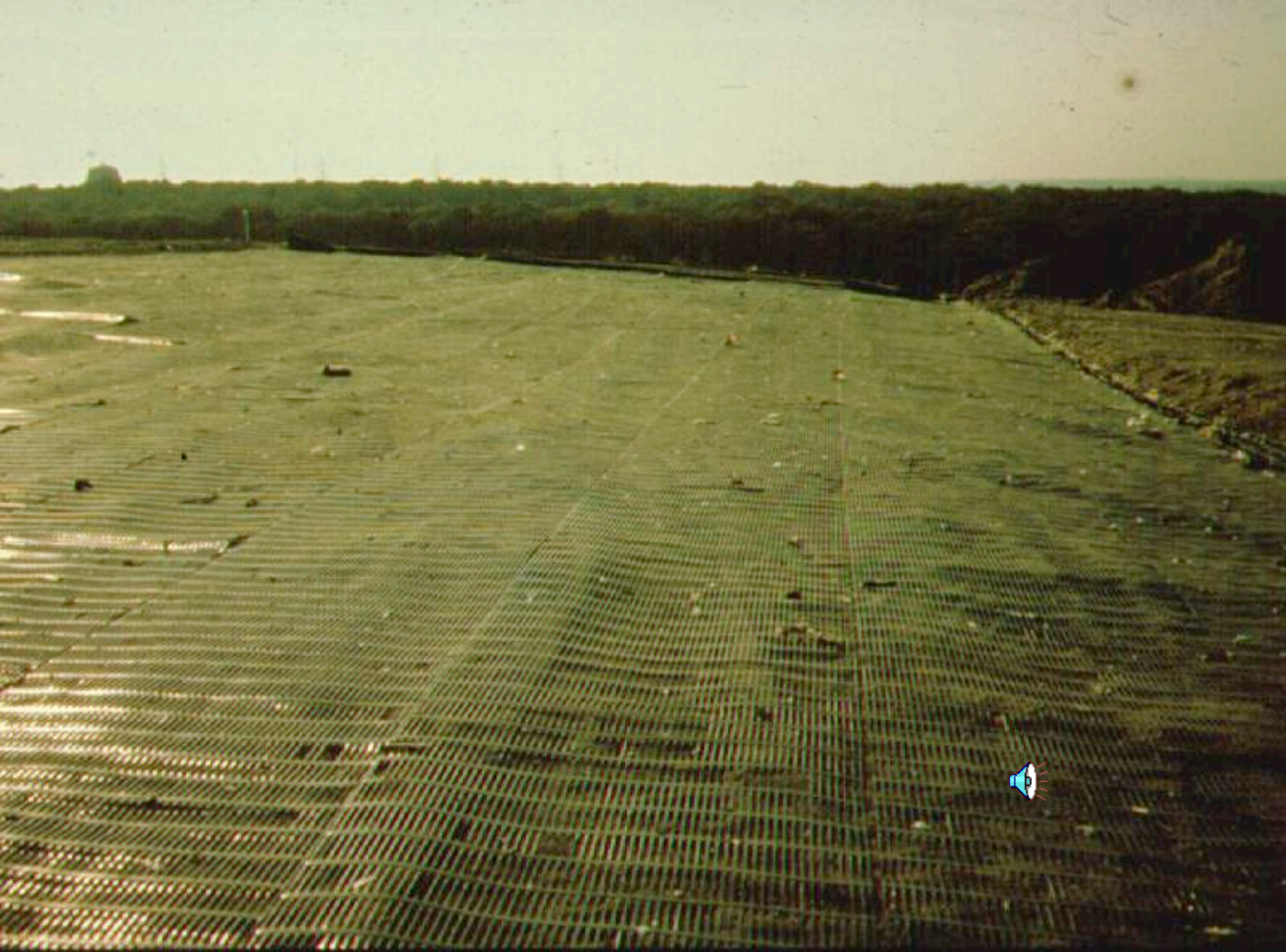
$$T_{reqd} = (24)(1.0)(0.73)$$
$$= 17.5 \text{kN/m}$$

also

$$T_{allow} = T_{ult}/\Pi RF$$
$$= 125/4.5$$
$$= 27.8 \text{kN/m}$$

therefore

$$FS = T_{allow}/T_{reqd}$$
$$= 27.8/17.5$$
$$FS = 1.59, \ \text{OK}$$



4.5 Provide Design Details, Plans & Specs

- reassess liquids collection system
- check overall stability
- plan for gas collection/utilization
- consider air emissions, i.e., use of a temporary cover
- plan for final cover
- consider post-closure use of site

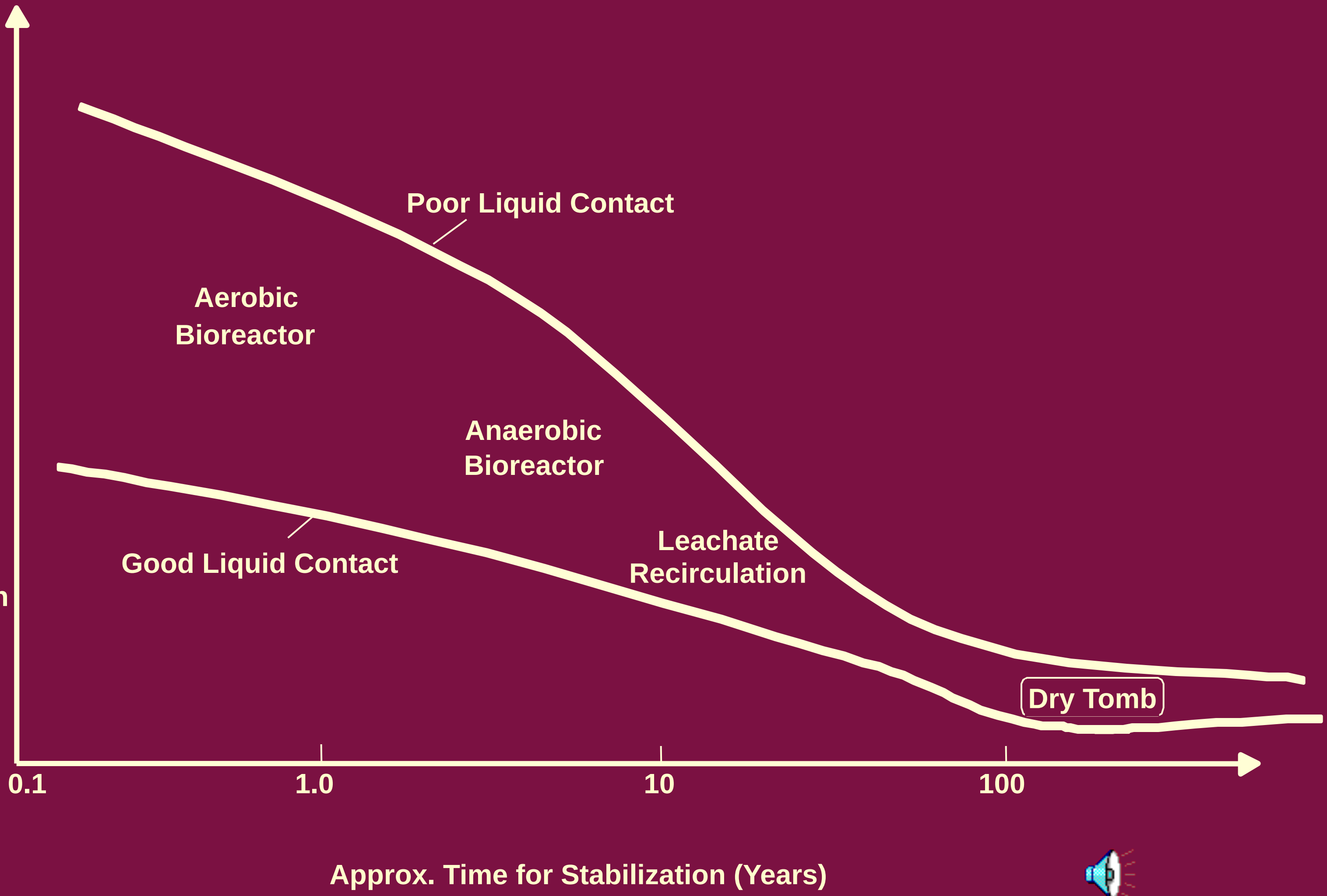
5. Accelerated Degradation

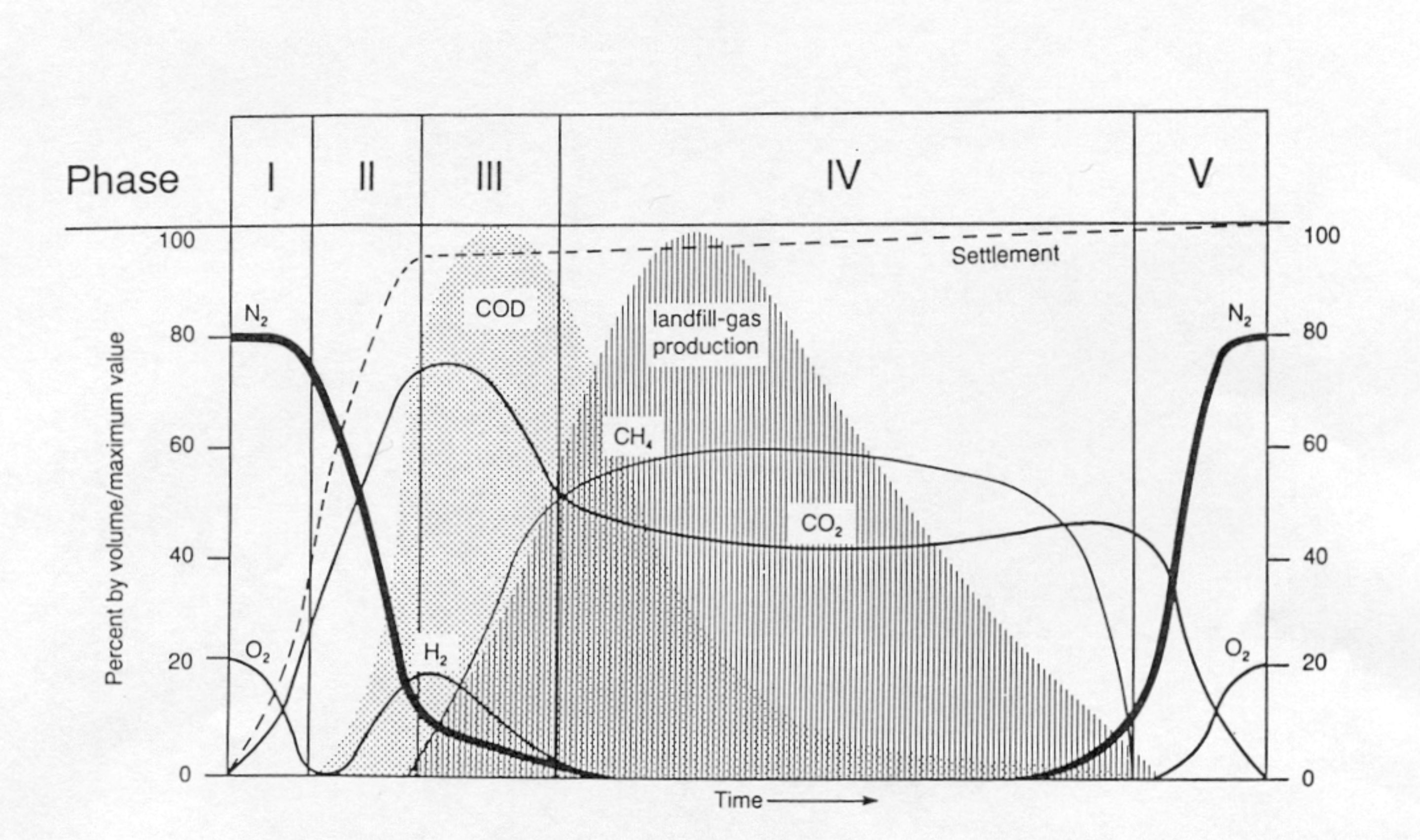
- consider adding moisture to waste:
  - accelerates waste degradation
  - hastens settlement (which improves waste stability)
  - hastens gas generation (which is attractive if used for power)
- above describes a “wet landfill”, but there are degrees of wetness
  - “standard” landfill
  - leachate recirculation
  - anaerobic bioreactor
  - aerobic bioreactor

see following

ACTIONS

- Required Liquid
- Temperature
- Settlement
- Gas Production
- Leachate Strength

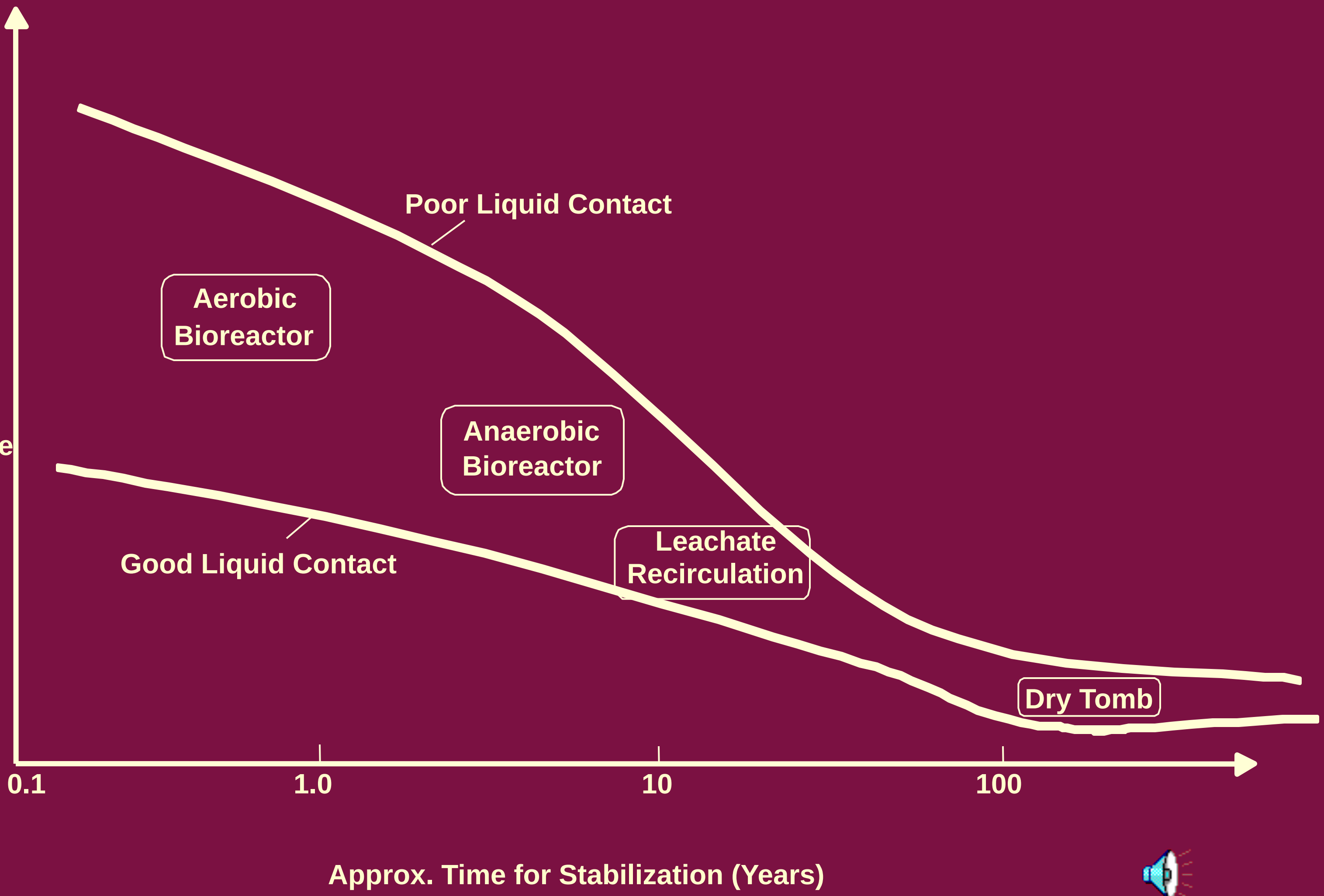




Five phases of landfill stabilization.
(Adapted from Pohland and Harper, 1986.)

CONCERNS

- Base Drainage
- Internal Drainage
- Waste Contact
- Stability



6. Post-Closure Site Usage

- using some form of wet landfill concept;
- time for total settlement is reduced
- time for differential settlement is reduced
- time for gas emissions are reduced
- final cover should eliminate gases
- results in many possible uses of sites

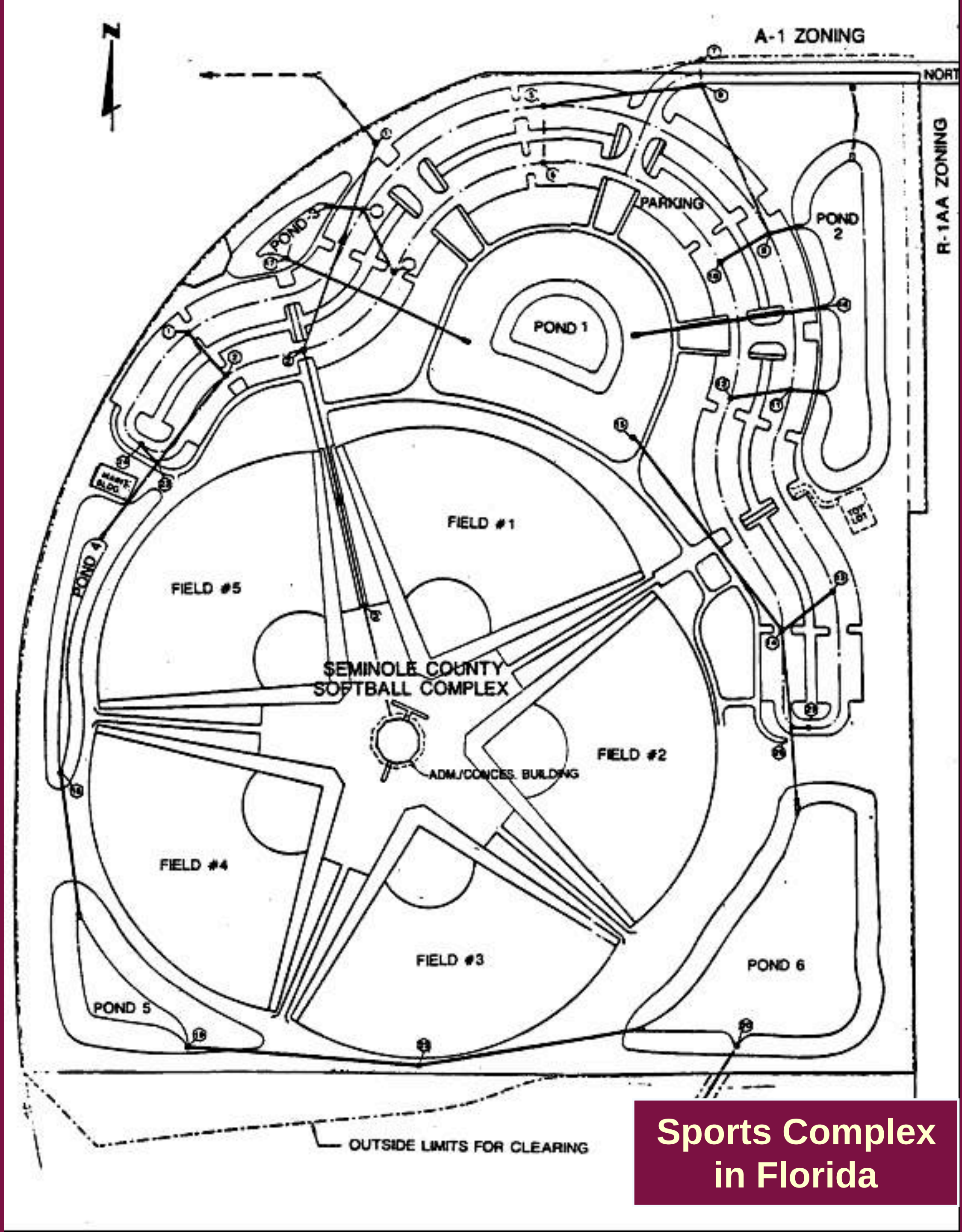
Golf Courses and Driving Ranges

- perfect fit for closed landfills
- need ≃ 200 acres for 18-holes
- Natl. Golf Fed. lists 62 references
- many examples exist
- see following (Mission Canyon, 1976)

Mission Canyon Landfill, Los Angeles, Waste Age, 1976!

Other Examples in Literature

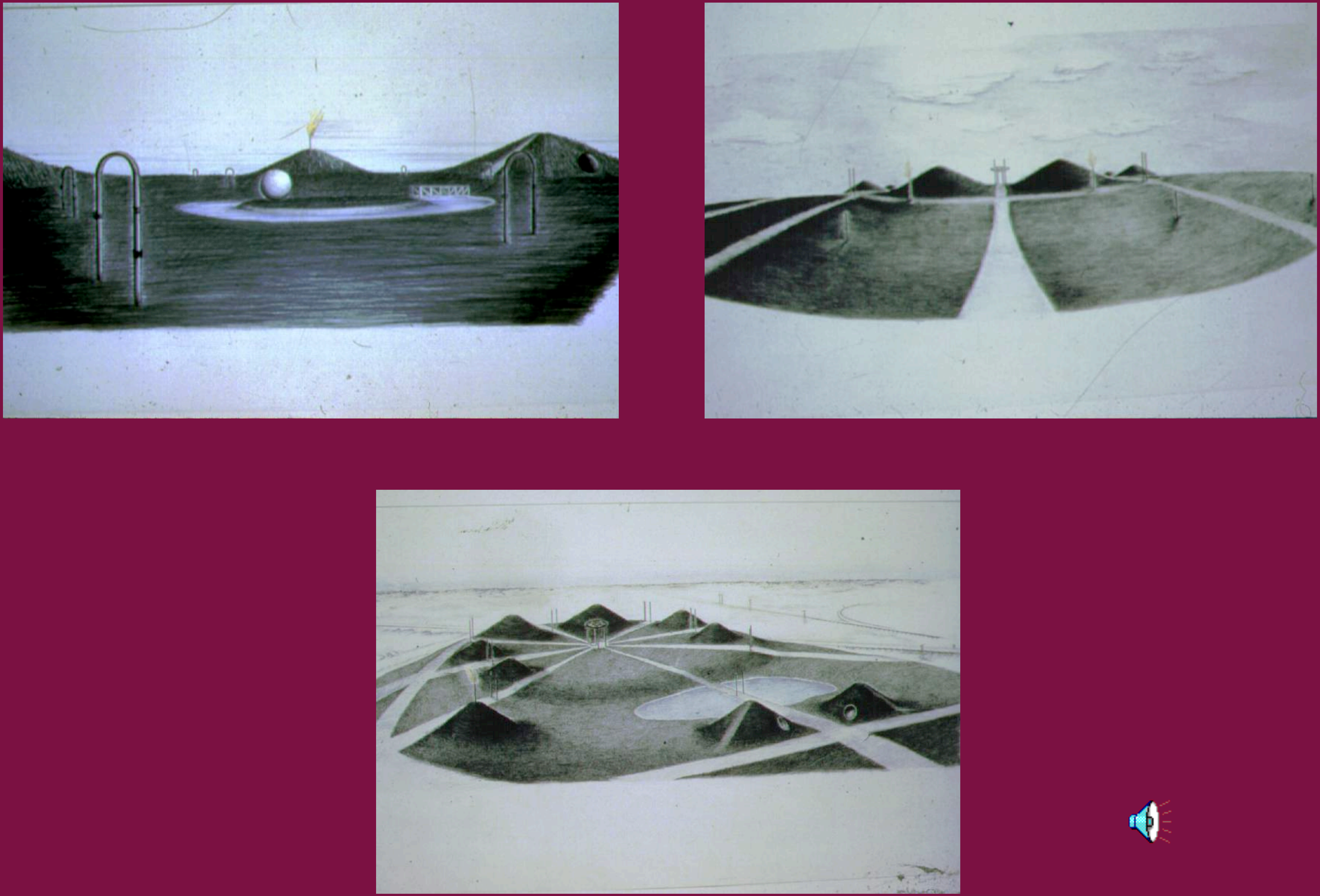
- airport runway expansions
- recreational facilities
- sport fields and paths
- wildlife refuge and gardens
- ski hills and motorcross courses
- heliport and pistol range
- windmill (in Holland, MI)
- cemetery (in Georgia)
- parking lots via U. S. EPA guide!



Sports Complex in Florida

Even Some Structures!

- waste transfer stations <u>are common</u>
- police station in Milwaukee, WI
- school and shopping center in Tampa, FL
- toy factory in Newark, NJ
- U. S. Post office in Dallas, TX
- auto plant in Detroit, MI
- commercial buildings in Syracuse, NY
- perhaps a massive artwork ???



7. Summary

- funding for the expense of closing a landfill is ugly if done in-isolation
- suggested herein is to entomb it within a modern landfill
- requires lateral and vertical expansions
- its within S-O-T-P (but not trivial)!
- incorporation of wet landfills is S-O-T-A
- needs considerable care and deliberation
- it allows rapid post closure use of site
- done properly everyone wins!

Thanks for Listening