APPENDIX H.6

PREVIOUS GEOTECHNICAL ANALYSES FOR PERMITTED CLINTON LANDFILL NO.3

- GEOTECHNICAL DESIGN MODEL
- FOUNDATION AND MASS STABILITY NARRATIVE
- BEARING CAPACITY CALCULATIONS
- SLOPE STABILITY CALCULATIONS
- SETTLEMENT CALCULATIONS
- HYDROSTATIC UPLIFT CALCULATIONS
- SIDEWALL LINER GEOSYNTHETIC MATERIAL STRESS CALCULATIONS
- ANCHOR TRENCH DESIGN CALCULATIONS
- LIQUEFACTION POTENTIAL CALCULATIONS

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APPENDIX 812.305-B: GEOTECHNICAL DESIGN MODEL

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GEOTECHNICAL DESIGN MODEL

Clinton Landfill No. 3

November 2006

SOIL STRATA	TOP / BOTTOM ELEV. (feet – MSL)	GEOTECHNICAL CHARACTERISTICS
BROWN AND GRAY SILTY CLAY (CL), with localized sand strata [Tiskilwa Formation]	Ground Surface / 670	Medium stiff to hard $\phi = 0$, c= 3,500 psf $\phi' = 26^0$, c′= 600 psf γ_t = 135 pcf, γ_{sat} = 140 pcf P_c = 6,000 psf C_c = 0.12, C_{cr} = 0.015, e_0 = 0.34
DARK BROWN ORGANIC SILT (OL) AND PEAT (Pt) [Roxana Silt / Robein Member]	670 / 660	Medium stiff to stiff $\phi = 0$, c= 1,400 psf $\phi' = 19^0$, c′= 1,500 psf γ_t = 100 pcf, γ_{sat} = 110 pcf P_c = 10,000 psf C_c = 0.45, C_{cr} = 0.06, e_0 = 1.20
GRAY CLAY (CL) [Berry Clay and Radnor Till]	660 / 483	Hard $\phi = 0$, c= 6,000 psf $\phi' = 18^0$, c′= 1,100 psf γ_t = 140 pcf, γ_{sat} = 148 pcf P_c = 35,000 psf C_c = 0.10, C_{cr} = 0.016, e_0 = 0.32
SAND AND GRAVEL (SP/GP) [Mahomet Sand Member]	< 483	Very dense (N > 50) $\phi' = 35^0$, c′= 0 psf γ_t = 135 pcf, γ_{sat} = 140 pcf

Note: This geotechnical design model is intended to conservatively represent prevalent subsurface conditions upon which the geotechnical design is based. Actual conditions will be observed by the CQA Officer during construction to verify that the design parameters are appropriate. The following pages document the development of this model.

IS _WA FORMATION

Strength Parameters

Unconsolidated – Undrained Shear Strength (short-term behavior)

Unconfined Compression Test Results:

Boring	Depth / Elevation (ft)	Unconfined Compressive Strength (tsf)
EX-10	12.5	4.0
EX-10	31.0	4.2
EX-10	39.0	2.2
EX-11	Elev. 691.2	3.7
	Average	3.53

Triaxial Shear (unconsolidated – undrained) Test Results:

Boring	Depth / Elevation (ft)	Deviator Stress (Shear Strength) (tsf)
CLG 1 & 2	12	1.38
CLG 1 & 2	12	2.34
CLG 1 & 2	12	3.17
CLG 3 & 4	38	1.93
CLG 3 & 4	38	3.12
CLG 3 & 4	38	3.43
EX-13	12	10.99
EX-13	12	4.90
EX-13	42	14.69
EX-17	19.5	2.51
EX-17	29.5	20.69
EX-19	45	8.87
EX-21	13	6.81
EX-21	31	1.03
EX-23	34.5	11.91
EX-24	11	14.46
EX-24	31	11.51
EX-24	55	10.75
	Average:	7.47

Field Pocket Penetrometer Data:

Ranges from ~0.5 tsf to >4.5 tsf, majority between 2.0 and 4.0 tsf

Φ = 0 (assumed)

C = Shear Strength / 2

Shear strength = 3.5 tsf based on lab and field tests

C = 3.5 tsf / 2

C = 1.75 tsf = 3,500 psf

Consolidated – Drained Shear Strength (long-term behavior)

See attached Figure 1.

Φ' = 26^0

C' = 0.3 tsf = 600 psf

Density

Boring	Depth / Elevation (ft)	Dry Density (pcf)	Moisture Content (%)	Total Density (pcf)
EX-10	12.5	124.2	10.8	138
EX-10	31.0	117.0	13.2	132
EX-10	39.0	111.5	14.0	127
EX-11	691.2	125.0	12.0	140
EX-13	12.0	121.9	12.1	137
EX-17	4.0	117.4	16.0	136
EX-17	14.0	122.6	13.9	140
EX-17	19.0	117.4	16.0	136
EX-21	31.0	122.8	13.3	139
EX-24	11.0	117.9	14.8	135
EX-24	55.0	124.2	13.0	140
			Average:	136.36

To be conservative, use **total unit weight = 135 pcf**

Saturated unit weight = 140 pcf

Consolidation Parameters

Consolidation Test Results Summary:

Boring	Depth / Elevation (ft)	e_0	C_c	C_{cr}	P_c (tsf)
EX-10	12.5	0.331	0.113	0.013	2.9
EX-11	Elev. 691.2	0.348	0.125	0.017	5.2
EX-19	Elev. 674	0.281	0.080	0.016	3.0
EX-23	Elev. 676	0.320	0.105	0.018	4.2
		0.32	0.106	0.016	3.83

For conservative design purposes, use:

e_0 = 0.34

C_c = 0.12

C_{cr} = 0.015

P_c = 3.0 tsf

DXANA / ROBEIN SILT

Strength Parameters

Unconsolidated – Undrained Shear Strength (short-term behavior)

Unconfined Compression Test Results:

Boring	Depth / Elevation (ft)	Unconfined Compressive Strength (tsf)
EX-6A	24.5	1.8
EX-6A	26.5	1.6
EX-6A	28.5	1.0
EX-6B	24.5	1.4
EX-6B	26.5	1.3
EX-6B	28.5	1.05
	Average	1.36

Triaxial Shear (unconsolidated – undrained) Test Results:

Boring	Depth / Elevation (ft)	Deviator Stress (Shear Strength) (tsf)
CLG 5	40	0.29
CLG 5	40	0.40
CLG 5	40	0.45
EX-13	52	8.17
EX-16	49.5	1.47
EX-19	55	6.96
	Average:	2.96

Φ = 0 (assumed)

C = Shear Strength / 2

Shear strength = 1.4 tsf based on lab tests

C = 1.4 tsf / 2

C = 0.7 tsf = 1,400 psf

Consolidated – Drained Shear Strength (long-term behavior)

See attached Figure 2.

Φ' = 19^0

C' = 0.75 tsf = 1,500 psf

Density

Boring	Depth / Elevation (ft)	Dry Density (pcf)	Moisture Content (%)	Total Density (pcf)
EX-6A	26.5	67.0	46.9	98
EX-6B	26.5	70.1	42.7	100
EX-16	49.5	70.2	46.4	103
EX-19	54	66.7	47.5	98
			Average:	99.75

To be conservative, use **total unit weight = 100 pcf**

Consolidation Parameters

Consolidation Test Results Summary:

Boring	Depth / Elevation (ft)	e_0	C_c	C_{cr}	P_c (tsf)
EX-6A	26.5	1.013	0.186	0.085	5.0
EX-6B	26.5	0.922	0.178	0.025	5.5
EX-16	Elev. 667.5	1.136	0.443	0.050	7.9
EX-23	Elev. 664	1.487	0.490	0.070	5.8
		1.14	0.324	0.058	6.05

For conservative design purposes, use:

e_0 = 1.20

C_c = 0.45

C_{cr} = 0.06

P_c = 5.0 tsf

B RY CLAY / RADNOR TILL

Strength Parameters

Unconsolidated – Undrained Shear Strength (short-term behavior)

Unconfined Compression Test Results:

Boring	Depth / Elevation (ft)	Unconfined Compressive Strength (tsf)
EX-4	64	9.17
EX-4	79	8.63
EX-5	69	9.07
EX-5	79	9.52
EX-5	90.5	10.14
EX-6	32	7.16
EX-6	49	13.90
EX-7	32	6.27
EX-7	47	13.90
	Average	9.75

Triaxial Shear (unconsolidated – undrained) Test Results:

Boring	Depth / Elevation (ft)	Deviator Stress (Shear Strength) (tsf)
EX-13	64	3.56
EX-16	72	2.41
EX-19	59	2.52
EX-19	69	19.97
EX-21	39	2.73
EX-23	60	6.15
EX-24	76	4.71
	Average:	6.01

Φ = 0 (assumed)

C = Shear Strength / 2

Shear strength = 6.0 tsf based on lab tests

C = 6.0 tsf / 2

C = 3.0 tsf = 6,000 psf

Consolidated – Drained Shear Strength (long-term behavior)

See attached Figure 3.

Φ' = 18^0

C' = 0.55 tsf = 1,100 psf

Density

Boring	Depth / Elevation (ft)	Dry Density (pcf)	Moisture Content (%)	Total Density (pcf)
EX-4	64	135.1	12.6	152
EX-4	79	139.0	8.4	151
EX-5	69	135.8	12.1	152
EX-5	79	144.7	7.8	156
EX-5	90.5	142.9	7.9	154
EX-6	32	114.6	18.4	136

EX-6	49	110.6	19.7	133
EX-7	32	118.4	17.6	139
EX-7	47	146.7	6.2	156
EX-13	62	109.1	18.7	130
EX-16	72	147.6	6.6	157
EX-19	59	113.6	16.2	132
EX-19	69	127.5	11.8	143
EX-21	39	112.9	16.8	132
EX-24	76	112.6	17.9	133
		Average:	13.25	143.73

Use total unit weight = 140 pcf

Consolidation Parameters

Consolidation Test Results Summary:

Boring	Depth / Elevation (ft)	e_0	C_c	C_{cr}	P_c (tsf)
EX-5	79	0.09	0.030	0.009	4.0
EX-13	Elev. 660	0.338	0.080	0.019	4.0
EX-21	Elev. 662	0.494	0.130	0.019	6.2
		0.307	0.08	0.016	4.73

The interpreted preconsolidation pressure from the consolidation tests appear incorrect. The likely reason is that the tests were not performed to high enough loads which surpass the preconsolidation pressure.

Check preconsolidation pressure based on Liquidity Index and geologic history.

Atterberg Limits Test Results Summary:

Boring	Depth / Elevation (ft)	Plastic Limit	Liquid Limit	Plasticity Index
B-23	66	19	31	12
B-21	54	18	26	8
B-11	88	18	27	9
EX-13	Elev. 660	11	37	25

EX-19	Elev. 658	13	30	17
EX-21	Elev. 662	13	38	25
EX-24	Elev. 660	12	39	27
EX-16	Elev. 645	11	16	5
EX-19	Elev. 649	11	20	9
EX-22	Elev. 664	11	32	21
EX-22	Elev. 659	9	27	18
EX-22	Elev. 654	10	30	21
EX-23	Elev. 648	6	18	12
	Average:	12.5	28.5	16.1

Liquidity Index = (Moisture Content – Plastic Limit) / Plasticity Index

Using average Moisture Content, PL and PI:

Liquidity Index = 0.04

Based on Figure 3, NAVFAC DM 7.1 – Preconsolidation Pressure vs. Liquidity Index (attached), the preconsolidation pressure could range from approx. 6.5 tsf to 25 tsf (13,000 psf to 50,000 psf).

The Berry Clay and Radnor Till are Illinoian glacial deposits. Therefore, they were overlain by Wisconsinan glaciers. According to notes from the Illinois State Geological Survey September 1997 and May 1998 field trips (attached), the Wisconsinan glaciers were approximately 700 feet thick over most of Illinois. Based on this, and a unit weight of ice (0.91 x 62.4 pounds per cubic foot), the preconsolidation pressure estimated from geologic history = 39,750 psf.

For conservative design purposes, use:

$e_0 = 0.32$

$C_c = 0.10$

$C_{cr} = 0.016$

$P_c = 35{,}000$ psf

PACTED EARTH LINER / COMPACTED CLAY FILL

Strength Parameters

Unconsolidated – Undrained Shear Strength (short-term behavior)

Triaxial Shear (unconsolidated – undrained) Test Results – Remolded Composite Samples (remolded to 92 - 97% standard Proctor):

Source	Deviator Stress (Shear Strength) (tsf)
Weathered Tiskilwa	2.68
Weathered Tiskilwa	2.36
Weathered Tiskilwa	2.31
Unweathered Tiskilwa	6.34
Unweathered Tiskilwa	6.21
Unweathered Tiskilwa	5.43
Berry Clay	4.36
Berry Clay	4.50
Berry Clay	4.57
Average	4.31

$\Phi = 0$ (assumed)

C = Shear Strength / 2

Shear strength = 3.0 tsf based on lab tests (conservative)

C = 3.0 tsf / 2

C = 1.5 tsf = 3,000 psf

Consolidated – Drained Shear Strength (long-term behavior)

See attached Figure 4.

$\Phi' = 21^0$

C' = 0.35 tsf = 700 psf

Density

From Clinton Landfill Earth Liner CQA testing, typical total density of compacted Earth Liner = 135 pcf.

Use total unit weight = 135 pcf

Consolidation Parameters

From NAVFAC DM 7.2, Chapter 2, Table 1:

@ 1.4 tsf, compression = 1.3%

@3.6 tsf, compression = 2.5%

Use the attached graph to estimate % compression for other loads.

VEGETATIVE COVER AND INTERMEDIATE COVER

Strength Parameters

Unconsolidated – Undrained Shear Strength (short-term behavior)

Triaxial Shear (unconsolidated – undrained) Test Results – Remolded Composite Samples (remolded to 86 - 88% standard Proctor):

Source	Deviator Stress (Shear Strength) (tsf)
Weathered Tiskilwa	0.90
Weathered Tiskilwa	0.89
Weathered Tiskilwa	1.04
Unweathered Tiskilwa	2.36
Unweathered Tiskilwa	1.72
Unweathered Tiskilwa	2.90
Average	1.64

Φ = 0 (assumed)

C = Shear Strength / 2

Shear strength = 1.35 tsf based on lab tests

C = 1.35 tsf / 2

C = 0.675 tsf = 1,350 psf

Consolidated – Drained Shear Strength (long-term behavior)

See attached Figure 5.

$\Phi' = 22^0$

C' = 0.65 tsf = 1,300 psf

Density: **Use total unit weight = 128 pcf**

NDFILLED WASTE

Strength Parameters

Non- to Partially Degraded Waste

From published and unpublished literature:

Source	phi	Cohesion (psf)
Sharma & Lewis (1994)	20^0	400
Duncan & Wright (2005)		
Kavazanjian et al. (1995[1])	33^0	0
Eid et al. (2000)	35^0	522
Stark (2005)	35^0	500
Stark & Huvaj-Sarihan (publication pending, 2006)		
$P_{ob} < 4200$ psf	35^0	125
$P_{ob} \geq 4200$ psf	30^0	625

Note 1. For overburden pressures (P_{ob}) greater than 775 psf)

For design use: $\Phi = 30^0$

$C = 500$ psf

Well Degraded Waste

From published and unpublished literature:

Source	phi	Cohesion (psf)
Duncan & Wright[1] (2005)	33^0	0
Stark (2005) and Stark & Huvaj-Sarihan (publication pending, 2006)[2]	20^0	0
Gabr, Hossain & Barlaz (publication pending, 2006)	24^0	0

Notes:

1. After Kavazanjian (1995 and 2001) for overburden pressures greater than 775 psf)
2. According to Stark & Huvaj-Sarihan "These parameters can be used to evaluate final slopes with leachate recirculation but should only be applied in areas that have undergone complete degradation, such as at or near the bottom of the waste mass."

For design use: $\Phi = 22^0$

$C = 0$ psf

Assume the lower 10 feet of waste is fully degraded during the landfill active phases (except during the initial two phases of landfill development). Assume the lower 24 feet of waste is fully degraded during the Post-Closure Period and thereafter.

Density:

Non- to Partially Degraded Waste

From article in *MSW Management* by R.T. Sprague and G.N. Richardson (Sept./Oct. 2001), MSW density versus depth can be estimated from density profile data from Puente Hills, California Landfill (after Kavazanjian, Matasovic, Bonaparte, and Schmertmann). Puente Hills Landfill waste is estimated to be at a moisture content of 22%. A plot of their data is attached.

Leachate recirculation will increase the moisture content of the landfilled waste. HELP modeling indicates an average waste moisture content throughout the Design Period of about 29%. Therefore, one must adjust the Puente Hills Landfill waste densities to account for the higher moisture contents expected at Clinton Landfill No. 3 using the following equation:

γ_{33} = unit weight at moisture content (w) = 29%

$= ((1 + 0.29) \times \gamma_{22}) / (1 + 0.22)$

$= 1.06 \times \gamma_{22}$

Depth Range (feet)	Average Unit Weight		
	W = 22%	W = 29%	
	(kN / m^3)	(kN / m^3)	(lbs / ft^3)
0 – 65	8.4	8.9	57
65 – 155	11.4	12.1	77
155 - 210	13.1	13.9	88

Weighted average γ_{33} = ((57 x 65) + (77 x 90) + (88 x 55)) / 210 = 74 pcf

According to Stark (2005), waste unit weight = 75 to 85 pcf

For design use **total density = 75 pcf** (inclusive of daily and intermediate cover)

Fully Degraded Waste

According to Stark (2005), fully degraded waste density = 100 to 110 pcf

For design use **total density = 105 pcf** (inclusive of daily and intermediate cover)

Waste Hydraulic Properties

References:

Geotechnical Aspects of Landfill Design and Construction; Qian, Koerner, and Gray; 2002

The Hydrologic Evaluation of Landfill Performance (HELP) Model, Engineering Documentation for Version 3; Schroeder, Dozier, Aappi, McEnroe, Sjostrom, and Peyton; EPA/600/R-94/168b; September 1994

The Hydrologic Evaluation of Landfill Performance (HELP) Model, User's Guide for Version 3; Schroeder, Lloyd and Zappi; EPA/600/R-94/168a; September 1994

Shear Strength of Municipal Solid Waste for Stability Analysis; Stark and Huvaj-Sarihan; unpublished, to be submitted for review and possible publication in the *Canadian Geotechnical Journal*; September 27, 2006

Initial Water Content

According to Qian, et.al. (Table 6.5, p. 188), the volumetric water content of landfilled waste varies from about 5% to 30%, with an average of 18.3%. Qian, et.al. also calculates the average dry gravimetric water content of waste as 26%. This is equivalent to 20% on a volumetric basis for a waste density of 60

pounds per cubic feet (pcf) and 25% on a volumetric basis for a waste density of 75 pcf. To be conservative, assume an initial volumetric water content of waste = 26% for the HELP Modelling.

Field Capacity

Waste at the bottom of the landfill is expected to become fully degraded with time (Stark and Huvaj-Sarihan). The overall unit weight of the landfilled waste mass (inclusive of daily and intermediate cover) is estimated to be 75 pounds per cubic foot (pcf). As the waste degrades, its density is estimated to increase to about 105 pcf (Stark and Huvaj-Sarihan). In addition to waste density, pertinent hydraulic properties of the waste used in the HELP Modeling (primarily field capacity and hydraulic conductivity) are also expected to change as the waste degrades.

The HELP Model default volumetric field capacity is 29.2% for a waste density of 900 pounds per cubic yard (33.3 pcf). According to Qian (p. 583), the field capacity increases as waste density increases. Waste densities using current placement and compaction equipment significantly exceeds 33.3 pounds per cubic foot. However, to be conservative, modeling of the landfill will be based on the HELP Model default volumetric field capacity of 29.2% for undegraded to partially degraded waste.

According to Stark and Huvaj-Sarihan, fully degraded waste has the consistency of clay (i.e. very small particles). Therefore, besides an increase in the waste density, the waste particle size is expected to decrease as the waste degrades. According to Qian (p. 583), an increase in density, and a decrease in particle size both increase the field capacity of waste. The HELP Model default volumetric field capacity for low density clays vary from 31% to 37.8%, with an average 35.0%. A field capacity of 31% is conservative for use in the HELP model for degraded waste.

Hydraulic Conductivity

The HELP Model default waste hydraulic conductivity = 1×10^{-3} cm/sec

(Although the HELP Model User's Guide indicates a waste density of 900 lb/yd^3, the HELP Model Engineering Documentation indicates that the default properties are for "well compacted municipal solid waste")

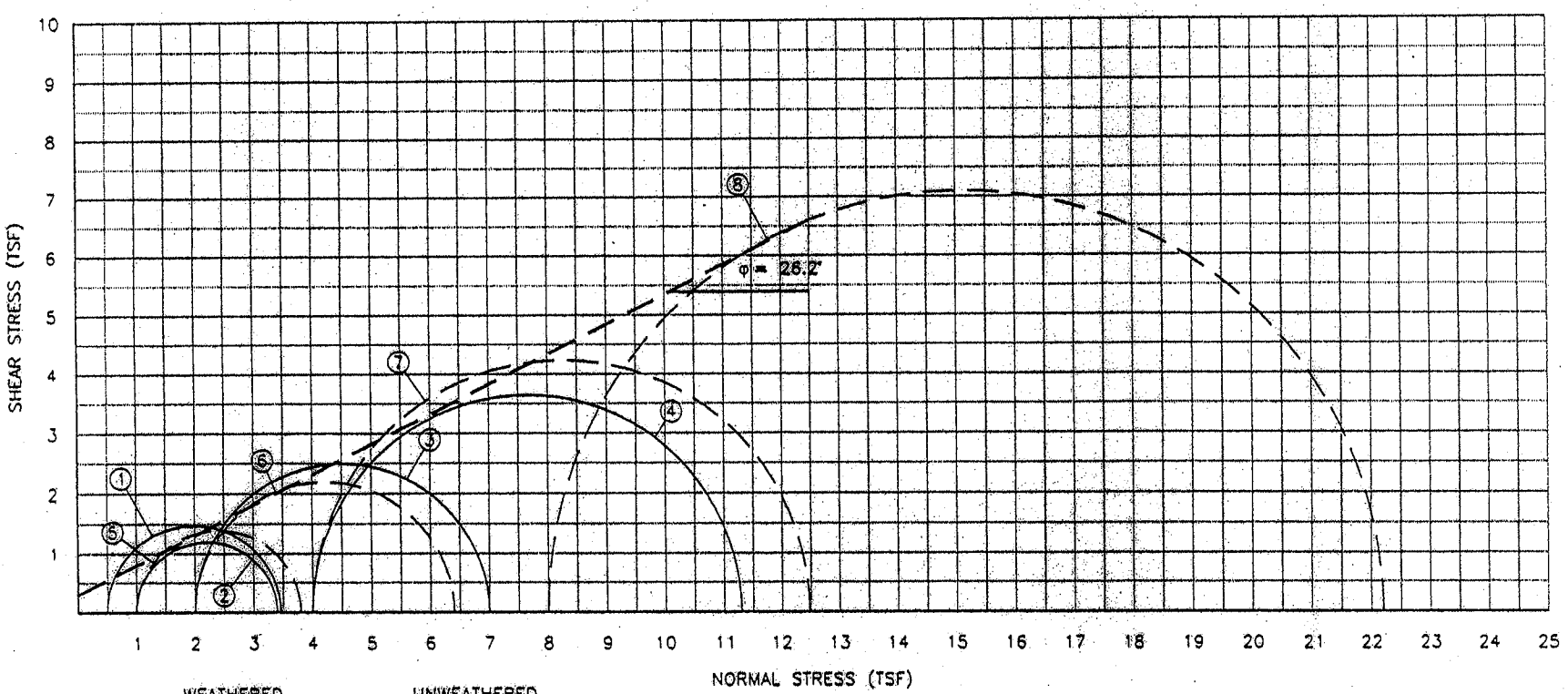
Qian, et.al. (Section 6.5) concludes that the "average hydraulic conductivity of municipal solid waste in landfills is approximately 1×10^{-3} cm/sec". This conclusion is based on data for waste densities varying from about 7 to 90 pcf. It is also noted that the data is from published sources dated 1994 and earlier. Heavier, more efficient waste compaction equipment, and leachate recirculation activities that have been used in more recent years would be expected to increase waste densities. Based on more recent data, Qian, et.al. (p. 185) concludes that waste densities are typically 55 to 70 pcf.

Figure 6.3 (Qian, et.al.) indicates a decreasing trend in waste hydraulic conductivity with increasing waste density. Plotting the median of their trend lines to a density typical of fully degraded waste (105 pcf or 16.4 kN/m^3) indicates a hydraulic conductivity equal to 0.8×10^{-5} m/sec (8.0×10^{-4} cm/sec). Therefore, a hydraulic conductivity for degraded waste equal to 8.0×10^{-4} cm/sec is appropriate for the HELP Modelling.

Porosity and Wilting Point

Waste porosity would be expected to increase, and wilting point would be expected to decrease as the waste degrades. Again, consistent with Stark and Huvaj-Sarihan's characterization of degraded waste as appearing similar to soft clay, use the average HELP Model default values for low density clay porosity and wilting point values (47.2% and 22.8%, respectively).

CAD DWG NO:91118I108 | NO: 9834 DATE/TIME: 06/07/06 09:25 ACAD-15.



WEATHERED SAMPLE SOURCE		UNWEATHERED SAMPLE SOURCE	
①	EX-13 @12'	⑤	EX-13 @42'
②	EX-17 @4'	⑥	EX-17 @14'
③	EX-21 @11'	⑦	EX-19 @44'
④	EX-24 @11'	⑧	EX-24 @31'

TISKILWA TILL
CONSOLIDATED DRAINED
RESIDUAL STRENGTH
(Long-Term Behavior)

$c = 0.3$

$\tan \varphi = \frac{3.25 - 0.3}{6.0 - 0}$

$\varphi = 26.2°$

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FIGURE 1

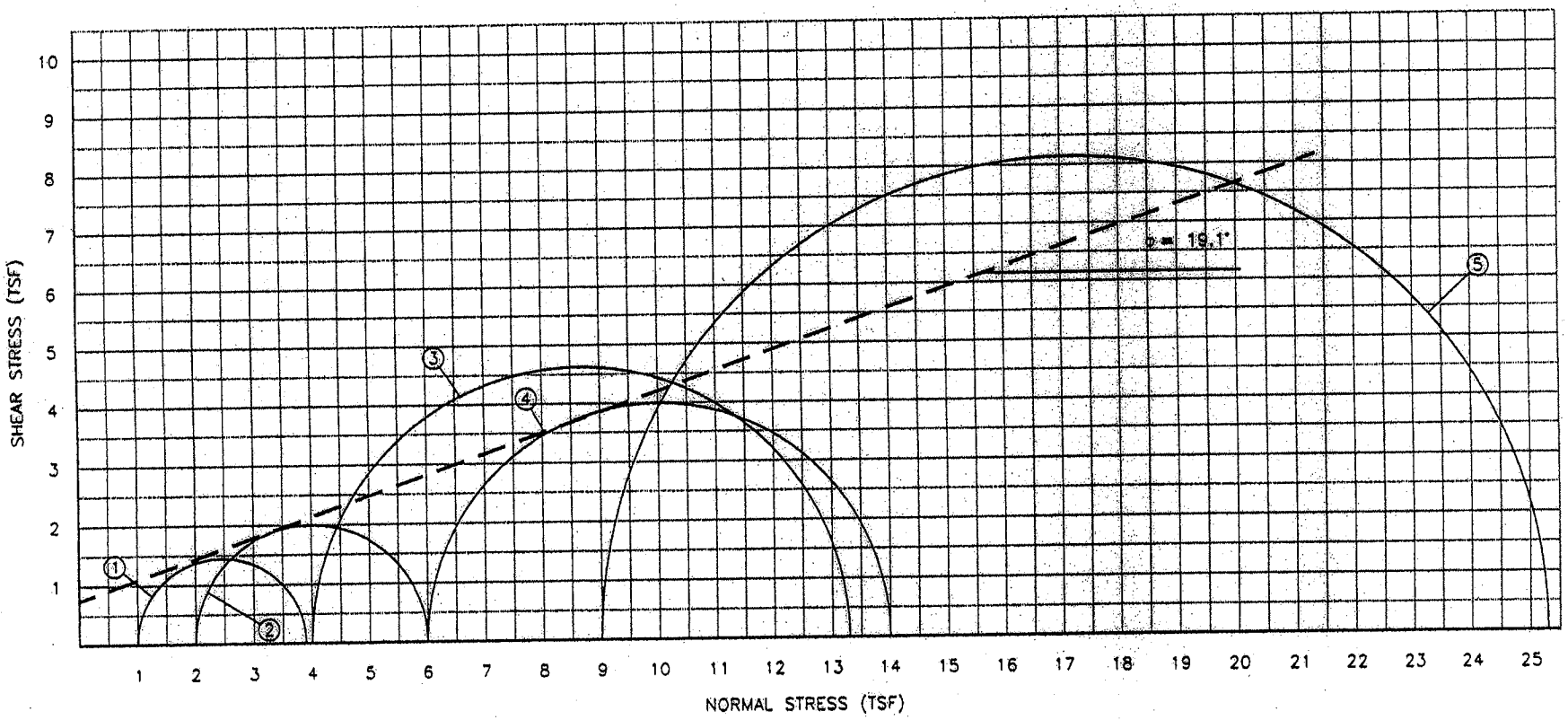
SHEAR TEST DATA

CLINTON LANDFILL NO. 3

CLINTON, ILLINOIS

PROJECT NO. 91-118

CAD DWG NO:91118110B6): 9834 DATE/TIME: 10/25/06 10:55, ACAD-16,



SAMPLE SOURCE

1. EX-24 @55'
2. EX-21 @31'
3. EX-19 @54'
4. EX-16 @49'
5. EX-13 @52'

ROBEIN/ROXANA SILT
CONSOLIDATED DRAINED
RESIDUAL STRENGTH
(Long-Term Behavior)

$c = 0.75$

$\tan \varphi = \frac{4.9 - .75}{12 - 0}$

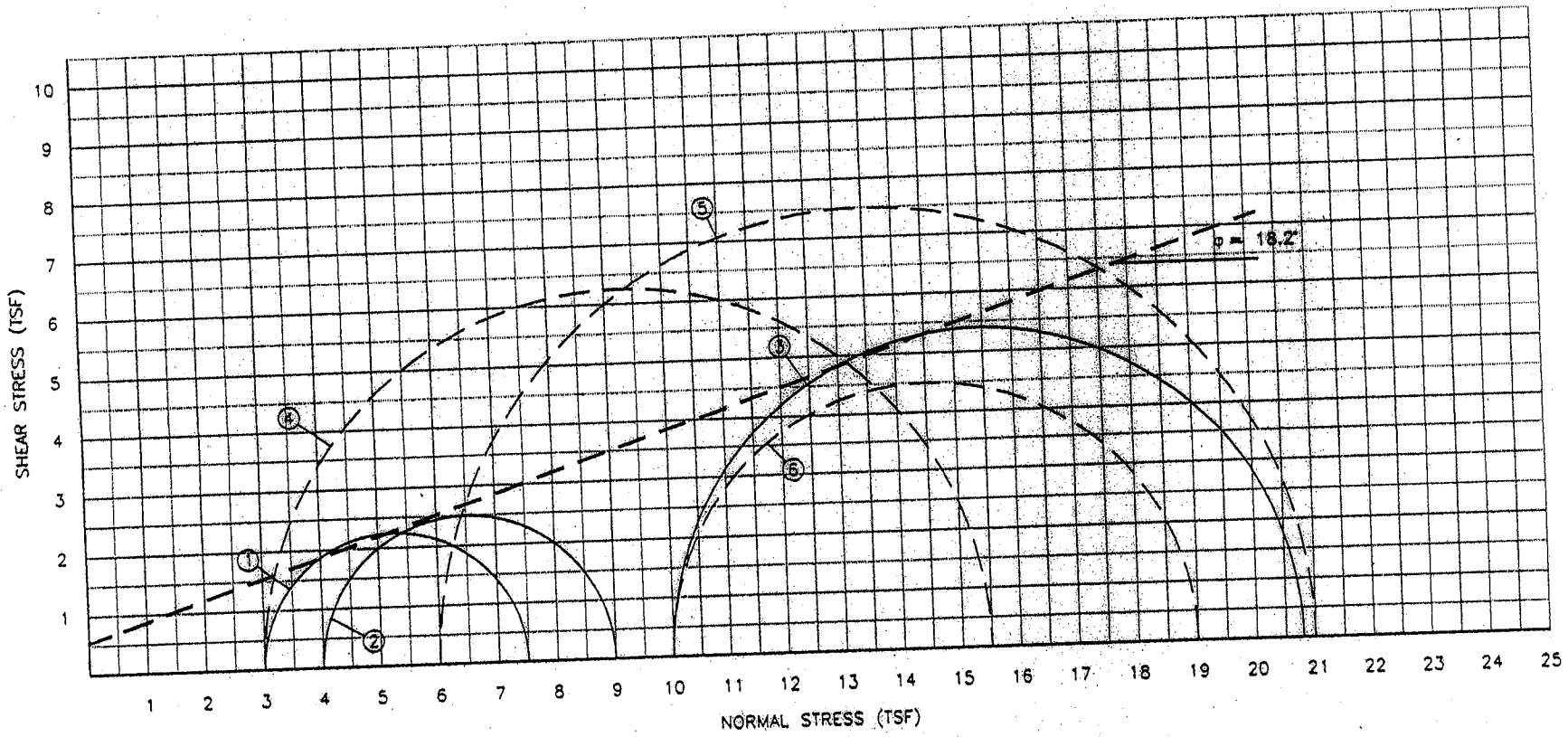
$\varphi = 19.1°$

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FIGURE 2
SHEAR TEST DATA
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

CAD DWG NO:91118\108 EMPLOYEE 69736 DATE/TIME: 12/22/05 16:21 ACAD-15.



BERRY CLAY
CONSOLIDATED DRAINED
RESIDUAL STRENGTH
(Long-Term Behavior)

SAMPLE SOURCE

① EX-21 @39'
② EX-19 @59'
③ EX-13 @62'

RADNOR TILL
CONSOLIDATED DRAINED
RESIDUAL STRENGTH
(Long-Term Behavior)

SAMPLE SOURCE

④ EX-16 @72'
⑤ EX-19 @69'
⑥ EX-24 @76'

$c = 0.55$

$\tan \varphi = \frac{4.5-.55}{12-0}$

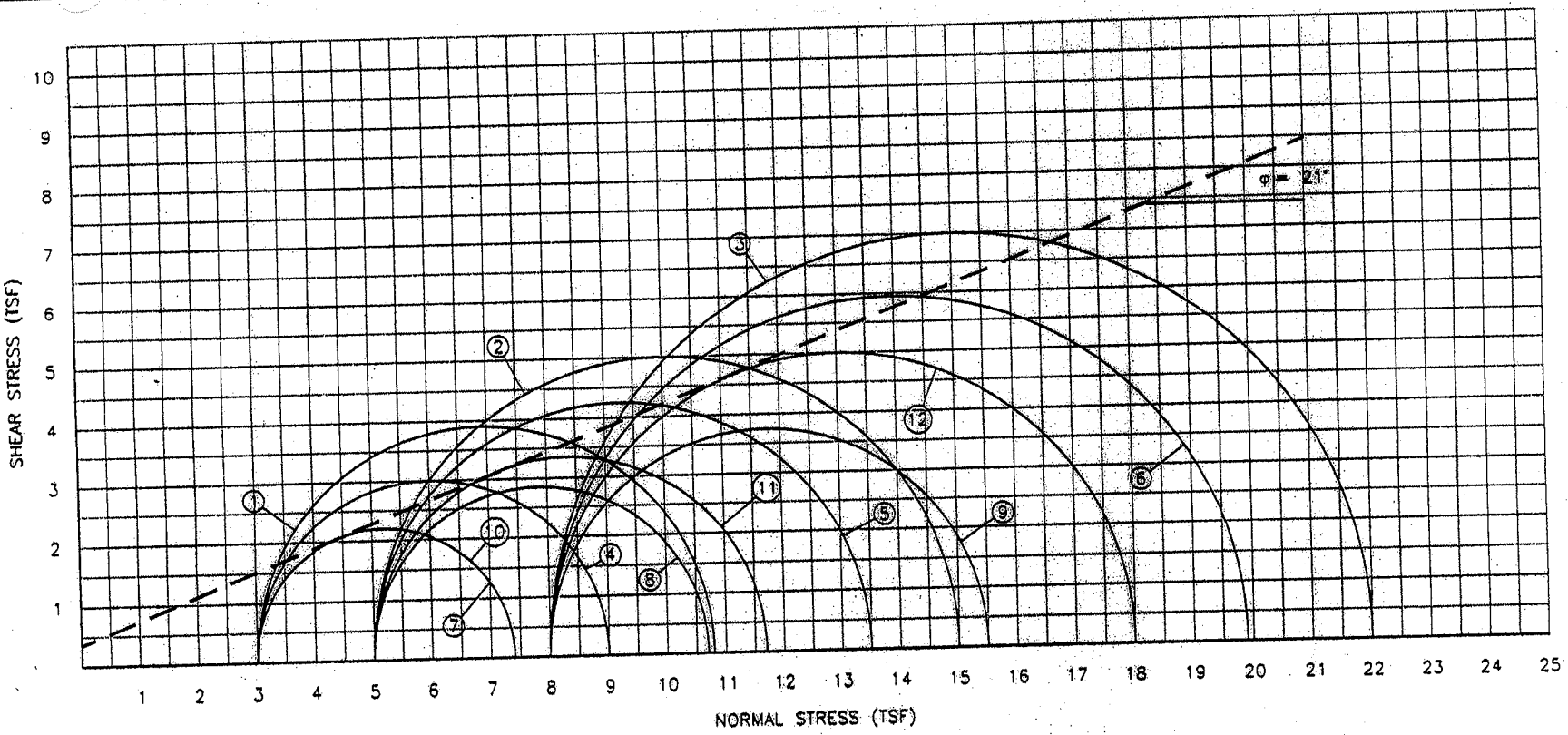
$\varphi = 18.2°$

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FIGURE 3
SHEAR TEST DATA
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

CAD DWG NO:91118I.1084 3834 DATE/TIME: 10/25/06 14:20 ACAD-16.



COMPACTION/GEOLOGICAL UNIT

①	95%/TISKILWA (WEATHERED)
②	95%/TISKILWA (WEATHERED)
③	95%/TISKILWA (WEATHERED)
④	95%/TISKILWA (UNWEATHERED)
⑤	95%/TISKILWA (UNWEATHERED)
⑥	95%/TISKILWA (UNWEATHERED)
⑦	95%/BERRY CLAY
⑧	95%/BERRY CLAY
⑨	95%/BERRY CLAY
⑩	95%/BERRY CLAY
⑪	95%/BERRY CLAY
⑫	95%/BERRY CLAY

COMPACTED EARTH LINER/AND COMPACTED CLAY FILL
CONSOLIDATED DRAINED
RESIDUAL STRENGTH
(Long-Term Behavior)

$c = 0.35$

$\tan \varphi = \frac{6.2-0.35}{15.0-0}$

$\varphi = 21°$

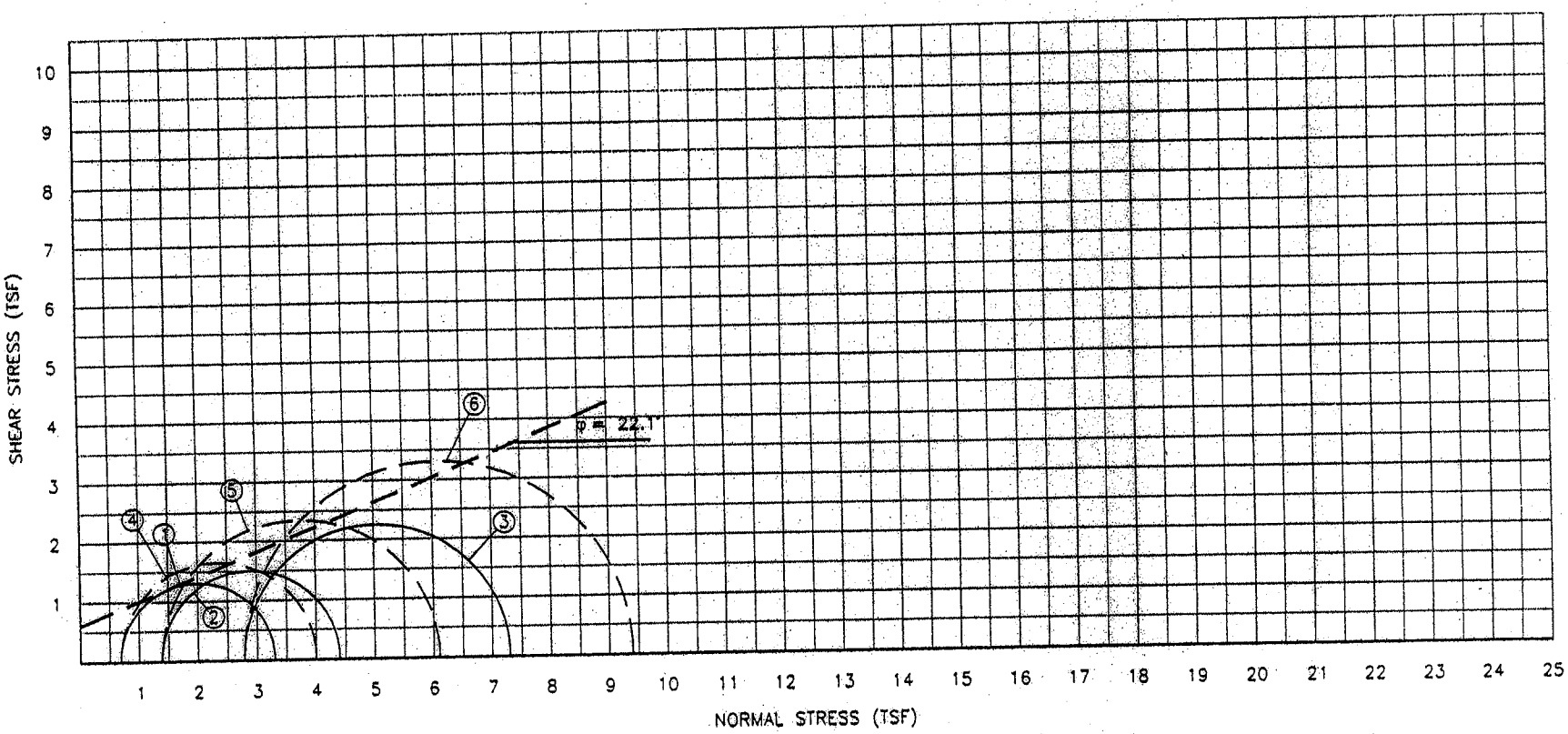
REVISED OCTOBER 25, 2006

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Peoria, Illinois

FIGURE 4
SHEAR TEST DATA
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

CAD DWG NO:9111811086 9834 DATE/TIME: 10/25/06 11:22 ACAD-16.



TISKILWA TILL (UNWEATHERED)
CONSOLIDATED DRAINED
REMOLDED COMPOSITE
RESIDUAL STRENGTH
(Long-Term Behavior)

TISKILWA TILL (WEATHERED)
CONSOLIDATED DRAINED
REMOLDED COMPOSITE
RESIDUAL STRENGTH
(Long-Term Behavior)

$c = 0.65$

$\tan \varphi = \frac{3.1 - 0.65}{6 - 0}$

$\varphi = 22.1°$

COMPACTION	
①	87%
②	87%
③	87%

COMPACTION	
④	87%
⑤	87%
⑥	87%

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Peoria, Illinois

FIGURE 5
SHEAR TEST DATA
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

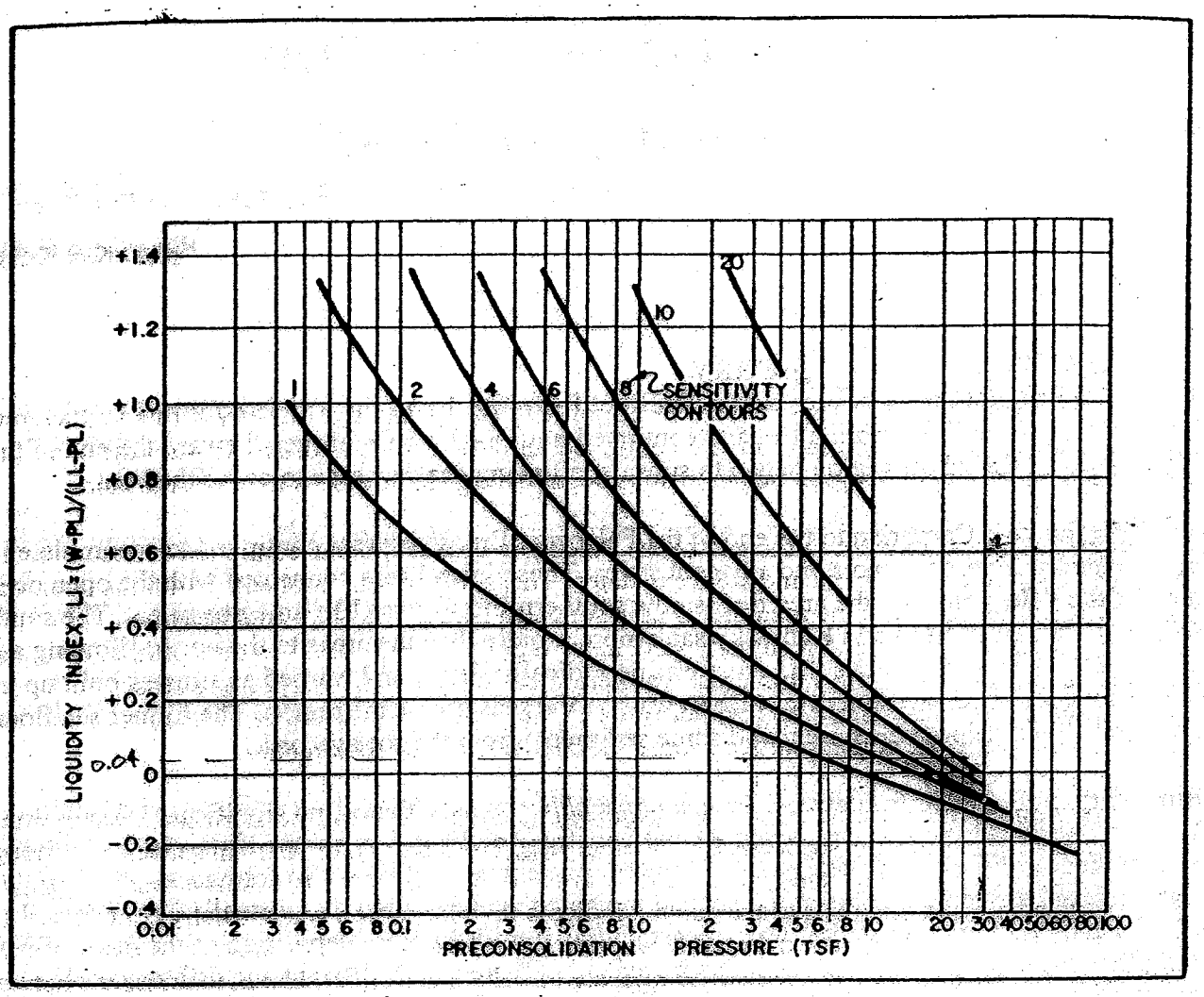


FIGURE 3
Preconsolidation Pressure vs. Liquidity Index

NAVFAC DM 7.1

ISGS Geological Field Trip

September 20, 1997 and May 30, 1998

Kankakee River State Park
Kankakee Cou

:UCTURAL AND DEPOSITIONAL HISTORY

ıoted previously, the Rough Creek Graben and the Reelfoot Rift, (fig. 1 and fig. 3), were formed by tectonic activity began in the later part of the Precambrian Era and continued until the Late Cambrian. Toward the end of the ıbrian, rifting ended and the whole region began to subside, allowing shallow seas to cover the land.

ozoic Era From the Late Cambrian to the end of the Paleozoic Era, sediments continued to accumulate in the ow seas that repeatedly covered Illinois and adjacent states. These inland seas connected with the open ocean to the ı during much of the Paleozoic, and the area that is now southern Illinois was like an embayment. The southern part inois and adjacent parts of Indiana and Kentucky sank more rapidly than the areas to the north, allowing a greater ness of sediment to accumulate. Earth's thin crust was periodically flexed and warped as stresses built up in places. e movements caused repeated invasions and withdrawals of the seas across the region. The former sea floors were periodically exposed to erosion, which removed some sediments from the rock record.

y of the sedimentary units, called formations, have *conformable* contacts, that is, no significant interruption in sition occurred as one formation was succeeded by another (fig. 2 and fig. 4). In some instances, even though th ɔosition and appearance of the rocks change significantly at the contact between two formations, the *fossils* in th ; and the relationships between the rocks at the contact indicate that deposition was virtually continuous. In some s, however, the top of the lower formation was at least partially eroded before deposition of the next formation ı. Fossils and other evidence in the two formations indicate that there is a significant age difference between the r unit and the overlying unit. This type of contact is called an *unconformity* (fig. 4). If the beds above and below an ıformity are parallel, the unconformity is called a *disconformity*, if the lower beds have been tilted and eroded e the overlying beds were deposited, the contact is called an angular unconformity.

nformities occur throughout the Palezoic rock record and are shown in the generalizied stratigraphic column (fig. wavy lines. Each unconformity represents an extended interval of time for which there is no rock record in this

the close of the Mississippian Period, gentle arching of the rocks in eastern Illinois initiated the development of the lle Anticlinorium (fig. 1 and fig. 5). This is a complex structure having smaller structures such as domes, *ines*, and *synclines* superimposed on the broad upwarp of the anticlinorium. Further gradual arching continued gh the Pennsylvanian Period. Because the youngest Pennsylvanian strata are absent from the area of the inorium (either because they were not deposited or because they were eroded), we cannot determine just when g ceased, perhaps by the end of the Pennsylvanian or a little later during the Permian Period , near the close of the zoic Era.

zoic Era During the Mesozoic Era, which followed the Paleozoic Era, the rise of the Pascola Arch (fig. 1) in ɜastern Missouri and western Tennessee, produced a structural barrier that helped form the current shape of the s *basin* by closing off the embayment and separating it from the open sea to the south. The Illinois Basin is a subsided region covering much of Illinois, southwestern Indiana, and western Kentucky (fig. 1). Developmen scola Arch, in conjunction with the earlier sinking of deeper parts of the area to the north, gave the basin its

present asymmetrical, spoon-shaped configuration. The geologic map (fig.7) shows the distribution of the rock *systems* of the various geologic time periods as they would appear if all the glacial, windblown, and surface materials were removed.

The Kankakee River State Park field trip area is located along the southwestern flank of the Kankakee Arch on the northeastern edge of the Illinois Basin. The arch, which trends northwest-southeast through northeastern Illinois and north-central Indiana, forms a broad divide, or saddle, that connects the Wisconsin Arch and Cincinnati Arch (fig. 5) and separates the Illinois Basin from the Michigan Basin. The limits of the Kankakee Arch are not precisely defined because dips on its flanks are extremely gentle. The Kankakee Arch was formed during the early Ordovician. The lower Ordovician rocks of the Prairie du Chien Group are arched and truncated by erosion (fig. 2). The overlying Ordovician St. Peter Sandstone and the middle Ordovician rocks of the Platteville Group thin across the arch (Nelson 1995). The axis of the Ordovician Kankakee Arch lay slightly northeast of the present arch.

During the Silurian Period, reefs developed in the shallow seas covering the arch, and the position of the reefs helps determine the boundary between the shallow sea and the deeper seas to the north and south. By the Middle Devonian Epoch, the division became almost complete between the Illinois and Michigan Basins. Not much is known about subsequent development because post-Devonian rocks have been eroded from the arch. Mississippian and Pennsylvanian sediments at least partially overlapped the Kankakee Arch, as shown by the presence of rocks of that age in the Des Plaines Disturbance, which lies on the north flank of the arch (fig. 5) (Nelson 1995). Silurian strata form the crest of the arch and are exposed along the Kankakee River, its tributaries, and in the quarries in the field trip area. The highest elevations reached by this bedrock occur on the crests of the Silurian reefs, 650 feet above sea level in north-central Kankakee County. The Silurian rocks are overlain by early Pennsylvanian rocks in western Kankakee County.

Younger rocks of the latest Pennsylvanian and, perhaps the Permian (the youngest rock systems of the Paleozoic), may have at one time covered the Silurian strata throughout Kankakee County. Mesozoic and Cenozoic rocks were also probably deposited here. Indirect evidence, based on the stage of development (rank) of coal deposits and the generation and maturation of petroleum from source rocks (Damberger 1971), indicates that perhaps as much as 1.5 miles of latest Pennsylvanian and younger rocks once covered southern Illinois. During the more than 240 million years since the end of the Paleozoic Era (and before the onset of *glaciation* 1 to 2 million years ago), however, several thousands of feet of strata may have been eroded. Nearly all traces of any Pennsylvanian bedrock that may have been present in Illinois were removed. During this extended period of erosion, deep valleys were carved into the gently tilted bedrock formations (fig. 8). Later, the topographic *relief* was reduced by repeated advances and melting back of continental *glaciers* that scoured and scraped the bedrock surface. This glacial erosion affected all the formations exposed at the bedrock surface in Illinois. The final melting of the glaciers left behind the non-lithified deposits in which our Modern Soil has developed.

Cenozoic Era: Glacial History As stated above, erosion that took place long before the glaciers advanced across the state left a network of deep valleys carved into the bedrock surface. Prior to glaciation, the Kankakee Arch served as a drainage divide, controlling drainage towards the north and northeast into the Michigan Basin and to the west and southwest into the Illinois Basin. The southeastern, southwestern, and northwestern portions of Kankakee County were drained by unnamed tributaries flowing into the Onarga, Kempton, and Ticona Bedrock Valleys respectively (fig. 8). Drainage in the northeastern part of the county was towards the Michigan Basin.

As glaciation began, the streams probably stopped eroding and began to aggrade. That is, their channels began to build up and fill in because the streams did not have sufficient volumes of water to carry and move the increased volumes of sediment.

These ancient stream valleys were completely filled by the outwash from later glaciations. The present Kankakee River valley was subsequently formed by glacial meltwater that cut a new channel that now flows east-west. It is of interest to note that most of the sediment that filled the older stream valleys was sand and gravels. These sands and gravels serve as major aquifers in part of southeastern Kankakee County. Because of the irregular bedrock surface formed by erosion,

al drift is unevenly distributed across Kankakee County.

ıg the Pleistocene *Epoch*, beginning about 1.6 million years ago, massive sheets of ice (called continental glacie up to thousands of feet thick and flowed slowly southward from Canada. During the Illinois Episode, which began ıd 300,000 years B.P., North American continental glaciers reached their southernmost position, approximately niles south of here, in the northern part of Johnson County (fig. 9). The last of these glaciers retreated (melted) northeastern Illinois about 13,500 years before the present (B.P.). The maximum thickness of these later onsin Episode glaciers in Illinois was about 2,000 feet in the Lake Michigan Basin, but the ice was only about 700 hick over most of Illinois' land surface (Clark et al. 1988).

opography of the bedrock surface throughout much of Illinois is largely hidden by glacial deposits, except along ıajor streams. In many areas, the glacial drift is thick enough to completely mask the underlying bedrock surface. es of mine shafts, water-well logs, and other drill-hole information, in addition to the scattered bedrock exposures ne stream valleys and roadcuts, show that the present land surface in the areas of Illinois where the glacial deposits ıickest does not reflect the underlying bedrock surface. The topography of the preglacial surface has been ficantly modified by glacial erosion and subdued by glacial deposits. Within the field trip area, the thickness of the ıl drift ranges from 0 feet, where it has been removed by erosion and the bedrock is exposed, to more than 200 feet, e moraines formed.

ıugh the Illinois Episode glaciers probably built morainic ridges similar to those formed by the later Wisconsin ıde glaciers, the Illinois Episode moraines apparently were not as numerous and have been exposed to weathering rosion for approximately 280,000 years longer than their younger counterparts. For these reasons, Illinoian glacial res generally are not as conspicuous as the younger Wisconsinan features.

lying the glacial deposits is a thin cover of material called the Peoria *Loess* (pronounced "luss"), which has now renamed the Peoria Silt (Hansel and Johnson 1996). These sediments were deposited by the wind during the onsin Episode from 25,000 to 12,500 years ago, and mantle the glacial drift throughout the field trip area. In akee County, the loess is generally thinner than 2 feet and thins from west to east. This fine grained dust, which 's most of Illinois, reaches thicknesses exceeding 15 feet west of the field trip area along the Illinois River. Soils in rea have developed in the loess, in the wind-blown sand, in the underlying weathered silty and clayey Wisconsin nd in exposed Silurian dolomite.

Jpdated: 6/17/99 SLD

Density of Ice

The Physics Factbook
Edited by Glenn Elert -- Written by his students
An educational, fair use website

Bibliographic Entry	Result (w/surrounding text)	Standardized Result
Cutnell, John D., & Kenneth W. Johnson. *Physics, 3rd Edition*. New York: Wiley, 1995: 315	"Mass Densities of Common Substances, Ice, 917 kg/m^3	917 kg/m^3
"Ice." *Encarta*. Redmond, WA: Microsoft, 1997-2000.	"One important property of ice is that it expands upon freezing. At 0° C it has specific gravity 0.9168 as compared to specific gravity 0.9998 of water at the same temperature. As a result, ice floats in water."	916.8 kg/m^3
About Water and Ice. Mathmol. New York University, 1996.	"The density of ice Ih is 0.931 gm/cubic cm. This compares with a density of 1.00 gm/cubic cm. for water. There are eleven different forms of crystalline ice that are know. The hexaganol [sic] form known as ice Ih is the only one that is found naturally."	931 kg/m^3
Weast, Robert C., *Handbook of Chemistry and Physics. 61st Edition*. Florida: CRC, 1981: F-1.	"Density of Various Solids, Ice, 0.917 g/cm^3"	917 kg/m^3
Density. Air Travelers. Oregon Museum of Science and Industry (OMSI), 1996.	"Substance, Ice; Density kg/m^3, 917"	917 kg/m^3

g time ago in a place far, far away a man stood up and said, "LET THIS TEA BE COLD!!", and it was. This amazing phenomenon occurred not because his man had God-like powers, but because he added a couple of ice cubes to his drink.

ce is the solid phase of water and is usually sustained within temperatures at or below 0 °C. An interesting property of water is that it is less dense in the solid hase (ice) than it is in the liquid phase. For all you non-believers, we can verify this fact by performing this simple experiment.

1. Obtain glass and household refreshment.
2. Hold glass upright and pour in drink.
3. Remove ice tray from freezer and place 1-4 ice cubes in drink.
4. Stare in awe as the ice cubes float.

Another interesting property of water explains how and why bodies of water freeze the way they do. As water approaches its freezing point, under STP conditions (0 °C and 1 atmosphere), it reaches it's maximum density at 4 °C. When the water on the surface cools to this point, it sinks and warmer water from below rises. This process continues until the entire body of water is at 4 °C. This explains why oceans freeze from top to bottom and not the other way around. ce plays an important part in ground erosion, usually during the winter. As water seeps into crevices in the ground and freezes, it expands and creates massive orce which cracks and erodes the earth.

n theory, ice has had a major effect on evolution and the development of the human species. For more information see The effect of the density of ice on volution by Sharon Fenton of Sheffield Hallam University.

Alex Dallas -- 2000

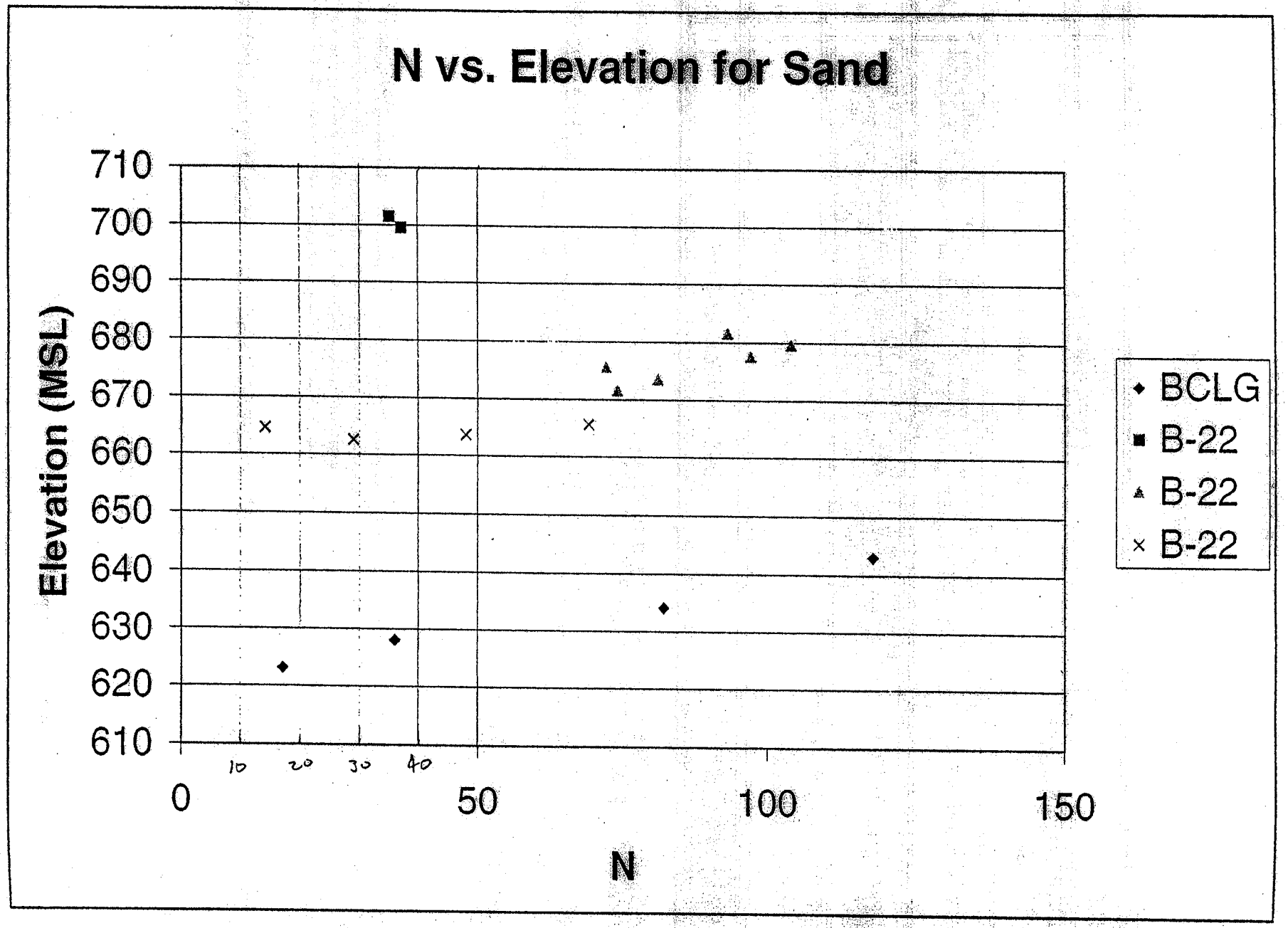

N vs. Elevation for Sand
Elevation (MSL)
710
700
690
680
670
660
650
640
630
620
610
0
50
100
150
N
10
20
30
40
BCLG
B-22
B-22
B-22

TABLE 1
Typical Properties of Compacted Soils

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Moisture, Percent	Typical Value of Compression		Typical Strength Characteristics				Typical Coefficient of Permeability ft./min.	Range of CBR Values	Range of Subgrade Modulus k lbs/cu in.
				At 1.4 tsf (20 psi)	At 3.4 tsf (50 psi)	Cohesion (as compacted) psf	Cohesion (saturated) psf	ϕ (Effective Stress Envelope Degrees)	Tan ϕ			
				Percent of Original Height								
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}	40 - 80	300 - 500
GP	Poorly graded clean gravels, gravel-sand mix	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}	30 - 60	250 - 400
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	.....	.....	>34	>0.67	$>10^{-6}$	20 - 60	100 - 400
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	.....	.....	>31	>0.60	$>10^{-7}$	20 - 40	100 - 300
SW	Well graded clean sands, gravelly sands.	110 - 130	16 - 9	0.6	1.2	0	0	38	0.79	$>10^{-3}$	20 - 40	200 - 300
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$	10 - 40	200 - 300
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	$5 \times >10^{-5}$	10 - 40	100 - 300
SM-SC	Sand-silt clay mix with slightly plastic fines.	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	$2 \times >10^{-6}$	5 - 30	100 - 300
SC	Clayey sands, poorly graded sand-clay-mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	$5 \times >10^{-7}$	5 - 20	100 - 300
ML	Inorganic silts and clayey silts.	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	$>10^{-5}$	15 or less	100 - 200
ML-CL	Mixture of inorganic silt and clay.	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	$5 \times >10^{-7}$	.....	
CL	Inorganic clays of low to medium plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	$>10^{-7}$	15 or less	50 - 200
OL	Organic silts and silt-clays, low plasticity.	80 - 100	33 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	50 - 100
MH	Inorganic clayey silts, elastic silts.	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	$5 \times >10^{-7}$	10 or less	50 - 100
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	$>10^{-7}$	15 or less	50 - 150
OH	Organic clays and silty clays	65 - 100	45 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	25 - 100

Notes:

1. All properties are for condition of "Standard Proctor" maximum density, except values of k and CBR which are for "modified Proctor" maximum density.
2. Typical stength characteristics are for effective strength envelopes and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater than the value shown.
   (..) indicates insufficient data available for an estimate.

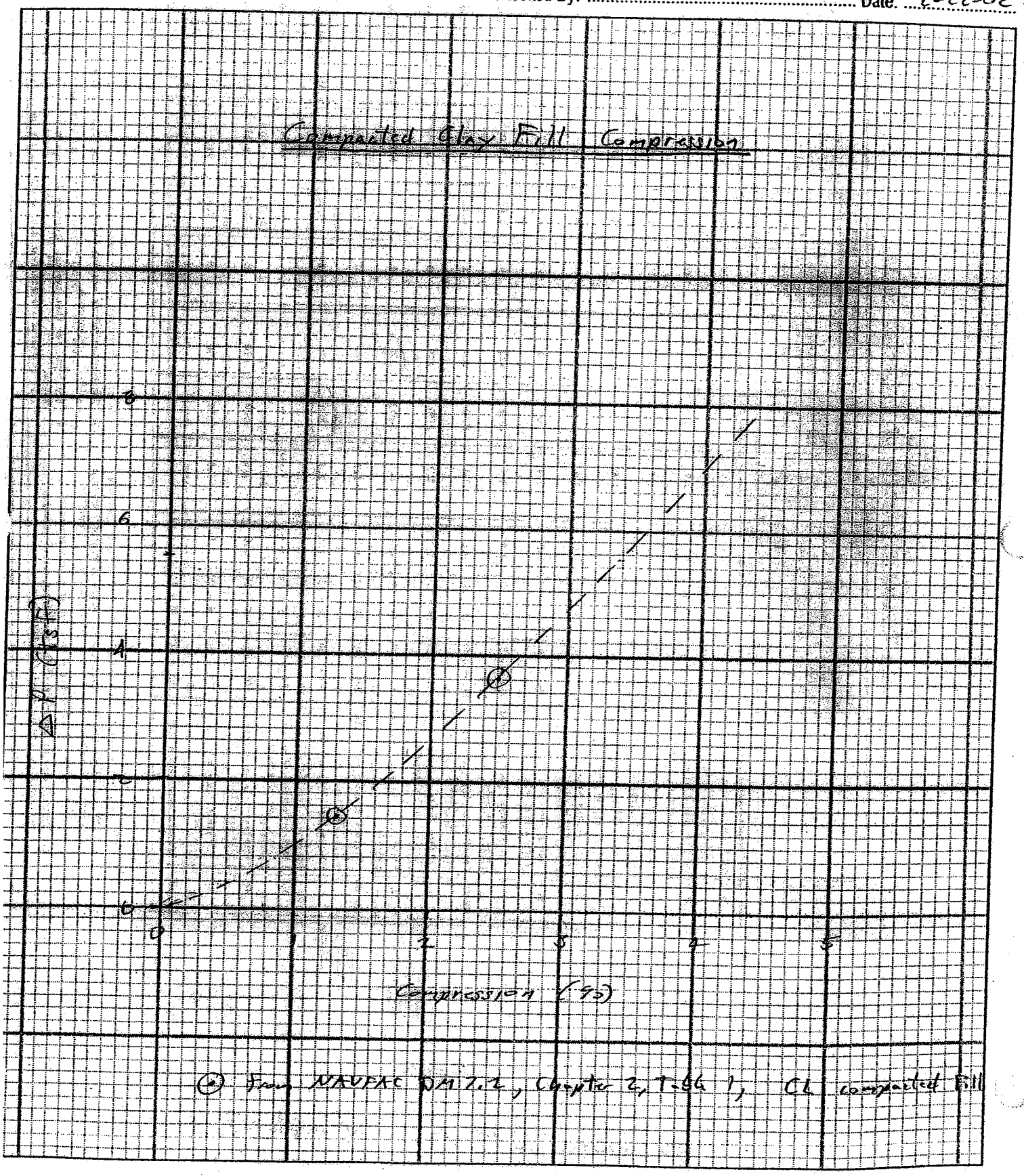
Final Cover →

NAVFAC DM 7.2, Chapter 2

PDC TECHNICAL SERVICES, INC.

Project: Clinton Landfill Siting Calculated By: G.L. Armstrong Sheet ____ of ____

Project No.: 91-0118.02 Task No.: ____ Checked By: ____ Date: 2-22-02



* From NAVFAC DM 7.2, Chapter 2, T-6G 1, CL compacted fill

Don't Let It Slide

Conducting stability analyses can prevent slope failures in bioreactors.

BIOREACTOR AND LEACHATE recirculation technology is gaining popularity in North America and Europe. Some of the benefits, such as accelerated waste biodegradation/stabilization, accelerated methane gas yield and recovery of landfill air space, make these technologies an attractive alternative to conventional landfills. However, their design can lead to many physical problems, especially slope failures. To keep slopes stable, careful testing, analysis and monitoring must be conducted to prevent unstable conditions from developing.

Slope stability is perhaps the paramount engineering issue for bioreactors and leachate recirculation landfills. A worst-case scenario for these facilities is that a slope becomes unstable through the presence of liquid or the use of injection pressure to introduce the liquid. In general, adding liquid to a landfill can destabilize it. However, there are at least 12 new bioreactor landfills in the United States and Canada that are operating successfully, the are proof that state-of-the practice techniques work.

And although the technology exists to do so, converting existing "dry-tomb" landfills to leachate recirculation or a bioreactor can be troublesome. Many of the design, construction and operation techniques used to advance the dry-tomb concept, such as using low-permeability daily covers, are detrimental to the subsequent addition of liquid. Whether the bioreactor is new or a converted facility, similar stability analyses are used to evaluate both situations.

In a new or converted bioreactor, the analyses must address the effect of additional liquid on the waste and the driving forces, the accelerated degradation of the waste in terms of the unit weight and shear strength, and the effect of adding liquid to the liner system. Stability analyses are also used to estimate the amount of liquid buildup or injection pressure that can be tolerated without lowering the safety of landfill slopes.

The five main effects of additional liquid considered in stability analyses are: a buildup of greater than 1 foot of hydraulic head on the liner system; perched liquids in the waste; perched liquids migrating along a low permeability layer and outbreaking on the slope face, which can result in a veneer or deep stability problem; a change in waste properties such as lower shear strength and higher unit weight; and an accelerated methane gas generation rate, which can further reduce the effective normal stress acting on a potential failure surface. Software used to analyze dry-tomb landfills also can be used to analyze bioreactor stability. The software analyzes the same stages for bioreactors as for the dry-tomb landfills: construction, interim/filling and final build-out. In each of these cases, searches for the critical cross-section and failure surface should be performed, including deep and shallow failure surfaces.

Although the analyses between dry-tomb and bioreactor landfills are similar, there are differences with a bioreactor, such as a greater leachate level at the liner system, perched liquid levels, and increased unit weight and lower shear strength for the degraded waste. The increased unit weight and reduced shear strength are clearly applicable for the final build-out stage analyses. Prorated values of increased unit weight and decreased shear strength can be used for the interim condition if it occurs early in the life of the bioreactor.

For the construction and initial filling analyses, engineering properties for non-degraded waste can be used, e.g., a cohesion of 500 pounds/square foot (psf), a friction angle of 35 degrees and a unit weight of 75 pounds per cubic foot (pcf) to 85 pcf. Ongoing research at North Carolina State University (NCSU), Raleigh, N.C., shows that the shear strength of waste decreases with degradation. Based on research and field observations conducted by the authors, a cohesion of 0 psf, a friction angle of 20 degrees and a unit weight of 100 pcf to 110 pcf is recommended for degraded waste. These parameters are representative of a cohesive soil, which better simulates degraded waste than fresh waste.

Using the non-degraded and degraded engineering properties identified above, a landfill designer develops an estimate of the liquid level acting on the liner system and the location and magnitude of perched liquids in the waste to conduct stability analyses to evaluate safety issues. The authors usually recommend a conservative leachate buildup of five feet on the liner system and a conservative perched liquid depth of 10 feet at various locations in the waste to evaluate safety. During operation of the bioreactor or leachate recirculation system, it is recommended that the landfill's liquid level be monitored to ensure the levels are not exceeding what the facility was designed to accommodate.

Stability analyses are used to evaluate the effect of injection pressures on safety and the impact of perched liquid levels throughout the waste. To reduce perched liquids' potential, bioreactor designs promoting uniform distribution and maximum liquid absorption are preferred.

— Timothy D. Stark, Professor of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, and J.W. Spear, Consulting Engineer, J. Spear Associates, Milwaukee, Wis.

Soil Strength and Slope Stability

J. Michael Duncan
Stephen G. Wright



WILEY
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Undrained strengths of compacted clays. Values of d ϕ (total stress shear strength parameters) for the ompacted condition can be determined by performng UU triaxial tests on specimens at their compaction water contents. Undrained strength envelopes for compacted, partially saturated clays tested are curved, as discussed in Chapter 3. Over a given range of stresses, however, a curved strength envelope can be approximated by a straight line and can be characterized in terms of c and ϕ. When this is done, it is especially important that the range of pressures used in the tests correspond to the range of pressures in the field conditions being evaluated. Alternatively, if the computer program used accommodates nonlinear strength envelopes, the strength test data can be represented directly.

Values of total stress c and ϕ for compacted clays vary with compaction water content and density. An example is shown in Figure 5.20 for compacted Pittsburgh sandy clay. The range of confining pressures used in these tests was 1.0 to 6.0 tons/ft^2. The value of c, the total stress cohesion intercept from UU tests, increases with dry density but is not much affected by compaction water content. The value of ϕ, the total stress friction angle, decreases as compaction water content increases, but is not so strongly affected by dry density.

If compacted clays are allowed to age prior to test- they become stronger, apparently due to thixoic effects. Therefore, undrained strengths measured sing freshly compacted laboratory test specimens provide a conservative estimate of the strength of the fill a few weeks or months after compaction.

MUNICIPAL SOLID WASTE

Waste materials have strengths comparable to the strengths of soils. Strengths of waste materials vary depending on the amounts of soil and sludge in the waste, as compared to the amounts of plastic and other materials that tend to interlock and provide tensile strength (Eid et al., 2000). Larger amounts of materials that interlock increase the strength of the waste. Although solid waste tends to decompose or degrade with time, Kavazanjian (2001) indicates that the strength after degradation is similar to the strength before degradation.

Kavazanjian et al. (1995) used laboratory test data and back analysis of stable slopes to develop the lower-bound strength envelope for municipal solid waste shown in Figure 5.21. The envelope is horizontal with a constant strength c = 24 kPa, ϕ = 0 at normal pressures less than 37 kPa. At pressures greater than 37 kPa, the envelope is inclined at ϕ = 33° with c = 0.

Eid et al. (2000) used results of large-scale direct shear tests (300 to 1500 mm shear boxes) and back analysis of failed slopes in waste to develop the range of strength envelopes show in Figure 5.22. All three envelopes (lower bound, average, and upper bound) are inclined at ϕ = 35°. The average envelope shown in Figure 5.22 corresponds to c = 25 kPa, and the lowest of the envelopes corresponds to c = 0.

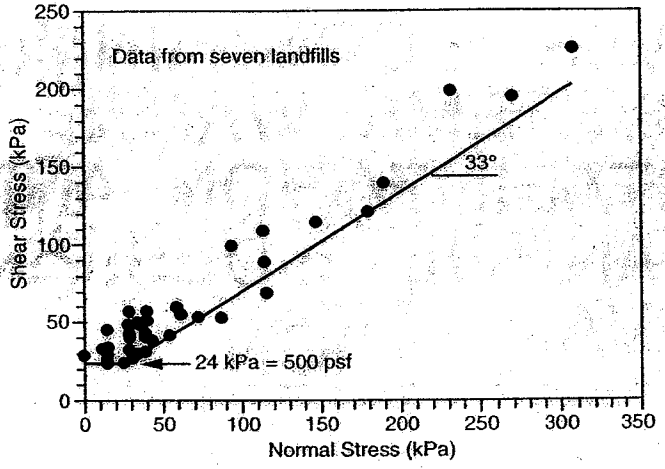


Figure 5.21 Shear strength envelope for municipal solid waste based on large-scale direct shear tests and back analysis of stable slopes. (After Kavazanjian et al., 1995.)

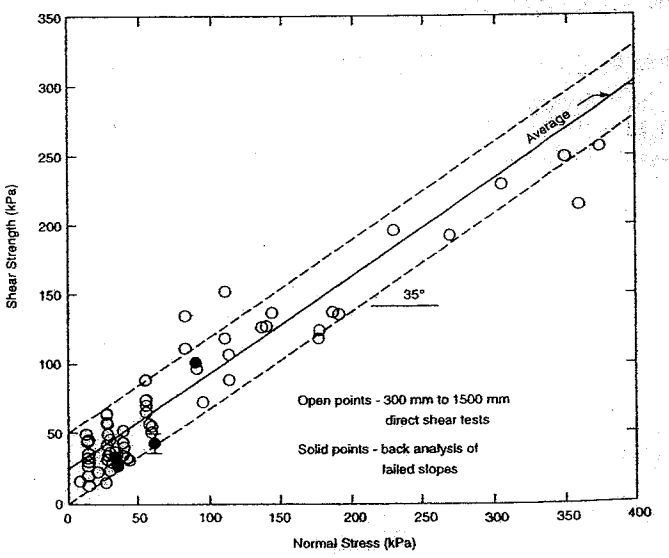


Figure 5.22 Range of shear strength envelopes for municipal solid waste based on large-scale direct shear tests and back analysis of failed slopes. (After Eid et al., 2000.)

Duncan & Wright

WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION, AND LANDFILLS: DESIGN AND EVALUATION

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with soil cover at a hazardous waste landfill site may weigh 101 lb/ft^3. Similarly, a unit weight of 90 lb/ft^3 was cited for a 30- to 40-deep landfill with 90 to 95 percent of its waste in metal drums. Kiln dust, sludge tar, creosote, and soil in about 62-foot-deep (average thickness) waste have been reported to weigh 75 lb/ft^3.

The information above indicates that waste unit weights vary significantly and that site-specific data should be collected for use in an engineering evaluation. The above-cited data may, however, be used in preliminary design.

2.4.7 Strength and Compressibility

Strength and compressibility for *municipal landfill* waste are important engineering considerations because these characteristics are required for landfill stability and settlement analyses. Due to variability in municipal refuse, reliance on conventional laboratory results is not prudent. Various laboratory and field tests have been reported in the literature. Landva and Clark (1990) and Singh and Murphy (1990) critically evaluated the results presented by various investigators. In general, strength and compressibility characteristics of municipal waste are not yet well understood and need further evaluation. No useful information is yet available on the stress-strain behavior of landfill materials. Until further information is obtained, the following can be used as a guide in landfill design.

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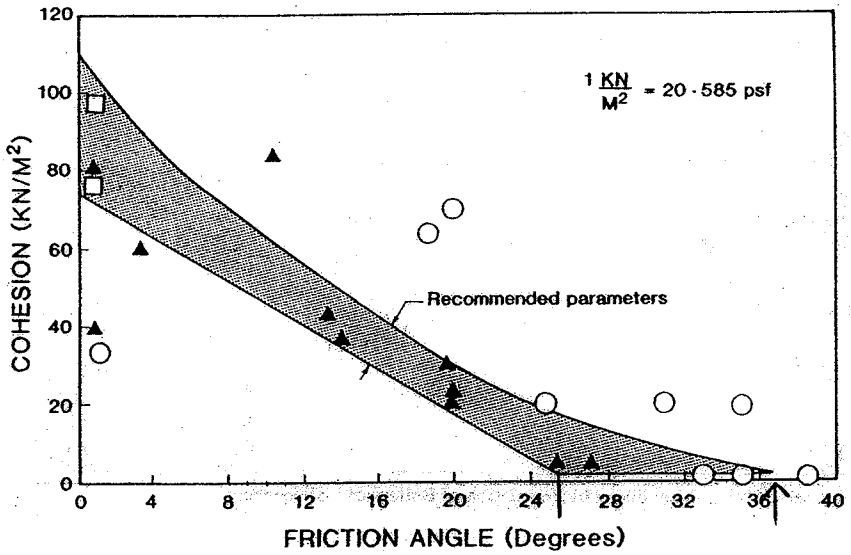


Figure 2.15 Summary plot for all tests with recommended parameters shaded. (From Singh and Murphy, 1990.)

Sharma & Lewis

recommended zone in this figure is close to the line for c–ϕ information obtained from full-scale field tests by Converse et al. (1975).

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TABLE 2.23 Strength Properties of Mineral Waste

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Unit wt. 12.6 kN/m^3			331	
Unit wt. 13.4 kN/m^3			587	
Unit wt. 13.8 kN/m^3				
Fly ash (silica 46%, aluminum 34%, calcium 7%)				
Slurry samples	0	37		
Compacted, undrained effective stress	0	41		
Compacted, drained	0	37		
West Virginia fly ash				
Shelby tube samples (consolidated, undrained)	0	34		
Shelby tube samples (consolidated, drained)	0	37.5		
West Virginia bottom ash		38–43		
Flue-gas desulfurization (FGD) sludge				
Consolidated, drained test	0	41.5		
Compacted	0–40	10–40		
Red mud (bauxite residue)				
Unleached			63	52
Leached			0	49
Mud: sand (5:1)			38	41

Source: Weis and Khera (1990). Reproduced by permission of Butterworth-Heinemann.

Sharma & Lewis

TABLE 2.
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Ash A v
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Ash B v
Ash B v
Lignite fly
Lime:fly a
6.3:43.7
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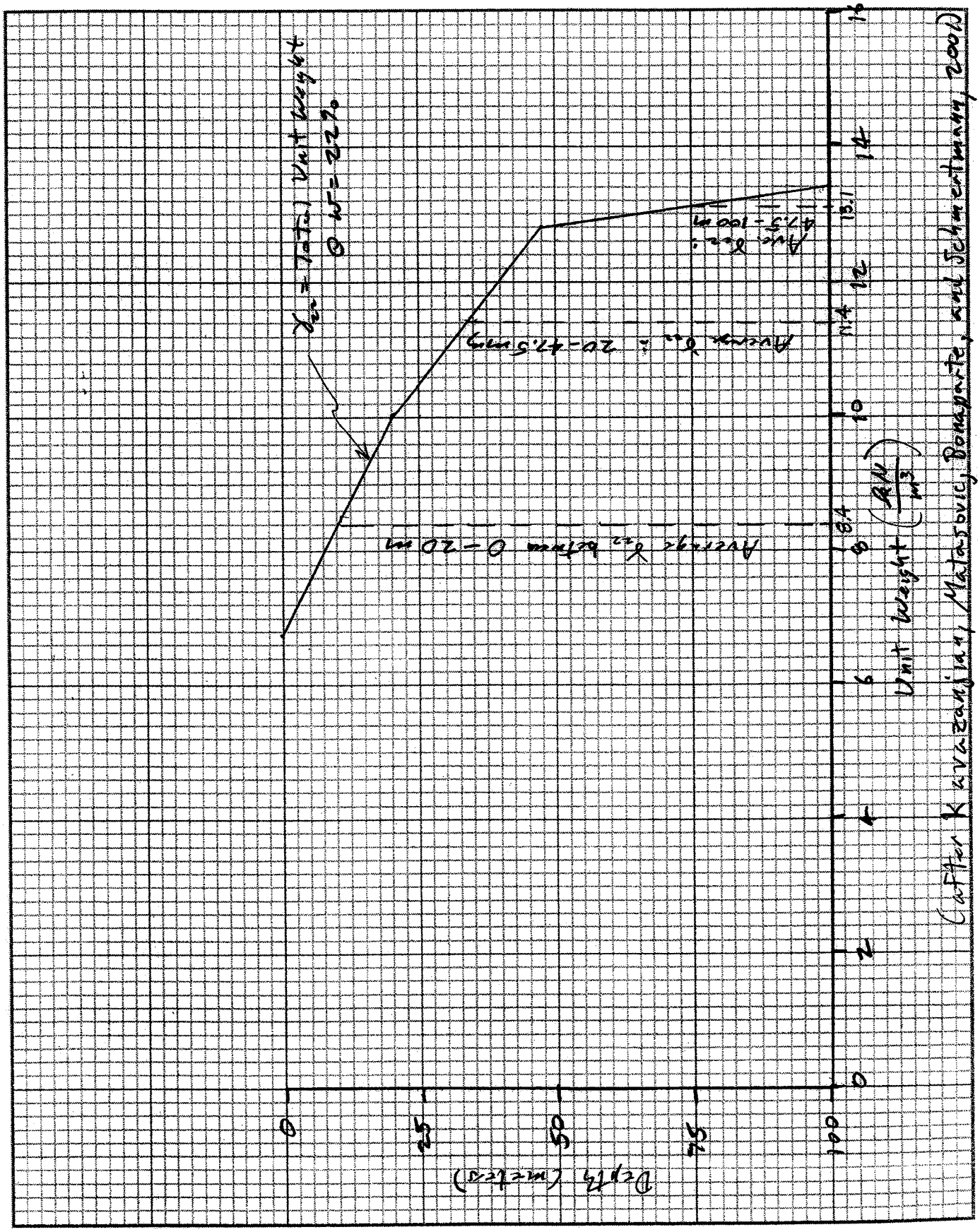
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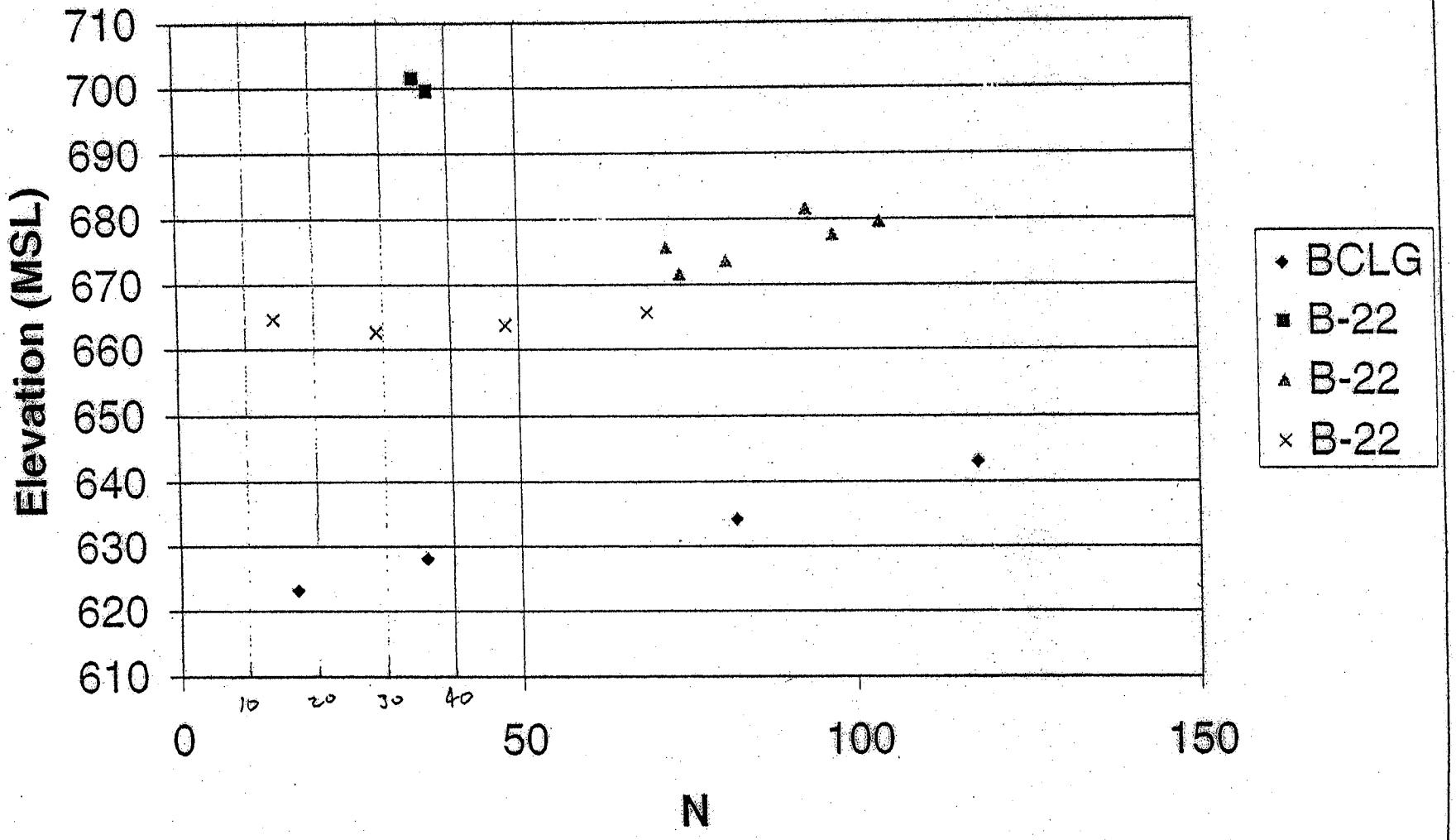
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N vs. Elevation for Sand



ABLE 1
Typical Properties of Compacted Soils

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Moisture, Percent	Typical Value of Compression		Typical Strength Characteristics				Typical Coefficient of Permeability ft./min.	Range of CBR Values	Range of Subgrade Modulus k lbs/cu in.
				At 1.4 tsf (20 psi)	At 3.6 tsf (50 psi)	Cohesion (as compacted) psf	Cohesion (saturated) psf	ϕ (Effective Stress Envelope Degrees)	Tan ϕ			
				Percent of Original Height								
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}	40 - 80	300 - 500
GP	Poorly graded clean gravels, gravel-sand mix	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}	30 - 60	250 - 400
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	.....	.....	>34	>0.67	$>10^{-6}$	20 - 60	100 - 400
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	.....	.....	>31	>0.60	$>10^{-7}$	20 - 40	100 - 300
SW	Well graded clean sands, gravelly sands.	110 - 130	16 - 9	0.6	1.2	0	0	38	0.79	$>10^{-3}$	20 - 40	200 - 300
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$	10 - 40	200 - 300
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	$5 \times >10^{-5}$	10 - 40	100 - 300
SM-SC	Sand-silt clay mix with slightly plastic fines.	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	$2 \times >10^{-6}$	5 - 30	100 - 300
SC	Clayey sands, poorly graded sand-clay-mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	$5 \times >10^{-7}$	5 - 20	100 - 300
ML	Inorganic silts and clayey silts.	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	$>10^{-5}$	15 or less	100 - 200
ML-CL	Mixture of inorganic silt and clay.	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	$5 \times >10^{-7}$	.....	
CL	Inorganic clays of low to medium plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	$>10^{-7}$	15 or less	50 - 200
OL	Organic silts and silt-clays, low plasticity.	80 - 100	33 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	50 - 100
MH	Inorganic clayey silts, elastic silts.	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	$5 \times >10^{-7}$	10 or less	50 - 100
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	$>10^{-7}$	15 or less	50 - 150
OH	Organic clays and silty clays	65 - 100	45 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	25 - 100

Notes:

1. All properties are for condition of "Standard Proctor" maximum density, except values of k and CBR which are for "modified Proctor" maximum density.
2. Typical stength characteristics are for effective strength envelopes and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater than the value shown.
   (..) indicates insufficient data available for an estimate.

Final Cover →

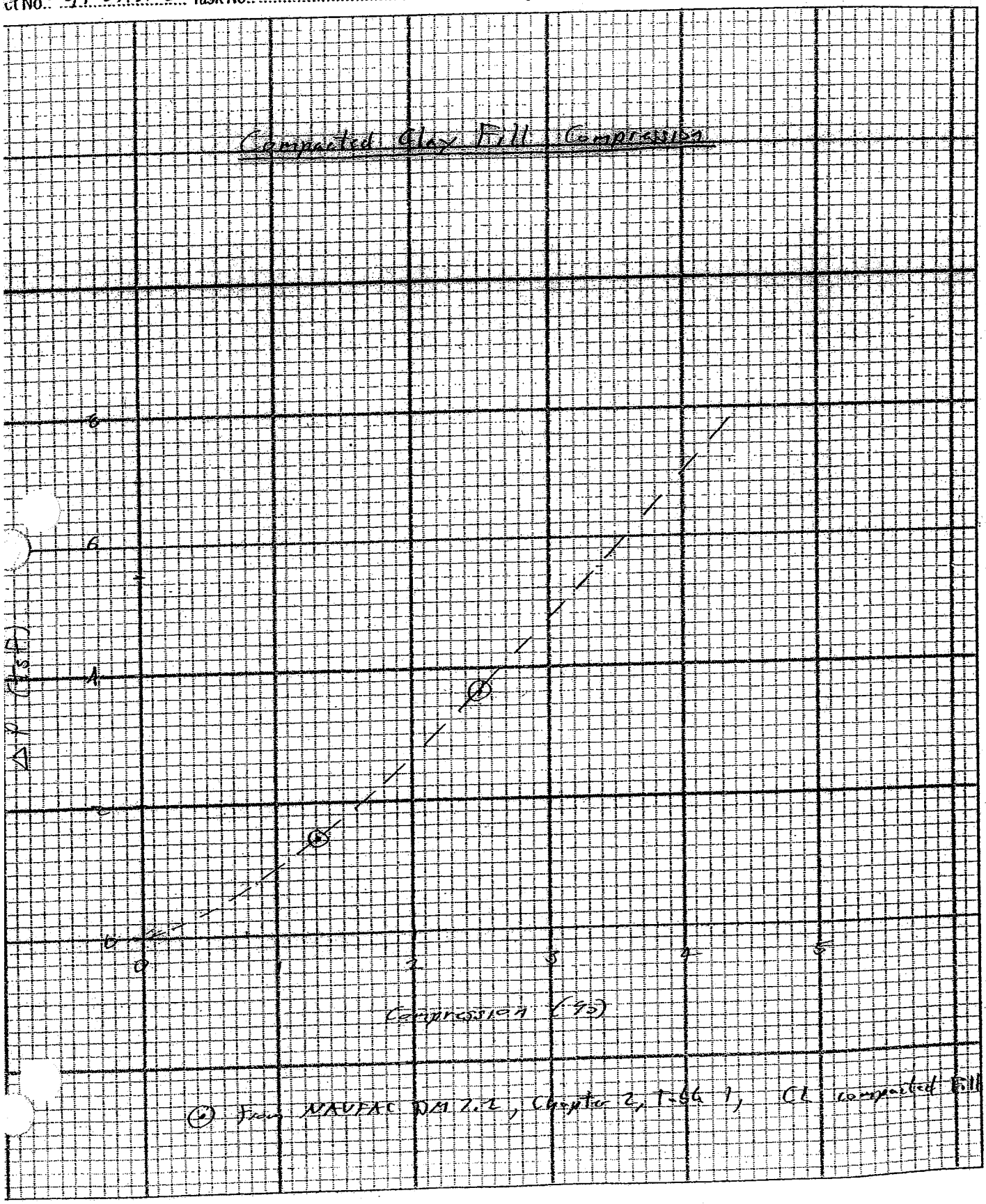
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NAVFAC DM 7.2, Chapter 2

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(a) From MAUFAC DM 7.2, Chapter 2, T-54 1, CL compacted fill

Don't Let It Slide

Conducting stability analyses can prevent slope failures in bioreactors.

BIOREACTOR AND LEACHATE recirculation technology is gaining popularity in North America and Europe. Some of the benefits, such as accelerated waste biodegradation/stabilization, accelerated methane gas yield and recovery of landfill air space, make these technologies an attractive alternative to conventional landfills. However, their design can lead to many physical problems, especially slope failures. To keep slopes stable, careful testing, analysis and monitoring must be conducted to prevent unstable conditions from developing.

Slope stability is perhaps the paramount engineering issue for bioreactors and leachate recirculation landfills. A worst-case scenario for these facilities is that a slope becomes unstable through the presence of liquid or the use of injection pressure to introduce the liquid. In general, adding liquid to a landfill can destabilize it. However, there are at least 12 new bioreactor landfills in the United States and Canada that are operating successfully, the are proof that state-of-the practice techniques work.

And although the technology exists to do so, converting existing "dry-tomb" landfills to leachate recirculation or a bioreactor can be troublesome. Many of the design, construction and operation techniques used to advance the dry-tomb concept, such as using low-permeability daily covers, are detrimental to the subsequent addition of liquid. Whether the bioreactor is new or a converted facility, similar stability analyses are used to evaluate both situations.

In a new or converted bioreactor, the analyses must address the effect of additional liquid on the waste and the driving forces, the accelerated degradation of the waste in terms of the unit weight and shear strength, and the effect of adding liquid to the liner system. Stability analyses are also used to estimate the amount of liquid buildup or injection pressure that can be tolerated without lowering the safety of landfill slopes.

The five main effects of additional liquid considered in stability analyses are: a buildup of greater than 1 foot of hydraulic head on the liner system; perched liquids in the waste; perched liquids migrating along a low permeability layer and outbreaking on the slope face, which can result in a veneer or deep stability problem; a change in waste properties such as lower shear strength and higher unit weight; and an accelerated methane gas generation rate, which can further reduce the effective normal stress acting on a potential failure surface. Software used to analyze dry-tomb landfills also can be used to analyze bioreactor stability. The software analyzes the same stages for bioreactors as for the dry-tomb landfills: construction, interim/filling and final build-out. In each of these cases, searches for the critical cross-section and failure surface should be performed, including deep and shallow failure surfaces.

Although the analyses between dry-tomb and bioreactor landfills are similar, there are differences with a bioreactor, such as a greater leachate level at the liner system, perched liquid levels, and increased unit weight and lower shear strength for the degraded waste. The increased unit weight and reduced shear strength are clearly applicable for the final build-out stage analyses. Prorated values of increased unit weight and decreased shear strength can be used for the interim condition if it occurs early in the life of the bioreactor.

For the construction and initial filling analyses, engineering properties for non-degraded waste can be used, e.g., a cohesion of 500 pounds/square foot (psf), a friction angle of 35 degrees and a unit weight of 75 pounds per cubic foot (pcf) to 85 pcf. Ongoing research at North Carolina State University (NCSU), Raleigh, N.C., shows that the shear strength of waste decreases with degradation. Based on research and field observations conducted by the authors, a cohesion of 0 psf, a friction angle of 20 degrees and a unit weight of 100 pcf to 110 pcf is recommended for degraded waste. These parameters are representative of a cohesive soil, which better simulates degraded waste than fresh waste.

Using the non-degraded and degraded engineering properties identified above, a landfill designer develops an estimate of the liquid level acting on the liner system and the location and magnitude of perched liquids in the waste to conduct stability analyses to evaluate safety issues. The authors usually recommend a conservative leachate buildup of five feet on the liner system and a conservative perched liquid depth of 10 feet at various locations in the waste to evaluate safety. During operation of the bioreactor or leachate recirculation system, it is recommended that the landfill's liquid level be monitored to ensure the levels are not exceeding what the facility was designed to accommodate.

Stability analyses are used to evaluate the effect of injection pressures on safety and the impact of perched liquid levels throughout the waste. To reduce perched liquids' potential, bioreactor designs promoting uniform distribution and maximum liquid absorption are preferred.

— Timothy D. Stark, Professor of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, and J.W. Spear, Consulting Engineer, J. Spear Associates, Milwaukee, Wis.

Soil Strength and Slope Stability

J. Michael Duncan
Stephen G. Wright



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strengths of compacted clays. Values of
l stress shear strength parameters) for the
cted condition can be determined by perform-
riaxial tests on specimens at their compaction
contents. Undrained strength envelopes for com-
, partially saturated clays tested are curved, as
sed in Chapter 3. Over a given range of stresses,
er, a curved strength envelope can be approxi-
by a straight line and can be characterized in
of c and ϕ. When this is done, it is especially
ant that the range of pressures used in the tests
pond to the range of pressures in the field con-
being evaluated. Alternatively, if the computer
m used accommodates nonlinear strength enve-
the strength test data can be represented directly.
ues of total stress c and ϕ for compacted clays
with compaction water content and density. An
ple is shown in Figure 5.20 for compacted Pitts-
sandy clay. The range of confining pressures
in these tests was 1.0 to 6.0 tons/ft^2. The value
he total stress cohesion intercept from UU tests,
ses with dry density but is not much affected by
action water content. The value of ϕ, the total
friction angle, decreases as compaction water
nt increases, but is not so strongly affected by dry
ty.

cted clays are allowed to age prior to test-
h become stronger, apparently due to thixo-
fects. Therefore, undrained strengths measured
eshly compacted laboratory test specimens pro-
a conservative estimate of the strength of the fill
weeks or months after compaction.

IICIPAL SOLID WASTE

e materials have strengths comparable to the
gths of soils. Strengths of waste materials vary
nding on the amounts of soil and sludge in the
e, as compared to the amounts of plastic and other
rials that tend to interlock and provide tensile
gth (Eid et al., 2000). Larger amounts of materials
interlock increase the strength of the waste. Al-
gh solid waste tends to decompose or degrade with
, Kavazanjian (2001) indicates that the strength af-
legradation is similar to the strength before deg-
tion.

avazanjian et al. (1995) used laboratory test data
back analysis of stable slopes to develop the lower-
id strength envelope for municipal solid waste
vn in Figure 5.21. The envelope is horizontal with
t strength c = 24 kPa, ϕ = 0 at normal pres-
sures less than 37 kPa. At pressures greater than 37 kPa, the envelope is inclined at ϕ = 33° with c = 0.

Eid et al. (2000) used results of large-scale direct shear tests (300 to 1500 mm shear boxes) and back analysis of failed slopes in waste to develop the range of strength envelopes show in Figure 5.22. All three envelopes (lower bound, average, and upper bound) are inclined at ϕ = 35°. The average envelope shown in Figure 5.22 corresponds to c = 25 kPa, and the lowest of the envelopes corresponds to c = 0.

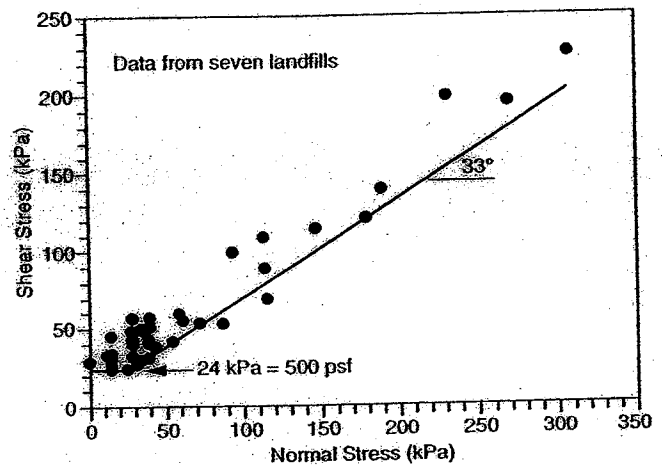


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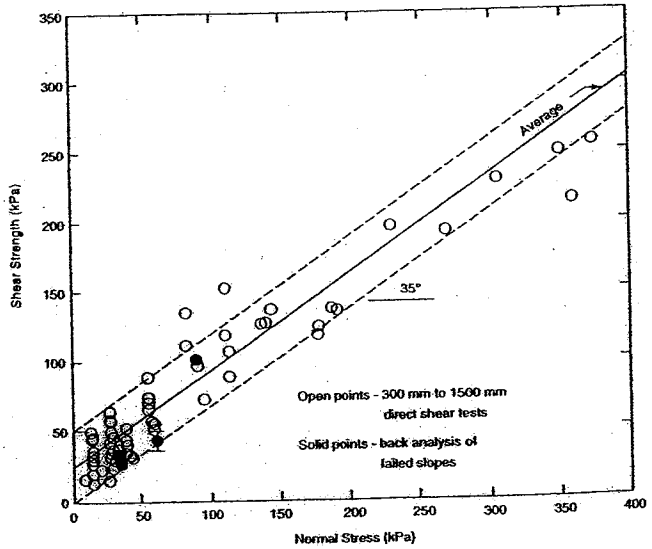


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WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION, AND LANDFILLS: DESIGN AND EVALUATION

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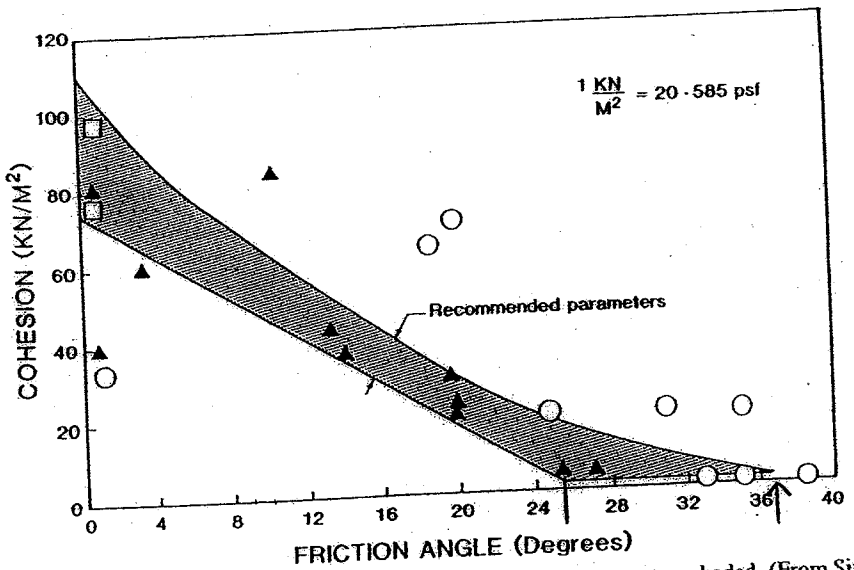


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Sharma & Lewis

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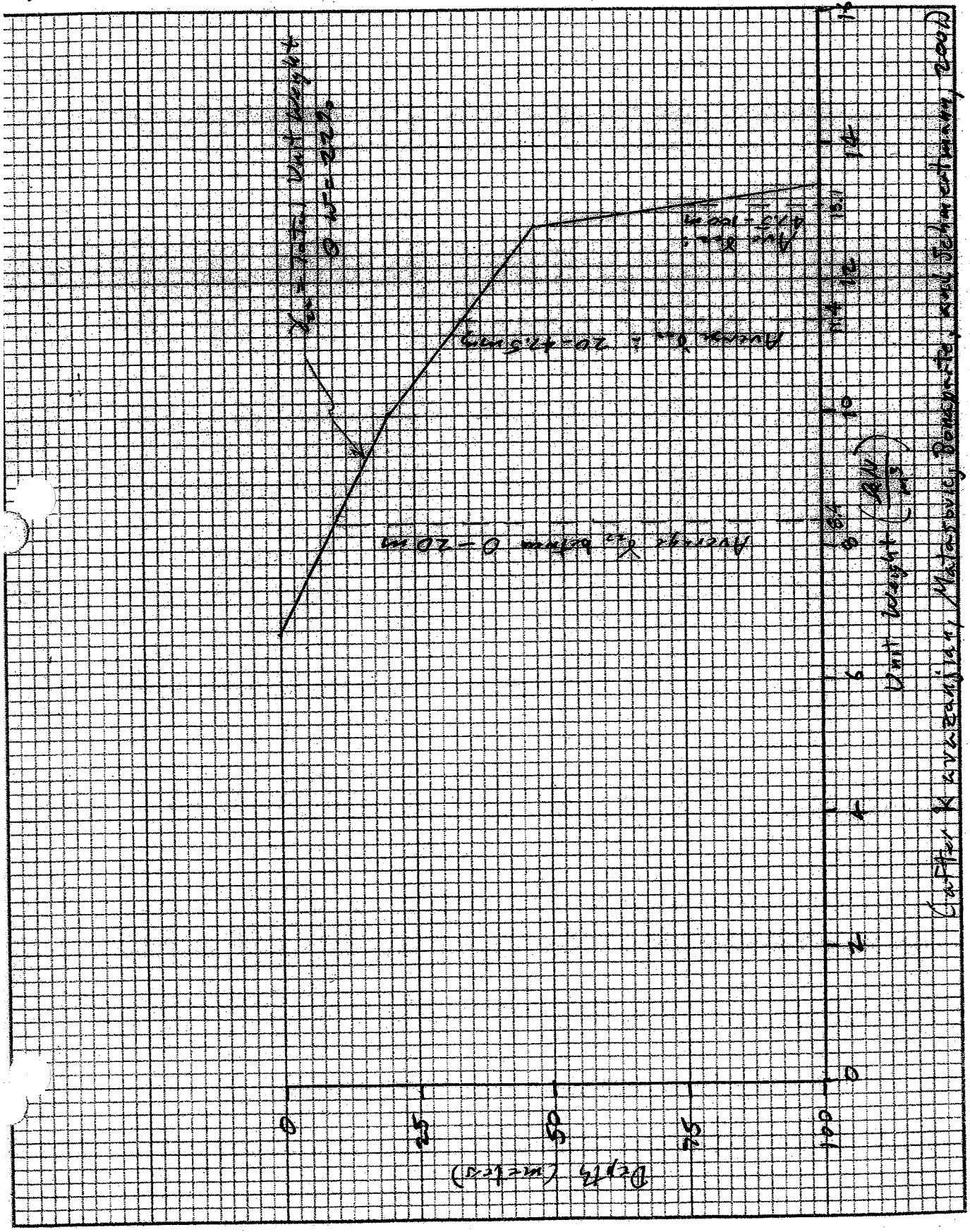
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GEOTECHNICAL ASPECTS OF LANDFILL DESIGN AND CONSTRUCTION

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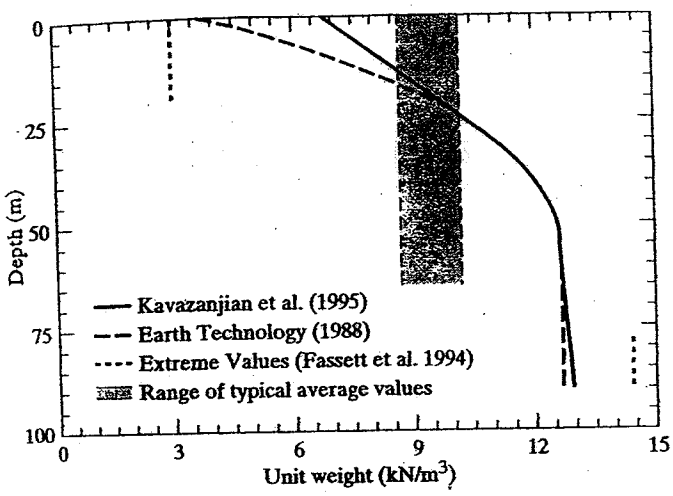


FIGURE 6.1 Unit Weight Profile for Municipal Solid Waste (Kavazanjian et al., 1995) Used with permission of ASCE.

Zornberg et al. (1999) conducted direct field measurements and spectral surface wave analysis (SASW) surveys to characterize the unit weight profile for the waste at a MSW landfill located in southern California. The waste unit weight obtained from direct field measurements ranged approximately from 64 lb/ft^3 to 95 lb/ft^3 (10 kN/m^3 to 15 kN/m^3) at a depth of between 26 ft and 164 ft (8 m and 50 m) below the landfill surface.

Based on the compaction equipment used in most landfills at present, the compaction ratio of loose waste to compacted waste usually ranges from 2:1 to 3:1. The average unit weight of compacted solid waste is usually 55 to 70 lb/ft^3 (55 to 70 kN/m^3) for modern solid waste landfills.

MOISTURE CONTENT OF MUNICIPAL SOLID WASTE

Two types of moisture content are used in landfill design. The first type of moisture content is defined as the percent by weight of water in the waste based on the dry weight of the waste. This dry gravimetric moisture content definition, commonly used in geotechnical engineering analyses, is written as

$$w_d = (W_w/W_s) \times 100 \tag{6.1}$$

where w_d = dry gravimetric moisture content, %;
W_w = weight of water; and
W_s = dry weight of solid waste.

In some references, moisture content is defined on the basis of wet weight of the wastes (i.e., w_w), written as

$$w_w = [W_w/(W_s + W_w)] \times 100 \tag{6.2}$$

where w_w = wet gravimetric moisture content, %;
W_w = weight of water; and
W_s = dry weight of solid waste.

This can be somewhat misleading in that it gives moisture content values much lower than those computed based on dry weight (i.e., in Equation 6.1). Unless stated otherwise, the dry weight definition will be used in this book, but the distinction must be kept in mind since many references use a wet weight basis for unit weight.

A different type of moisture content is defined as the percent by volume of water in the waste based on the total volume of the waste. This volumetric moisture content definition is widely used in hydrology and environmental engineering analyses. Mathematically,

$$\theta = (V_w/V) \times 100 \tag{6.3}$$

where θ = volumetric moisture content of solid waste, %;
V_w = volume of water; and
V = total volume of solid waste.

If the moisture content is known by either a weight or volume basis, the following equations can be used to convert dry gravimetric moisture content to volumetric moisture content or vice versa:

$$\theta = \frac{w_d \cdot \gamma}{(1 + w_d) \cdot \gamma_w} \tag{6.4}$$

$$w_d = \frac{\theta \cdot \gamma_w}{\gamma - \theta \cdot \gamma_w} \tag{6.5}$$

Where θ = volumetric moisture content of solid waste;
w_d = dry gravimetric moisture content of solid waste;
γ = unit weight of solid waste, lb/ft^3 or kN/m^3; and
γ_w = unit weight of water, 62.4 lb/ft^3 or 9.81 kN/m^3.

The moisture content discussed herein is the volumetric or dry gravimetric moisture content of MSW that has been placed in a landfill. The moisture content of MSW in landfills is highly dependent on several interrelated factors (Fassett, et al., 1994) composition of the waste (e.g., organic content), types of waste (e.g., liquid waste sludge), waste properties (e.g., hydraulic conductivity and field capacity), local climatic conditions (e.g., precipitation and season), landfill operating procedure (e.g. leachate circulation), effectiveness of leachate collection and removal system (e.g. leachate head control), and amount of moisture generated by biological process within the landfill (Mitchell and Mitchell, 1992).

The gravimetric water content on a dry-weight basis of MSW reported by Sowers (1968) and CalRecovery, Inc. (1993) usually ranged between 21% and 35%. Zornberg et al. (1999) reported an average dry gravimetric water content of 28% in a MSW landfill in Southern California. His measured water content values did not increase significantly with depth. The relationship between the values of dry gravimetric water content and organic content determined on the various refuse samples from different areas of Canada are compiled in Figure 6.2 (Landva and Clark, 1990). In general, water content seems to increase with increasing organic content, as might be expected. The moisture content may also vary with location as well because of differences in climate, landfill operating procedures, and waste compositions at each location.

TABLE 6.5 Index Properties of Solid Waste

Source	Unit Weight lb/ft³	Unit Weight kN/m³	Volumetric Moisture Content	Porosity	Void Ratio
Rovers and Farquhar (1973)	59	9.3	0.16	–	–
Pungaroli (1979)	63	9.9	0.05	–	–
Wigh (1979)	73	11.5	0.08	–	–
Walsh and Kinman (1979)	90	14.1	0.17	–	–
Walsh and Kinman (1981)	89	14.0	0.17	–	–
Schroeder et al. (1984a, b)	–	–	0.28	0.52	1.08
Oweis et al. (1990)	40 to 90	6.3 to 14.1	0.10 to 0.20	0.40 to 0.50	0.67 to 1.0
Schroeder et al. (1994a, b)	–	–	0.29	0.67	2.03
Zornberg et al. (1999)	64 to 95	10 to 15	0.30	0.49 to 0.62	1.02 to 1.65

Based on its constituent composition the average moisture content of the solid waste shown in Table 6.4 can be calculated as follows:

$$\begin{aligned} w_d &= [(60.0)(10.4) + (50.0)(19.1) + (20.0)(34.6) + (10.0)(6.0) + (15.0)(5.0) \\ &\quad + (15.0)(9.5) + (2.0)(4.0) + (2.0)(7.2) + (8.0)(2.8) + (3.0)(1.4)]/100 \\ &= (624 + 955 + 692 + 60 + 75 + 142.5 + 8 + 14.4 + 22.4 + 4.2)/100 \\ &= 2597.5/100 \\ &= 26.0\% \quad \text{(dry gravimetric } w\text{)} \end{aligned}$$

Thus, the average dry gravimetric moisture content of the solid waste shown in Table 6.4 is 26.0%.

More information about the moisture content of solid waste can be found in Table 6.5. It should be noted that the values of moisture content listed in Table 6.5 are calculated on a volume basis and differ from those calculated on a weight basis, which is more common to geotechnical analyses.

6.4 POROSITY OF MUNICIPAL SOLID WASTE

Porosity is defined as the ratio of the volume of voids to the total volume occupied by a solid waste or soil. Void ratio is defined as the ratio of the volume of voids to the volume of solids. Porosity can be related to the void ratio by using the relationships

$$n = \frac{e}{1 + e} \tag{6.7}$$

and

$$e = \frac{n}{1 - n} \tag{6.8}$$

where n = porosity of solid waste; and
e = void ratio of solid waste.

.2 Field Capacity Moisture Content

It is critical that careful control of the moisture content of the waste mass be maintained in order to produce the various phases and time frames described in Figure 15.1. The target moisture content is called *field capacity*. This value of waste moisture content must eventually be met and held at every location within the landfill in order to complete the degradation process.

Field capacity is defined as that moisture content of the waste at which the maximum amount of liquid is held in the voids against gravity drainage. The mechanisms involved are absorption and capillary forces. At moisture contents greater than field capacity, gravitational drainage occurs. The excess moisture either provides field capacity conditions at lower elevations in the landfill, or enters the leachate collection and removal system, where it is captured and recycled.

Field capacity for MSW can be calculated on the basis of wet weight or dry weight. (See Table 15.3.) In either case, it is a very high value, particularly considering the low unit weight of MSW. It should be noted that the unit weight data of Table 15.3 are from relatively old (probably poorly compacted) landfills. Current waste compaction is such that considerably higher densities usually result.

Clearly, higher unit weights result in higher values of field capacity (Fungaroli and Steiner, 1979). Also, the finer the particle size of the waste, the greater is its field capacity. Thus, shredding the waste has the effect of increasing the field capacity (Hentrich et al., 1979).

The intent of this discussion on field capacity values is to recognize that a considerable amount of moisture must be added to MSW to reach its targeted moisture content. By way of illustration, Figure 15.2 presents the quantity of liquid required on the basis of incoming waste volume. The quantities are considerably higher than the typical leachate generation of most landfills. Thus, landfills will generally require additional liquid to be added to the quantity which is recycled from the base of the

TABLE 15.3 Field Capacity Moisture Values (modified from Reinhart and Townsend, 1998)

Unit Weight of Waste			Gravimetric Field Capacity	
kg/m^3	lb/yd^3	lb/ft^3	% wet wt.	% dry wt.
500–800	843–1350	27–50	54	117
500–800*	843–1350*	27–50*	43–50*	75–100
690–950*	1160–1600*	43–59*	53*	113
710	1200	44	47	89
688	1160	43	20–35	25–54
310	520	19	37	59
287	485	18	29	41
503	850	31	31–48	45–92
440	735	27	48	92
474	800	30	35	54

*shredded waste

The porosity of MSW varies typically from 0.40 to 0.67 depending on the compaction and composition of the waste. For comparison, a typical compacted clay liner material will have a porosity of about 0.40. Table 6.5 shows a summary of the index properties of municipal solid waste, which includes initial volumetric moisture content, initial porosity, initial void ratio and unit weight data.

AULIC CONDUCTIVITY OF MUNICIPAL SOLID WASTE

per assessment of the hydraulic conductivity of municipal solid waste is important he design of leachate collection systems and in leachate recirculation planning parlarly for bioreactor landfills (see Chapter 15). The hydraulic conductivity can be asured using a field leachate pumping test and a large-scale percolation test in test s or by using large-diameter permeameters in the laboratory.

Hydraulic conductivity measured in test pits at several landfills in Canada by ndva and Clark (1990) is plotted against unit weight in Figure 6.3. The values shown ' d on an intermediate stage of water level recession, after the flow had stabi- d before any debris could clog the voids. The measured coefficients of ulic conductivity (1.0×10^{-3} to 4.0×10^{-2} cm/sec) correspond to those associd with clean sand and gravel. Qian (1994) used three-year field data from an active dfill in the state of Michigan to develop a relationship between precipitation and chate volume from a primary leachate collection system with time. With this inforation, the hydraulic conductivity of the waste can be calculated based on the water vel time, hydraulic gradient, and waste thickness. The hydraulic conductivity calcued in this way was estimated to be about 9.2×10^{-4} to 1.1×10^{-3} cm/sec. Table 6.6 mmarizes the hydraulic conductivity of different types of MSW taken from the

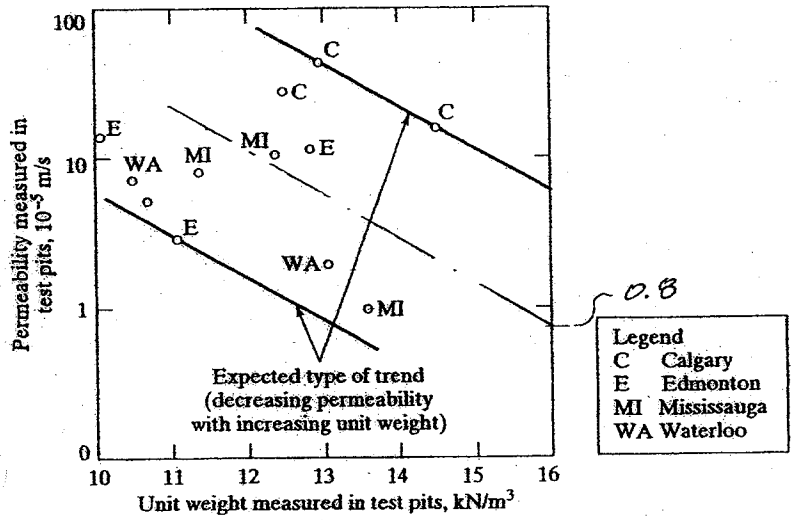


FIGURE 6.3 Unit Weight and Permeability (from Percolation) as Measured in Landfill Test Pits (Landva and Clark, 1990)

TABLE 6.6 Summary of Hydraulic Conductivity of Municipal Solid Waste

Source	Unit Weight		Hydraulic Conductivity (cm/sec)	Method
	lb/ft^3	kN/m^3		
Fungaroli et al. (1979)	7 to 26 milled waste	1.1 to 4.1 milled waste	1.0×10^{-3} to 2.0×10^{-2}	Lysimeter determination
Schroder et al. (1984a, b)	–	–	2.0×10^{-4}	Estimated based on summary
Oweis and Khera (1986)	41 (estimated)	6.4 (estimated)	Order of 10^{-3}	Estimated based on field data
Landva and Clark (1990)	64 to 92	10.1 to 14.5	1.0×10^{-3} to 4.0×10^{-2}	Test pits
Oweis et al. (1990)	41	6.4	1.0×10^{-3}	Pumping tests
Oweis et al. (1990)	60 to 90 (estimated)	9.4 to 14.1 (estimated)	1.5×10^{-4}	Falling head field test
Oweis et al. (1990)	40 to 60 (estimated)	6.3 to 9.4 (estimated)	1.1×10^{-3}	Test pit
Qian (1994)	–	–	9.2×10^{-4} to 1.1×10^{-3}	Estimated based on field data
Schroder et al. (1994a, b)	–	–	1.0×10^{-3}	Estimated based on summary

literature. The average hydraulic conductivity of municipal solid waste in landfills is approximately 1.0×10^{-3} cm/sec. The hydraulic conductivities of other types of waste are listed in Table 6.7 for comparison.

6.6 FIELD CAPACITY AND WILTING POINT OF MUNICIPAL SOLID WASTE

Field capacity (θ_{FC}) is defined as the residual volumetric water content after a prolonged period of gravity drainage. It is an important parameter in bioreactor landfill technology (Chapter 15) for it signifies the amount of moisture that can be absorbed into, and surrounding, each waste particle. MSW at field capacity represents the target moisture state for optimal waste degradation. Wilting point is defined as the lowest volumetric water content that can be achieved by moisture removal via plant transpiration. The difference between the moisture content at field capacity and the wilting point is the moisture-holding capacity or available water content of a soil or waste. The

TABLE 6.7 Hydraulic Conductivities of Different Waste Materials (Schroder et al., 1994a & 1994b)

Waste Material	Hydraulic Conductivity (cm/sec)	Reference
Stabilized Incinerator Fly Ash	8.8×10^{-5}	Poran and Ahtchi-Ali (1989)
High-Density Pulverized Fly Ash	2.5×10^{-5}	Swain (1979)
Electroplating Sludge	1.6×10^{-5}	Bartos and Palermo (1977)
Nickel/Cadmium Battery Sludge	3.5×10^{-6}	Bartos and Palermo (1977)
Inorganic Pigment Sludge	5.0×10^{-6}	Bartos and Palermo (1977)
Brine Sludge–Chlorine Production	8.2×10^{-5}	Bartos and Palermo (1977)
Calcium Fluoride Sludge	3.2×10^{-5}	Bartos and Palermo (1977)
High Ash Papermill Sludge	1.4×10^{-6}	Perry and Schultz (1977)

ATTACHMENT 6 – Revised Section 812.305 (Foundation and Mass Stability)

SECTION 812.305 - FOUNDATION AND MASS STABILITY

812.305.1 Geotechnical Conditions

The geotechnical conditions beneath the site were evaluated using field and laboratory test data obtained from the Clinton Landfill No. 3 site and the adjacent Clinton No. 2 Landfill site. A description of the field exploration program, as well as boring logs, is provided in Section 812.314 of this application. Geotechnical laboratory test reports are provided in Appendix 812.305-A.

The geotechnical laboratory testing program was designed to evaluate both short-term and long-term soil behavior. Both unconsolidated-undrained and consolidated-drained shear strength testing were conducted on the foundation soils. Unconsolidated-undrained strength parameters are used to assess stability immediately after the loads are applied. Consolidated-drained strength parameters are used to assess long-term stability. Since excess porewater pressures in clays do not dissipate during seismic loading, all seismic analyses are conducted assuming undrained soil behavior.

Although the site lithology varies somewhat, a conservative geotechnical design model was established to facilitate the geotechnical evaluation. The derivation of the geotechnical characteristics of the native soil, compacted Earth Liner / Compacted Clay Fill, final cover, and landfilled waste is documented in Appendix 812.305-B.

CLI has also conducted specialized interface shear strength testing of various geosynthetic and soil materials. These data were used to help select the specified interface shear strengths which were used in the stability analyses. The interface shear strength test data are provided in Appendix 812.305-C. Required interface shear strengths are included in the Geomembrane, Geotextile, Geonet, and Geocomposite Specifications. The Construction Quality Assurance (CQA) Plan includes provisions for ensuring that the specified interface shear strengths are achieved.

812.305.2 Design Criteria

The facility will be designed to meet or exceed the design criteria specified in the applicable Illinois solid waste regulations. Current regulations provided in 35 Illinois Administrative Code

(IAC) 811.304 require that the landfill's foundation achieve a safety factor against bearing capacity failure of at least 2.0 under static conditions and 1.5 under seismic loadings. Similarly, the site must achieve a factor of safety against slope failure of at least 1.5 under static conditions and 1.3 under seismic loadings. Finally, the potential for earthquake- or blast- induced liquefaction must be considered, as well as the potential for landslide or earthquake-induced liquefaction outside of the landfill, if such events could affect the site.

CLI intends to recirculate leachate at the landfill. The effects of leachate recirculation have been accounted for in the landfill design. For instance, the strength properties of the waste near the bottom of the landfill are drastically reduced in the stability analyses of the appropriate modeled profiles to account for waste degradation. Furthermore, the stability analyses conservatively assume 5-feet thick layers of perched leachate approximately mid-height in the waste and at the bottom of the waste (except 11 feet of leachate is assumed at the bottom of the landfill for the Post Design stability analyses). In addition, recirculating leachate will increase the moisture content, and therefore, the weight of the landfilled waste. The analyses demonstrate that the landfill is stable under short-term loading (i.e. those during construction and during all stages of landfill development) and long-term loading (i.e. centuries after the landfill is closed).

The following sections describe the geotechnical evaluations and present the findings of the analyses. As demonstrated below, the analyses were performed to assess the landfill stability throughout its lifecycle to ensure that the design is adequate during all phases of construction, operation, and post-closure.

812.305.3 Bearing Capacity

Bearing capacity refers to the ability of the landfill unit's foundation to support the landfill weight without general shear or punching failure. Such a failure mode would cause the landfill to displace vertically with some lateral rotation possible. A bearing failure would affect the whole landfill unit and, thus, could be catastrophic.

The majority of the landfill liner system will be directly founded on the Berry Clay/Radnor Till, which exhibits high strength and low compressibility. In some areas, however, organic-rich or otherwise unsuitable soils might be present at the liner subgrade. In these areas, the unsuitable soils will be overexcavated and backfilled with Compacted Clay Fill as described in the Specifications and Construction Quality Assurance (CQA) Plan. As much as about 10 feet of



overexcavation and backfilling with Compacted Clay Fill is anticipated. The Compacted Clay Fill is expected to exhibit moderate strength.

The overall foundation and leachate collection system bearing capacities for static conditions were calculated using the general bearing capacity equation. The effect of the Earth Liner and Compacted Clay Fill was evaluated separately using a methodology accounting for stratified foundation soils. The factor of safety against bearing capacity failure during an earthquake (i.e. seismic condition) was calculated assuming an eccentrically loaded horizontal earthquake force. A conservative seismic force, that associated with an earthquake with a 10 percent probability of not being exceeded in 250 years, was used in the seismic evaluations. Bearing capacity calculations are provided in Appendix 812.305-D, and summarized in Table 812.305-1.

TABLE 812.305-1

BEARING CAPACITY FACTORS OF SAFETY

	FACTOR OF SAFETY	
	MIN. REQUIRED	**MIN. CALCULATED**
Landfill Foundation		
Static Condition	2.0	2.7
Seismic Condition	1.5	2.7
Leachate Collection System		
Static Condition	2.0	150
Seismic Condition	1.5	146

As demonstrated by the bearing capacity analyses, the landfill achieves the standards for bearing capacity stability for both short-term and long-term conditions.

812.305.4 Slope Stability

Slope stability is the ability of slopes to resist down-slope and/or rotational shear failure. Although slope instability could result in unacceptable damage, most instances would occur in

relatively localized areas and thus could be corrected. Four slope conditions potentially affecting the landfill stability are considered to be critical throughout the landfill life cycle. These are:

1) The excavation slope for the sidewall liner at its maximum height prior to waste placement. This is the critical stage during landfill construction. The maximum sidewall liner excavation slope will occur in the northern portions of the landfill. This condition will only occur during construction and initial waste placement. Therefore, only short term (i.e. undrained) soil behavior will occur. (Note that in all cases, undrained soil behavior controls the design).

2) The waste mass at the completion of landfill development Phases 1 and 2 ("Active Phase – Initial Stage of Development"). This stage of development is considered critical since the least amount of waste buttressing will be in place. Three critical cases were analyzed, one considering failure along the weakest liner interfaces along the landfill floor and sidewall. The second case considers failure along the weakest liner interface along the landfill floor and through the landfilled waste. The third case considers a circular failure surface through the waste and/or foundation soils. Two 5-feet thick perched leachate zones were assumed: one approximately mid-height within the landfill, the other at the landfill base. The interior waste slope is modeled at 3 horizontal to 1 vertical (3:1).

   This is a temporary operating condition that will occur for only a short period of time. Therefore, undrained soil behavior and partially degraded waste characteristics were assumed for each analysis case.

3) The waste mass during the active phase while the waste thickness is at its greatest near the center of the landfill ("Active Phase – Maximum Slope Height"). This stage of development is considered critical since the waste slope height will be at its maximum. Two critical cases were analyzed, one considering failure along the weakest liner interface along the landfill floor. The second case considers a circular failure surface through the waste and/or foundation soils. Several hundred trial failure surfaces were analyzed in order to ensure the failure surfaces with the lowest factor of safety were identified. Two 5-feet thick perched leachate zones were assumed: one approximately mid-height within the landfill, the other at the landfill base.

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This loading condition will occur for a moderately long period of time. Therefore, both undrained and drained soil behaviors were evaluated. Furthermore, the analyses assume that the lower portions (10 feet) of the waste have fully degraded.

4) The waste mass at closure and following the post-closure care period ("Post Design Period"). This case considers the stability of the landfill immediately after closure as well as the long-term stability of the landfill. The critical location for this case is along the southern landfill boundary where the final exterior slope is at its highest. This location also includes a containment berm. Two critical cases were analyzed for both short term behavior (i.e. just after the landfill closes) and long-term behavior (i.e. hundreds of years after landfill closure). One case considers failure along the weakest liner interfaces along the landfill floor and sidewall. The second case considers a circular failure surface through the waste/foundation, and containment berm. Several hundred trial failure surfaces were analyzed in order to ensure the failure surfaces with the lowest factor of safety were identified. One 5-feet thick perched leachate zone was assumed approximately mid-height within the landfill.

   The short-term static analyses assume 5 feet of leachate on the landfill floor and that the lower 10 feet of the waste has fully degraded. The long-term static and seismic analyses are based on the assumption that 11 feet of leachate develops on the landfill floor and that the lower 24 feet of wastes have fully degraded. All analyses assume full design waste thickness, i.e. waste settlement was conservatively not considered.

Stability analyses along the liner interfaces, i.e. "Planar Failure Surface", were analyzed using the Janbu Block Method; circular failure surfaces were analyzed using the Simplified Bishop Method of Slices. The commercially available slope stability software *PCSTABL6* developed by Purdue University was used to perform these calculations. The slopes were analyzed for both static and seismic conditions. The seismic coefficient is based on an earthquake with no more than a 10 percent probability of exceedance in 250 years (equivalent to a 2 percent probability of exceedance in 50 years - see Appendix 812.305-D). Soil and waste properties were as provided in Appendix 812.305-B. Saturated residual geosynthetic interface shear strengths were used for the static analyses, saturated peak geosynthetic interface shear strengths were used for seismic analyses. Geosynthetic interface shear test data are provided in Appendix 812.305-C. Interface

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shear testing requirements to ensure that the assumed interface shear strength are achieved are described in the CQA Plan.

Because the liner interfaces are confined to very thin zones, the liner interface layers were combined with the sand drainage layer on the landfill floor and the 18-inch protective soil layer on the landfill sidewall. The layer densities were set to the sand/protective soil densities; however, the layer strength parameters were set equal to the specified interface shear strength properties.

The analyses of potential sliding along the liner interfaces were conducted using the software's sliding block trial slip generator. In this method, the trial failure surfaces were forced to occur through either the model layer simulating the liner interface or the immediately underlying compacted Earth Liner. This was done to ensure that the trial failure surfaces consider the fact that, under high overburden pressure, the liner interface shear strength exceeds that of the underlying compacted Earth Liner. At that location, the critical shear plane would be expected to transition from the liner interface downward into the compacted Earths Liner. The sliding plane earch boundaries were initially set to encompass the whole modeled landfill. The results of this search were then used to narrow the search boundaries to encompass the 10 critical failure planes to refine the analyses. In this manner, the search was concentrated in the critical region to identify the failure plane exhibiting the lowest factor of safety.

Slope stability calculations, including graphical output for all cases analyzed and full output for the critical failure surfaces, are provided in Appendix 812.305-E, and summarized in Table 812.305-2.

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TABLE 812.305-2

SLOPE STABILITY FACTORS OF SAFETY

	FACTOR OF SAFETY	
	MIN. REQUIRED	MIN. CALCULATED
Sidewall Liner Excavation		
Static Condition	1.50	2.69
Seismic Condition	1.30	1.89
Active Phase – Initial Stage of Development		
Static Condition	1.50	1.53
Seismic Condition	1.30	1.31
Active Phase – Maximum Waste Height		
Static Condition	1.50	1.55
Seismic Condition	1.30	1.35
Post Design Period		
Static Condition	1.50	1.76
Seismic Condition	1.30	1.48

As demonstrated by the slope stability analyses, the proposed landfill meets the slope stability standards at all stages of landfill construction, operations, and post-closure.

812.305.5 Settlement And Swell

Two types of settlement occur whenever soil is loaded: consolidation settlement (fine-grained soil only), and elastic settlement.

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Consolidation settlement occurs as the load-induced pore water pressure dissipates from fine-grained soil. In saturated clays, consolidation settlement can occur over a period of several years. The magnitude of consolidation settlement is highly dependent upon the loading history (i.e. preconsolidation) of the fine-grained soil. The site (as essentially all of central Illinois) was subjected to numerous periods of glaciation. The weight of glaciers over the Clinton Landfill No. 3 foundation soils preconsolidated the foundation soils. The maximum pressure exerted by the landfill mass will not exceed the underlying soil's preconsolidation pressure (P_c). As a result, consolidation settlement is minimal.

The elasticity of soil and, thus elastic settlement, is related to the degree of overconsolidation and the soil plasticity. The landfill foundation soils are mostly described as being of low plasticity. This, coupled with the preloading from historical glaciation, results in the foundation soils having relatively low elasticity.

Perhaps more important than the overall magnitude of settlement is the amount of differential settlement that will occur. Consideration of differential settlement is especially important to ensure that the leachate collection system will continue to drain correctly, and that the liner will not be subjected to excessive strain after settlement has occurred. For this reason, settlements were calculated for four different locations within the landfill. Evaluations of the affects of differential settlement on leachate drainage and liner stresses are provided in Section 812.306 and 812.307 of this application, respectively.

Calculations of the consolidation and elastic settlement resulting from the landfill are provided in Appendix 812.305-F. As demonstrated by the calculations, the magnitude of total and differential settlements are very minimal and will not cause or contribute to the failure of the liner and leachate collection system.

Clayey soils swell as their moisture content increases. Although highly plastic clays can exert substantial swell pressure, low plasticity clays, such as those that predominate the site, do not exhibit significant swell potential. Furthermore, the clay liner (which is expected to primarily be derived from the low plasticity Berry Clay or Tiskilwa Formation clays) moisture content will be controlled to at least optimum during construction; therefore, substantial increases in the liner's moisture content will not occur once constructed. Considering these factors, soil swelling is not expected to cause or contribute to failure of the liner and leachate collection system.

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812.305.6 Hydrostatic Uplift

As discussed Section 812.314 of this application, the eastern one-half (approximately) of the landfill floor lies below the upper-most aquifer's potentiometric surface. This condition results in hydrostatic uplift forces at the landfill invert. The excavation could become unstable due to heaving if the hydrostatic uplift forces exceed the weight of the overburden above the upper-most aquifer. This condition is most critical during cell construction since the placement of waste above the landfill invert will add overburden resistance to the hydrostatic uplift forces.

A detailed evaluation of the potential for hydrostatic uplift is provided in Appendix 812.305-G. As shown in Appendix 812.305-F, the greatest uplift forces will occur where the upper-most aquifer's potentiometric surface is highest, at the northeastern corner of the landfill. The calculations demonstrate adequate factors of safety against heave.

812.305.7 Liquefaction Potential

Liquefaction is the temporary loss of shear strength in water-saturated soil and is induced by a momentary shock such as that produced by an earthquake or large blast. In general, the soils most susceptible to liquefaction are saturated clean sands. Increasing confining pressure (i.e. depth) reduces the potential for liquefaction. Soils generally not susceptible to liquefaction include clays and gravel.

Based on this, the Tiskilwa Formation sand units encountered in the northwestern portions of the site are judged to be the soils that are most susceptible to liquefaction.

Well known correlations have been developed to evaluate liquefaction potential based upon Standard Penetration Test N-values and the seismic acceleration as a percentage of gravity. Calculations of the liquefaction potential are provided in Appendix 812.305-H. These calculations demonstrate that soils beneath the site are not susceptible to liquefaction during the design earthquake.

APPENDIX 812.305-D: BEARING CAPACITY CALCULATIONS

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PDC TECHNICAL SERVICES, INC.

Project: Clinton Landfill No. 3 Computed by: ECA Sheet 1 of 19

Project No.: 91-0116 Task No.: Checked By: WWS-can Date: 6-8-06 11/16/06

Foundation Bearing Capacity

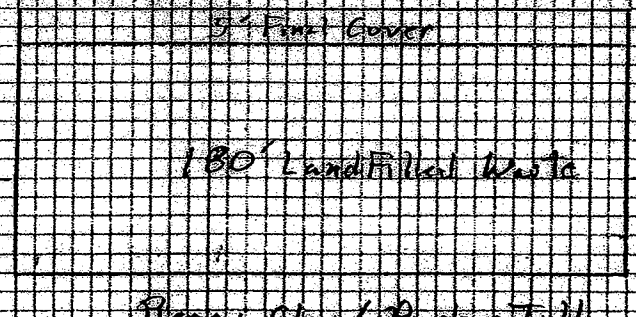
Evaluate the landfill foundation bearing capacity by conservatively assuming the average waste thickness acts over the entire landfill floor.

References: (1) Foundation Engineering Handbook, Winterkorn & Fang

(2) Foundation Analysis and Design, Bowles

(3) United States Geological Survey National Seismic Hazards Mapping Project

Bearing Capacity Model:



Foundation Bearing Pressure

As detailed in the Geotechnical Design Model, the unit weight of partially degraded waste is estimated to be 75 pcf, whereas the fully degraded waste unit weight is estimated to be 105 pcf. The waste mass does not increase in the transition from partially to fully degraded and, in fact, the mass decreases (primarily as waste decomposition products — landfill gas — is extracted).

(Log Removed)

Foundation Bearing Pressure (continued)

Therefore, although the density of the landfilled waste will increase with time as it degrades, the overall mass of the landfill will not increase (again, as discussed above, the landfill mass will decrease with time after closure). As a result, the maximum foundation bearing pressure will occur when final cover over the location in question is placed. The foundation bearing pressure after that time will decrease.

Leachate recirculation will accelerate the rate at which waste decomposes. However, according to Stark and Hilvaji-Serhan (pending publication, 2006), complete degradation would only be expected to occur at or near the bottom of the waste. To be conservative, assume that the lower 10 feet of waste has fully degraded at the time final cover is placed.

→ Maximum Foundation bearing pressure (p_{max})

$$p_{max} = \left(3' \times 120 \frac{lb}{ft^3}\right) + \left(2' \times 135 \frac{lb}{ft^3}\right) + \left(170' \times 75 \frac{lb}{ft^3}\right) + \left(10' \times 105 \frac{lb}{ft^3}\right)$$

(← Final cover → | ← Landfilled waste →)

$$p_{max} = 14,454 \text{ psf}$$

Static-Short Term Bearing Capacity

Use unconsolidated-undrained shear strengths for static short-term loading conditions. This corresponds to the point in time immediately after final cover is placed.

$$q_u = c N_c s_c + q N_q s_q + \frac{1}{2} \gamma B N_\gamma s_\gamma$$

(Winterkorn + Fang, Eq. 3.11)

B = Landfill Floor Width = 2,000' } Dwg
L = Landfill Floor Length = 2450' } D-105

Foundation Soils (Berry Clay and Radnor Till):

$c = 6{,}000$ psf

$\phi = 0$

$\gamma = 140$ pcf

Bearing Capacity Factors (Table 3.1):

$N_c = 5.14$; $N_q = 1.0$; $N_\gamma = 0$

Shape Factors (Rectangular $B/L = 0.8$, Table 3.2)

$S_c = 1 + \left(0.8 \times \frac{N_q}{N_c}\right) = 1.16$

$S_q = 1 + (0.8 \tan\phi) = 1.0$

$S_\gamma = 1 - (0.4 \times 0.8) = 0.68$

q_o = Confining pressure $= D \times \gamma_{\text{Thickness Formation}}$

$= 30' \times 135 \frac{lb}{ft^3} = 4050$ psf

$\Rightarrow q_{ult} = (6{,}000 \times 5.14 \times 1.16) + (4050 \times 1.0 \times 1.0) + 0$

$= 39{,}516$ psf

$$\text{Factor of Safety} = \frac{q_{ult}}{p} = \frac{39{,}516}{14{,}454} = 2.7 > 2.0 \quad \therefore \text{OK}$$

Static Long-Term Bearing Capacity

To be conservative, assume no reduction in the foundation bearing pressure. Base long-term capacity on consolidated-drained shear strengths

Foundation Soils, $c = 0$ shear strengths:

$c = 1{,}100$ psf

$\phi = 18°$

Bearing Capacity Factors:

$N_c = 13.10$; $N_q = 5.26$; $N_\gamma = 4.07$

Shape Factors:

$$S_c = 1 + \left(0.8 \times \frac{5.26}{13.10}\right) = 1.32$$

$$S_q = 1 + 0.8 \tan 18° = 1.26$$

$$S_\gamma = 0.68 \quad \text{(as before)}$$

$$\Rightarrow q_u = (0.100 \times 13.10 \times 1.32) + (4050 \times 5.26 \times 1.26) + (0.5 \times 140 \times 2{,}000 \times 4.07 \times 0.68)$$

$$= 433{,}327 \text{ psf}$$

$$\Rightarrow \text{Factor of Safety} = \frac{433{,}327}{14{,}454} = 30 > 2.0 \quad \therefore \text{OK}$$

Leachate Collection System Bearing Capacity

Assume typical strength properties for sand and gravel:

$\phi = 30°$ (Conservative)

$c = 0$

$\gamma = 135$ pcf

Bearing Capacity Factors:

$N_c = 30.14$; $N_q = 16.40$; $N_\gamma = 22.40$

Shape Factors:

$$S_c = 1 + (0.8)\left(\frac{16.40}{30.14}\right) = 1.44$$

$$S_q = 1 + 0.8 \tan 30° = 1.46$$

$$S_\gamma = 0.68$$

$$\Rightarrow q_u = 0 + (4050 \times 16.40 \times 1.46) + (0.5 \times 135 \times 2{,}000 \times 22.40 \times 0.68)$$

$$= 2{,}165{,}119 \text{ psf}$$

$$\Rightarrow \text{Factor of Safety} = \frac{2{,}165{,}119 \text{ psf}}{14{,}454} = 150 > 2.0 \quad \therefore \text{OK}$$

Check for Punching Failure Through Earth Liner and Compacted Clay Fill

The landfill floor will be underlain by 3' compacted Earth Liner and, in some areas, as much as 10' of Compacted Clay Fill. Check the factor of safety against punching failure through these layers.

$q_{ult} = c_1 N_c (1 + \delta_c' + d_c') + \bar{\gamma} N_q$ (Bowles, Eq. 4-3)

$c_1 = 3{,}000$ psf (Minimum specified undrained shear strength for compacted Earth Liner and Compacted Clay Fill = 3.0 tsf, this corresponds to $c = 3{,}000$ psf)

N_c = Adjusted N_c From Fig. 4-3

$\frac{d}{b} = \frac{30'}{2{,}000} = 0.015$

$\frac{c_2}{c_1} = \frac{6{,}000}{3{,}000} = 2.0$

The compacted Earth Liner and Compacted Clay Fill can be assumed to be overconsolidated due to the compactive effort. Berry Clay / Kalmar Till are also overconsolidated. However, to be conservative, assume $K = 1.0$.

$\Rightarrow$ From Figure 4-3 ($K = 1.0$) $N_c = 10.8$

$\delta_c' = 0.2 \times \frac{B}{L} = 0.2 \frac{2000}{2450} = 0.16$

$d_c' = 0.4 \frac{D}{B} = 0.4 \frac{30}{2000} = 0.01$

$\bar{\gamma} = 4050$ psf (as before)

$\Rightarrow q_{ult} = 3000(10.8)(1 + 0.16 + 0.01) + (4050)(1.0)$

$= 41{,}684$ psf

$\Rightarrow$ Factor of Safety $= \frac{41{,}684}{14{,}454} = 2.9 > 2.0$ $\therefore$ OK

Seismic Loading

Apply seismic loading as a horizontal eccentric load mid-height of landfill above its base.

Compare the maximum seismic-induced bearing pressure to the ultimate bearing pressures calculated before.

Seismic-Induced Bearing Pressure

$$p_{xx} = \frac{\Sigma P}{BL}\left(1 \pm \frac{6e}{L}\right)$$

Winterkorn & Fang Eq. 16.4a, for $e \le \frac{L}{6}$

$$\frac{\Sigma P}{BL} = p_{max} = 14,454 \text{ psf}$$

$$e = \frac{M}{P}$$

M = Moment caused by eccentric load

P = Force on Landfill Floor

$$P = p \times B \times L$$
$$= 14,454 \times 2000 \times 2150$$
$$= 7.08 \times 10^{10} \text{ lbs}$$

$$M = P \times a_h \times \tfrac{1}{2} \text{ Ave. Landfill Height}$$

$P = 7.08 \times 10^{10}$ lbs

$a_h = 0.10$ (0.565, 2% probability of exceedance in 50 years, see attached)

Average Landfill Height = 185' (see pg 1)

$$\Rightarrow M = (7.08 \times 10^{10})(0.1)(0.5 \times 185)$$
$$= 6.55 \times 10^{11} \text{ ft-lbs}$$

$$\Rightarrow e = \frac{6.55 \times 90'' \times 1.15}{1.08 \times 10^{10} \times 16} = 9.25''$$

$$\frac{L}{6} = \frac{2450}{6} = 408''$$

$$\Rightarrow e < \frac{L}{6} \quad \therefore \text{Eq. 16.4a applies}$$

$$\Rightarrow p_{e2} = 14,401\ psf \times \left(1 + \frac{6 \times 9.25}{2,450}\right)$$

$$= 14,781\ psf$$

Foundation Soils

$q_{ult} = 39,516\ psf$ (Conventional case, p. 3)

$\Rightarrow$ Seismic Factor of Safety $= \frac{q_{ult}}{p_{e2}}$

$= \frac{39,516}{14,781} = 2.7$

$> 1.5 \quad \therefore$ OK

Leachate Collection System

$q_{ult} = 2,165,119\ psf$ (p. 4)

$\Rightarrow$ Seismic Factor of Safety $= \frac{2,165,119}{14,781}$

$= 146 \quad > 1.5 \quad \therefore$ OK

Punching Failure

$q_{ult} = 41,884\ psf$ (p. 5)

$\Rightarrow$ Seismic Factor of Safety $= \frac{41,884}{14,781}$

$= 2.8 \quad > 1.5 \quad \therefore$ OK

8/19

FOUNDATION ENGINEERING HANDBOOK

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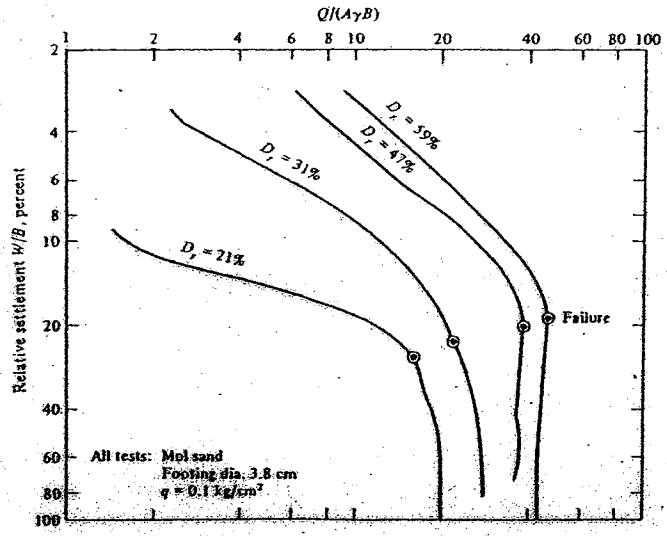


Fig. 3.12 Ultimate load criterion based on plot of log load vs. log settlement. (After De Beer, 1967.)

terion, suggested in recent years by Christiaens (De Beer, 1967), defines the ultimate load at the point of break of the load-settlement curve in a log/log plot (Fig. 3.12). Both criteria require, however, that the loading test be carried to very large displacements, preferably of the order of 50 percent of the foundation size. Thus, from the practical point of view, it may be preferable to establish some other criterion of critical settlement. Such a criterion is no doubt justified by the basic philosophy of foundation design, which considers excessive settlement as failure of the foundation.

It is thus of special interest to know the magnitude of settlements of footings needed to mobilize ultimate loads. Observations in saturated clays (Skempton, 1951) indicate that these settlements may be about 3 to 7 percent of the footing width for surface footings, increasing up to 15 percent for deep footings. For footings in sand somewhat higher values are found, ranging from 5 to 15 percent for surface footings and as high as 25 percent for deep footings (Muhs and Kahl, 1954; De Beer and Vesić, 1958; Vesić, 1963a; De Beer, 1967). As shown in Fig. 3.13, there appears to be a general tendency of increase of ultimate settlements with increased size of footings (De Beer, 1965a, 1967).

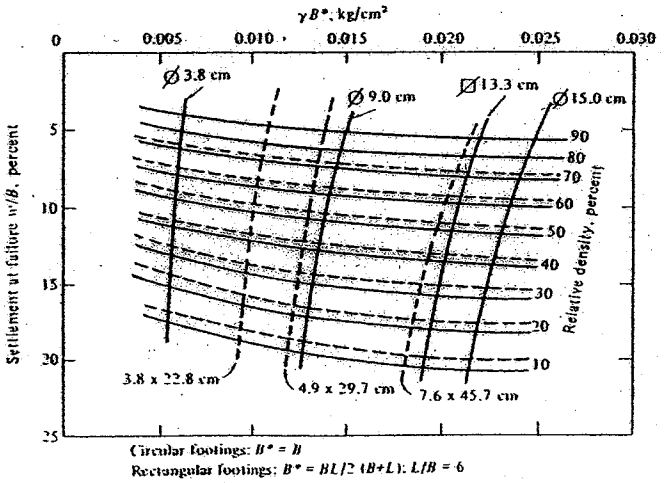


Fig. 3.13 Ultimate settlements of surface footings. (After De Beer, 1967.)

Considering these facts, unless a clearly defined ultimate load can be observed earlier, it is advisable to carry load tests on footings and plates on loose and compressible soils to settlements equal to at least 25 percent of the footing width. In cases in which a peak load cannot be established with certainty, it is expedient to adopt a limit of critical settlement, such as 10 percent of the footing depth. (The same limit has been often proposed and used for driven piles; see Vesić, 1967.)

3.4 COMPUTATION OF ULTIMATE LOAD

The computation of ultimate load for a shallow footing resting on soil represents a problem of elastic-plastic equilibrium which can, in principle, be solved for at least the plane-strain and the axially symmetric cases. The foremost difficulty in finding acceptable solutions lies undoubtedly in the selection of a mathematical model of soil behavior or its constitutive (stress-strain-time) relationships. In spite of greatly improved capabilities for solution of boundary value problems of this kind, the theory of bearing capacity is still limited almost exclusively to solutions developed for the rigid-plastic solid of the classical Theory of Plasticity. As known, this solid is assumed to exhibit no deformation whatsoever prior to shear failure and a plastic flow at constant stress after failure. Thus, the capabilities of theoretical prediction of the ultimate load are, strictly speaking, limited at present to relatively incompressible soils or to the general shear failure mode. However, it is rather common in practice to use the available solutions for compressible soils as well, with possible reduction for the effects of compressibility.

The problem is generally posed as follows (Fig. 3.14a). Consider a rectangular foundation of width B and length L, resting in a soil mass at a depth D. The soil mass is of semi-infinite extent and is homogeneous. It has an effective unit weight γ and shear strength properties defined by a straight-line Mohr envelope, with strength characteristics c and ϕ, and a stress-strain curve of a rigid-plastic body, shown in Fig. 3.14b. To be determined is the maximum unit load $q_0 = Q_0/BL$ which this foundation can support.

To solve this problem, the following simplifications are usually made:

a) the shearing resistance of the overburden soil (along bc, Fig. 14a) is neglected;

b) the friction between the overburden soil and the foundation (along ad, Fig. 3.14a) as well as between the overburden and supporting soil (along ab, Fig. 3.14a) is neglected;

c) the length L is assumed to be large in comparison with the width B of the foundation.

In other terms, the overburden soil is replaced by a uniformly distributed surcharge $q = \gamma D$. At the same time plane strain conditions are assumed.

Simplifications (a) and (b) are justified in most cases and are always on the safe side. The overburden soil is usually weaker or cracked, while the foundation is placed by excavation and backfilling. Simplification (c), equivalent to assuming the foundation to be an infinite strip of width B, is justified, strictly speaking for $L/B > 10$ and practically for $L/B > 5$. The corrections to be introduced for $L/B < 5$ and shapes other than a rectangle will be discussed later.

The problem, formulated as shown in Fig. 14c, has been solved by the methods of the Theory of Plasticity. The

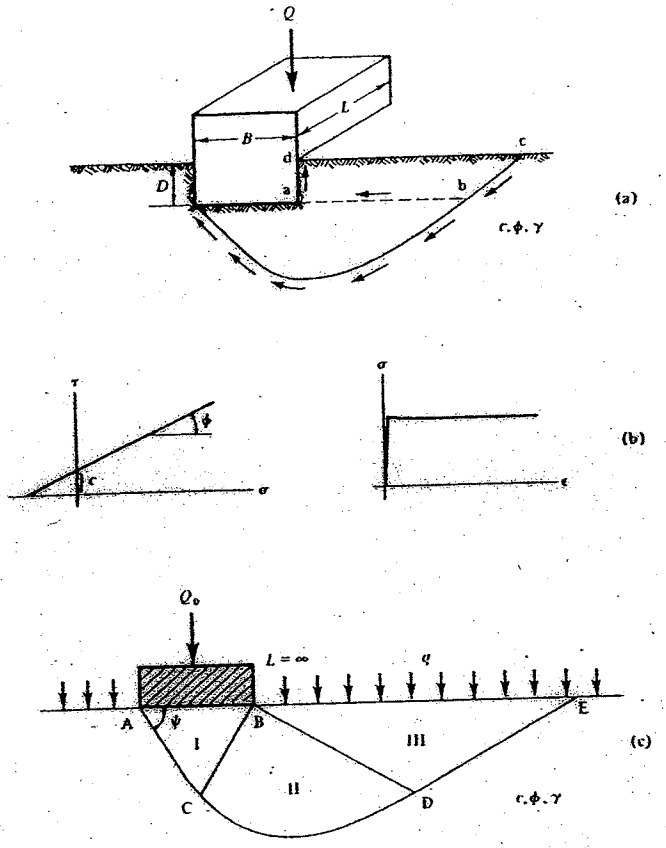


Fig. 3.14 The problem of bearing capacity of shallow footings.

basic solution available (Prandtl, 1921; Reissner, 1924) indicates that the failure pattern should consist of three zones: I, II, and III. Zone I is an active Rankine zone, which pushes the radial Prandtl zone II sideways and the passive Rankine zone III in an upward direction. The lower boundary ACDE of the displaced soil mass is composed of two straight lines AC and DE, inclined at $45° + \phi/2$ and $45° - \phi/2$, respectively, to the horizontal. The shape of the connecting curve CD depends on the angle ϕ and on the ratio $\gamma B/q$. For $\gamma B/q \to 0$ ("weightless soil") the curve becomes a logarithmic spiral which for $\gamma = 0$ degenerates into a circle. In the general case ($\gamma B \neq 0$) the curve lies between a spiral and a circle, as long as $\phi \neq 0$. For a frictionless soil ($\phi = 0$) the curve is always a circle. All these findings have been confirmed experimentally (De Beer and Vesić, 1958), though the angle ψ may be slightly larger than $45° + \phi/2$, at least for long rectangular footings on the surface of sand.

A closed analytical solution of this problem, as posed, has not yet been found and probably will not be found, except for special cases. For weightless soil ($\gamma = 0$), Prandtl and Reissner have found that:

$$q_0 = cN_c + qN_q \tag{3.5}$$

where N_c and N_q are dimensionless *bearing capacity factors*, defined by

$$N_q = e^{\pi \tan \phi} \tan^2 (\pi/4 + \phi/2)$$
$$N_c = (N_q - 1) \cot \phi \tag{3.6}$$

The numerical values of these factors are given in Table 3.1 and shown graphically in Fig. 3.15.

For cohesionless soil without overburden ($c = 0, q = 0$) it can be shown that:

$$q_0 = \tfrac{1}{2} \gamma B N_\gamma \tag{3.7}$$

where N_γ is again a dimensionless bearing capacity factor which can be evaluated only numerically. This factor varies sharply with angle ψ. The numerical values shown by dashed lines in Fig. 3.15 are taken from an analysis made by Caquot and Kérisel (1953) under assumption that $\psi = 45° + \phi/2$. It can be shown (Vesić, 1970) that these values of N_γ can be approximated with an error on the safe side (not exceeding 10 percent for $15° < \phi < 45°$ and not ex-

TABLE 3.1. BEARING CAPACITY FACTORS

ϕ	N_c	N_q	N_γ	N_q/N_c	tan ϕ
0	5.14	1.00	0.00	0.20	0.00
1	5.38	1.09	0.07	0.20	0.02
2	5.63	1.20	0.15	0.21	0.03
3	5.90	1.31	0.24	0.22	0.05
4	6.19	1.43	0.34	0.23	0.07
5	6.49	1.57	0.45	0.24	0.09
6	6.81	1.72	0.57	0.25	0.11
7	7.16	1.88	0.71	0.26	0.12
8	7.53	2.06	0.86	0.27	0.14
9	7.92	2.25	1.03	0.28	0.16
10	8.35	2.47	1.22	0.30	0.18
11	8.80	2.71	1.44	0.31	0.19
12	9.28	2.97	1.69	0.32	0.21
13	9.81	3.26	1.97	0.33	0.23
14	10.37	3.59	2.29	0.35	0.25
15	10.98	3.94	2.65	0.36	0.27
16	11.63	4.34	3.06	0.37	0.29
17	12.34	4.77	3.53	0.39	0.31
18	13.10	5.26	4.07	0.40	0.32
19	13.93	5.80	4.68	0.42	0.34
20	14.83	6.40	5.39	0.43	0.36
21	15.82	7.07	6.20	0.45	0.38
22	16.88	7.82	7.13	0.46	0.40
23	18.05	8.66	8.20	0.48	0.42
24	19.32	9.60	9.44	0.50	0.45
25	20.72	10.66	10.88	0.51	0.47
26	22.25	11.85	12.54	0.53	0.49
27	23.94	13.20	14.47	0.55	0.51
28	25.80	14.72	16.72	0.57	0.53
29	27.86	16.44	19.34	0.59	0.55
30	30.14	18.40	22.40	0.61	0.58
31	32.67	20.63	25.99	0.63	0.60
32	35.49	23.18	30.22	0.65	0.62
33	38.64	26.09	35.19	0.68	0.65
34	42.16	29.44	41.06	0.70	0.67
35	46.12	33.30	48.03	0.72	0.70
36	50.59	37.75	56.31	0.75	0.73
37	55.63	42.92	66.19	0.77	0.75
38	61.35	48.93	78.03	0.80	0.78
39	67.87	55.96	92.25	0.82	0.81
40	75.31	64.20	109.41	0.85	0.84
41	83.86	73.90	130.22	0.88	0.87
42	93.71	85.38	155.55	0.91	0.90
43	105.11	99.02	186.54	0.94	0.93
44	118.37	115.31	224.64	0.97	0.97
45	133.88	134.88	271.76	1.01	1.00
46	152.10	158.51	330.35	1.04	1.04
47	173.64	187.21	403.67	1.08	1.07
48	199.26	222.31	496.01	1.12	1.11
49	229.93	265.51	613.16	1.15	1.15
50	266.89	319.07	762.89	1.20	1.19

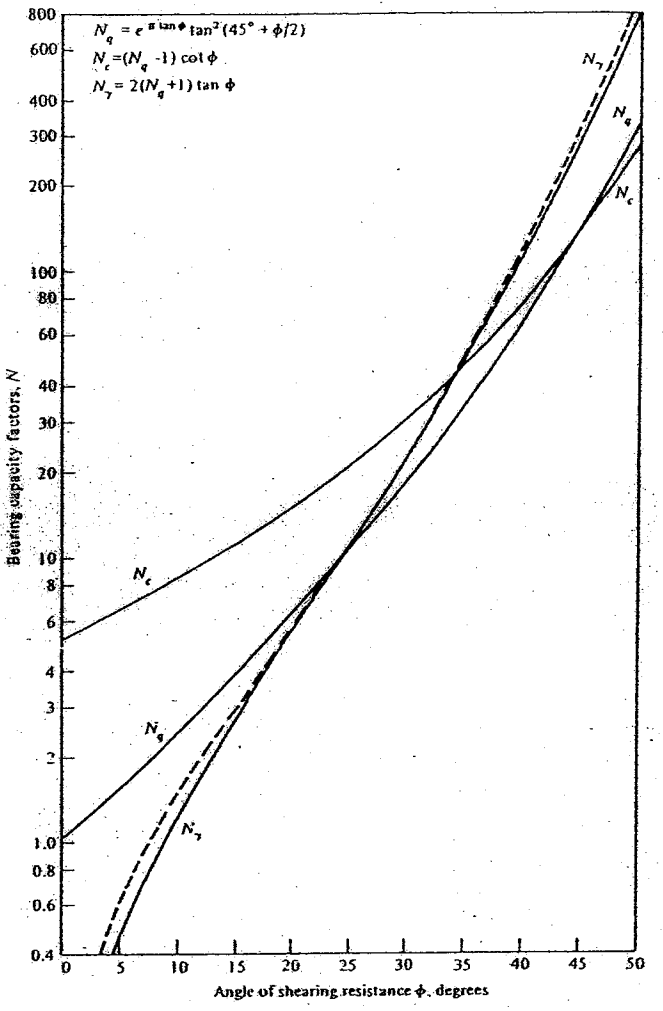


Fig. 3.15 Bearing capacity factors for shallow footings.

ceeding 5 percent for $20° < \phi < 40°$) by the analytical expression

$$N_\gamma \simeq 2(N_q + 1) \tan\phi \qquad (3.8)$$

The N_γ-values according to 3.8 are given in Table 3.1 and also presented graphically in Fig. 3.15.

For all intermediate cases, where $c \neq 0$, $q \neq 0$, and $\gamma \neq 0$, Eqs. 3.5 and 3.7 are combined into

$$q_0 = cN_c + qN_q + \tfrac{1}{2}\gamma BN_\gamma \qquad (3.9)$$

known as Buisman-Terzaghi equation (Buisman, 1940; Terzaghi, 1943). This superposition is not strictly correct; however, it leads to errors which are on the safe side, not exceeding 17 to 20 percent for $\phi = 30°$ to $40°$, while equal to 0 for $\phi = 0°$ (Lundgren and Mortensen, 1953; Hansen and Christensen, 1969).

It should be mentioned here that there exists in the literature a great variety of proposed solutions to this problem. While the variations in N_c- and N_q-values proposed remain relatively insignificant, the differences in N_γ-values, coming primarily from the mentioned sharp variation of N_γ with ψ, are substantial, ranging from about one-third to double the values shown in Table 3.1.

In spite of the intensified experimental work on this subject, the question of "correct" N_γ-values remains somewhat unsettled, because of difficulties in selecting a representative value of angle of shearing resistance ϕ for the bearing capacity computations. Some authors (Meyerhof, 1963; Brinch Hansen, 1970) use the plane-strain value of ϕ, which, according to their views, may be up to 10 percent higher than the corresponding conventional triaxial test value. This can help explain the results of tests with long rectangular plates on soil surface; however, it only contributes to difficulties in interpreting the results of tests with circular plates placed at a certain depth. (At any rate, there remains the question as to what degree the conditions of soil elements along a slip surface under a circular footing are closer to $\sigma_2 = \sigma_3$ than to plane-strain conditions.)

Much stronger is the argument that a shear failure in soil under the footing is a phenomenon of progressive rupture at variable stress levels (Muhs, 1963; De Beer, 1965a, b, 1967). Consequently when the slip line ACDE in Fig. 3.14 reaches E, just mobilizing the peak shearing strength at that point, the soil strength at the beginning of the slip line (point A) must be well below the peak. In addition, the stress level at A is higher than at E. Thus, in view of known curvature of Mohr's envelope in the low stress range, the ϕ-angle at A must be lower than at E. A representative ϕ-value must be sought with due consideration of these facts. Working along these lines, it has been suggested (De Beer, 1965a) that the bearing capacity evaluations should be made using strength characteristics corresponding to an average mean normal stress equal to

$$\sigma_0 = \tfrac{1}{4}(q_0 + 3q)(1 - \sin\phi) \qquad (3.10)$$

While the discussions and investigations of these and other questions associated with evaluation of the bearing capacity continue, there is an increased trend among both practicing engineers and researchers to retain the Prandtl-Reissner and Caquot-Kérisel factors given in Table 3.1 as the most reliable factors available at present. The widely used Terzaghi factors, though not substantially different numerically, are being gradually abandoned, as they are based on obviously incorrect failure patterns.

3.5 EFFECT OF FOUNDATION SHAPE

For foundation shapes other than the long rectangle, the mathematical difficulties in obtaining solutions are considerable. Only the axially-symmetrical case of a circular footing has been solved so far (Ishlinskii, 1944; Berezantsev, 1952; Mizuno, 1953; Eason and Shield, 1960; Cox, Eason, and Hopkins, 1961). The proposed solutions make use of some assumptions about soil behavior that remain to be proved experimentally ("complete plasticity") and their results are, at least in part, at some variance with observations (cf. Hansen and Christensen, 1969).

In view of these facts, the engineering approach to evaluation of effect of foundation shape has been mostly semi-empirical. On the basis of comparative loading tests with footings of different shapes, including long rectangles, the following modification of Eq. 3.9 has come into general use:

$$q_0 = cN_c\zeta_c + qN_q\zeta_q + \tfrac{1}{2}\gamma BN_\gamma\zeta_\gamma \qquad (3.11)$$

In this expression N_c, N_q, and N_γ are, as before, bearing capacity factors for an infinite strip or long rectangle and ζ_c, ζ_q, ζ_γ are dimensionless parameters called *shape factors*.

Shape factors also depend on the angle of shearing resistance ϕ of the soil, as well as on some other parameters. However, many of them are taken to be constants or simply

3.2. SHAPE FACTORS FOR SHALLOW FOUNDATIONS.
(After De Beer, 1967, as modified by Vesić, 1970).

Shape of the Base	ζ_c	ζ_q	ζ_γ
Strip	1.00	1.00	1.00
Rectangle	$1 + (B/L)(N_q/N_c)$	$1 + (B/L)\tan\phi$	$1 - 0.4B/L$
Circle and Square	$1 + (N_q/N_c)$	$1 + \tan\phi$	0.60

functions of the geometrical form of the foundation. Recommended expressions of shape factors based primarily on extensive experiments at Ghent (De Beer, 1967) are given in Table 3.2. Numerical values of N_q/N_c and $\tan\phi$ appearing in these expressions are given in Table 3.1.

EXAMPLE 3.1: A rectangular footing 28 feet wide and 84 feet long is to be placed at a depth of 10 feet in a deep stratum of soft, saturated clay (bulk unit weight 105 lb/ft^3). The water table is at 8 feet below ground surface. Find the ultimate bearing capacity under the following two conditions:

(a) assuming that the rate of application of dead and live loads is fast in comparison with the rate of dissipation of excess pore-water pressures caused by loads, so that undrained conditions prevail at failure;

(b) assuming, as the other extreme, that the rate of loading is slow enough that no excess pore-water pressures are introduced in the foundation soil.

The strength parameters of the soil, obtained from unconsolidated, undrained tests are $c_u = 0.22$ ton/ft^2, $\phi_u = 0$. Consolidated, drained tests give $c_d = 0.04$ ton/ft^2, $\phi_d = 23°$.

Condition (a):

Submerged unit weight of soil: $\gamma' = 105 - 62 = 43$ lb/ft^3

Overburden stress: $q = [(8)(105) + (2)(43)]/(2000) = 0.463$ ton/ft^2

Bearing capacity factors (Table 3.1): $N_c = 5.14, N_q = 1, N_\gamma = 0$

Shape factors (Table 3.2): $\zeta_c = 1 + (1/3)(0.20) = 1.067$, $\zeta_q = 1.00$

Ultimate bearing pressure (Eq. 3.11):

$$q_0 = (0.22)(5.14)(1.067) + (0.463)(1)(1.00) = 1.21 + 0.46 = 1.67 \text{ ton/ft}^2$$

Condition (b)

Bearing capacity factors: $N_c = 18.05$; $N_q = 8.66$; $N_\gamma = 8.20$

Shape factors: $\zeta_c = 1 + (1/3)(0.48) = 1.16$; $\zeta_q = 1 + (1/3)(0.42) = 1.14$; $\zeta_\gamma = 1 - (0.4)(1/3) = 0.87$

Ultimate bearing pressure:

$$q_0 = (0.04)(18.05)(1.16) + (0.463)(8.66)(1.14) + (1/2)(43)(28)(8.20)(0.87)/(2000) = 0.72 + 4.57 + 2.14 = 7.43 \text{ ton/ft}^2$$

Remark: The computed values of q_0 represent the upper limit of bearing capacity under the assumption of incompressible soil. The analyses of effects of compressibility for this case are presented in Example 3.7.

EXAMPLE 3.2: Solve the problem described in Example 3.1 if the footing is placed at the same depth (10 feet) in a deep stratum of medium dense sand. Assume for sand a saturated unit weight of 118 lb/ft^3 and an average moist unit weight above the water table of 100 lb/ft^3. Drained triaxial tests on sand samples show that the angle ϕ of shearing resistance of sand varies with mean normal stress σ_0 according to the equation

$$\phi = \phi_1 - (5.5°)\log_{10}(\sigma/\sigma_1)$$

where $\sigma_1 = 38°$ is the angle of shearing resistance at mean normal stress $\sigma_1 = 1$ ton/ft^2.

Solution:

Submerged unit weight of sand: $\gamma' = 118 - 62 = 56$ lb/ft^3

Overburden stress: $q = (8)(100) + (2)(56)/(2000) = 0.456$ ton/ft^2

To find the mean normal stress, according to Eq. 3.10, a preliminary estimate of bearing capacity is needed. It is assumed for this preliminary analysis that $\phi = 34°$.

Bearing capacity factors (Table 3.1): $N_q = 29.44$; $N_\gamma = 41.06$

Shape factors: $\zeta_q = 1 + (1/3)(0.67) = 1.22$; $\zeta_\gamma = 1 - 0.4(1/3) = 0.87$

Ultimate bearing pressure (Eq. 3.11):

$$q_0 = (0.456)(29.44)(1.22) + (1/2)(56)(28)(41.06)(0.87)/(2000) = 16.4 + 14.0 = 30.4 \text{ ton/ft}^2$$

Mean normal stress along the slip surface (Eq. 3.10):

$$\sigma_0 = (1/4)[30.4 + (3)(0.456)](1 - 0.559) = 3.5 \text{ ton/ft}^2$$

Representative angle of shearing resistance:

$$\phi = 38° - (5.5°)(0.544) = 35°$$

The analysis is now repeated with $\phi = 35°$:

$$N_q = 33.3;\ N_\gamma = 48.0;\ \zeta_q = 1 + (1/3)(0.70) = 1.23;\ \zeta_\gamma = 0.87;$$

$$q_0 = (0.456)(33.3)(1.23) + (1/2)(56)(28)(48.0)(0.87)/(2000) = 18.7 + 16.4 = 35.1 \text{ ton/ft}^2$$

In view of small change in mean normal stress from the previously found value, this answer is retained.

Remarks: (1) The analysis of compressibility effects for this case is presented in Example 3.8.

(2) Because of high value of ultimate bearing capacity it is possible that the allowable bearing pressure may be controlled by maximum tolerable settlement for the structure in question.

3.6 EFFECT OF INCLINATION AND ECCENTRICITY OF THE LOAD

The preceding discussions were all concerned with a footing loaded by a central, vertical load. If the load is inclined or eccentric, or, as it most often happens, both inclined and eccentric, the problem is somewhat more complicated because of the presence of the horizontal component P of the footing reaction (Fig. 3.16a). Failure can occur either by sliding of the footing along its base AB, or by general shear of the underlying soil.

At the verge of sliding the horizontal component P is related to the vertical component Q of the footing reaction

beneath it after the concrete has hardened or by using a base form which is later removed to leave an open space.

The designer should be relatively certain that the strap is rigid; otherwise, the solution will be poor. As will be seen, the statics of this problem can be satisfied (numerically) by connecting the two footings with a cable; the reality, however, is something else. It is expected that if the strap has a moment of inertia of two to four times that of the footing to which it is attached it will be sufficiently rigid to satisfy the assumptions made.

The footings should be proportioned so that the least lateral dimensions (B-values) are within 1–2 feet of each other and the soil pressures are approximately equal. This will insure approximately equal settlements due to both soil pressure intensity and footing size effects.

Proportioning of a strap footing is as follows, referring to Fig. 16.7 where the terms used in the following outline are identified.

(1) Assume a reasonable value of footing half-length for column 1. This establishes the eccentricity of R_1 with respect to column 1:

$$e = x_e - x_1$$

and the footing dimension L is

$$L = 2(e + w_1)$$

(2) Sum moments about the center of column 2 and obtain the soil reaction R_1 beneath footing 1 as

$$R_1 = \frac{P_1 x_c}{x_1} + W_s \frac{x_s}{x_1} \qquad (16.3)$$

This equation includes the weight of the strap which must be assumed at this point. Alternatively, if the strap is relatively short this term can be neglected with little error.

(3) Sum forces in the vertical direction ($\Sigma F_v = 0$)

$$R_2 = P_1 + P_2 + W_s - R_1$$

(4) Compute width of footing 1 and dimensions of footing 2 using the allowable soil pressures and the dimensions assumed in Step 1:

$$B_1 = \frac{R_1}{L_q}$$

and

$$B_2 R_2 q = R_2$$

from which reasonable proportions can be established to control settlement.

EXAMPLE 16.3. Proportion a strap footing for the conditions shown in Fig. E3.1.

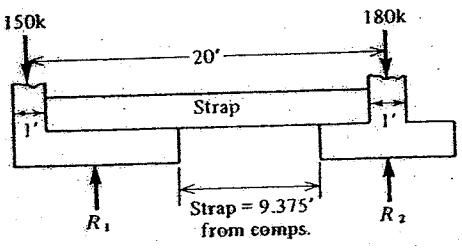


Fig. E3.1

Solution:

We have $q_a = 3$ ksf. Then $B \cong \sqrt{\frac{170}{3}} \cong 7.5'$

Try $e = 3.5'$ and neglect weight of strap

$$R_1 (20 - 3.5) - 20(150) = 0$$

$$R_1 = \frac{20(150)}{16.5} = 182\ k > 170 \quad \text{but O.K.}$$

$$R_2 + 182 - 150 - 180 = 0$$

$$R_2 = 148\ k$$

$$B_2 = \frac{148}{3} = 7.07 \text{ use } 7.25' \times 7.25'$$

$$B_1 = \frac{182}{3} = 7.8 \text{ use } 8' \times 8'$$

With these proportions settlements should be nearly equal. Draw shear and moment diagrams to complete design (not shown).

16.6 ECCENTRICALLY LOADED RIGID FOOTINGS

Rigid footings are eccentrically loaded with a nonuniform soil pressure distribution when the center of area of footing is not coincident with the resultant of the column forces. This statement is applicable to any type footing: spread, combined, raft, etc. Figure 16.8 presents several situations where eccentricity can occur.

These situations require an adjustment in bearing capacity computations (section 15.7) to account for the full footing width not being effective. The adjusted bearing capacity also attempts to reduce the effect of differential pressure in causing footing rotation. This section is not concerned with repeating the bearing capacity computations, but rather with the "actual" pressure beneath the footing.

Conventional design assumes a rigid footing; therefore, the soil pressure is computed as

$$q = \frac{\Sigma P}{A} + \frac{\Sigma P e c}{I} \qquad (16.4)$$

which can be simplified to

$$q = \frac{\Sigma P}{BL}\left(1 \pm \frac{6e}{L}\right) \qquad (16.4a)$$

where q = soil pressure at footing extremities (+) = compression

e = eccentricity of loading with center of footing area ($e \leq L/6$)

$B_1 L$ = footing dimensions

Several observations can be made at this point:

(a) Since soil cannot take tension stresses with any degree of reliability the limit of eccentricity is $e = L/6$. For eccentricities larger than this the footing is only partially effective.

(b) The moment of inertia is computed as $BL^3/12$, where B and L are the footing plan dimensions. Since the footing thickness does not show up in this equation, one could be computing a resisting value for a very flexible member.

(c) With eccentricity, a rectangular footing (with L ori-

14/19

FOUNDATION ANALYSIS AND DESIGN

Third Edition

Joseph E. Bowles

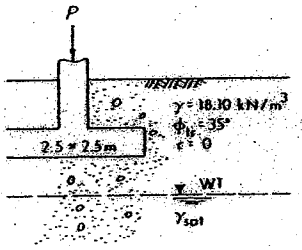
Consulting Engineer/Software Consultant
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Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

15/19

ed is to be placed on a cohes-
ollows:



4-6

en equation of Table 4-1 and a

own but would depend on the
mpute several values of q_a
q_a.

I these values. Estimate the

m^3

m^3

m^3

voids

N/m^3

$5 + \phi/2) = 2.40$ m. Substitution

$\frac{07}{}(2.40 - 0.85)^2$

on using Tables 4-1 and 4-5. Do

4)

$4\frac{B}{L} = 0.6$

or are 1.0,

Substituting values,

$$q_{ult} = 18.10(1.1)(33)(1.70)(1.11) + 0.5(14.86)(2.5)(34)(0.6)(1.0)$$

$$= 1240 + 379 = 1619 \text{ kPa}$$

$$q_a = \frac{1619}{2} = 810 \text{ kPa (a very large bearing pressure)}$$

It is unlikely that this large a bearing pressure would be allowed—possibly a maximum is 500 kPa (about 10 ksf). We might simply neglect the $\gamma_s BN_\gamma$ term to obtain $q_a = 620$ kPa (still large). If the latter term is neglected, the computations are considerably simplified and with little effect on what would normally be recommended as q_a (around 500 kPa in most cases).

////

4-7 BEARING CAPACITY FOR FOOTINGS ON LAYERED SOILS

It may be necessary to place footings on stratified deposits where the thickness of the top stratum is insufficient to fully enclose the rupture zone (surface *ade* of Fig. 4-1*a*). If the rupture zone extends into the lower layer (or layers if very thin) the ultimate bearing capacity will be modified to some extent. One would expect it to increase if the lower soil is of better quality and decrease for poorer soil. Numerous solutions have been proposed to enable one to make an estimate of the bearing capacity. One of the first proposals was by Button (1953) for a $\phi = 0°$ analysis. With $\phi = 0°$ the curved sector *ad* of Fig. 4-1*b* becomes circular, and Button actually used a circular segment *cade* with the center above and to the left of point *c*. The solution was limited to a two-layer system with $\phi = 0°$ in both soils. The solution was obtained by finding the minimum value of the pressure ratio

$$N_c = \frac{\Delta q}{c_1}$$

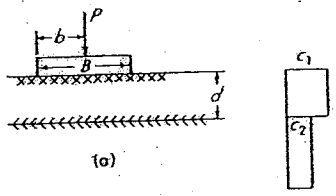
where Δq is applied footing contact pressure across the width B and c_1 is the cohesion of the soil stratum immediately underlying the footing.

Reddy and Srinivasan (1967) extended the Button solution to anisotropic soils defined by a coefficient of anisotropy of the soil immediately underlying the footing as

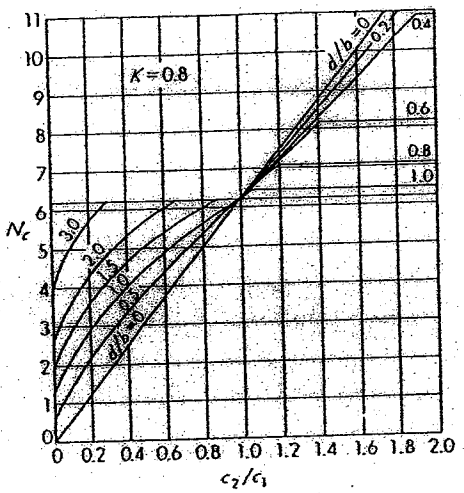
$$K = \frac{q_1}{q_3}$$

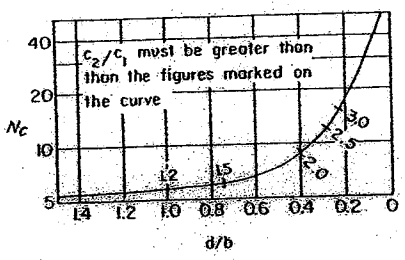
where q_1 = vertical shear strength
q_3 = horizontal shear strength

A value of $K < 1$ indicates overconsolidation; $K = 1$ is isotropic, and $K > 1$ is normally consolidated. Charts from Reddy and Srinivasan are shown for three K values of 0.8, 1.0, and 1.2 in Fig. 4-3*c*. The values for $K = 1.0$ are identical to those of Button (1953). The charts are made up for the angle between the failure plane and the minor principal stress of 35° which was used from an

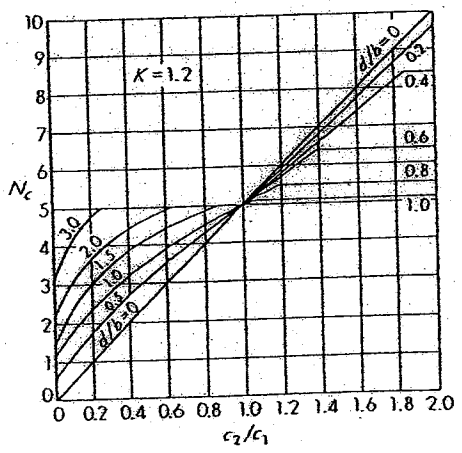


(a)





(b) Circles tangent to lower layer; (After Button, 1953).



(c)

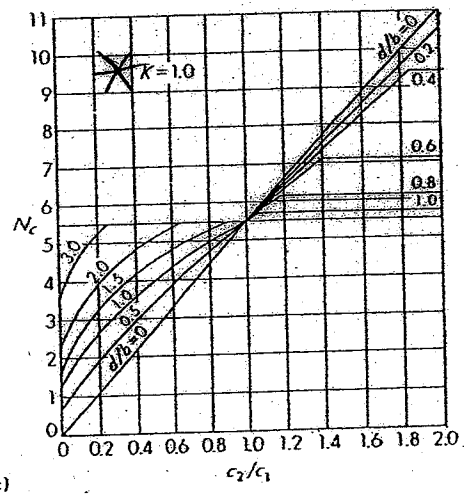


Figure 4-3 Bearing-capacity factors for a footing located on a two-layer cohesive soil system, with cohesion in each layer as shown. [*After Reddy and Srinivasan (1967).*]

earlier summary of tests by Lo (1965). Button, and as shown in Fig. 4-3 for $K = 1.0$, used an average value of $N_c = 5.5$ for the case of a single layer which is an approximate average of the values 5.14 and 5.7 shown in Tables 4-2 and 4-5. Meyerhof and Brown (1967) show that the additional charts for various K values are not needed; the chart for $K = 1$ is sufficient if one uses an average $q_u = (q_1 + q_3)/2$ and the corresponding cohesion. Errors associated with this would be not more than 10 percent and are less than the assumption of a circular failure surface. A circular failure surface is obviously an erroneous assumption with anisotropy, since there is a ϕ angle.

The bearing capacity for the layered soil conditions of Fig. 4-3*a* is computed from the Hansen equation of Table 4-1 as

$$q_{uH} = c_1 N_c (1 + s'_c + d'_c) + \bar{q} N_q \tag{4-2}$$

where N_c is now obtained from Fig. 4-3*c*, and c_1 is the cohesion of the soil immediately underlying the footing. Figure 4-3*b* illustrates the limiting d/b and c_2/c_1 values to have a failure zone all in the top layer with the rupture circle just tangent to the second layer. This figure can be obtained from the curves of $K = 1$ from (*c*) at the breaks in the d/b lines beyond which N_c = constant. Any c_2/c_1 ratios larger than the "limiting" values for that d/b ratio will result in the bearing-capacity failure occurring entirely within the top soil layer.

A possible alternative for $\phi - c$ soils with a number of thin layers is to use average values of c and ϕ obtained as

$$c_{av} = \frac{c_1 H_1 + c_2 H_2 + c_3 H_3 + \cdots + c_n H_n}{\Sigma H_i} \tag{4-3}$$

$$\phi_{av} = \tan^{-1} \frac{H_1 \tan \phi_1 + H_2 \tan \phi_2 + \cdots + H_n \tan \phi_n}{\Sigma H_i} \tag{4-4}$$

where c_i = cohesion in stratum of thickness H_i; c may be 0
ϕ_i = angle of internal friction in stratum of thickness H_i; ϕ may be zero

Any H_i may be multiplied by a weighting factor (1.0 is used in these equations) if desired. The effective shear depth of interest is limited to approximately $0.5B \tan (45 + \phi/2)$. One or two iterations may be required to obtain the best average $\phi - c$ values, since B is not usually fixed until the bearing capacity is established.

One can use a slope-stability program such as Bowles (1974*a*) to obtain the bearing capacity for layered soils. The program as given in that reference would require modification to treat the footing pressure as a surcharge. An increase in shear strength with depth could be approximated by addition of "soils" with the same $\phi - c$ and γ properties but increased shear strength. The ultimate bearing capacity is that value of q_o producing $F = 1$.

The finite-element method for the elastic continuum as given in Zienkiewicz (1977) can also be used to estimate the bearing capacity. It would be necessary to obtain the soil parameters E, and μ instead of ϕ and c. It would also be necessary to define "failure" as either excessive deflection or a specified stress level (the

Table 4-5 Shape, depth, inclination, and other factors for use in the Hansen bearing capacity equation in Table 4-1
Table combined from Hansen (1970), De Beer (1970), and Vesic (1973). Primed factors for undrained (U) conditions and $\phi = 0$

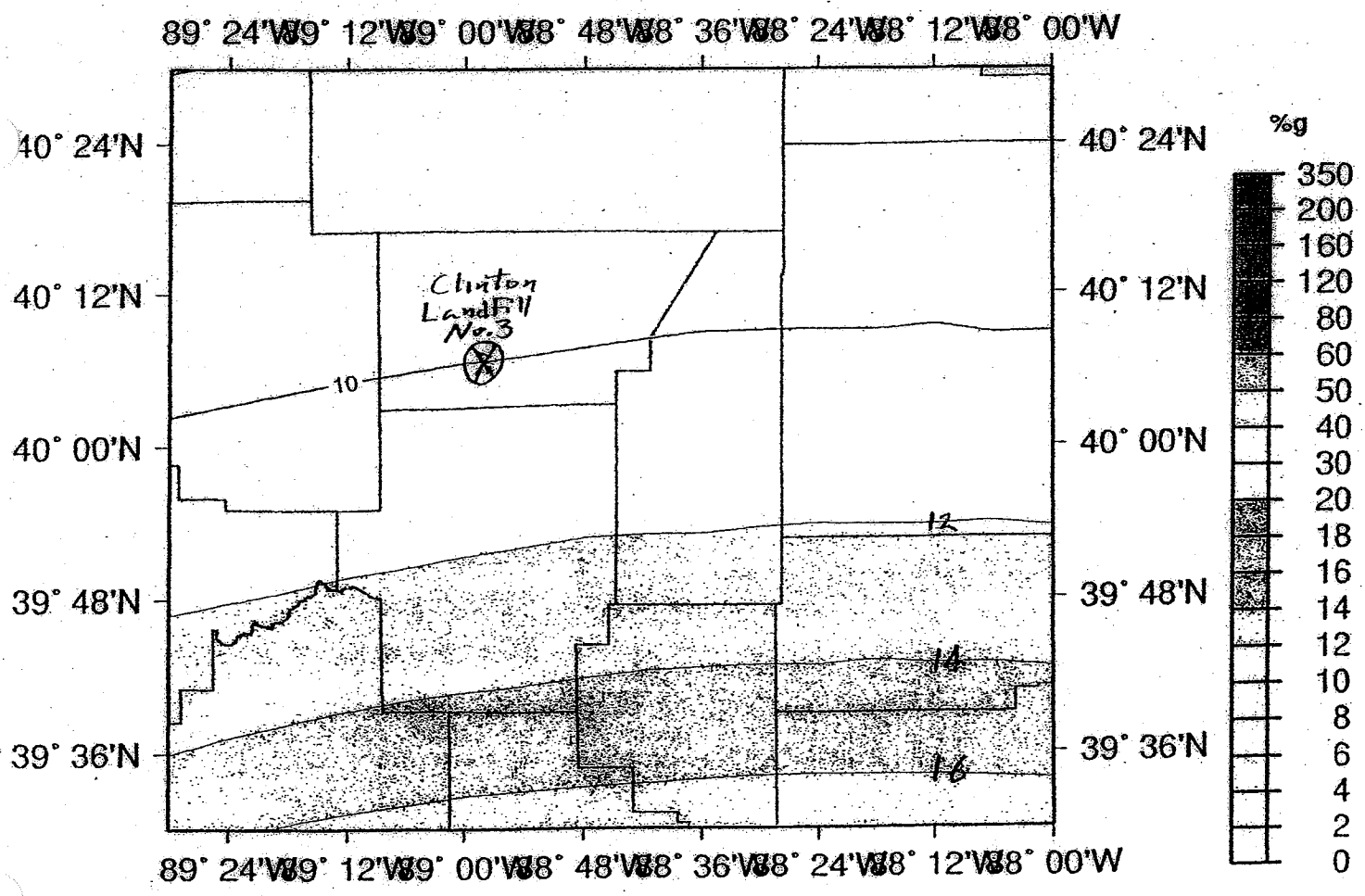
Shape factors	Depth factors		Inclination factors	Ground factors (see figure)
$s'_c = 0.2B/L$	$d'_c = 0.4D/B$	$D \le B$	$i'_c = 0.5 - 0.5\sqrt{1 - H/A_f c_a}$	$g'_c = \psi°/147°$
$s_c = 1 + N_q B/N_c L$	$d'_c = 0.4 \tan^{-1} \frac{D}{B}$	$D > B$	$i_c = i_q - (1 - i_q)/(N_q - 1)$	for horizontal ground use $g'_c = 0.0$
	$d_c = 1 + 0.4 \frac{D}{B}$	$D \le B$		$g_c = 1 - \psi°/147°$
	$d_c = 1 + 0.4 \tan^{-1} \frac{D}{B}$	$D > B$		$g_q = g_\gamma = (1 - 0.5 \tan \psi°)^5$
$s_q = 1 + (B/L) \tan \phi$	$d_q = 1 + 2 \tan \phi (1 - \sin \phi)^2 \frac{D}{B}$	$D \le B$	$i_q = \left(1 - \frac{0.5H}{V + A_f c_a \cot \phi}\right)^5$	Base factors (see figure)
	$d_q = 1 + 2 \tan \phi (1 - \sin \phi)^2 \tan^{-1} \frac{D}{B}$	$D > B$		$b'_c = \eta°/147°$
				for horizontal ground use $b'_c = 0.0$
				$b_c = 1 - \eta°/147°$
$s_\gamma = 1 - 0.4B/L$	$d_\gamma = 1.00$ for all ϕ		Horizontal ground: $i_\gamma = \left(1 - \frac{0.7H}{V + A_f c_a \cot \phi}\right)^5$	$b_q = b_\gamma = \exp(-2\eta \tan \phi)$
			Sloping ground: $i_\gamma = \left(1 - \frac{(0.7 - \eta°/450°)H}{V + A_f c_a \cot \phi}\right)^5$	η = radians for b_q

Table 4-5 *cont'd*

where A_f = effective footing contact area $B'L'$

18/19

19/19



Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary

miles
0 5

U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area Projection
Standard Parallels: 29.5 and 45.5 degrees

APPENDIX 812.305-E: SLOPE STABILITY CALCULATIONS

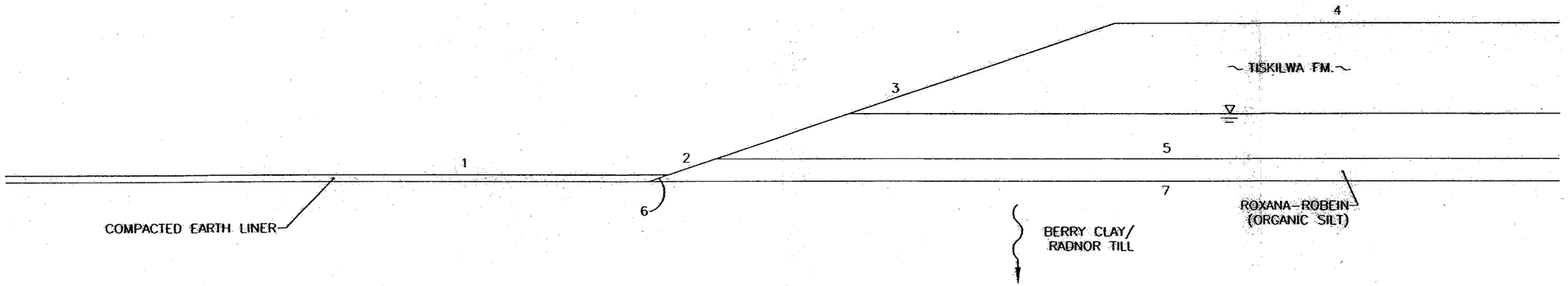
100% recycled paper

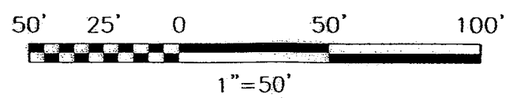
SLOPE STABILITY CALCULATIONS

SIDEWALL LINER EXCAVATION

CAD DWG NO:911181149 EMPLOYEE NO: 89239 DATE/TIME: 11/17/06 13:36 ACAD-16.

SIDEWALL LINER STABILITY - EXCAVATION





SOIL IDENTITY	SOIL TYPE NO.
TISKILWA FORMATION	1
COMPACTED EARTH LINER	2
ROXANA ROBEIN: ORGANIC SILT	3
BERRY CLAY/ RADNOR TILL	4

LEGEND

2 BOUNDARY NO.

PIEZOMETRIC SURFACE

Illinois Licensed Professional Design Firm 184-001145

PDC Technical Services, Inc.
Peoria, Illinois

APP. 812.305-E: FIGURE A
SIDEWALL LINER EXCAVATION
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

SLOPE STABILITY CALCULATIONS

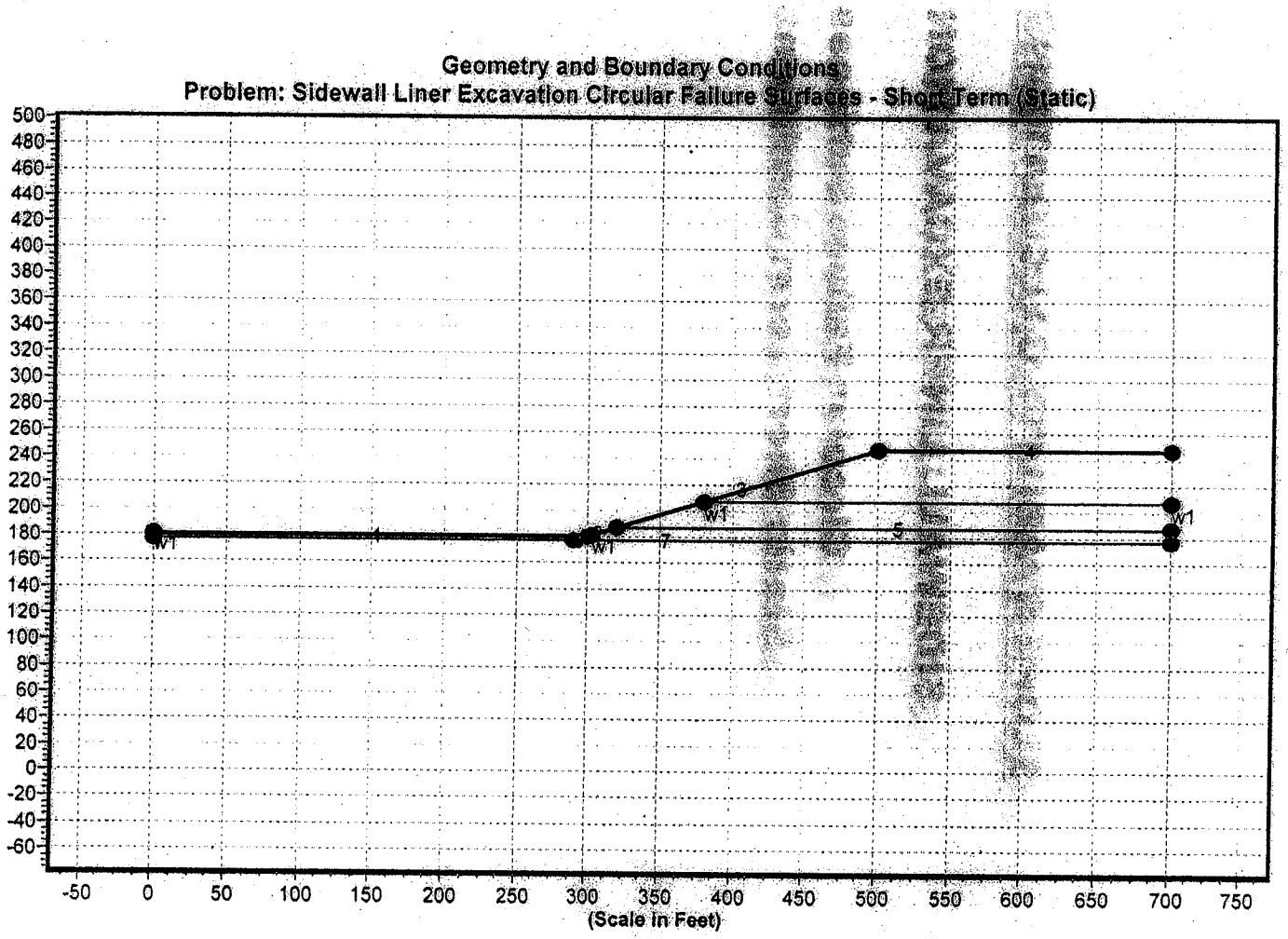
SIDEWALL LINER EXCAVATION

Circular Failure Surfaces
Static Short Term Conditions

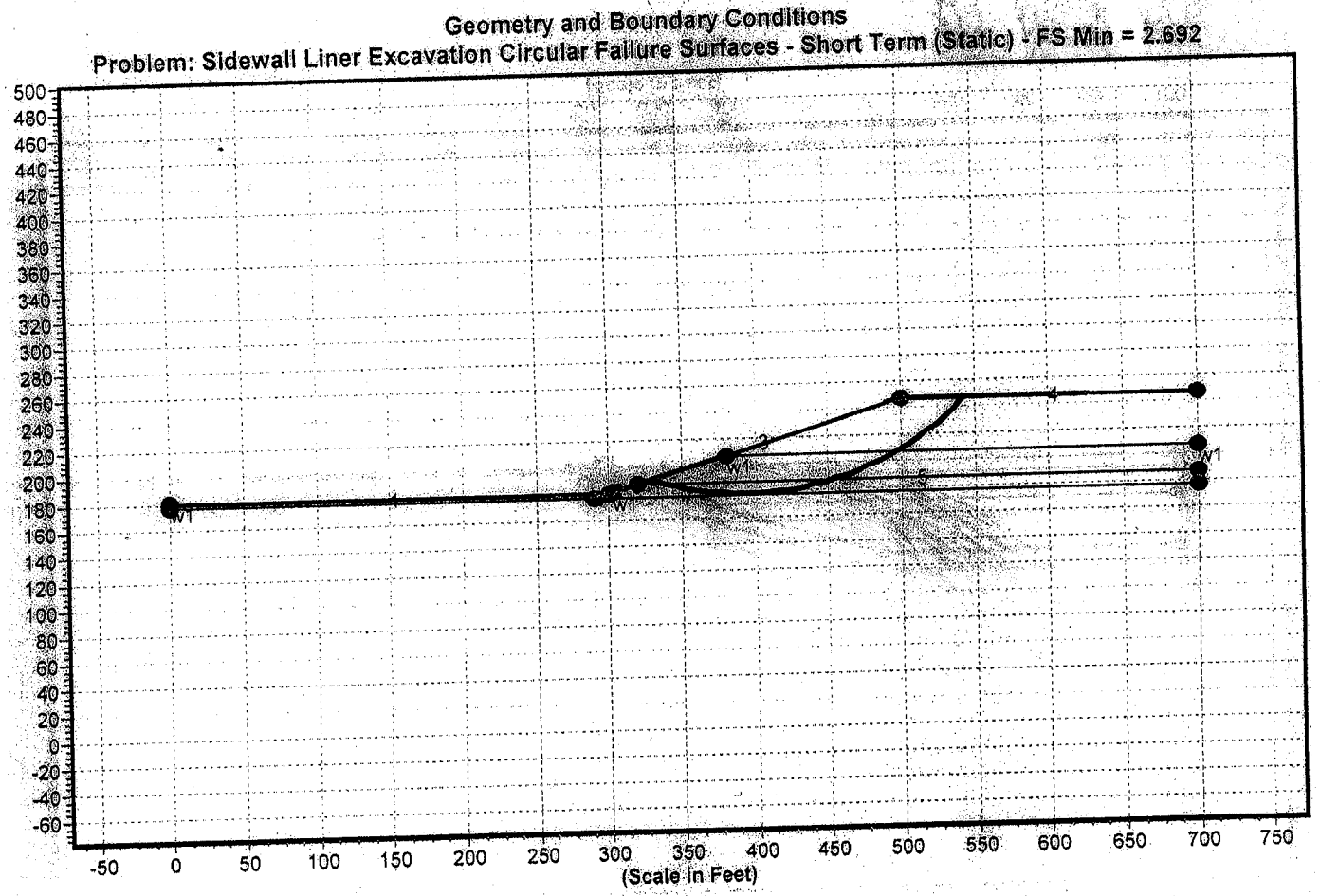
Key Assumptions:

Undrained Shear Strengths

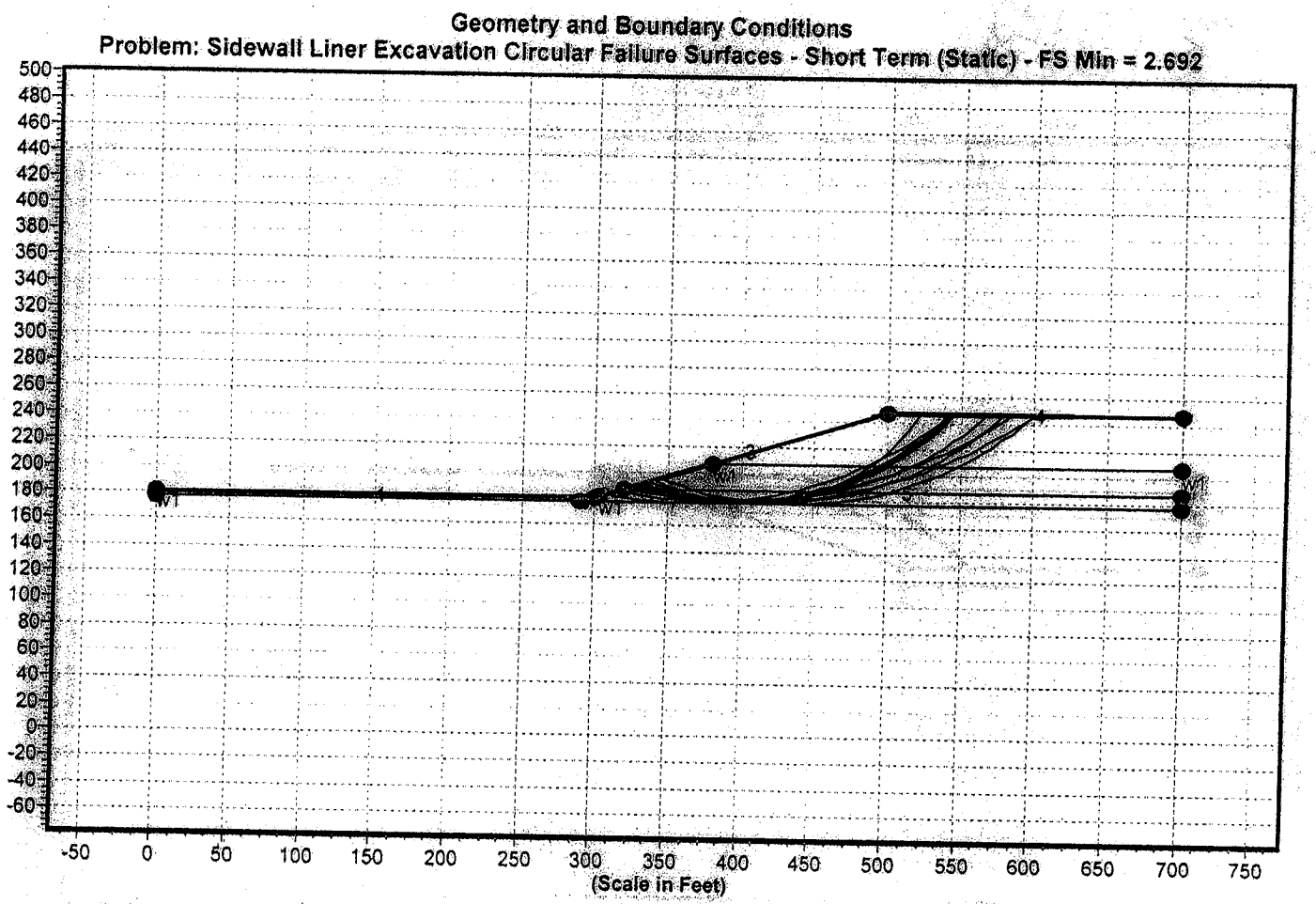
Perched water in Tiskilwa Formation


Geometry and Boundary Conditions
Problem: Sidewall Liner Excavation Circular Failure Surfaces - Short Term (Static)
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
(Scale in Feet)
w1
w1
w1
w1
1
2
3
4
5
6
7

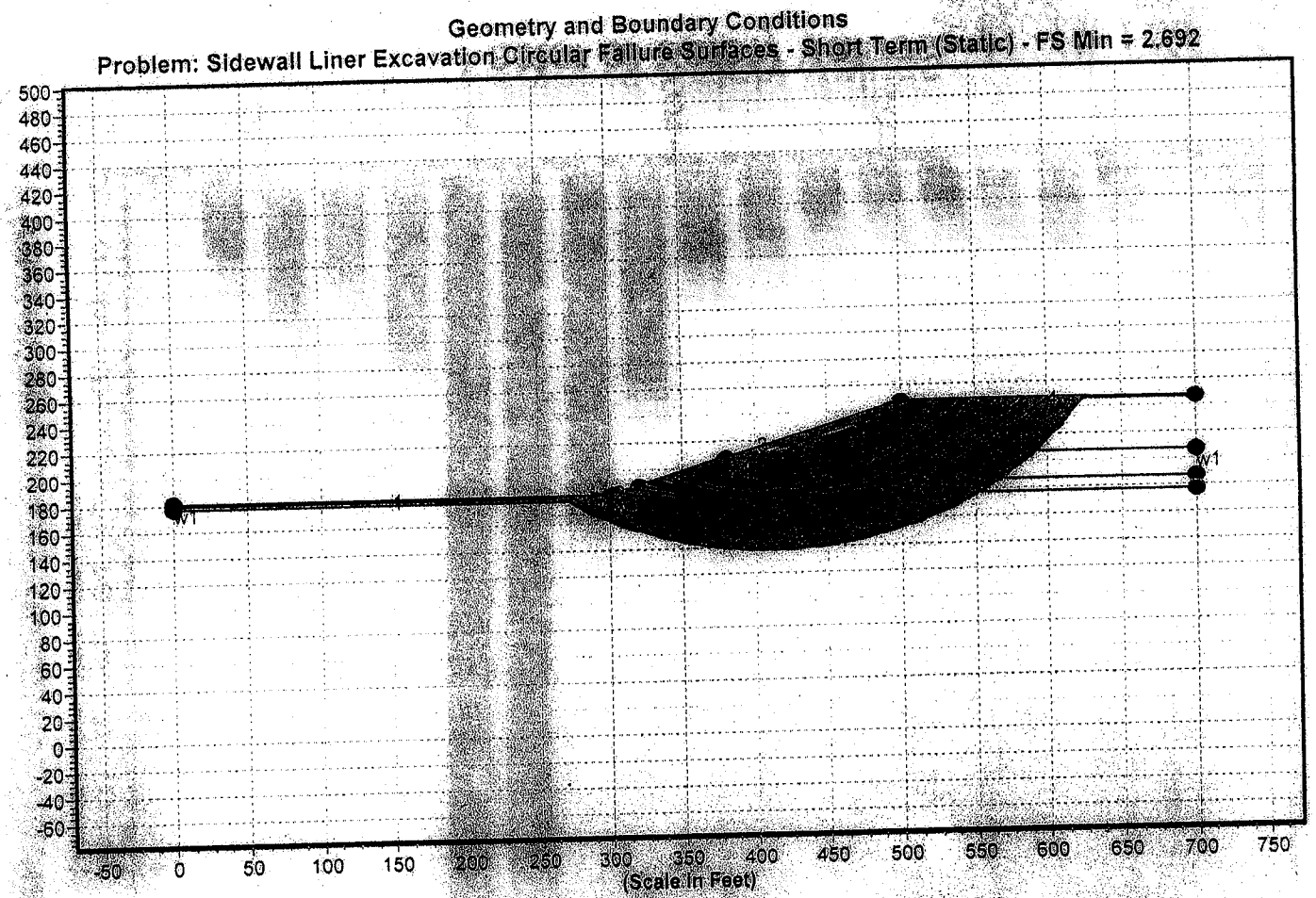
Profile

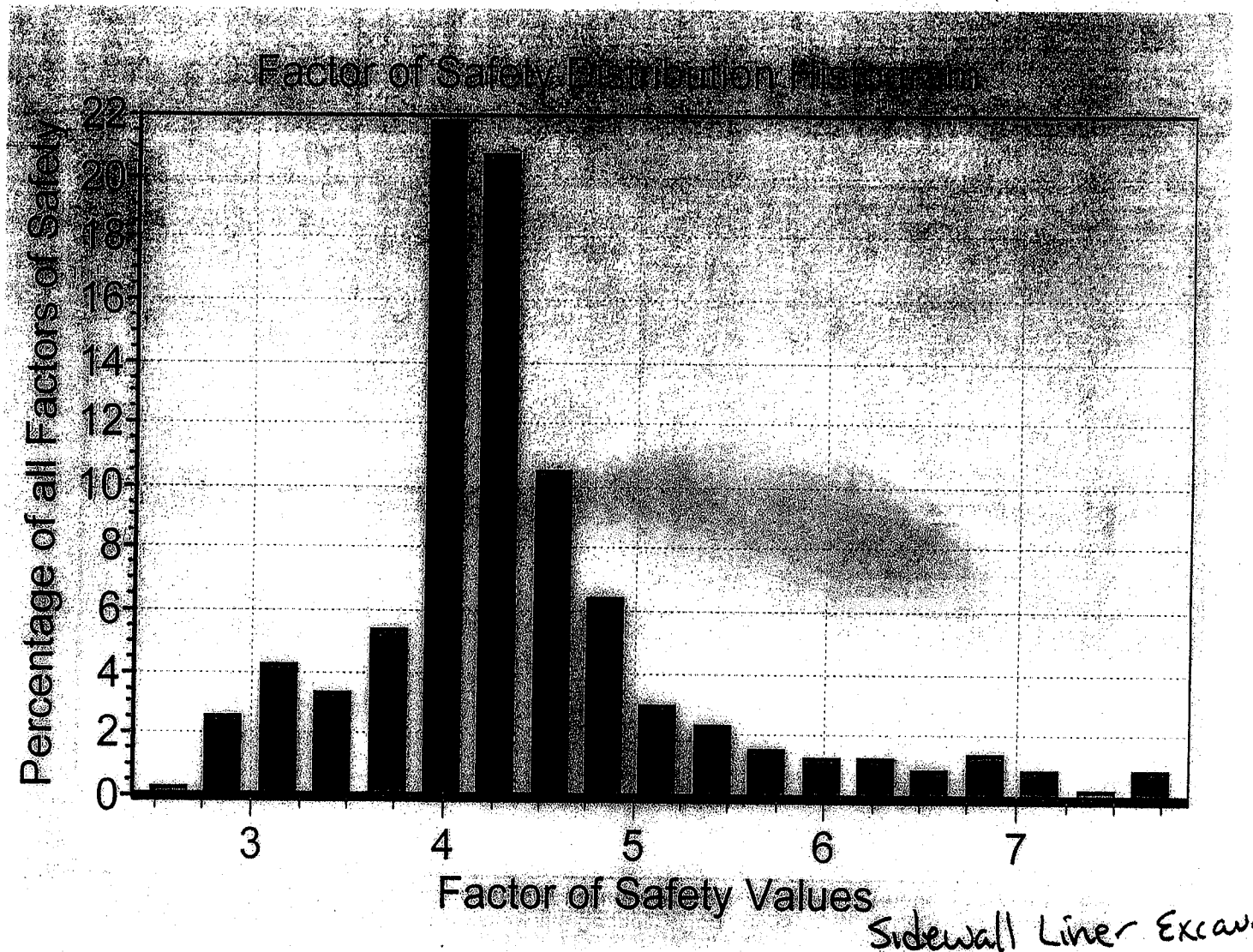


Critical Surface



10 Most Critical Surfaces


Geometry and Boundary Conditions
Problem: Sidewall Liner Excavation Circular Failure Surfaces - Short Term (Static) - FS Min = 2.692
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
(Scale in Feet)



Sidewall Liner Excavation
Circular Failure Surfaces
Short Term (Static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Sidewall Liner Excavation Circular Failu
re Surfaces - Short Term (Static)

BOUNDARY COORDINATES

4 Top Boundaries
7 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	180.00	299.00	180.00	2
2	299.00	180.00	320.00	187.00	3
3	320.00	187.00	500.00	247.00	1
4	500.00	247.00	700.00	247.00	1
5	320.00	187.00	700.00	187.00	3
6	290.00	177.00	299.00	180.00	3
7	0.00	177.00	700.00	177.00	4

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	135.0	140.0	3500.0	0.0	0.00	0.0	1
2	135.0	140.0	3000.0	0.0	0.00	0.0	1
3	100.0	110.0	1400.0	0.0	0.00	0.0	1
4	140.0	148.0	6000.0	0.0	0.00	0.0	0

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	181.00
2	302.00	181.00
3	380.00	207.00
4	700.00	207.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

1200 Trial Surfaces Have Been Generated.

40 Surfaces Initiate From Each Of 30 Points Equally Spaced Along The Ground Surface Between X = 265.00 ft.
and X = 375.00 ft.

Each Surface Terminates Between X = 490.00 ft.
and X = 625.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =100.00 ft.

8.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -33.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 31 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	329.48	190.16
2	337.05	187.57
3	344.72	185.30
4	352.48	183.34
5	360.31	181.71
6	368.20	180.41
7	376.14	179.43
8	384.12	178.78
9	392.11	178.46
10	400.11	178.48
11	408.10	178.83
12	416.08	179.50
13	424.01	180.51
14	431.90	181.85
15	439.73	183.51
16	447.48	185.49
17	455.14	187.79
18	462.70	190.41
19	470.14	193.34
20	477.46	196.58
21	484.63	200.11
22	491.66	203.94
23	498.51	208.06
24	505.20	212.46
25	511.69	217.13
26	517.99	222.07
27	524.07	227.26
28	529.93	232.71
29	535.57	238.39
30	540.96	244.29
31	543.24	247.00

result

Circle Center At X = 395.7 ; Y = 371.4 and Radius, 193.0

*** 2.692 ***

Individual data on the 35 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	7.6	2704.3	0.0	1212.4	0.0	0.0	0.0	0.0	0.0
2	1.9	1538.6	0.0	680.7	0.0	0.0	0.0	0.0	0.0
3	5.7	6384.4	0.0	2889.7	0.0	0.0	0.0	0.0	0.0
4	7.8	12618.0	0.0	5792.6	0.0	0.0	0.0	0.0	0.0
5	7.8	17123.8	0.0	7875.0	0.0	0.0	0.0	0.0	0.0
6	7.9	21419.7	0.0	9814.3	0.0	0.0	0.0	0.0	0.0
7	7.9	25470.9	0.0	11607.1	0.0	0.0	0.0	0.0	0.0
8	3.9	13701.0	0.0	6211.4	0.0	0.0	0.0	0.0	0.0
9	4.1	15559.7	0.0	7232.3	0.0	0.0	0.0	0.0	0.0
10	8.0	32668.3	0.0	14166.2	0.0	0.0	0.0	0.0	0.0
11	8.0	35705.4	0.0	14241.5	0.0	0.0	0.0	0.0	0.0
12	8.0	38388.8	0.0	14151.2	0.0	0.0	0.0	0.0	0.0
13	8.0	40701.0	0.0	13895.6	0.0	0.0	0.0	0.0	0.0

					result				
14	7.9	42627.9	0.0	13475.1	0.0	0.0	0.0	0.0	0.0
15	7.9	44159.3	0.0	12890.4	0.0	0.0	0.0	0.0	0.0
16	7.8	45288.8	0.0	12142.5	0.0	0.0	0.0	0.0	0.0
17	7.8	46014.0	0.0	11232.8	0.0	0.0	0.0	0.0	0.0
18	5.0	30293.9	0.0	6791.4	0.0	0.0	0.0	0.0	0.0
19	2.6	16011.2	0.0	3371.4	0.0	0.0	0.0	0.0	0.0
20	7.6	45785.0	0.0	8934.2	0.0	0.0	0.0	0.0	0.0
21	7.4	44710.3	0.0	7549.4	0.0	0.0	0.0	0.0	0.0
22	7.3	43214.9	0.0	6010.4	0.0	0.0	0.0	0.0	0.0
23	7.2	41324.1	0.0	4320.2	0.0	0.0	0.0	0.0	0.0
24	7.0	39067.1	0.0	2481.5	0.0	0.0	0.0	0.0	0.0
25	5.1	27241.8	0.0	565.9	0.0	0.0	0.0	0.0	0.0
26	1.8	9239.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1.5	7660.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	5.2	25431.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	6.5	28232.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	6.3	23283.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	6.1	18345.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	5.9	13470.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	5.6	8712.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	5.4	4121.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	2.3	415.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 31 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43
2	340.68	188.39
3	348.21	185.70
4	355.86	183.36
5	363.61	181.38
6	371.45	179.76
7	379.35	178.50
8	387.30	177.61
9	395.28	177.09
10	403.28	176.94
11	411.28	177.16
12	419.26	177.74
13	427.20	178.70
14	435.09	180.02
15	442.91	181.70
16	450.64	183.75
17	458.28	186.15
18	465.79	188.90
19	473.16	191.99
20	480.39	195.43
21	487.45	199.19
22	494.33	203.28
23	501.01	207.67
24	507.48	212.38
25	513.73	217.38
26	519.74	222.66
27	525.50	228.21
28	530.99	234.02
29	536.21	240.08
30	541.15	246.38
31	541.59	247.00

Circle Center At X = 402.6 ; Y = 349.9 and Radius, 173.0

result

*** 2.698 ***

1

Failure Surface Specified By 34 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	337.07	192.69
2	344.58	189.94
3	352.19	187.46
4	359.88	185.25
5	367.64	183.32
6	375.47	181.66
7	383.35	180.29
8	391.27	179.20
9	399.23	178.40
10	407.22	177.88
11	415.21	177.65
12	423.21	177.70
13	431.21	178.04
14	439.18	178.67
15	447.13	179.58
16	455.04	180.78
17	462.90	182.25
18	470.71	184.01
19	478.44	186.05
20	486.10	188.36
21	493.67	190.94
22	501.15	193.79
23	508.51	196.91
24	515.76	200.29
25	522.89	203.93
26	529.88	207.82
27	536.73	211.96
28	543.42	216.34
29	549.95	220.96
30	556.32	225.80
31	562.50	230.88
32	568.51	236.17
33	574.31	241.67
34	579.55	247.00

Circle Center At X = 417.7 ; Y = 401.1 and Radius, 223.5

*** 2.700 ***

Failure Surface Specified By 31 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43

result

2	340.79	188.67
3	348.41	186.23
4	356.12	184.13
5	363.93	182.36
6	371.80	180.92
7	379.72	179.82
8	387.68	179.06
9	395.67	178.65
10	403.67	178.57
11	411.67	178.84
12	419.65	179.46
13	427.59	180.41
14	435.48	181.70
15	443.32	183.33
16	451.07	185.29
17	458.74	187.59
18	466.29	190.21
19	473.73	193.15
20	481.04	196.40
21	488.20	199.97
22	495.20	203.84
23	502.03	208.01
24	508.68	212.46
25	515.12	217.20
26	521.36	222.21
27	527.38	227.48
28	533.17	233.00
29	538.71	238.77
30	544.01	244.77
31	545.82	247.00

Circle Center At X = 401.4 ; Y = 365.3 and Radius, 186.7

*** 2.709 ***

1

Failure Surface Specified By 37 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	314.31	185.10
2	322.16	183.55
3	330.04	182.18
4	337.95	181.00
5	345.89	180.02
6	353.85	179.23
7	361.83	178.62
8	369.82	178.22
9	377.82	178.00
10	385.82	177.98
11	393.82	178.15
12	401.81	178.51
13	409.79	179.07
14	417.75	179.82
15	425.70	180.76
16	433.62	181.89
17	441.51	183.21

		result
18	449.36	184.73
19	457.18	186.43
20	464.95	188.32
21	472.68	190.40
22	480.35	192.66
23	487.97	195.11
24	495.52	197.74
25	503.01	200.55
26	510.43	203.54
27	517.78	206.71
28	525.04	210.06
29	532.23	213.58
30	539.32	217.27
31	546.33	221.14
32	553.24	225.17
33	560.05	229.36
34	566.76	233.72
35	573.36	238.24
36	579.85	242.92
37	585.23	247.00

Circle Center At X = 382.7 ; Y = 509.5 and Radius, 331.5

*** 2.744 ***

Failure Surface Specified By 38 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	321.90	187.63
2	329.69	185.82
3	337.52	184.21
4	345.40	182.78
5	353.30	181.55
6	361.23	180.51
7	369.19	179.66
8	377.16	179.01
9	385.15	178.56
10	393.14	178.29
11	401.14	178.23
12	409.14	178.36
13	417.14	178.68
14	425.12	179.20
15	433.09	179.92
16	441.04	180.83
17	448.96	181.93
18	456.85	183.23
19	464.71	184.72
20	472.53	186.40
21	480.31	188.27
22	488.04	190.33
23	495.72	192.58
24	503.34	195.02
25	510.90	197.64
26	518.39	200.44
27	525.81	203.43
28	533.16	206.60

		result
29	540.43	209.94
30	547.61	213.47
31	554.70	217.16
32	561.70	221.03
33	568.61	225.07
34	575.42	229.28
35	582.12	233.65
36	588.71	238.18
37	595.19	242.88
38	600.60	247.00

Circle Center At X = 399.8 ; Y = 505.7 and Radius, 327.4

*** 2.759 ***

1

Failure Surface Specified By 33 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43
2	340.88	188.94
3	348.57	186.73
4	356.33	184.79
5	364.16	183.13
6	372.03	181.74
7	379.96	180.64
8	387.92	179.83
9	395.90	179.29
10	403.90	179.04
11	411.89	179.08
12	419.89	179.39
13	427.87	180.00
14	435.82	180.88
15	443.73	182.05
16	451.60	183.50
17	459.41	185.23
18	467.15	187.24
19	474.82	189.52
20	482.40	192.07
21	489.89	194.89
22	497.27	197.97
23	504.54	201.31
24	511.68	204.92
25	518.70	208.77
26	525.57	212.87
27	532.28	217.21
28	538.85	221.79
29	545.24	226.60
30	551.46	231.63
31	557.49	236.88
32	563.34	242.34
33	567.98	247.00

Circle Center At X = 406.9 ; Y = 403.9 and Radius, 224.8

result

*** 2.767 ***

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	340.86	193.95
2	348.02	190.38
3	355.37	187.23
4	362.90	184.52
5	370.58	182.27
6	378.37	180.47
7	386.26	179.14
8	394.21	178.27
9	402.20	177.88
10	410.20	177.96
11	418.18	178.52
12	426.12	179.54
13	433.98	181.04
14	441.73	182.99
15	449.36	185.41
16	456.83	188.27
17	464.12	191.56
18	471.20	195.29
19	478.05	199.42
20	484.64	203.95
21	490.95	208.87
22	496.96	214.15
23	502.65	219.78
24	507.99	225.73
25	512.98	231.99
26	517.58	238.53
27	521.79	245.34
28	522.68	247.00

Circle Center At X = 404.8 ; Y = 312.9 and Radius, 135.0

*** 2.777 ***

1

Failure Surface Specified By 33 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	306.72	182.57
2	314.59	181.09
3	322.49	179.84
4	330.42	178.82
5	338.38	178.04
6	346.36	177.49
7	354.36	177.17
8	362.36	177.09

		result
9	370.36	177.24
10	378.35	177.63
11	386.32	178.25
12	394.28	179.11
13	402.20	180.20
14	410.09	181.52
15	417.94	183.07
16	425.74	184.85
17	433.48	186.86
18	441.16	189.10
19	448.78	191.56
20	456.31	194.24
21	463.77	197.15
22	471.13	200.27
23	478.41	203.60
24	485.58	207.15
25	492.64	210.91
26	499.59	214.87
27	506.42	219.03
28	513.13	223.40
29	519.70	227.95
30	526.14	232.70
31	532.43	237.64
32	538.58	242.76
33	543.38	247.00

Circle Center At X = 361.1 ; Y = 449.6 and Radius, 272.6

*** 2.784 ***

Failure Surface Specified By 36 Coordinate Points

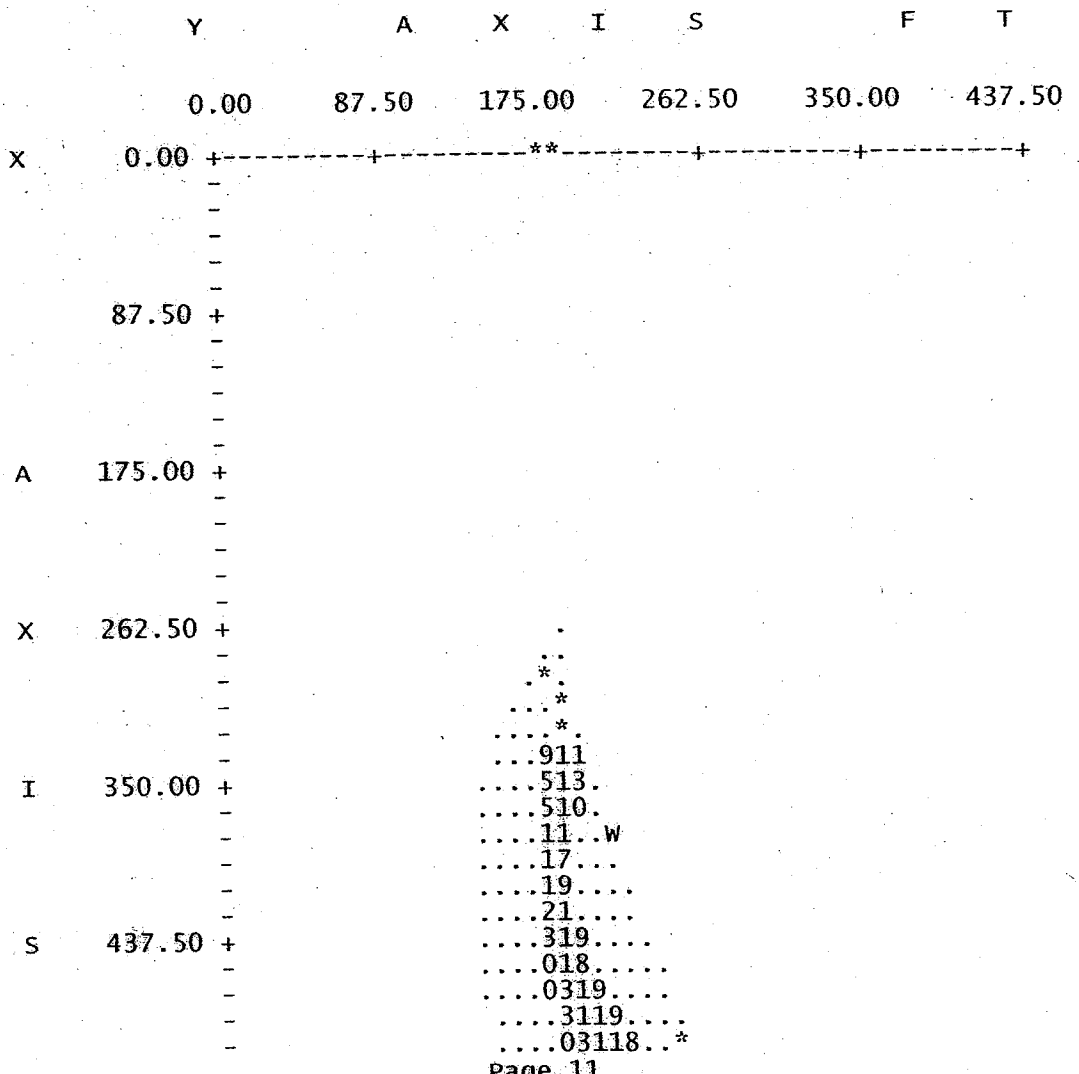
Point No.	X-Surf (ft)	Y-Surf (ft)
1	344.66	195.22
2	352.08	192.23
3	359.60	189.50
4	367.21	187.03
5	374.90	184.84
6	382.66	182.90
7	390.49	181.25
8	398.37	179.86
9	406.29	178.75
10	414.25	177.92
11	422.23	177.36
12	430.22	177.08
13	438.22	177.08
14	446.22	177.36
15	454.20	177.91
16	462.15	178.75
17	470.08	179.86
18	477.96	181.24
19	485.78	182.90
20	493.55	184.83
21	501.24	187.03
22	508.85	189.49
23	516.37	192.22

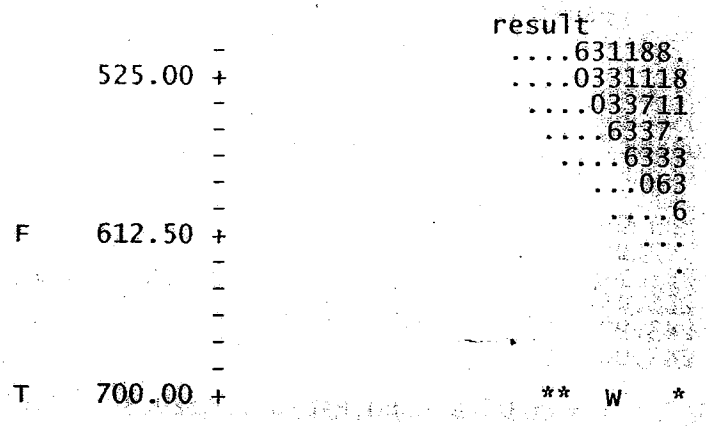
		result
24	523.79	195.21
25	531.10	198.45
26	538.30	201.95
27	545.37	205.69
28	552.30	209.68
29	559.09	213.91
30	565.73	218.37
31	572.21	223.06
32	578.53	227.98
33	584.67	233.11
34	590.62	238.45
35	596.39	243.99
36	599.31	247.00

Circle Center At X = 434.2 ; Y = 406.8 and Radius, 229.8

*** 2.806 ***

1




result
....631188.
....0331118
....033711
....6337.
....6333
...063
....6
...
.
525.00
612.50
700.00
F
T
**
W
*

SLOPE STABILITY CALCULATIONS

SIDEWALL LINER EXCAVATION

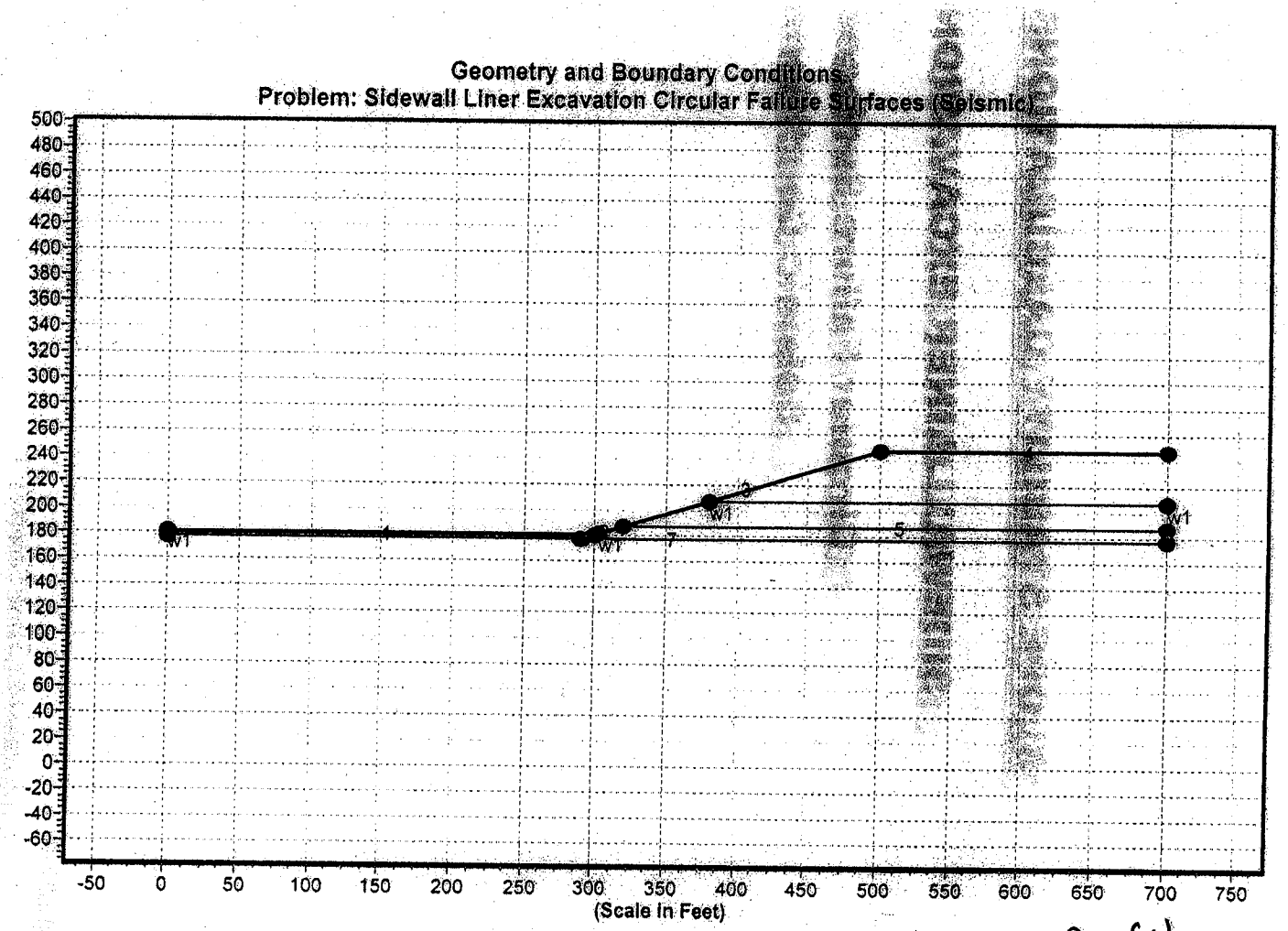
Circular Failure Surfaces
Seismic Conditions

Key Assumptions:

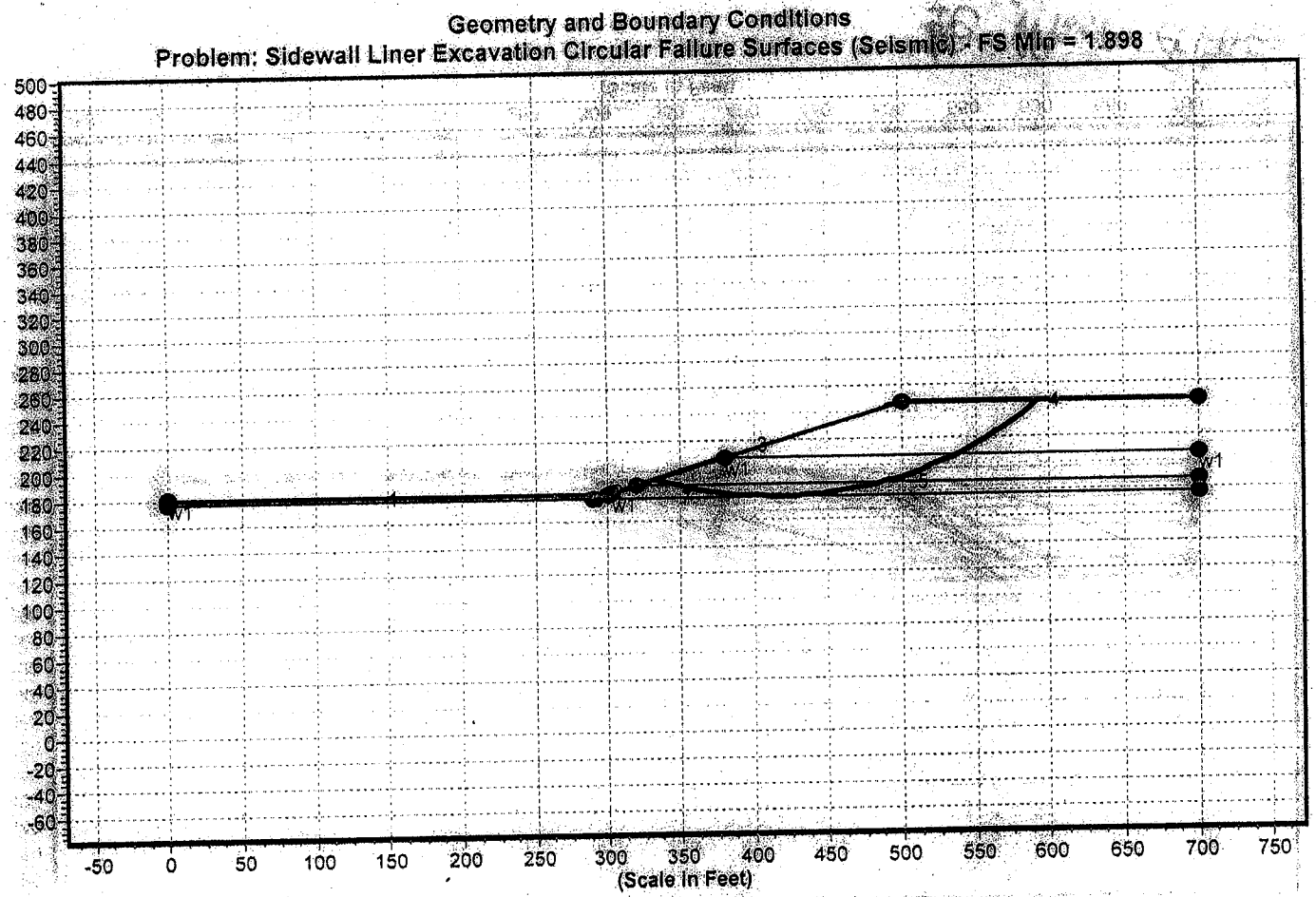
Undrained Shear Strengths

Perched water in Tiskilwa Formation

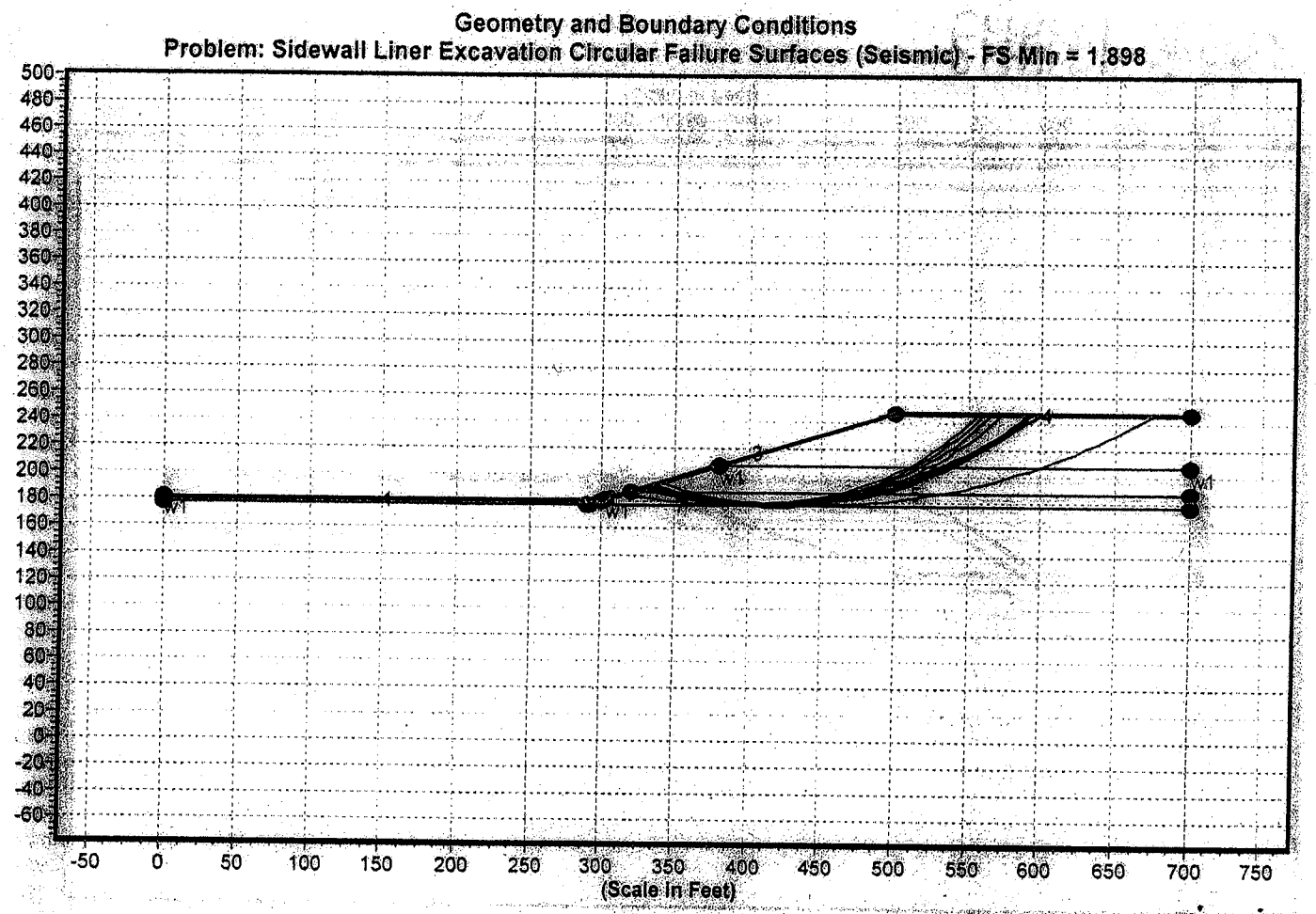
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Sidewall Liner Excavation Circular Failure Surfaces (Seismic)
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
(Scale In Feet)
W1
W1
W1
W1
1
2
3
5
7

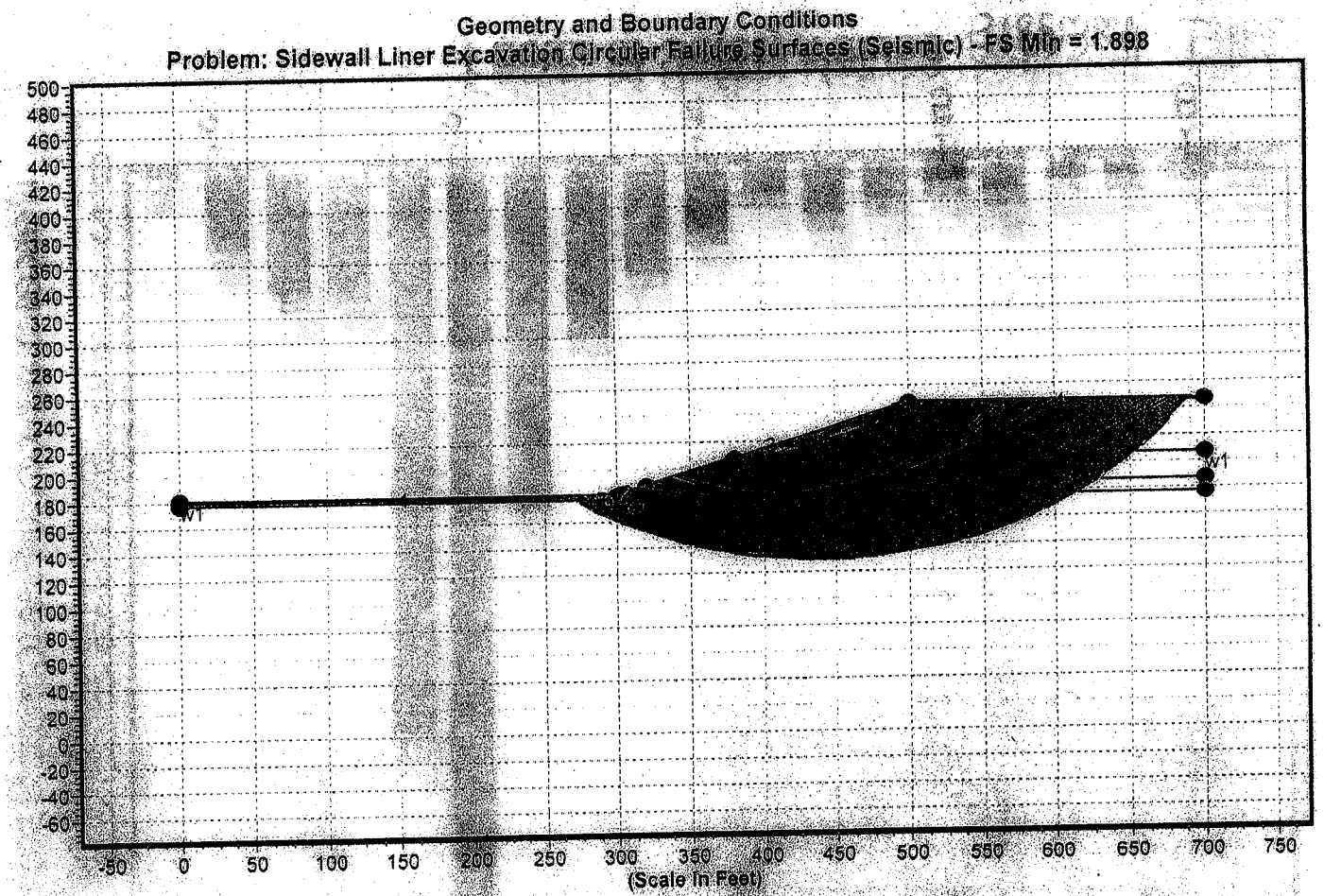
Profile



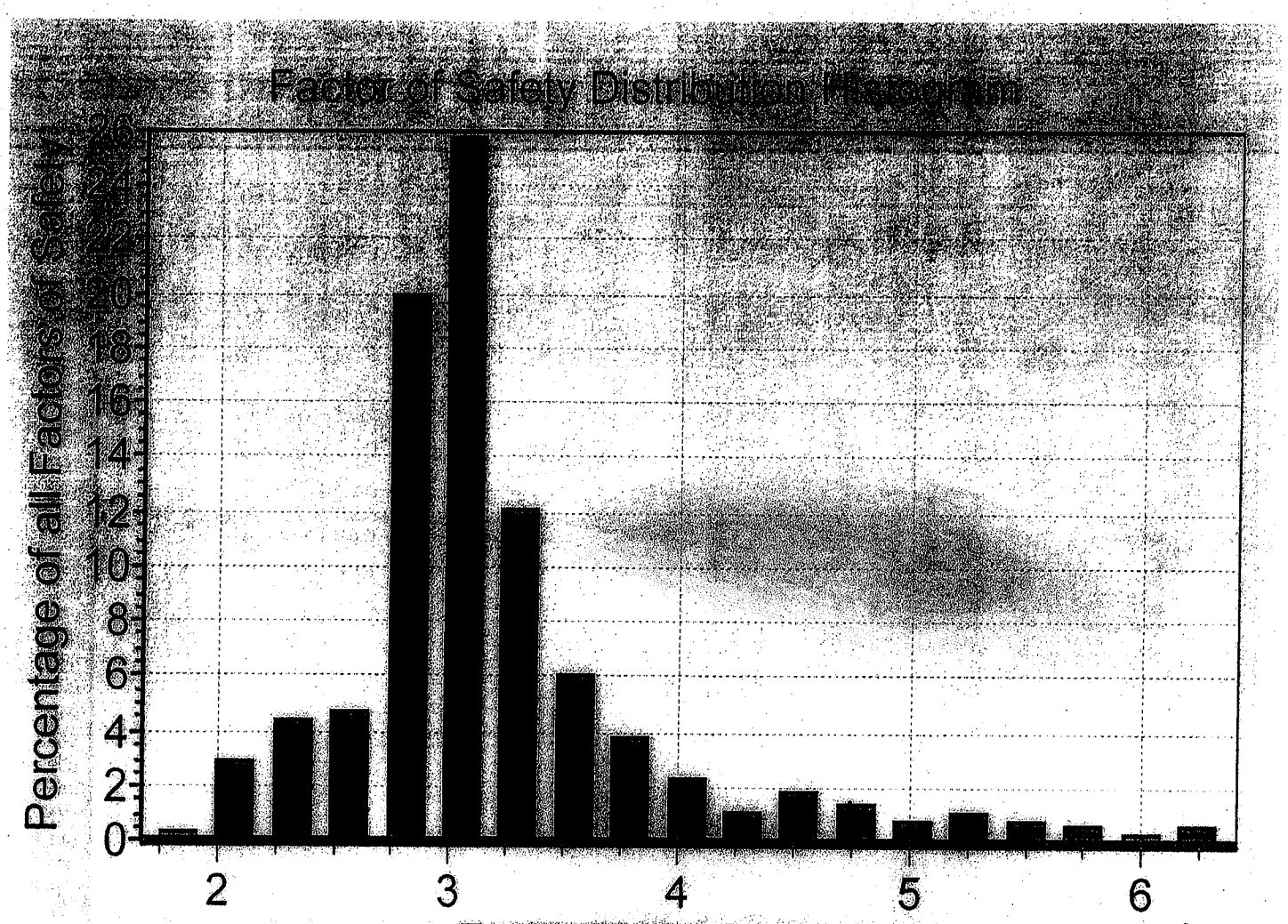
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Sidewall Liner Excavation
Circular Failure Surfaces
(Seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Sidewall Liner Excavation Circular Failu
re Surfaces (Seismic)

BOUNDARY COORDINATES

4 Top Boundaries
7 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	180.00	299.00	180.00	2
2	299.00	180.00	320.00	187.00	3
3	320.00	187.00	500.00	247.00	1
4	500.00	247.00	700.00	247.00	1
5	320.00	187.00	700.00	187.00	3
6	290.00	177.00	299.00	180.00	3
7	0.00	177.00	700.00	177.00	4

1

ISOTROPIC SOIL PARAMETERS

4 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	135.0	140.0	3500.0	0.0	0.00	0.0	1
2	135.0	140.0	3000.0	0.0	0.00	0.0	1
3	100.0	110.0	1400.0	0.0	0.00	0.0	1
4	140.0	148.0	6000.0	0.0	0.00	0.0	0

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	181.00
2	302.00	181.00
3	380.00	207.00
4	700.00	207.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

1200 Trial Surfaces Have Been Generated.

40 Surfaces Initiate From Each Of 30 Points Equally Spaced Along The Ground Surface Between X = 265.00 ft.
and X = 375.00 ft.

Each Surface Terminates Between X = 490.00 ft.
and X = 690.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y = 0.00 ft.

8.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -33.0 And 30.0 deg.

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical

result

First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 36 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43
2	340.88	188.94
3	348.56	186.69
4	356.30	184.68
5	364.10	182.92
6	371.96	181.39
7	379.85	180.11
8	387.79	179.08
9	395.75	178.29
10	403.73	177.76
11	411.73	177.47
12	419.73	177.42
13	427.72	177.63
14	435.71	178.09
15	443.68	178.79
16	451.62	179.74
17	459.53	180.94
18	467.40	182.38
19	475.22	184.06
20	482.99	185.99
21	490.69	188.16
22	498.32	190.57
23	505.87	193.21
24	513.33	196.08
25	520.71	199.19
26	527.98	202.52
27	535.14	206.08
28	542.19	209.86
29	549.12	213.85
30	555.93	218.06
31	562.60	222.48
32	569.13	227.11
33	575.51	231.93
34	581.74	236.95
35	587.81	242.16
36	593.10	247.00

Circle Center At X = 417.1 ; Y = 434.8 and Radius, 257.4

*** 1.898 ***

Individual data on the 40 slices

Water Force	Water Force	Force	Force	Earthquake Force	Surcharge

Slice No.	Width (ft)	Weight (lbs)	Top (lbs)	Bot (lbs)	result Norm (lbs)	Tan (lbs)	Hor (lbs)	Ver (lbs)	Load (lbs)
1	7.6	2667.4	0.0	1190.4	0.0	0.0	266.7	0.0	0.0
2	6.6	6567.7	0.0	2902.9	0.0	0.0	656.8	0.0	0.0
3	1.1	1392.9	0.0	617.8	0.0	0.0	139.3	0.0	0.0
4	7.7	12813.9	0.0	5749.0	0.0	0.0	1281.4	0.0	0.0
5	7.8	17352.8	0.0	7873.0	0.0	0.0	1735.3	0.0	0.0
6	7.9	21748.5	0.0	9890.8	0.0	0.0	2174.9	0.0	0.0
7	7.9	25980.8	0.0	11800.3	0.0	0.0	2598.1	0.0	0.0
8	0.1	515.9	0.0	233.6	0.0	0.0	51.6	0.0	0.0
9	7.8	29519.9	0.0	13433.6	0.0	0.0	2952.0	0.0	0.0
10	8.0	33787.5	0.0	14133.8	0.0	0.0	3378.8	0.0	0.0
11	8.0	37319.7	0.0	14464.4	0.0	0.0	3732.0	0.0	0.0
12	8.0	40618.1	0.0	14671.2	0.0	0.0	4061.8	0.0	0.0
13	8.0	43669.3	0.0	14754.0	0.0	0.0	4366.9	0.0	0.0
14	8.0	46461.1	0.0	14712.8	0.0	0.0	4646.1	0.0	0.0
15	8.0	48983.1	0.0	14547.6	0.0	0.0	4898.3	0.0	0.0
16	8.0	51226.1	0.0	14258.5	0.0	0.0	5122.6	0.0	0.0
17	7.9	53182.5	0.0	13845.8	0.0	0.0	5318.3	0.0	0.0
18	7.9	54846.6	0.0	13309.9	0.0	0.0	5484.7	0.0	0.0
19	7.9	56214.0	0.0	12651.3	0.0	0.0	5621.4	0.0	0.0
20	7.8	57282.5	0.0	11870.7	0.0	0.0	5728.2	0.0	0.0
21	7.8	58051.0	0.0	10968.8	0.0	0.0	5805.1	0.0	0.0
22	3.6	27129.0	0.0	4763.3	0.0	0.0	2712.9	0.0	0.0
23	4.1	31319.2	0.0	5183.2	0.0	0.0	3131.9	0.0	0.0
24	7.6	58151.2	0.0	8804.8	0.0	0.0	5815.1	0.0	0.0
25	1.7	12835.1	0.0	1796.9	0.0	0.0	1283.5	0.0	0.0
26	5.9	43854.6	0.0	5747.9	0.0	0.0	4385.5	0.0	0.0
27	7.5	53226.2	0.0	6167.6	0.0	0.0	5322.6	0.0	0.0
28	7.4	49476.8	0.0	4674.7	0.0	0.0	4947.7	0.0	0.0
29	7.3	45527.0	0.0	3067.4	0.0	0.0	4552.7	0.0	0.0
30	7.2	41400.4	0.0	1347.3	0.0	0.0	4140.0	0.0	0.0
31	1.7	9382.6	0.0	55.9	0.0	0.0	938.3	0.0	0.0
32	5.3	27776.2	0.0	0.0	0.0	0.0	2777.6	0.0	0.0
33	6.9	32881.1	0.0	0.0	0.0	0.0	3288.1	0.0	0.0
34	6.8	28508.6	0.0	0.0	0.0	0.0	2850.9	0.0	0.0
35	6.7	24062.7	0.0	0.0	0.0	0.0	2406.3	0.0	0.0
36	6.5	19571.3	0.0	0.0	0.0	0.0	1957.1	0.0	0.0
37	6.4	15061.4	0.0	0.0	0.0	0.0	1506.1	0.0	0.0
38	6.2	10561.3	0.0	0.0	0.0	0.0	1056.1	0.0	0.0
39	6.1	6099.8	0.0	0.0	0.0	0.0	610.0	0.0	0.0
40	5.3	1728.8	0.0	0.0	0.0	0.0	172.9	0.0	0.0

Failure Surface Specified By 33 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	329.48	190.16
2	337.05	187.57
3	344.71	185.27
4	352.46	183.26
5	360.27	181.55
6	368.15	180.14
7	376.07	179.02
8	384.03	178.21
9	392.01	177.71
10	400.01	177.50
11	408.01	177.60
12	416.00	178.01
13	423.97	178.72
14	431.90	179.73

		result
15	439.79	181.04
16	447.63	182.65
17	455.40	184.56
18	463.09	186.76
19	470.69	189.25
20	478.19	192.03
21	485.59	195.09
22	492.85	198.43
23	499.99	202.05
24	506.98	205.93
25	513.83	210.08
26	520.50	214.48
27	527.01	219.14
28	533.33	224.04
29	539.47	229.17
30	545.40	234.54
31	551.13	240.13
32	556.64	245.93
33	557.58	247.00

Circle Center At X = 401.4 ; Y = 387.9 and Radius, 210.4

*** 1.917 ***

1

Failure Surface Specified By 33 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43
2	340.79	188.67
3	348.40	186.21
4	356.10	184.04
5	363.88	182.18
6	371.73	180.63
7	379.63	179.38
8	387.58	178.45
9	395.55	177.82
10	403.55	177.51
11	411.55	177.51
12	419.54	177.83
13	427.51	178.45
14	435.46	179.39
15	443.36	180.64
16	451.21	182.19
17	458.99	184.05
18	466.69	186.22
19	474.30	188.68
20	481.81	191.44
21	489.21	194.49
22	496.48	197.83
23	503.61	201.45
24	510.60	205.35
25	517.43	209.51
26	524.09	213.94
27	530.57	218.63
28	536.87	223.57

result

29	542.96	228.75
30	548.85	234.16
31	554.53	239.80
32	559.98	245.66
33	561.13	247.00

Circle Center At X = 407.5 ; Y = 382.0 and Radius, 204.5

*** 1.918 ***

Failure Surface Specified By 34 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	337.07	192.69
2	344.59	189.95
3	352.20	187.49
4	359.90	185.31
5	367.67	183.42
6	375.51	181.81
7	383.40	180.49
8	391.33	179.47
9	399.30	178.73
10	407.28	178.29
11	415.28	178.14
12	423.28	178.29
13	431.27	178.73
14	439.24	179.46
15	447.17	180.49
16	455.06	181.81
17	462.90	183.41
18	470.67	185.31
19	478.37	187.48
20	485.98	189.94
21	493.50	192.68
22	500.91	195.69
23	508.20	198.98
24	515.37	202.53
25	522.41	206.34
26	529.30	210.40
27	536.03	214.72
28	542.61	219.28
29	549.01	224.08
30	555.23	229.11
31	561.26	234.37
32	567.09	239.84
33	572.72	245.53
34	574.07	247.00

Circle Center At X = 415.3 ; Y = 395.6 and Radius, 217.5

*** 1.954 ***

1

result

Failure Surface Specified By 37 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	329.48	190.16
2	337.19	188.00
3	344.95	186.07
4	352.76	184.35
5	360.62	182.86
6	368.52	181.60
7	376.45	180.56
8	384.41	179.74
9	392.39	179.16
10	400.38	178.80
11	408.38	178.67
12	416.38	178.77
13	424.37	179.09
14	432.36	179.65
15	440.32	180.43
16	448.25	181.44
17	456.16	182.68
18	464.02	184.14
19	471.84	185.82
20	479.61	187.73
21	487.33	189.85
22	494.97	192.20
23	502.55	194.76
24	510.05	197.54
25	517.47	200.54
26	524.80	203.74
27	532.04	207.15
28	539.18	210.76
29	546.21	214.58
30	553.13	218.60
31	559.93	222.81
32	566.61	227.21
33	573.15	231.81
34	579.57	236.59
35	585.85	241.55
36	591.98	246.68
37	592.34	247.00

Circle Center At X = 408.9 ; Y = 459.0 and Radius, 280.3

*** 1.966 ***

Failure Surface Specified By 38 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	325.69	188.90
2	333.46	187.00
3	341.28	185.30
4	349.14	183.80

		result
5	357.03	182.50
6	364.96	181.40
7	372.91	180.51
8	380.88	179.82
9	388.86	179.33
10	396.86	179.04
11	404.85	178.96
12	412.85	179.08
13	420.85	179.40
14	428.83	179.93
15	436.80	180.67
16	444.74	181.60
17	452.66	182.74
18	460.55	184.07
19	468.40	185.61
20	476.21	187.35
21	483.97	189.29
22	491.68	191.42
23	499.33	193.75
24	506.92	196.27
25	514.45	198.99
26	521.90	201.89
27	529.28	204.99
28	536.58	208.27
29	543.79	211.74
30	550.90	215.39
31	557.93	219.22
32	564.85	223.22
33	571.67	227.41
34	578.38	231.76
35	584.98	236.28
36	591.46	240.97
37	597.82	245.83
38	599.28	247.00

Circle Center At X = 404.1 ; Y = 493.0 and Radius, 314.0

*** 1.982 ***

1

Failure Surface Specified By 36 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	340.86	193.95
2	348.39	191.25
3	356.00	188.79
4	363.70	186.59
5	371.46	184.65
6	379.28	182.97
7	387.15	181.55
8	395.07	180.39
9	403.02	179.50
10	410.99	178.88
11	418.98	178.52
12	426.98	178.42
13	434.98	178.60

		result
14	442.97	179.04
15	450.94	179.75
16	458.88	180.72
17	466.78	181.95
18	474.64	183.45
19	482.45	185.22
20	490.19	187.24
21	497.86	189.51
22	505.44	192.04
23	512.94	194.83
24	520.35	197.86
25	527.65	201.14
26	534.83	204.66
27	541.89	208.41
28	548.83	212.40
29	555.62	216.62
30	562.28	221.07
31	568.78	225.73
32	575.12	230.61
33	581.29	235.69
34	587.30	240.98
35	593.12	246.47
36	593.65	247.00

Circle Center At X = 425.8 ; Y = 418.2 and Radius, 239.8

*** 1.984 ***

Failure Surface Specified By 39 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	314.31	185.10
2	322.18	183.67
3	330.08	182.40
4	338.00	181.31
5	345.95	180.38
6	353.92	179.63
7	361.89	179.04
8	369.88	178.63
9	377.88	178.38
10	385.88	178.31
11	393.88	178.41
12	401.87	178.68
13	409.86	179.12
14	417.84	179.74
15	425.80	180.52
16	433.74	181.47
17	441.66	182.60
18	449.56	183.89
19	457.42	185.35
20	465.26	186.98
21	473.05	188.78
22	480.81	190.74
23	488.52	192.87
24	496.18	195.16
25	503.80	197.62

result

26	511.36	200.24
27	518.86	203.02
28	526.30	205.96
29	533.67	209.06
30	540.98	212.31
31	548.22	215.72
32	555.38	219.29
33	562.46	223.01
34	569.46	226.88
35	576.38	230.89
36	583.21	235.06
37	589.95	239.37
38	596.60	243.82
39	601.12	247.00

Circle Center At X = 385.2 ; Y = 552.0 and Radius, 373.7

*** 1.989 ***

1

Failure Surface Specified By 33 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	337.07	192.69
2	344.59	189.96
3	352.21	187.53
4	359.92	185.39
5	367.70	183.54
6	375.55	181.99
7	383.45	180.74
8	391.40	179.80
9	399.37	179.15
10	407.36	178.82
11	415.36	178.79
12	423.36	179.06
13	431.34	179.64
14	439.29	180.52
15	447.20	181.71
16	455.06	183.20
17	462.86	184.99
18	470.58	187.07
19	478.22	189.45
20	485.76	192.11
21	493.20	195.07
22	500.52	198.30
23	507.70	201.81
24	514.75	205.60
25	521.65	209.65
26	528.39	213.96
27	534.96	218.52
28	541.35	223.33
29	547.55	228.39
30	553.56	233.67
31	559.36	239.18
32	564.94	244.91
33	566.83	247.00

result

Circle Center At X = 412.2 ; Y = 388.2 and Radius, 209.5

*** 1.997 ***

Failure Surface Specified By 46 Coordinate Points

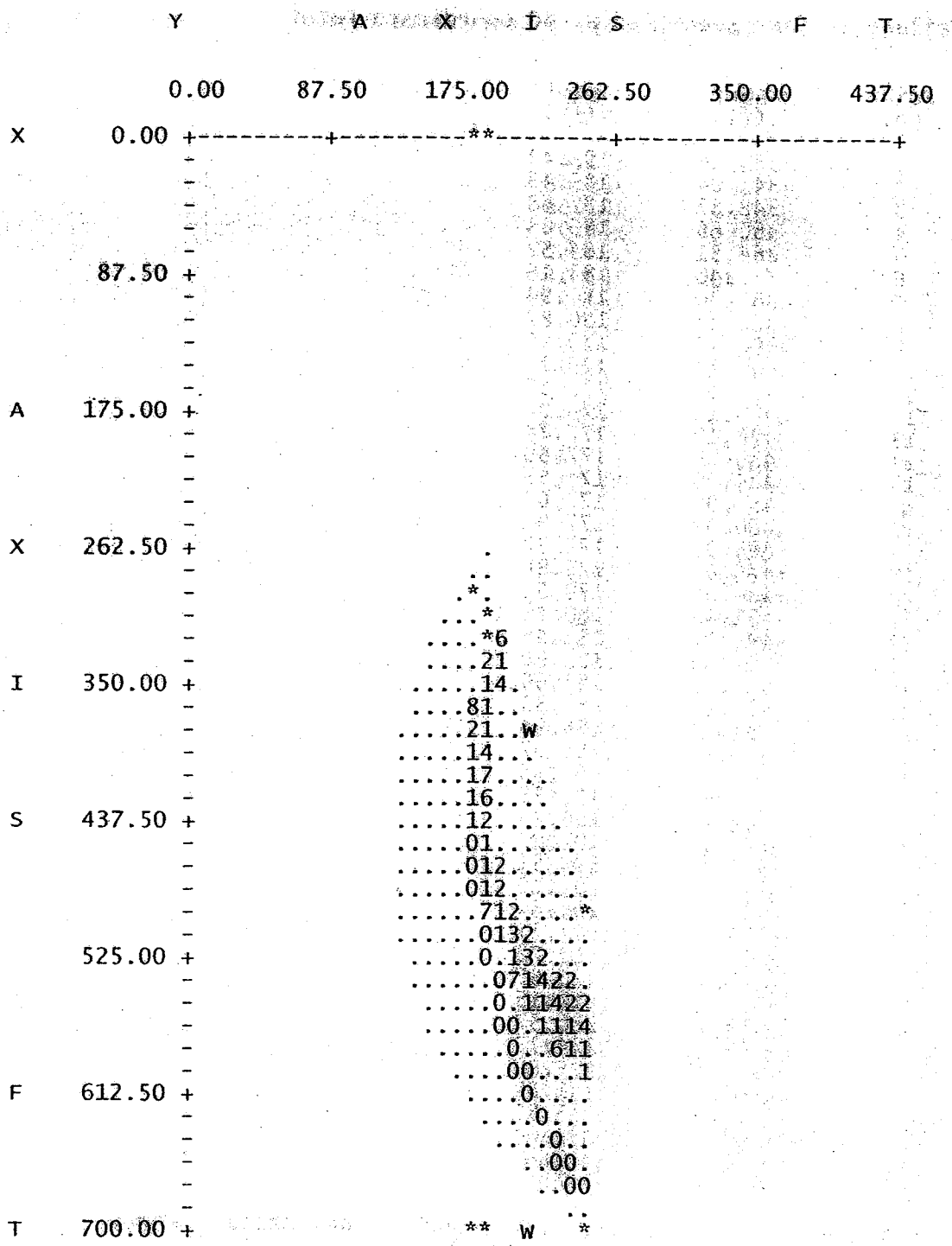
Point No.	X-Surf (ft)	Y-Surf (ft)
1	333.28	191.43
2	341.04	189.48
3	348.83	187.68
4	356.66	186.03
5	364.51	184.52
6	372.40	183.16
7	380.30	181.94
8	388.23	180.87
9	396.18	179.95
10	404.14	179.17
11	412.12	178.55
12	420.10	178.07
13	428.10	177.74
14	436.09	177.56
15	444.09	177.53
16	452.09	177.64
17	460.09	177.91
18	468.08	178.32
19	476.06	178.88
20	484.03	179.59
21	491.98	180.45
22	499.92	181.45
23	507.83	182.60
24	515.73	183.90
25	523.60	185.35
26	531.44	186.94
27	539.25	188.67
28	547.02	190.55
29	554.76	192.58
30	562.46	194.75
31	570.12	197.06
32	577.74	199.51
33	585.31	202.10
34	592.82	204.84
35	600.29	207.71
36	607.70	210.72
37	615.06	213.87
38	622.35	217.15
39	629.58	220.57
40	636.75	224.12
41	643.85	227.80
42	650.89	231.62
43	657.84	235.57
44	664.73	239.64
45	671.54	243.84
46	676.45	247.00

Circle Center At X = 441.8 ; Y = 608.3 and Radius, 430.8

result

*** 1.999 ***

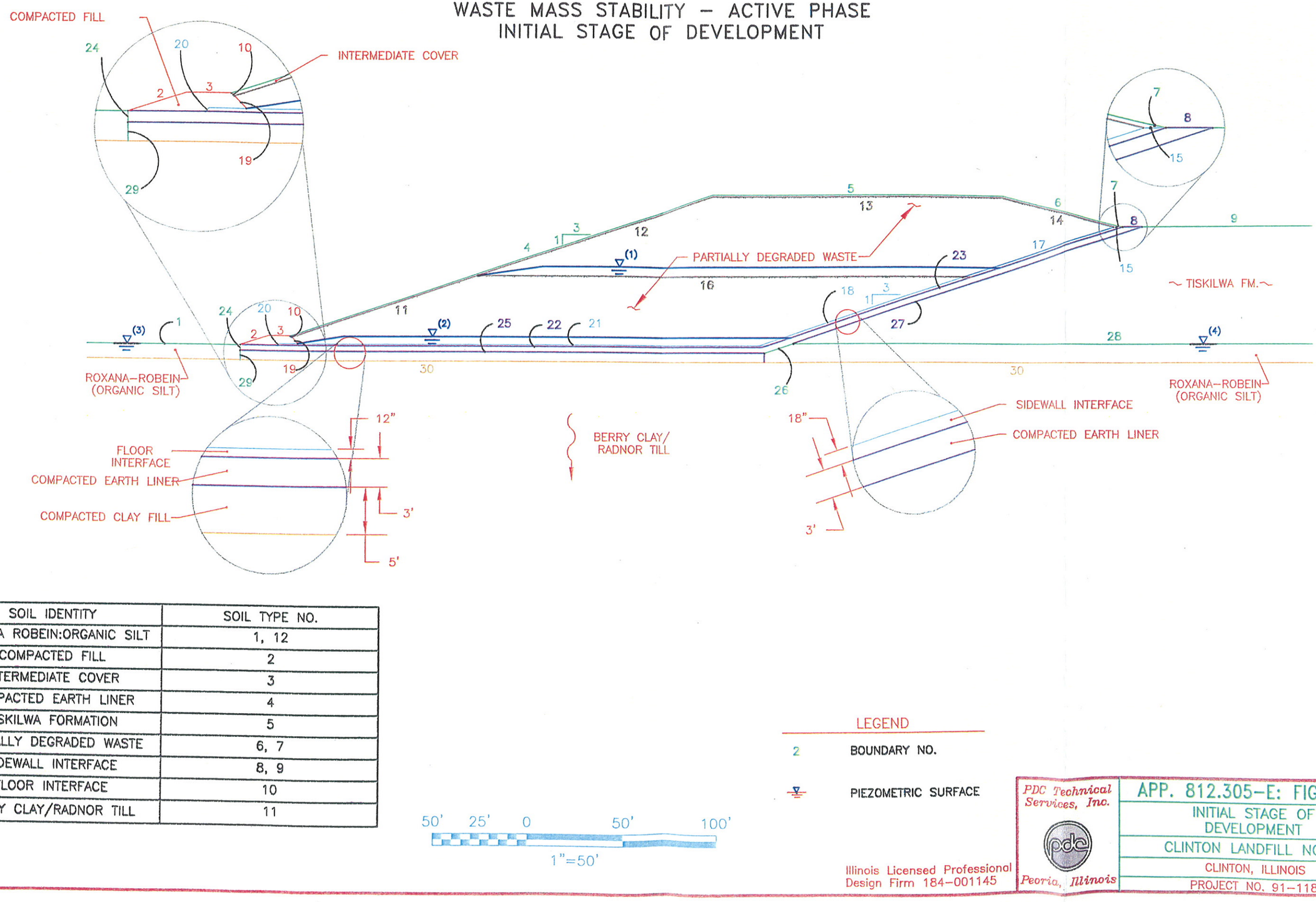
1



SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

WASTE MASS STABILITY – ACTIVE PHASE
INITIAL STAGE OF DEVELOPMENT



SOIL IDENTITY	SOIL TYPE NO.
ROXANA ROBEIN:ORGANIC SILT	1, 12
COMPACTED FILL	2
INTERMEDIATE COVER	3
COMPACTED EARTH LINER	4
TISKILWA FORMATION	5
PARTIALLY DEGRADED WASTE	6, 7
SIDEWALL INTERFACE	8, 9
FLOOR INTERFACE	10
BERRY CLAY/RADNOR TILL	11

50' 25' 0 50' 100'

1"=50'

LEGEND

2 BOUNDARY NO.

PIEZOMETRIC SURFACE

Illinois Licensed Professional Design Firm 184-001145

PDC Technical Services, Inc.
Peoria, Illinois

APP. 812.305-E: FIGURE B
INITIAL STAGE OF DEVELOPMENT
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118

SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

Circular Failure Surfaces
Static Conditions

Key Assumptions:

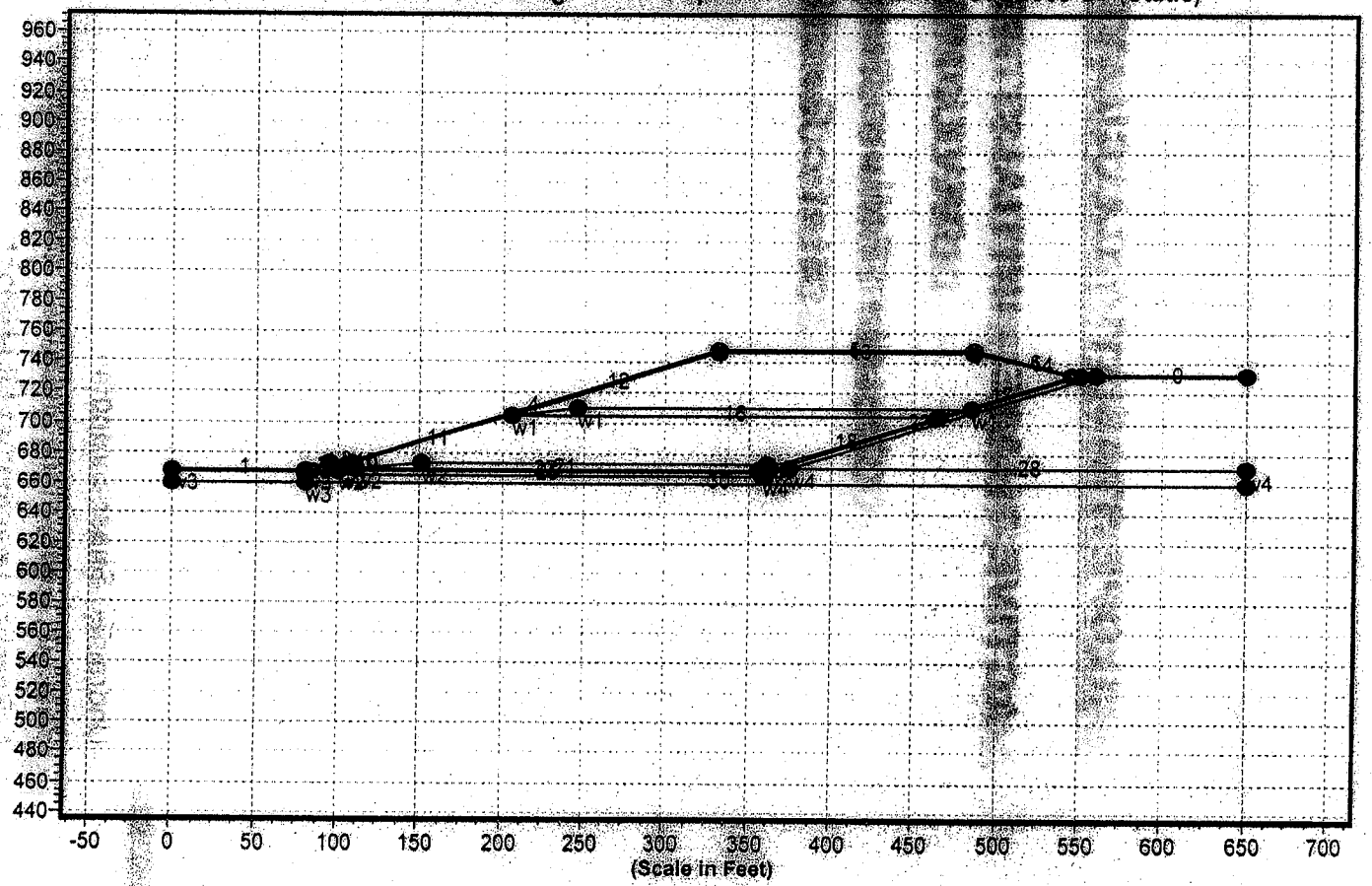
Undrained Shear Strengths

Residual Geosynthetic Interface Shear Strengths

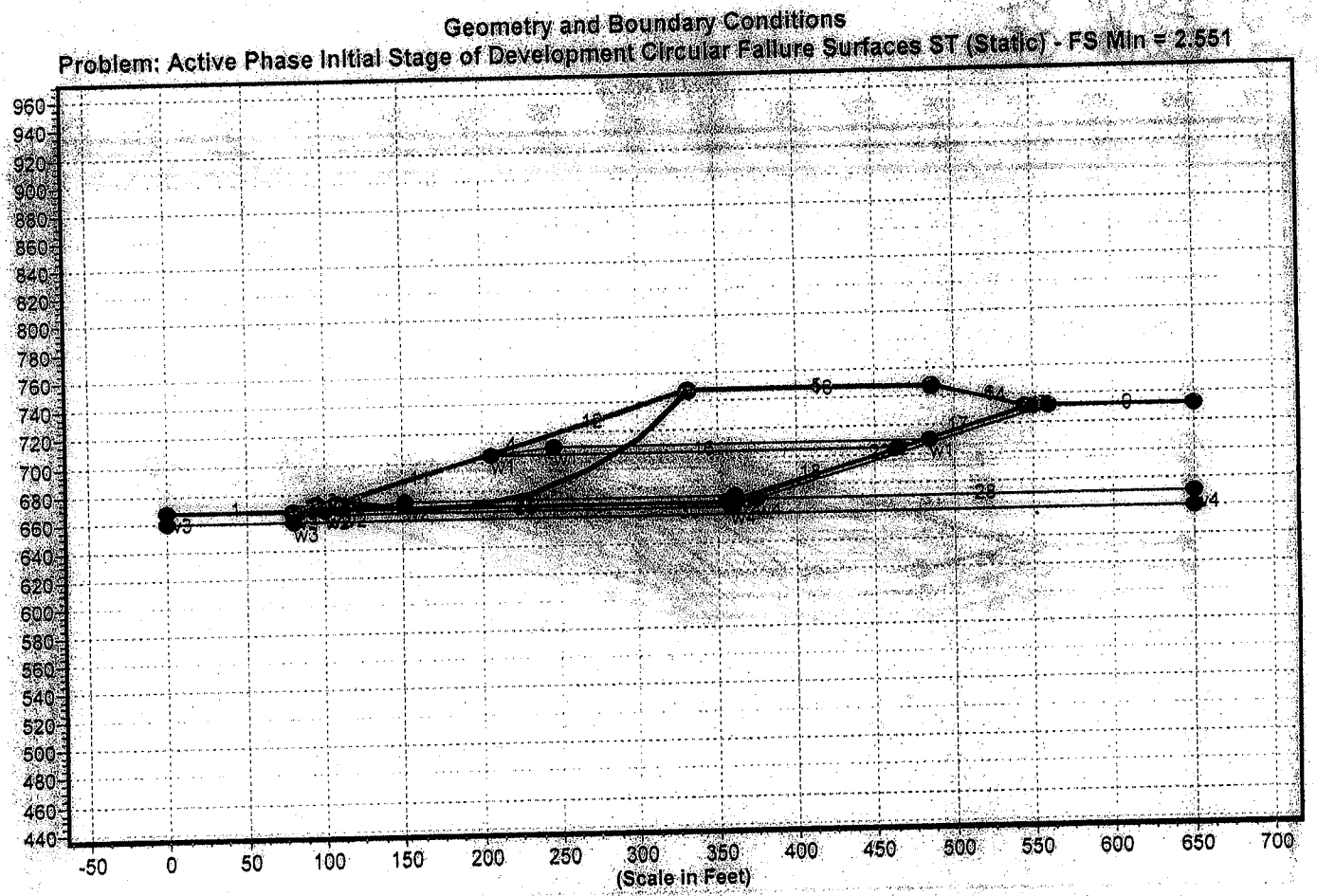
5' Perched Leachate at Mid-Height

5' Leachate on Landfill Floor

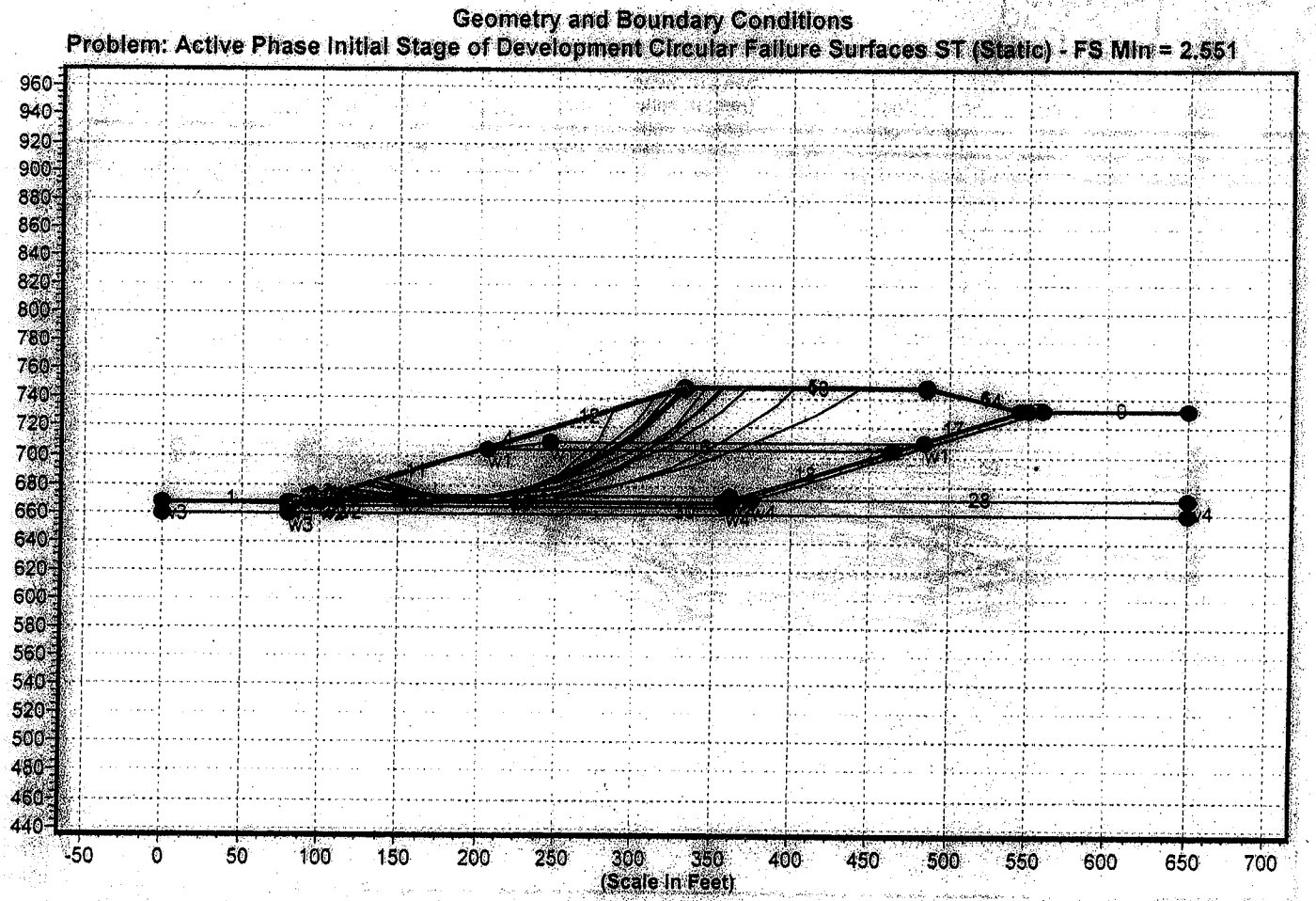
3:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Circular Failure Surfaces ST (Static)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale in Feet)

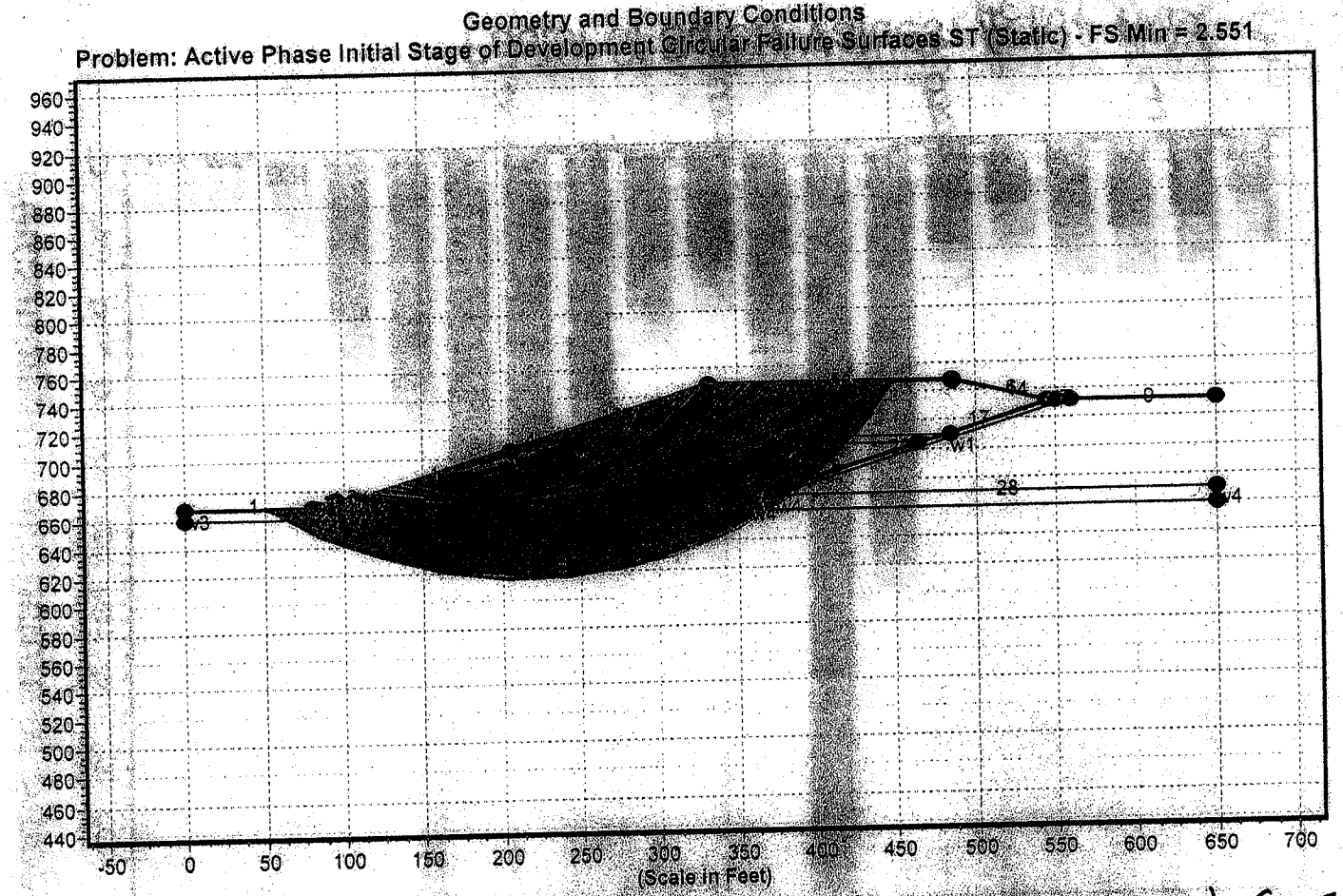
Profile



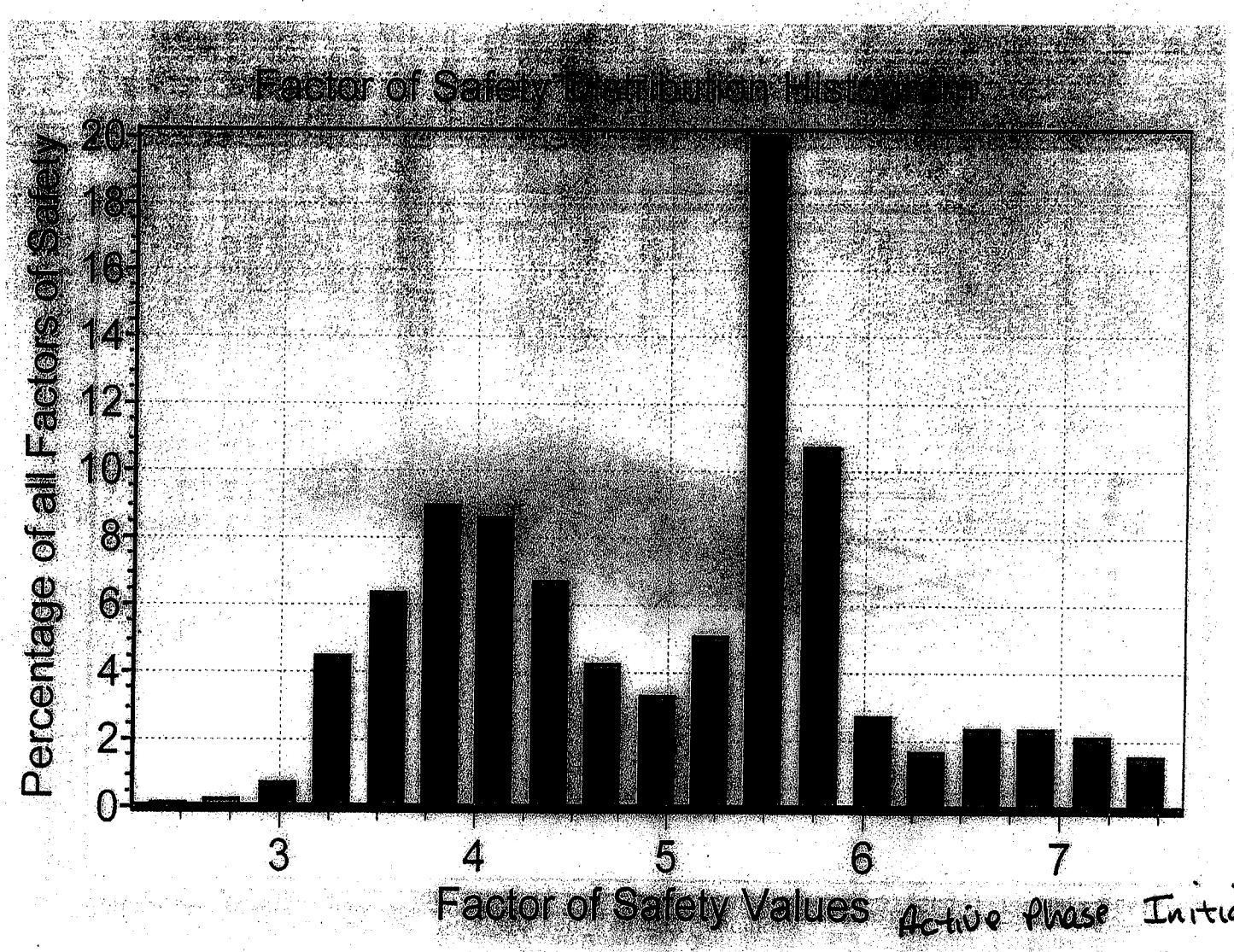
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase Initial Stage of Development Circular Failure Surfaces Short Term (Static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Developmen
t Circular Failure Surfaces ST (Static)

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	107.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	10.0	0.00	0.0	1
9	128.0	134.0	0.0	10.0	0.00	0.0	2
10	135.0	140.0	0.0	10.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

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4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

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Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

1000 Trial Surfaces Have Been Generated.

40 Surfaces Initiate From Each Of 25 Points Equally Spaced Along The Ground Surface Between X = 50.00 ft.
and X = 175.00 ft.

Each Surface Terminates Between X = 250.00 ft.
and X = 450.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =400.00 ft.

40.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles of -33.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	112.50	674.80
2	151.91	667.97
3	191.90	668.82
4	230.98	677.34
5	267.70	693.21
6	300.69	715.84
7	328.72	744.38
8	330.83	747.58

Circle Center At X = 167.5 ; Y = 873.7 and Radius, 206.3

*** 2.551 ***

Individual data on the 20 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	2.0	125.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	18.7	9069.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	12.7	13801.0	0.0	1399.7	0.0	0.0	0.0	0.0	0.0
4	5.1	7468.4	0.0	1357.6	0.0	0.0	0.0	0.0	0.0
5	0.6	989.2	0.0	194.4	0.0	0.0	0.0	0.0	0.0
6	0.2	324.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1.6	2665.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	38.4	79719.8	0.0	10986.9	0.0	0.0	0.0	0.0	0.0
9	0.8	2029.4	0.0	212.1	0.0	0.0	0.0	0.0	0.0
10	13.5	34607.4	0.0	2182.8	0.0	0.0	0.0	0.0	0.0
11	4.8	12641.6	0.0	160.3	0.0	0.0	0.0	0.0	0.0
12	19.9	54623.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	15.3	42327.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	21.4	56493.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	17.2	40004.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	7.3	14612.3	0.0	1379.0	0.0	0.0	0.0	0.0	0.0
17	8.5	15286.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	28.0	26994.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1.2	230.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.9	60.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	117.71	676.54
2	156.88	668.43
3	196.87	669.04

		result
4	235.77	678.36
5	271.71	695.93
6	302.95	720.91
7	322.01	744.64

Circle Center At X = 174.1 ; Y = 850.1 and Radius, 182.5

*** 2.603 ***

1

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	117.71	676.54
2	156.86	668.35
3	196.85	669.35
4	235.54	679.51
5	270.87	698.26
6	300.95	724.63
7	313.11	741.67

Circle Center At X = 172.5 ; Y = 840.8 and Radius, 173.2

*** 2.767 ***

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	138.54	683.48
2	176.44	670.69
3	216.34	667.79
4	255.69	674.96
5	291.99	691.75
6	322.95	717.09
7	345.57	748.00

Circle Center At X = 207.8 ; Y = 826.2 and Radius, 158.6

*** 2.941 ***

1

Failure Surface Specified By 6 Coordinate Points

Point	X-Surf	Y-Surf

No.	(ft)	result (ft)
1	133.33	681.75
2	170.86	667.89
3	210.85	668.64
4	247.83	683.90
5	276.72	711.56
6	286.59	732.83

Circle Center At X = 188.4 ; Y = 771.9 and Radius, 105.6

*** 2.941 ***

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	117.71	676.54
2	157.33	671.07
3	197.33	671.72
4	236.75	678.47
5	274.68	691.18
6	310.22	709.53
7	342.54	733.11
8	357.48	748.00

Circle Center At X = 173.2 ; Y = 928.5 and Radius, 258.0

*** 3.016 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.13	680.01
2	167.09	670.97
3	206.96	667.74
4	246.87	670.40
5	285.96	678.89
6	323.38	693.01
7	358.33	712.48
8	390.03	736.87
9	400.79	748.00

Circle Center At X = 208.9 ; Y = 939.6 and Radius, 271.9

*** 3.023 ***

result

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.29	673.07
2	147.07	668.88
3	187.06	667.98
4	226.99	670.37
5	266.59	676.04
6	305.58	684.95
7	343.71	697.03
8	380.72	712.22
9	416.35	730.39
10	444.80	748.00

Circle Center At X = 178.0 ; Y = 1152.0 and Radius, 484.2

*** 3.088 ***

1

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	133.33	681.75
2	172.19	672.26
3	212.17	670.89
4	251.58	677.71
5	288.78	692.42
6	322.19	714.41
7	350.42	742.75
8	353.85	748.00

Circle Center At X = 198.8 ; Y = 864.1 and Radius, 193.7

*** 3.096 ***

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.13	680.01
2	167.56	673.32
3	207.56	672.80
4	247.15	678.48
5	285.39	690.22
6	321.36	707.72

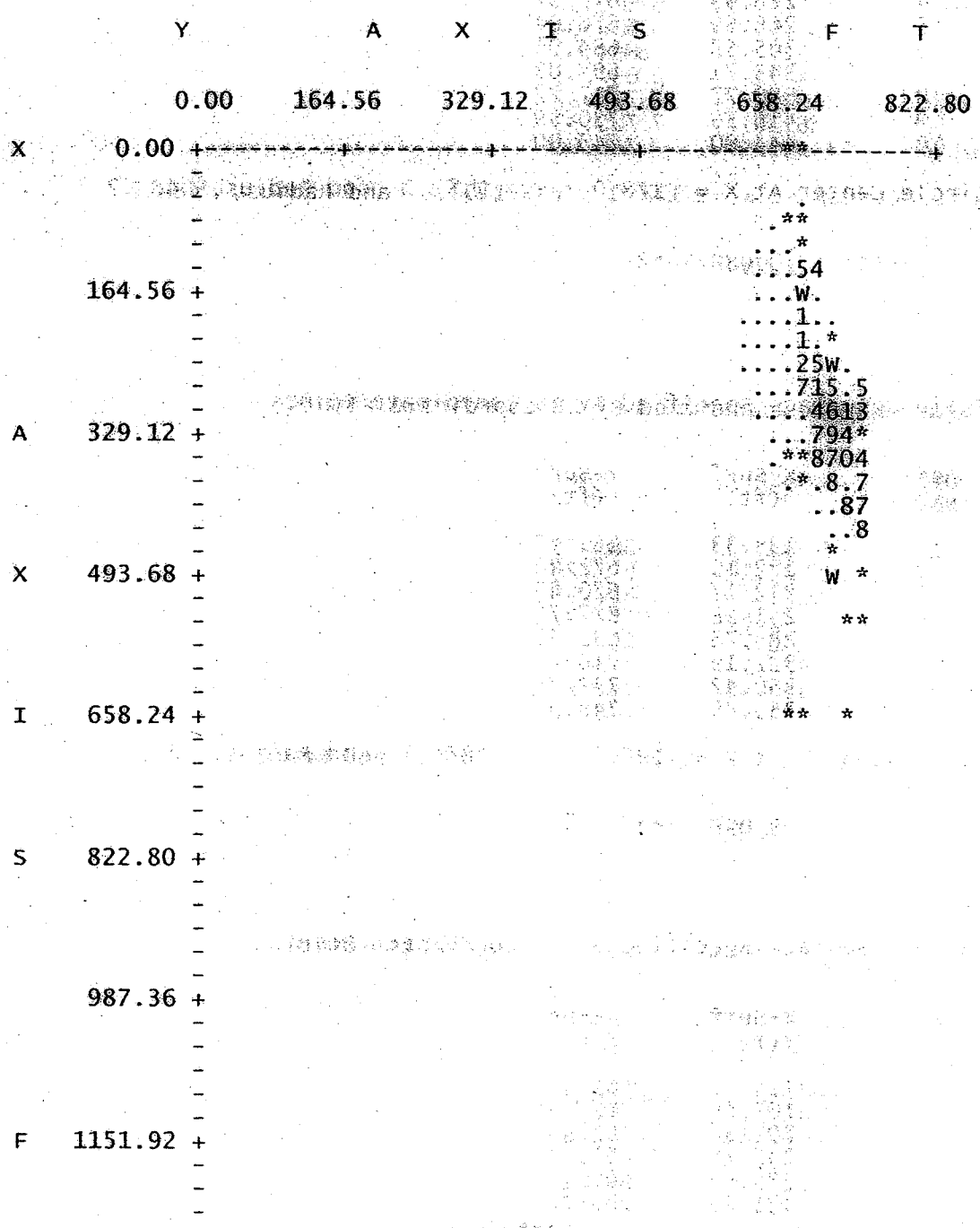
result

7	354.18	730.59
8	372.37	748.00

Circle Center At X = 190.8 ; Y = 927.5 and Radius, 255.3

*** 3.125 ***

1



result

T 1316.48 +

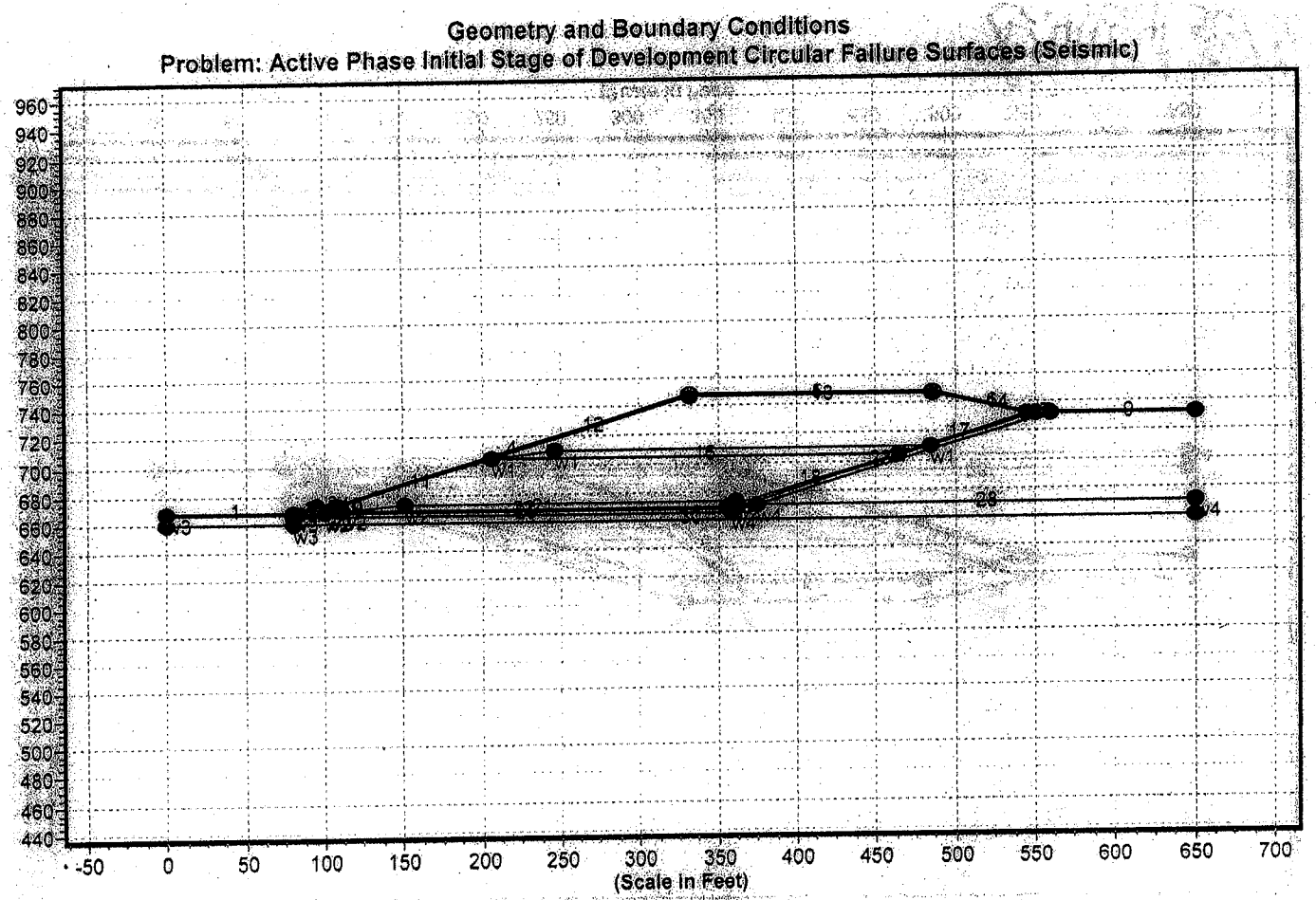
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

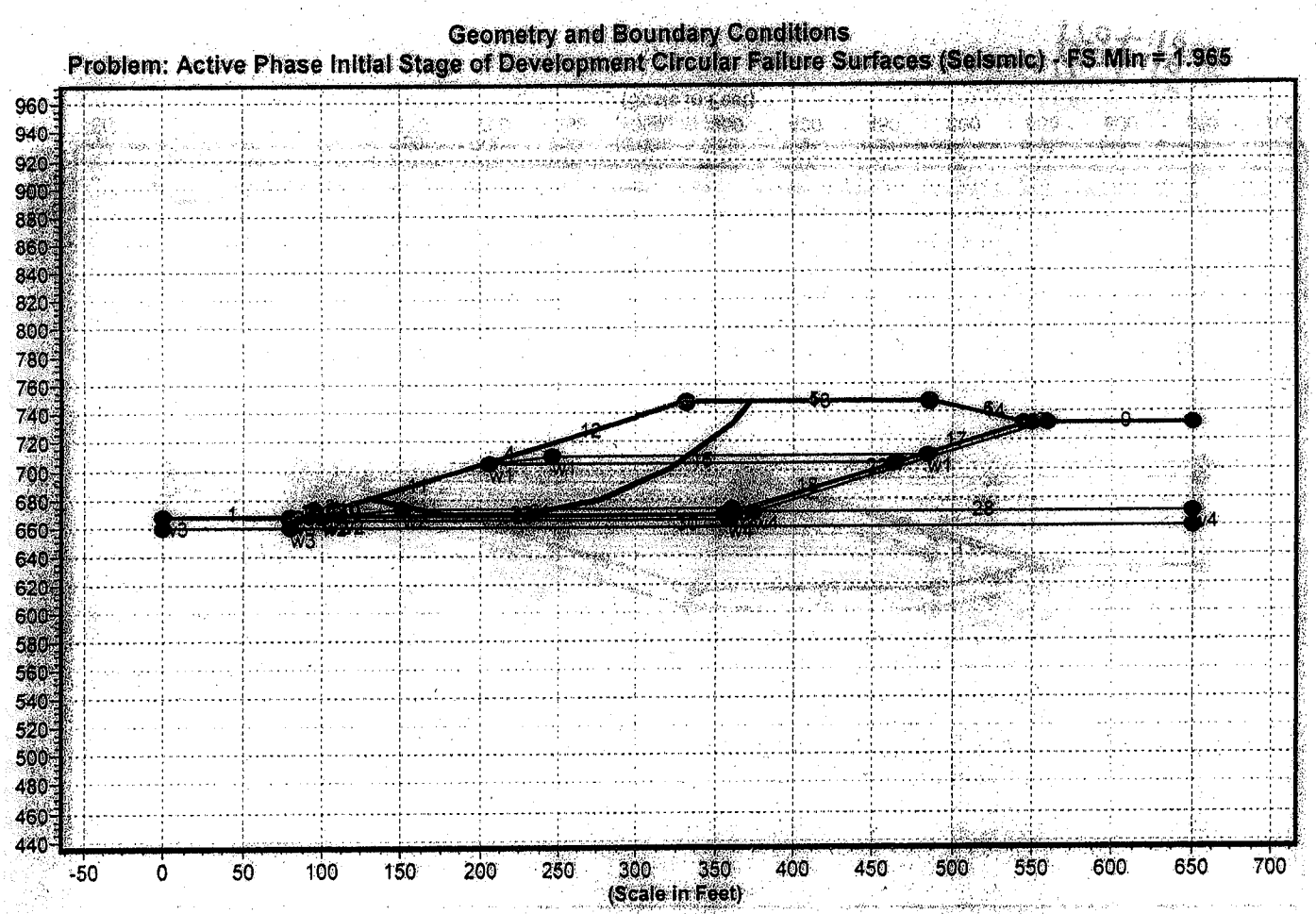
Circular Failure Surfaces
Seismic Conditions

Key Assumptions:

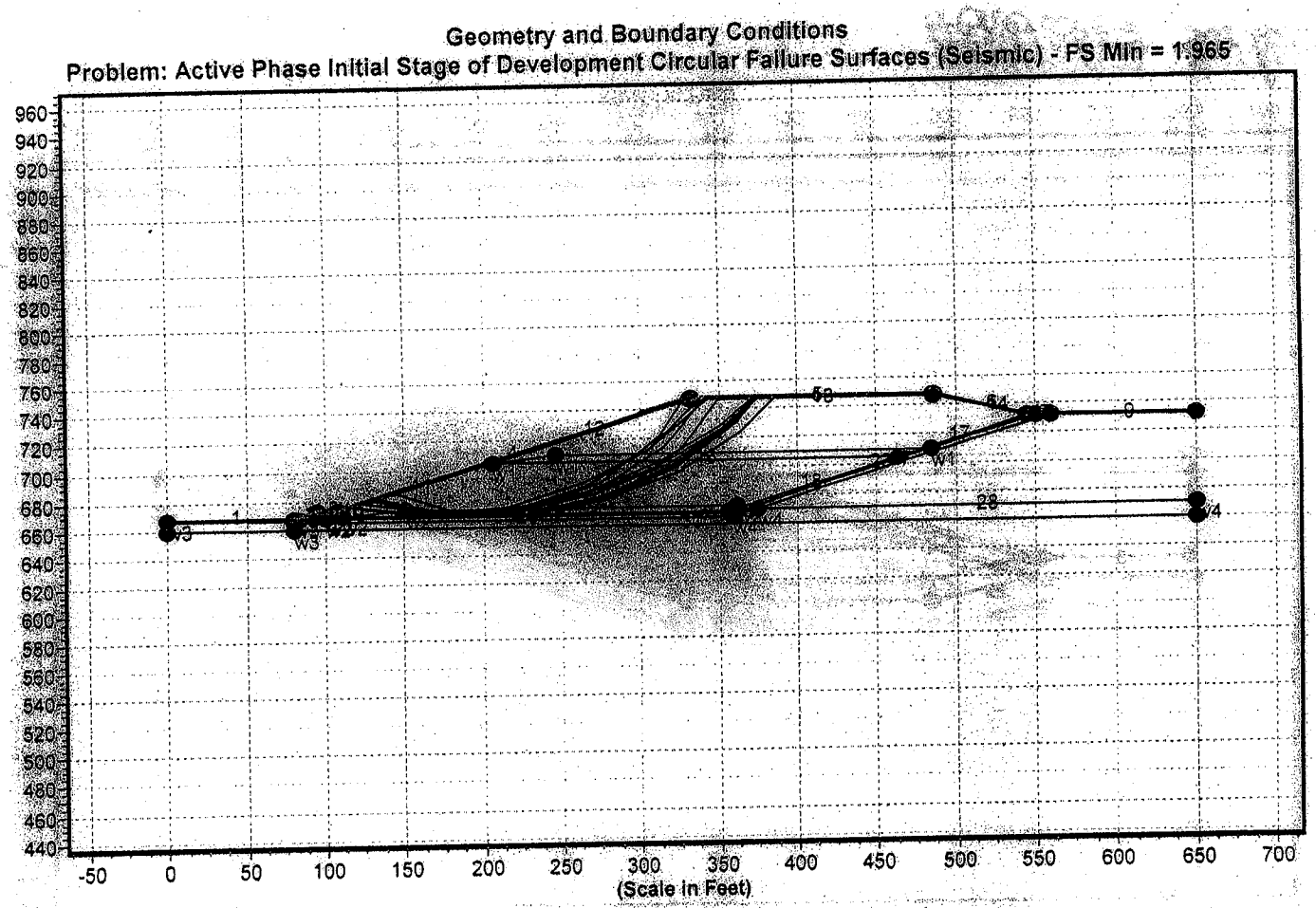
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
3:1 (Horizontal to Vertical) Waste Slope
0.1 g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Circular Failure Surfaces (Seismic)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale In Feet)
W1
W2
W3
13
14
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24

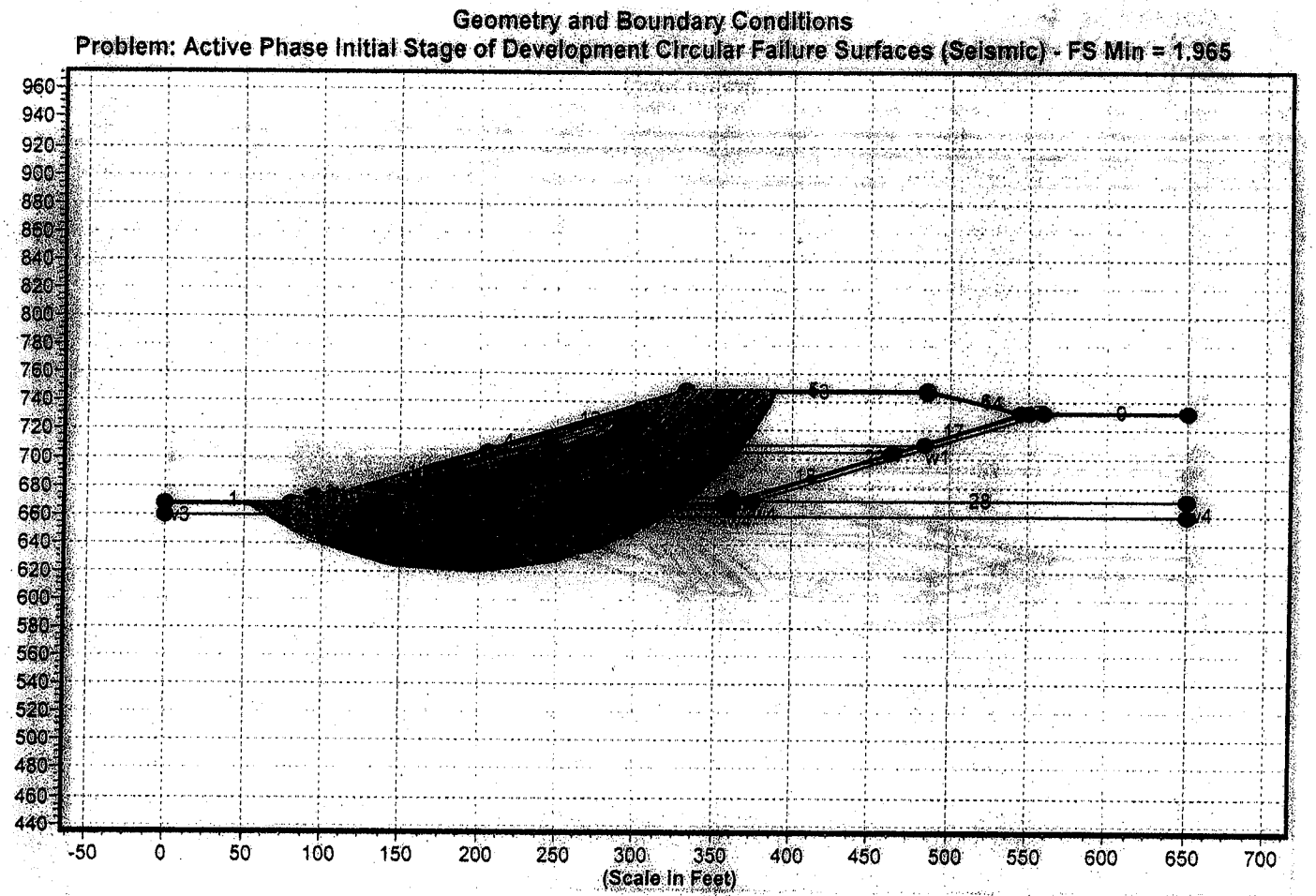
Profile



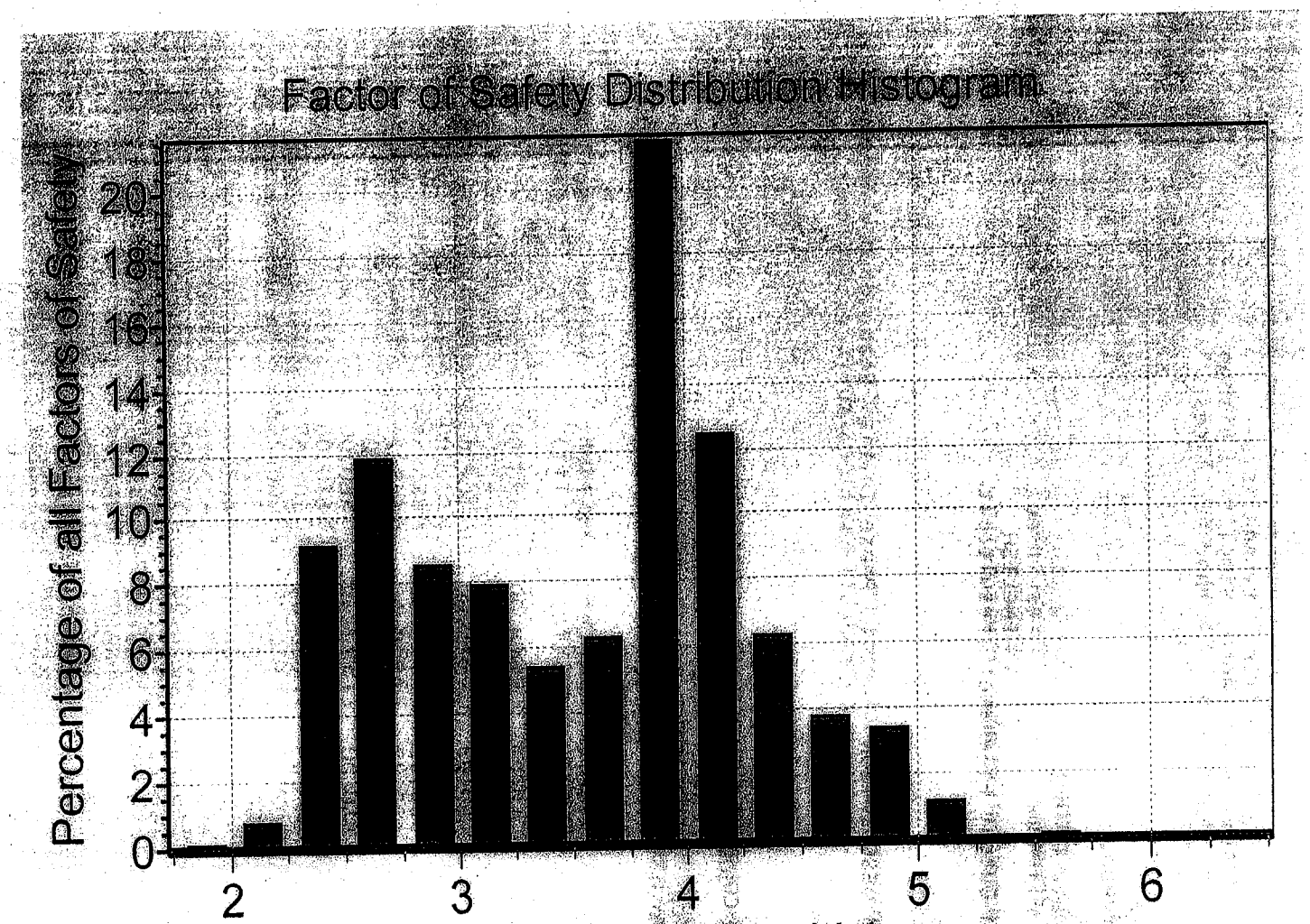
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active phase Initial Stage of
Development Circular Failure
Surfaces (Seismic)

result
** PCSTABL6 **

by
Purdue University

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--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Developmen
t Circular Failure Surfaces (Seismic)

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	107.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	15.0	0.00	0.0	1
9	128.0	134.0	0.0	15.0	0.00	0.0	2
10	135.0	140.0	0.0	16.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

800 Trial Surfaces Have Been Generated.

40 Surfaces Initiate From Each Of 20 Points Equally Spaced
Along The Ground Surface Between X = 50.00 ft.
and X = 175.00 ft.

Each Surface Terminates Between X = 300.00 ft.
and X = 390.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y =400.00 ft.

50.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -33.0
And 30.0 deg.

result

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.95	680.29
2	177.65	668.95
3	227.64	668.71
4	276.45	679.60
5	321.61	701.06
6	360.87	732.02
7	373.76	748.00

Circle Center At X = 203.7 ; Y = 891.0 and Radius, 223.6

*** 1.965 ***

Individual data on the 18 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	1.8	114.9	0.0	0.0	0.0	0.0	11.5	0.0	0.0
2	29.5	22311.9	0.0	0.0	0.0	0.0	2231.2	0.0	0.0
3	17.2	30030.3	0.0	2201.2	0.0	0.0	3003.0	0.0	0.0
4	0.2	485.1	0.0	59.0	0.0	0.0	48.5	0.0	0.0
5	28.6	71361.4	0.0	7356.3	0.0	0.0	7136.1	0.0	0.0
6	21.4	67053.7	0.0	5652.6	0.0	0.0	6705.4	0.0	0.0
7	1.3	4363.2	0.0	339.3	0.0	0.0	436.3	0.0	0.0
8	17.3	60212.2	0.0	2290.4	0.0	0.0	6021.2	0.0	0.0
9	0.6	2119.4	0.0	2.5	0.0	0.0	211.9	0.0	0.0
10	29.6	108662.2	0.0	0.0	0.0	0.0	10866.2	0.0	0.0
11	45.2	160530.2	0.0	0.0	0.0	0.0	16053.0	0.0	0.0
12	5.0	16135.2	0.0	0.0	0.0	0.0	1613.5	0.0	0.0
13	5.5	16737.3	0.0	1236.9	0.0	0.0	1673.7	0.0	0.0
14	0.2	501.5	0.0	8.2	0.0	0.0	50.2	0.0	0.0
15	0.7	1997.5	0.0	14.6	0.0	0.0	199.7	0.0	0.0
16	27.9	58005.7	0.0	0.0	0.0	0.0	5800.6	0.0	0.0
17	12.1	8337.7	0.0	0.0	0.0	0.0	833.8	0.0	0.0
18	0.8	51.6	0.0	0.0	0.0	0.0	5.2	0.0	0.0

Failure Surface Specified By 6 Coordinate Points

result

Point No.	X-Surf (ft)	Y-Surf (ft)
1	142.11	684.67
2	189.36	668.33
3	239.36	667.93
4	286.87	683.50
5	326.93	713.43
6	350.81	748.00

Circle Center At X = 215.3 ; Y = 819.0 and Radius, 153.0

*** 2.089 ***

1

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.95	680.29
2	177.74	669.38
3	227.74	668.57
4	276.86	677.91
5	323.07	696.99
6	364.47	725.04
7	386.80	748.00

Circle Center At X = 206.7 ; Y = 913.4 and Radius, 245.7

*** 2.132 ***

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.95	680.29
2	177.32	667.63
3	227.29	669.46
4	274.60	685.63
5	315.24	714.75
6	340.85	748.00

Circle Center At X = 195.9 ; Y = 836.2 and Radius, 169.7

*** 2.183 ***

1

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	115.79	675.90
2	165.08	667.48
3	214.94	671.12
4	262.49	686.60
5	304.94	713.02
6	339.00	748.00

Circle Center At X = 175.0 ; Y = 874.1 and Radius, 206.8

*** 2.228 ***

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	115.79	675.90
2	165.33	669.10
3	215.29	671.09
4	264.12	681.81
5	310.33	700.92
6	352.46	727.84
7	374.34	748.00

Circle Center At X = 179.0 ; Y = 952.9 and Radius, 284.1

*** 2.238 ***

1

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	115.79	675.90
2	165.42	669.81
3	215.35	672.33
4	264.11	683.41
5	310.24	702.71
6	352.36	729.64
7	372.39	748.00

Circle Center At X = 175.8 ; Y = 959.4 and Radius, 289.7

*** 2.251 ***

result

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	128.95	680.29
2	177.39	667.89
3	227.27	671.25
4	273.61	690.02
5	311.77	722.34
6	326.34	746.08

Circle Center At X = 191.5 ; Y = 821.6 and Radius, 154.5

*** 2.265 ***

1

Failure Surface Specified By 7 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	122.37	678.09
2	171.71	669.99
3	221.69	671.36
4	270.51	682.15
5	316.42	701.97
6	357.75	730.10
7	375.56	748.00

Circle Center At X = 189.5 ; Y = 932.8 and Radius, 263.4

*** 2.272 ***

Failure Surface Specified By 7 Coordinate Points

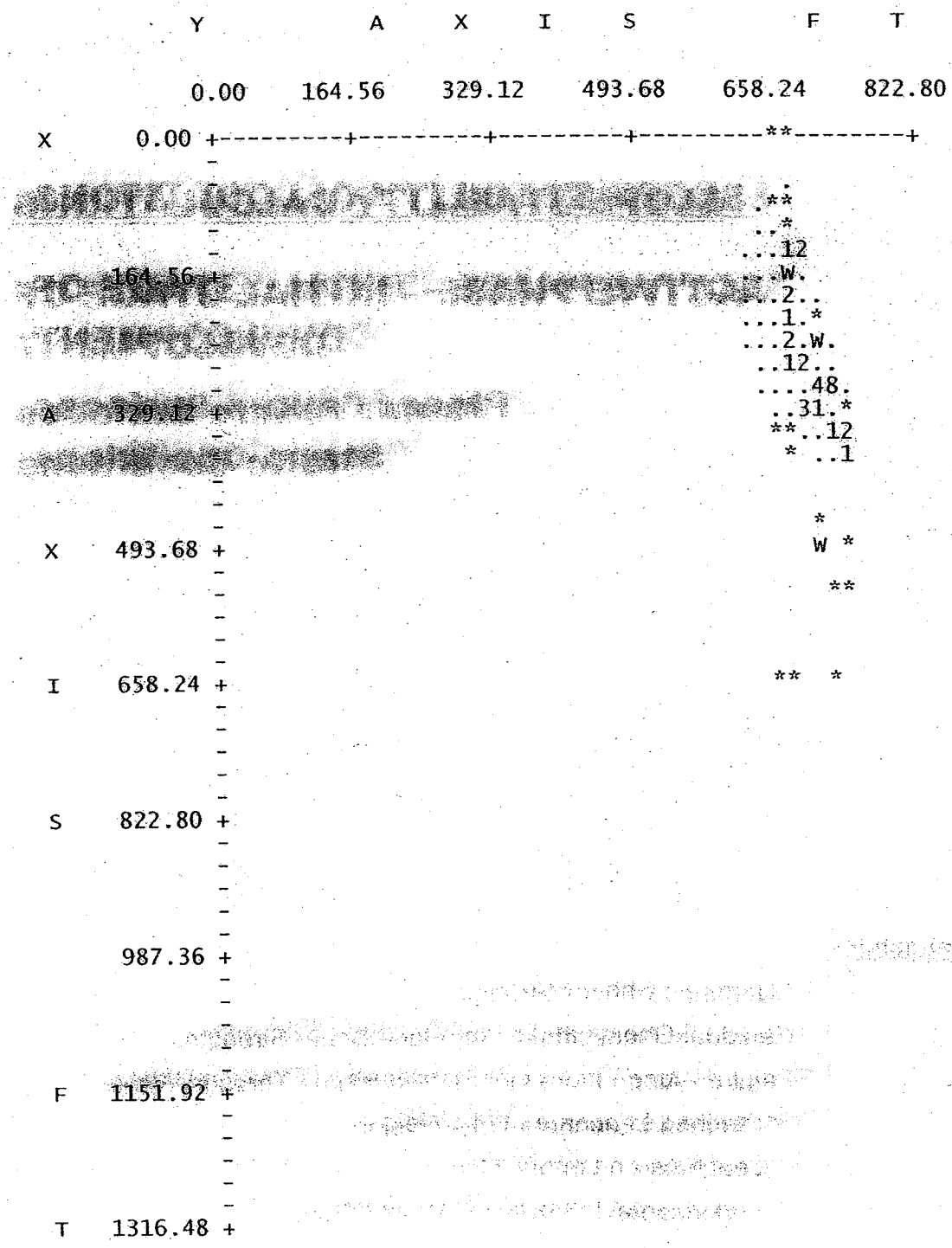
Point No.	X-Surf (ft)	Y-Surf (ft)
1	115.79	675.90
2	165.42	669.80
3	215.21	674.38
4	262.89	689.43
5	306.28	714.28
6	343.40	747.77
7	343.56	748.00

Circle Center At X = 169.0 ; Y = 903.7 and Radius, 234.0

result

*** 2.285 ***

1



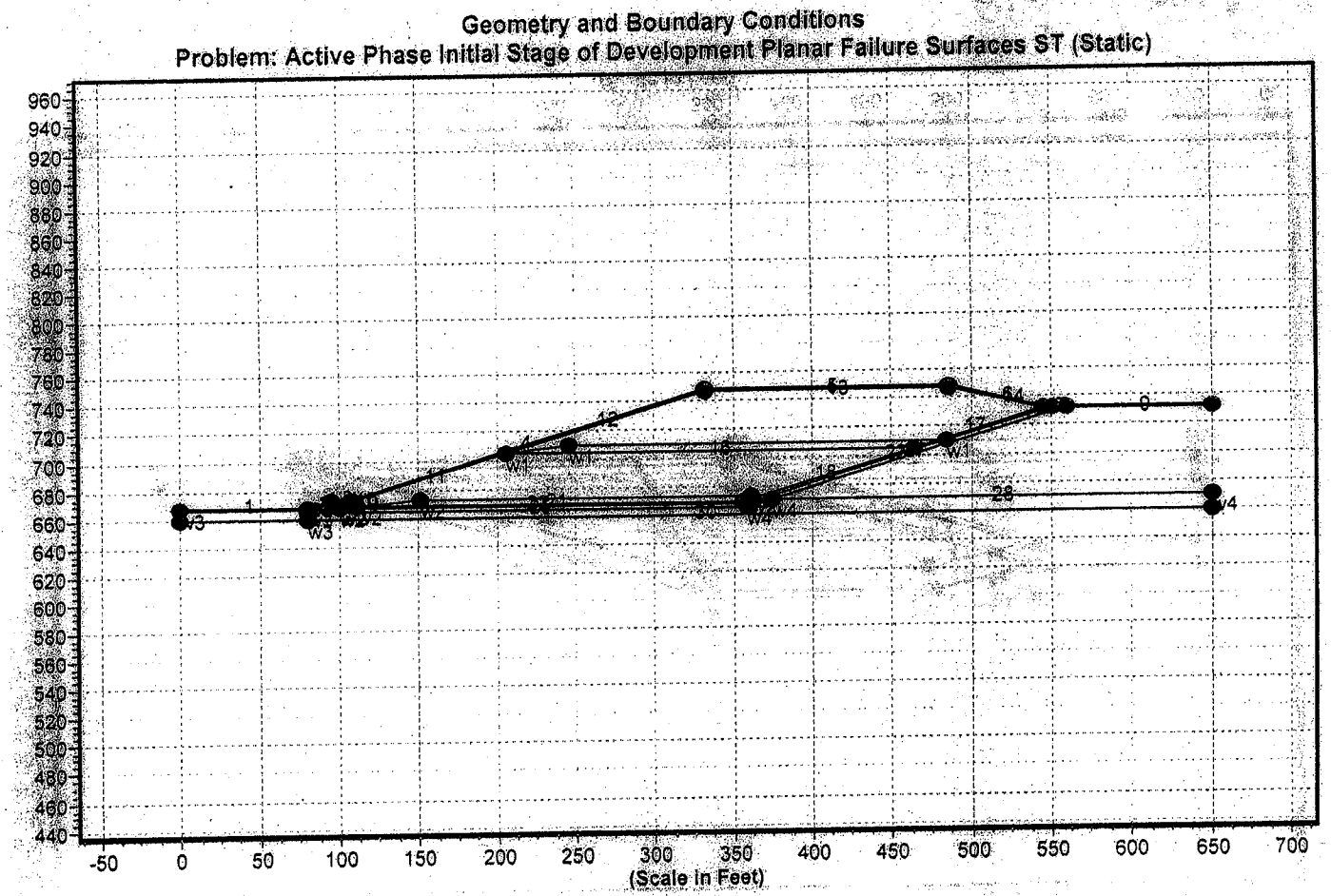
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

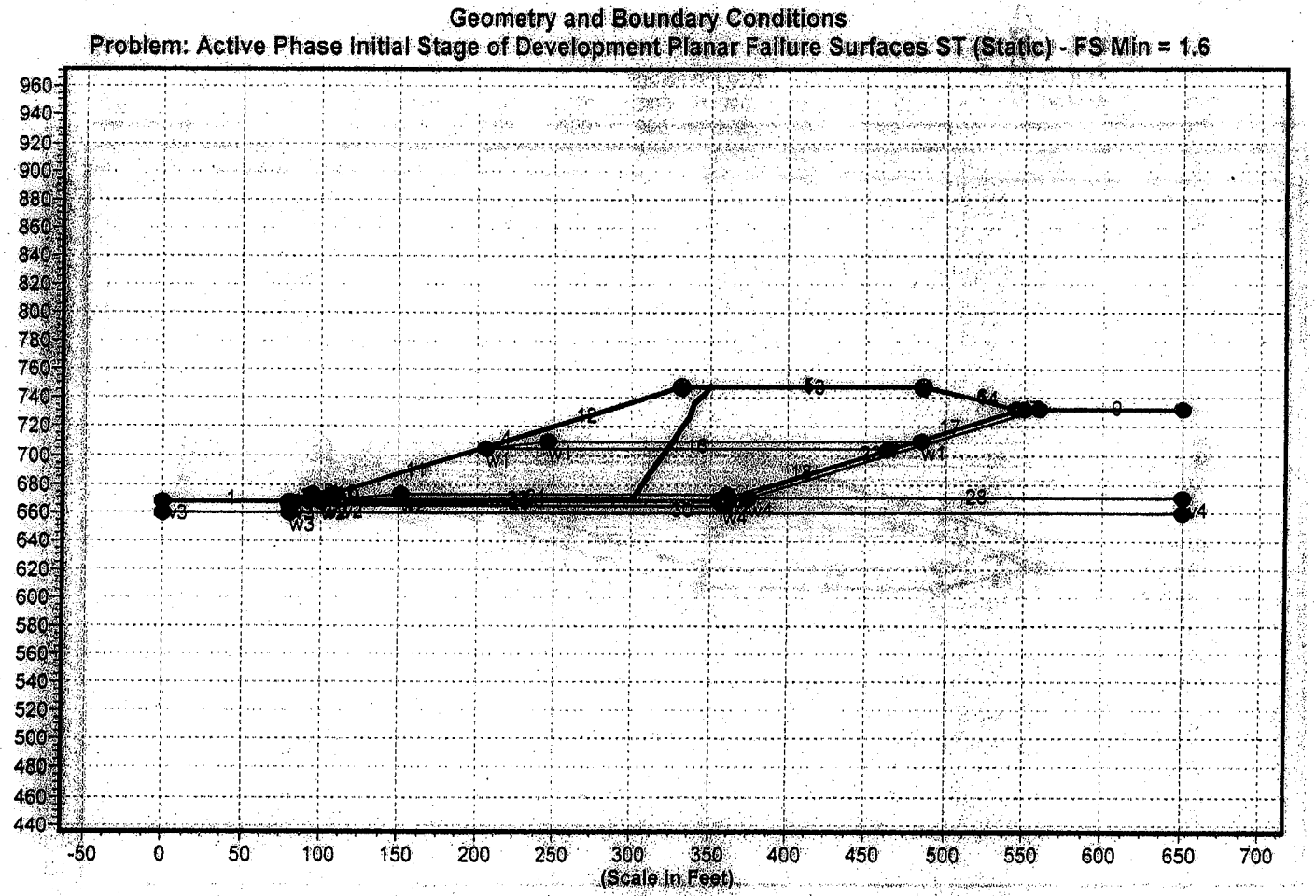
Planar Failure Surfaces
Static Conditions

Key Assumptions:

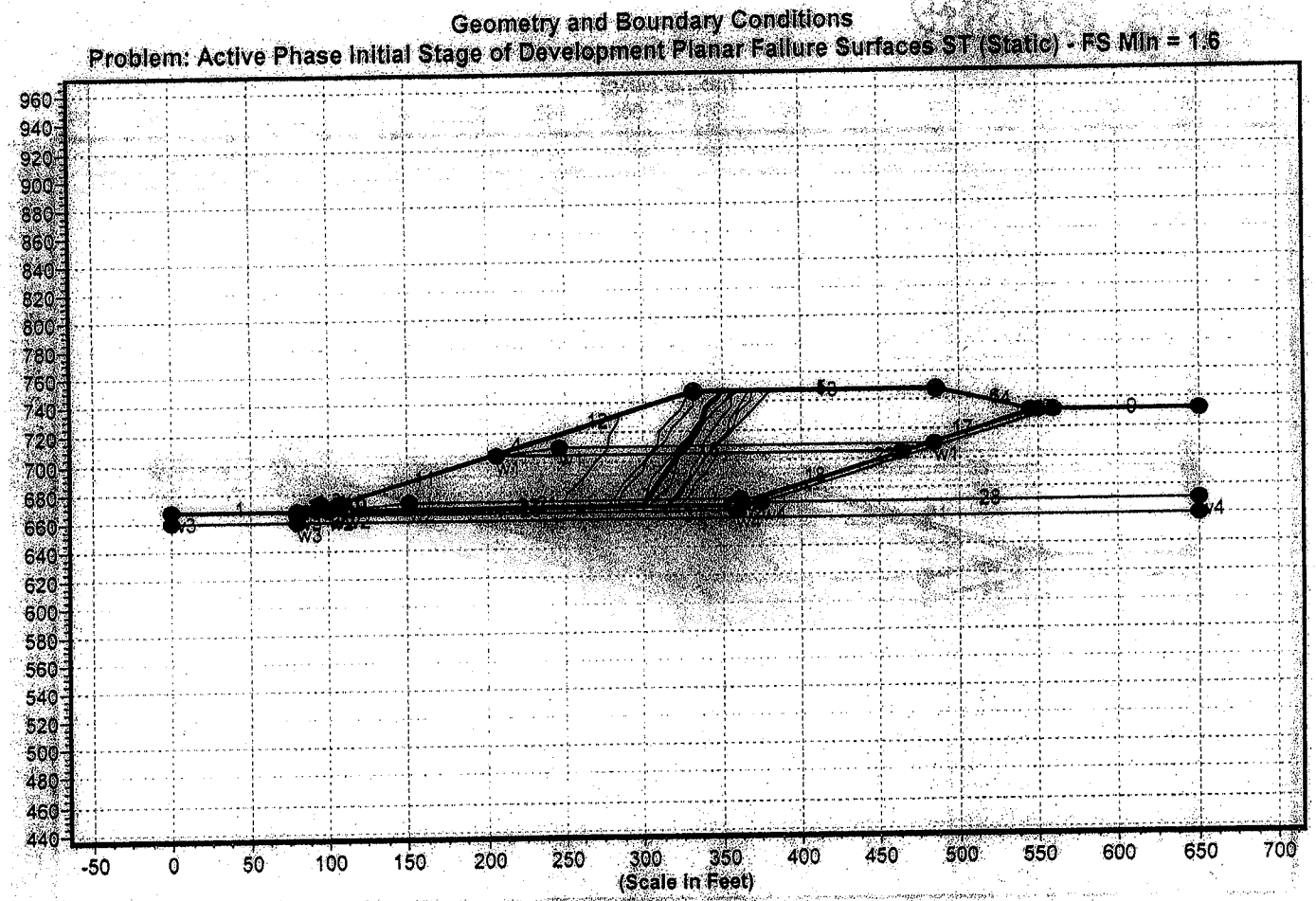
Undrained Shear Strengths
Residual Geosynthetic Interface Shear Strengths
Failure Along Floor Liner Interface and Through Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
3:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Planar Failure Surfaces ST (Static)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale in Feet)
W1
W2
W3
W4

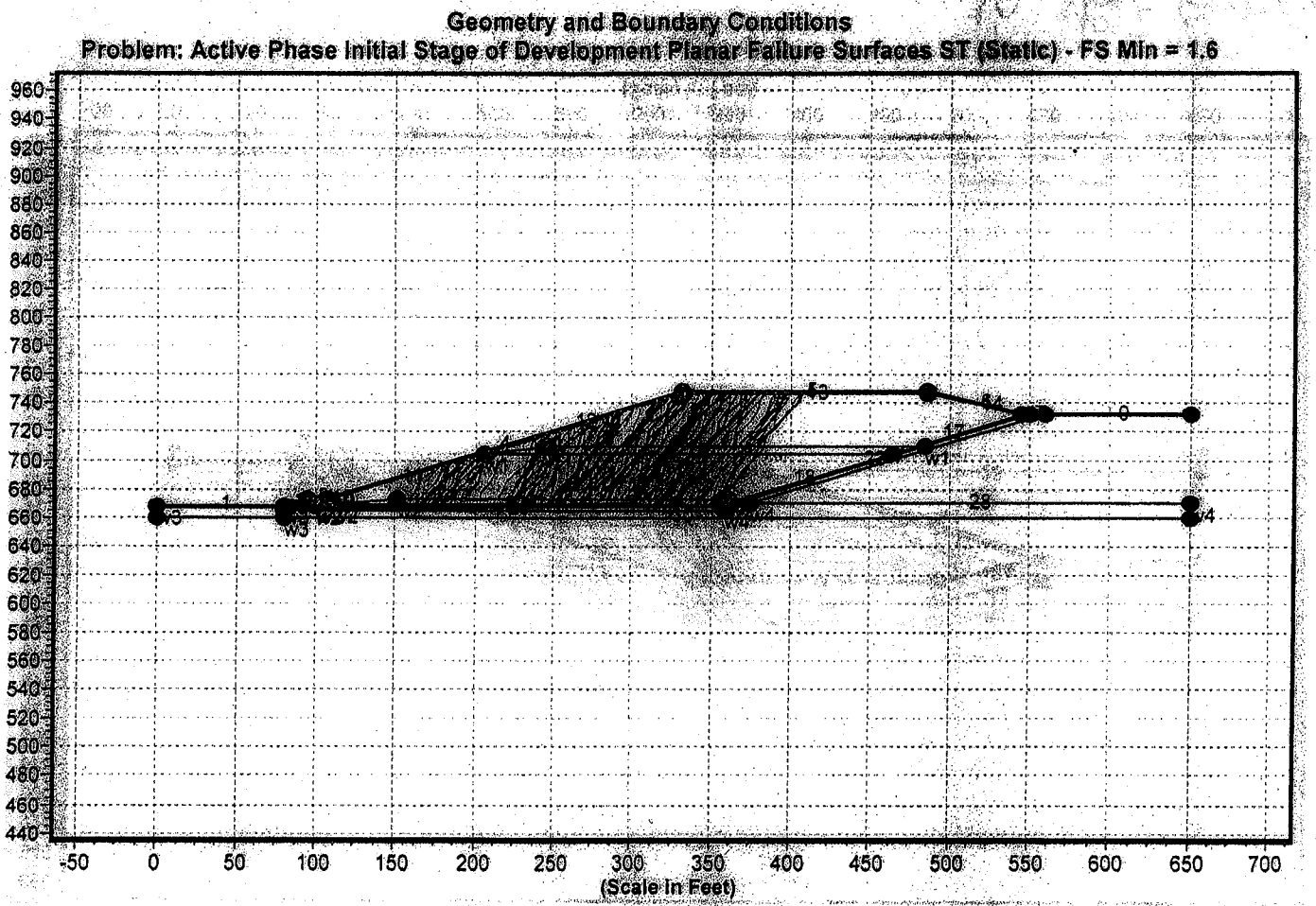
Profile



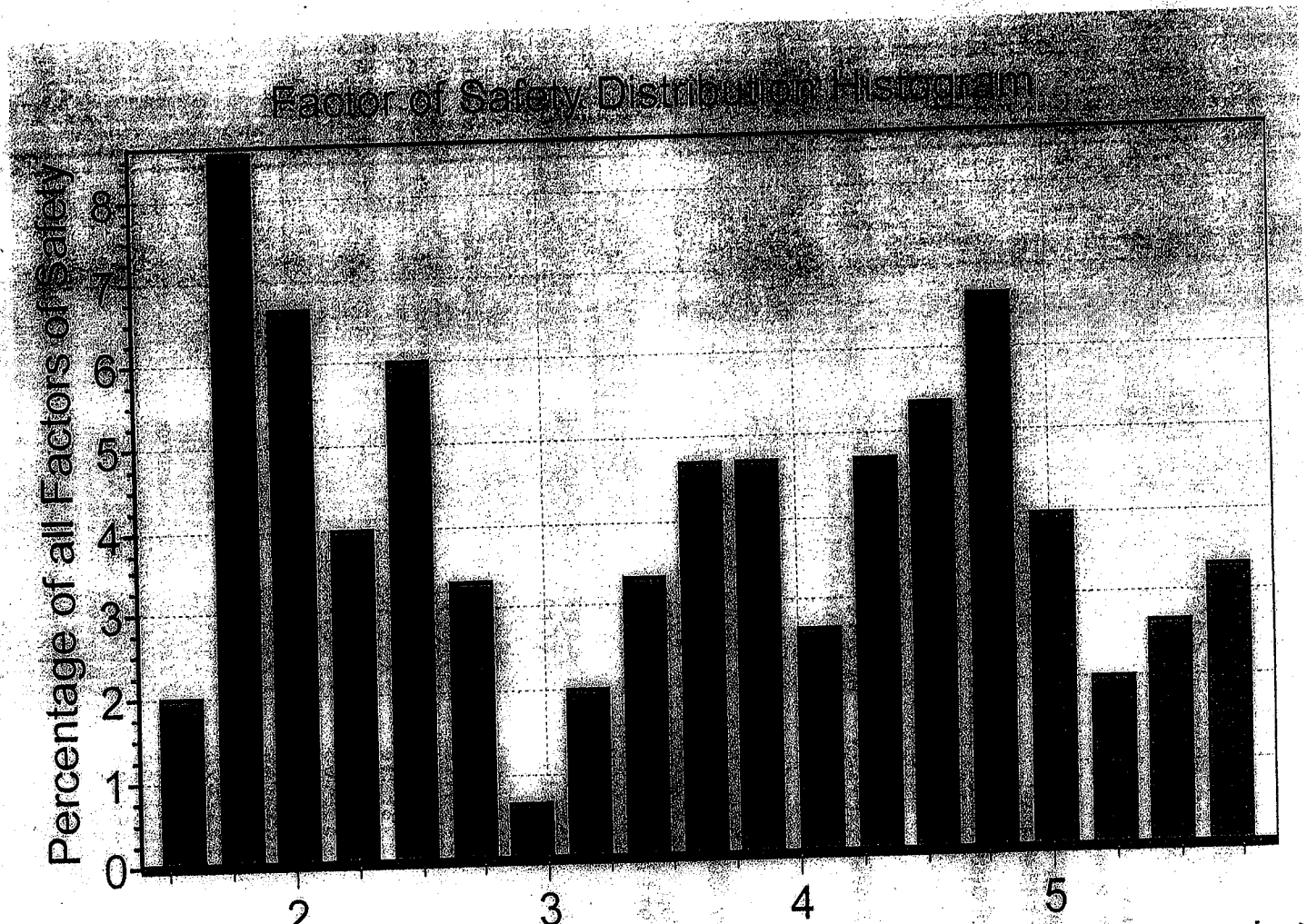
Critical Surface



10 Most Critical



Generated Surfaces



Active Phase Initial Stage of Development Planar Failure Surfaces
Short Term (Static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Dev Planar
Failure Surfaces ST (Static)

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	102.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	10.0	0.00	0.0	1
9	128.0	134.0	0.0	10.0	0.00	0.0	2
10	135.0	140.0	0.0	10.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

Janbus Empirical Coef is being used for the case of C=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

2 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	112.00	668.00	120.00	668.00	2.00
2	150.00	668.00	359.00	668.00	2.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.02	673.64
2	115.82	668.00
3	298.93	668.98
4	304.38	677.36
5	310.01	685.62
6	316.11	693.54
7	320.36	702.60
8	326.64	710.38
9	331.20	719.28
10	337.73	726.85
11	339.83	736.63
12	346.86	743.74
13	351.01	748.00

result

*** 1.600 ***

Individual data on the 25 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	0.9	54.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	4.4	1387.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.4	199.6	0.0	5.4	0.0	0.0	0.0	0.0	0.0
4	1.2	752.8	0.0	88.3	0.0	0.0	0.0	0.0	0.0
5	35.3	40168.1	0.0	6873.3	0.0	0.0	0.0	0.0	0.0
6	55.2	123438.0	0.0	16050.7	0.0	0.0	0.0	0.0	0.0
7	40.0	135704.9	0.0	11007.0	0.0	0.0	0.0	0.0	0.0
8	52.7	237862.0	0.0	13683.9	0.0	0.0	0.0	0.0	0.0
9	0.0	81.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0
10	2.6	13104.8	0.0	595.6	0.0	0.0	0.0	0.0	0.0
11	2.8	13580.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	5.6	24879.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	6.1	24188.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	4.2	14661.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1.9	6020.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	4.0	11714.1	0.0	1002.8	0.0	0.0	0.0	0.0	0.0
17	0.3	836.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	4.6	11224.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.9	1931.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.2	361.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	5.5	10260.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	2.1	2681.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	7.0	4490.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	3.2	793.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1.0	62.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.60	673.50

		result
2	114.58	668.97
3	317.23	668.74
4	322.69	677.12
5	328.98	684.89
6	334.11	693.47
7	339.10	702.14
8	345.80	709.57
9	352.79	716.72
10	359.53	724.10
11	366.52	731.26
12	372.69	739.12
13	379.42	746.52
14	380.87	748.00

*** 1.606 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.50	673.47
2	114.57	668.24
3	314.67	668.53
4	320.71	676.50
5	326.44	684.69
6	333.51	691.77
7	337.96	700.72
8	344.07	708.64
9	350.68	716.14
10	357.73	723.23
11	360.36	732.88
12	367.37	740.02
13	369.77	748.00

*** 1.633 ***

Failure Surface Specified By 15 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.65	673.19
2	109.95	671.66
3	119.50	668.70
4	302.41	668.13
5	309.47	675.21
6	316.52	682.30
7	320.20	691.60
8	322.21	701.40
9	329.28	708.47
10	333.76	717.41

		result
11	338.19	726.38
12	345.25	733.45
13	352.26	740.59
14	359.32	747.67
15	359.65	748.00

*** 1.684 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.51	673.81
2	116.15	668.40
3	275.98	668.06
4	282.19	675.90
5	287.10	684.61
6	293.65	692.16
7	300.40	699.54
8	307.13	706.94
9	314.20	714.01
10	318.59	722.99
11	325.63	730.10
12	331.31	738.33
13	332.13	748.00

*** 1.740 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	111.15	674.35
2	118.33	668.70
3	299.96	668.39
4	301.91	678.20
5	305.12	687.67
6	311.89	695.03
7	318.06	702.90
8	324.27	710.74
9	330.90	718.22
10	337.93	725.34
11	344.39	732.97
12	351.40	740.10
13	356.33	748.00

*** 1.742 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.88	673.60
2	116.03	668.02
3	316.06	668.57
4	323.05	675.71
5	327.75	684.54
6	330.18	694.24
7	336.24	702.19
8	338.14	712.01
9	343.11	720.69
10	349.49	728.40
11	355.96	736.02
12	356.42	746.01
13	358.41	748.00

*** 1.768 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.61	673.51
2	115.36	668.31
3	322.17	668.06
4	329.22	675.15
5	332.42	684.62
6	339.34	691.84
7	345.05	700.06
8	346.93	709.88
9	353.52	717.40
10	354.95	727.30
11	360.39	735.69
12	365.48	744.30
13	366.37	748.00

*** 1.797 ***

1

Failure Surface Specified By 11 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.69	673.20

		result
2	112.22	668.71
3	247.25	668.44
4	251.25	677.60
5	257.57	685.36
6	264.58	692.49
7	270.33	700.67
8	276.11	708.83
9	278.64	718.50
10	283.14	727.44
11	285.41	732.44

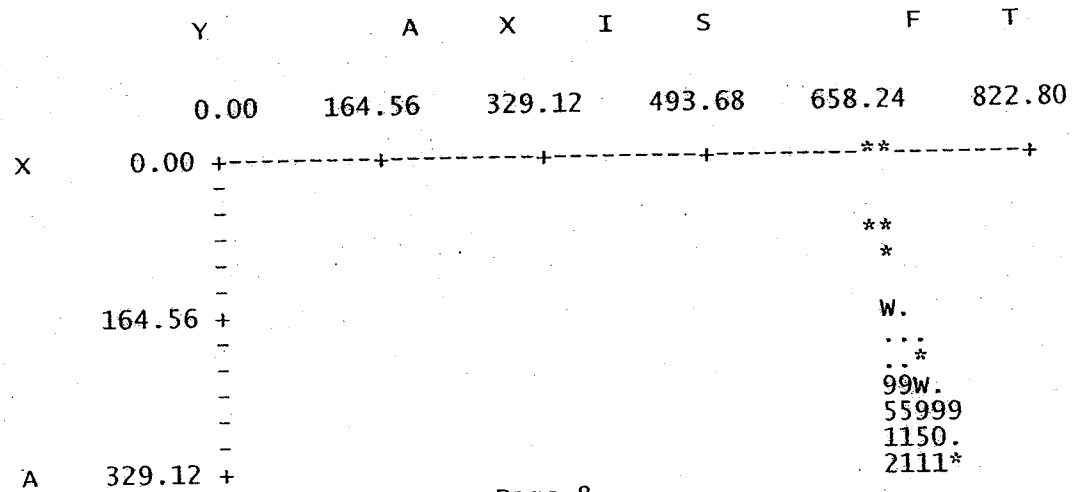
*** 1.804 ***

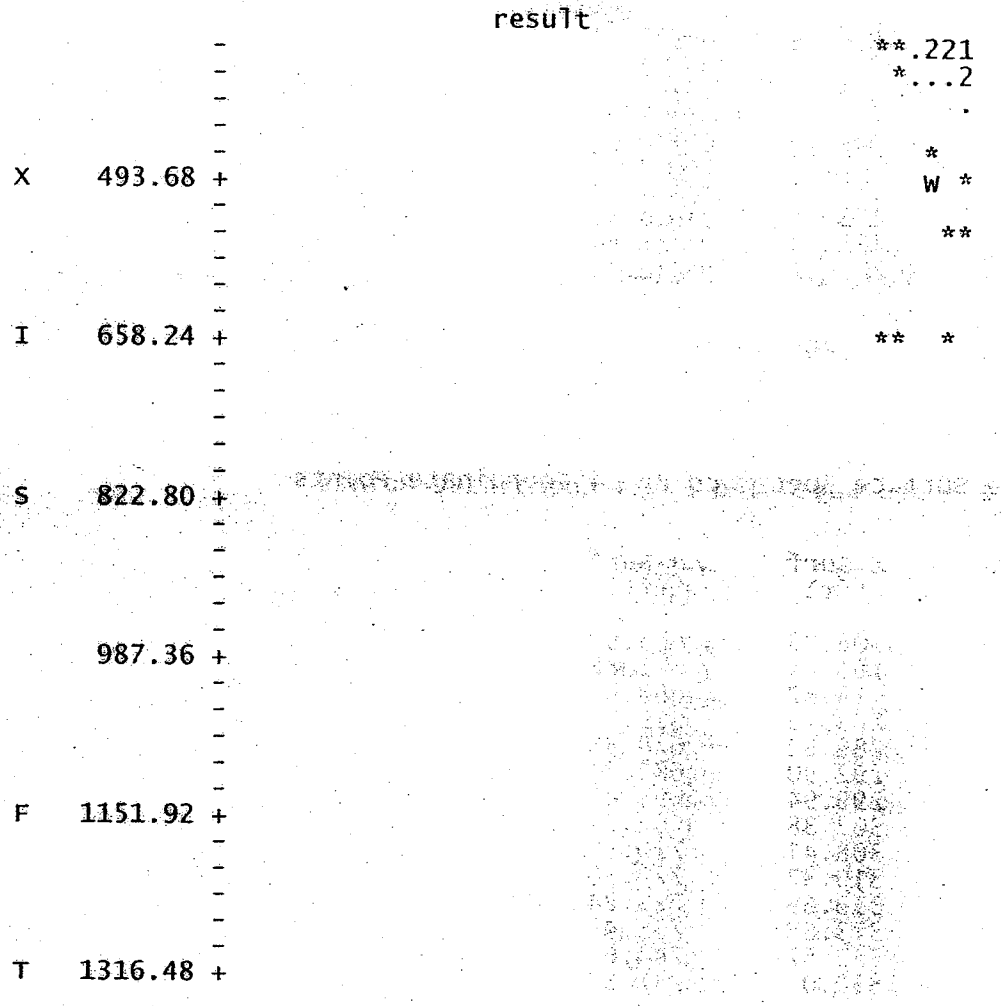
Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	106.03	673.00
2	109.44	671.88
3	118.67	668.02
4	283.49	668.79
5	286.32	678.38
6	292.90	685.91
7	299.94	693.02
8	302.38	702.71
9	308.41	710.69
10	310.37	720.50
11	316.69	728.24
12	323.68	735.40
13	327.57	744.61
14	330.04	747.32

*** 1.843 ***

1




result
**.221
*...2
.
*
W *
**
X 493.68 +
I 658.24 +
** *
S 822.80 +
987.36 +
F 1151.92 +
T 1316.48 +

SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

Planar Failure Surfaces - Sidewall Static Conditions

Key Assumptions:

Undrained Shear Strengths

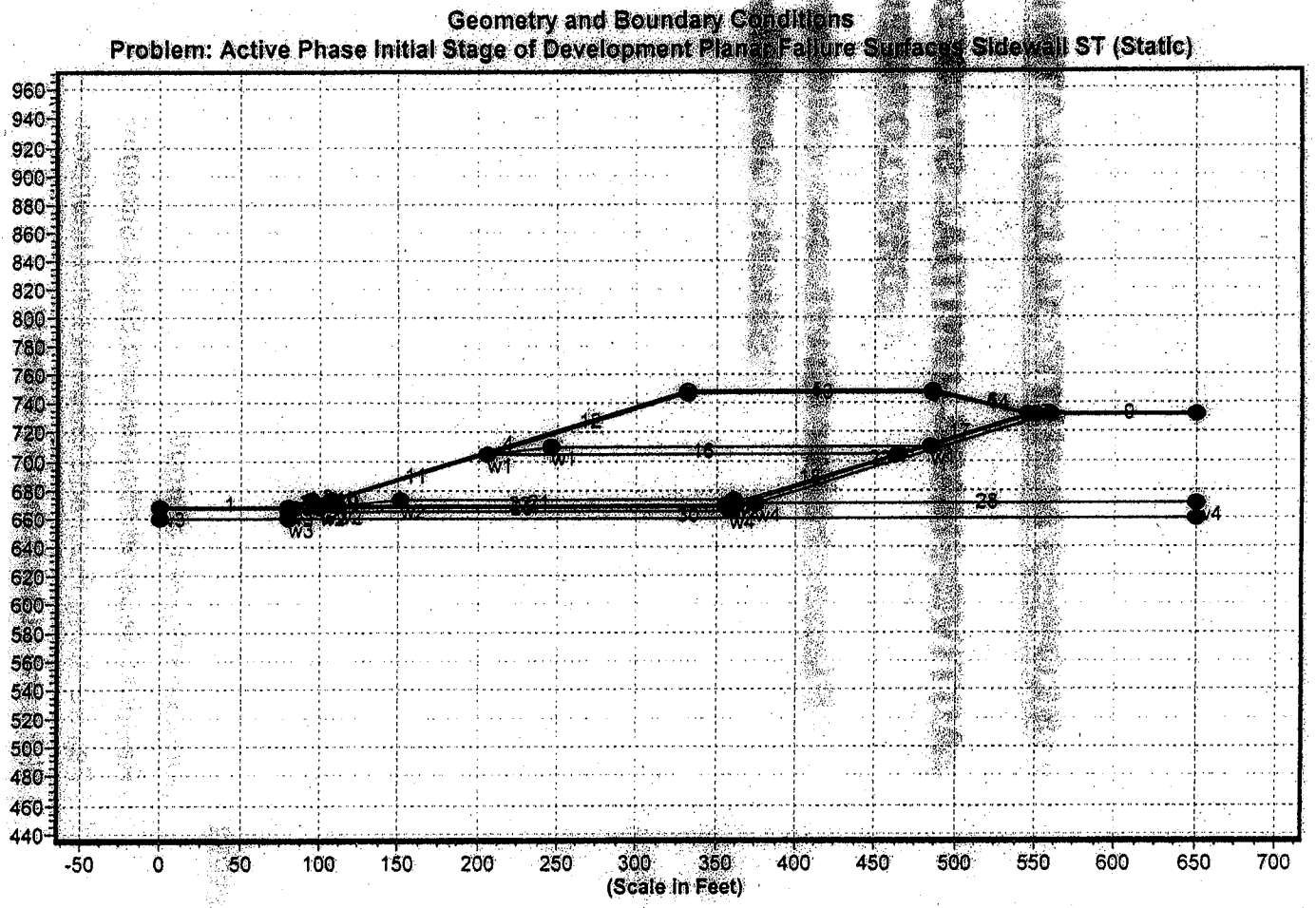
Residual Geosynthetic Interface Shear Strengths

Failure Along Floor and Sidewall Liner Interfaces

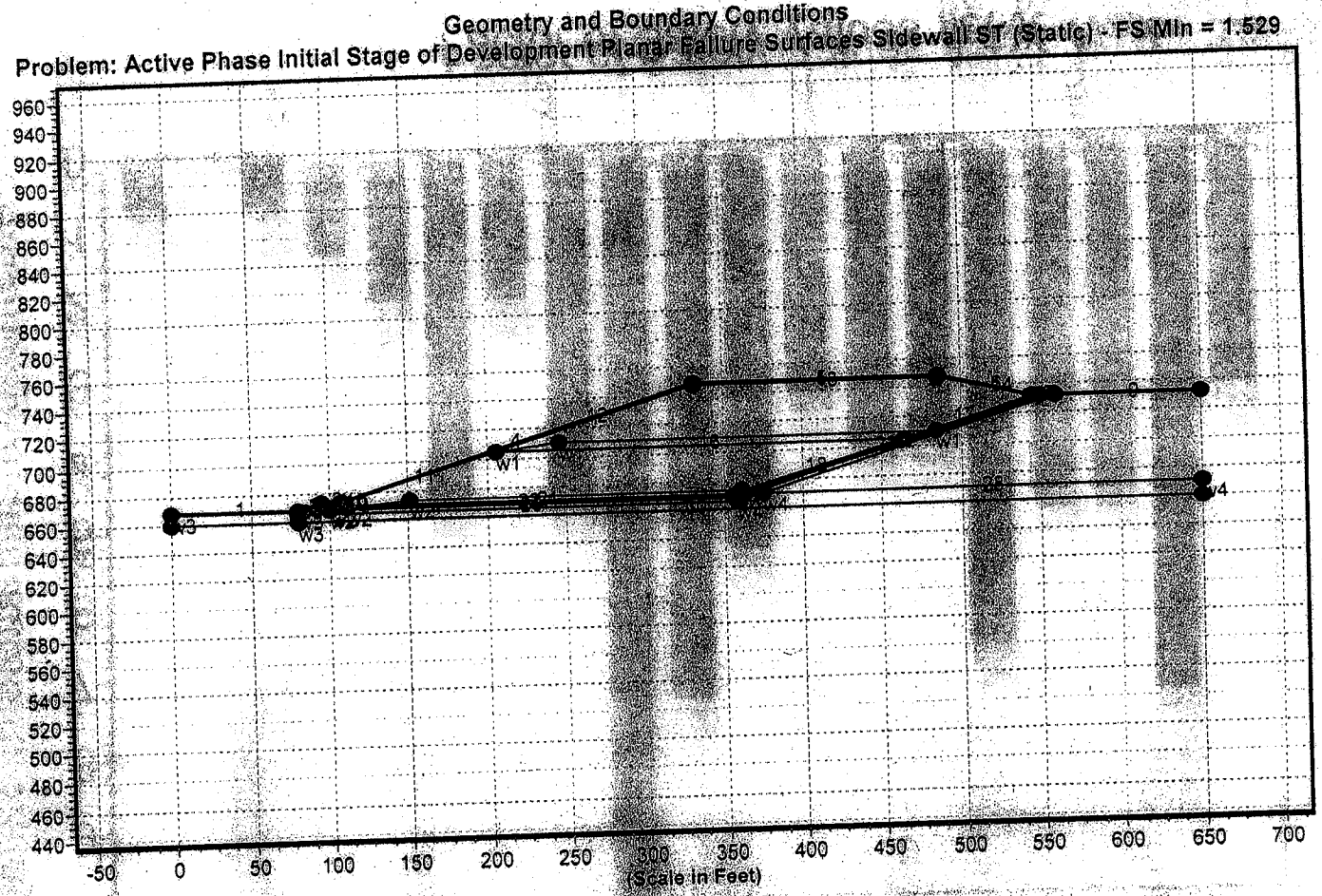
5' Perched Leachate at Mid-Height

5' Leachate on Landfill Floor

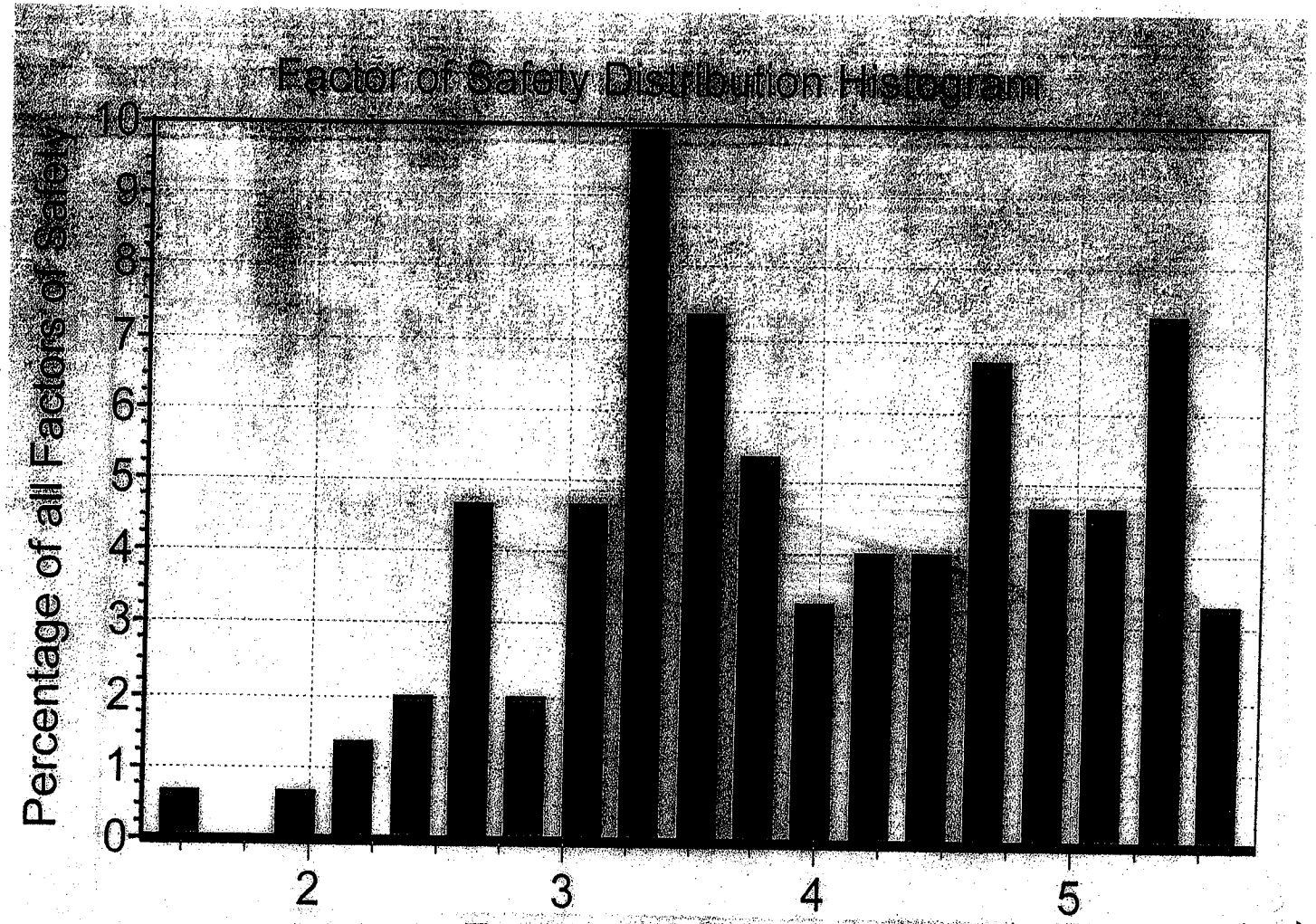
3:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Planar Failure Surfaces Sidewall ST (Static)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale in Feet)
W1
W2
W3
W4
1
11
12
16
25
9
4

Profile



Critical Surface



Active Phase Initial Stage of Development Planar Failure Surfaces Sidewall Short Term (Static

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Developmen
t Planar Failure Surfaces Sidewall ST (S

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	107.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	10.0	0.00	0.0	1
9	128.0	134.0	0.0	10.0	0.00	0.0	2
10	135.0	140.0	0.0	10.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

1

4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

3 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	112.00	668.00	120.00	668.00	2.00
2	350.00	668.00	359.00	668.00	2.00
3	545.00	730.00	560.00	730.00	1.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 5 Coordinate Points

result

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.88	673.26
2	112.28	668.88
3	355.00	668.53
4	545.61	730.41
5	547.70	732.50

*** 1.529 ***

Individual data on the 24 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	0.7	47.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	3.4	1024.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.1	46.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
4	0.1	60.5	0.0	1.9	0.0	0.0	0.0	0.0	0.0
5	38.8	38402.1	0.0	5326.3	0.0	0.0	0.0	0.0	0.0
6	55.2	120006.5	0.0	14521.0	0.0	0.0	0.0	0.0	0.0
7	40.0	135012.1	0.0	10698.0	0.0	0.0	0.0	0.0	0.0
8	85.8	425784.2	0.0	23437.5	0.0	0.0	0.0	0.0	0.0
9	0.2	1027.0	0.0	47.1	0.0	0.0	0.0	0.0	0.0
10	22.7	137356.2	0.0	6318.8	0.0	0.0	0.0	0.0	0.0
11	1.3	7607.7	0.0	353.9	0.0	0.0	0.0	0.0	0.0
12	0.2	1099.2	0.0	48.6	0.0	0.0	0.0	0.0	0.0
13	4.6	27006.7	0.0	974.6	0.0	0.0	0.0	0.0	0.0
14	103.3	479041.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	15.0	48498.0	0.0	3508.2	0.0	0.0	0.0	0.0	0.0
16	3.5	10477.6	0.0	129.1	0.0	0.0	0.0	0.0	0.0
17	2.5	7390.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.1	348.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	45.6	88011.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	14.3	9393.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.4	119.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.2	59.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1.4	260.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.5	19.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	111.80	674.57
2	117.40	668.99
3	356.45	668.84
4	546.66	730.41
5	548.01	732.43

*** 2.052 ***

1

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	106.96	673.00
2	112.22	668.71
3	354.19	668.44
4	546.17	730.19
5	548.31	732.37

*** 2.106 ***

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.05	673.65
2	114.34	668.36
3	357.59	668.95
4	546.75	730.44
5	548.60	732.30

*** 2.140 ***

1

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	110.69	674.20
2	110.83	674.15
3	118.94	668.30
4	355.59	668.87
5	545.82	729.69
6	547.58	732.53

*** 2.365 ***

Failure Surface Specified By 6 Coordinate Points

result

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.41	673.11
2	110.04	670.52
3	119.87	668.68
4	355.38	668.68
5	547.75	730.37
6	547.99	732.44

*** 2.418 ***

1

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.50	673.14
2	112.36	668.32
3	354.15	668.76
4	545.43	729.69
5	547.88	732.46

*** 2.470 ***

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.85	673.92
2	116.35	668.02
3	355.51	668.28
4	548.26	730.44
5	549.83	732.04

*** 2.554 ***

1

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	110.49	674.13
2	117.57	667.98
3	357.14	668.34

		result
4	546.57	730.43
5	547.23	732.60

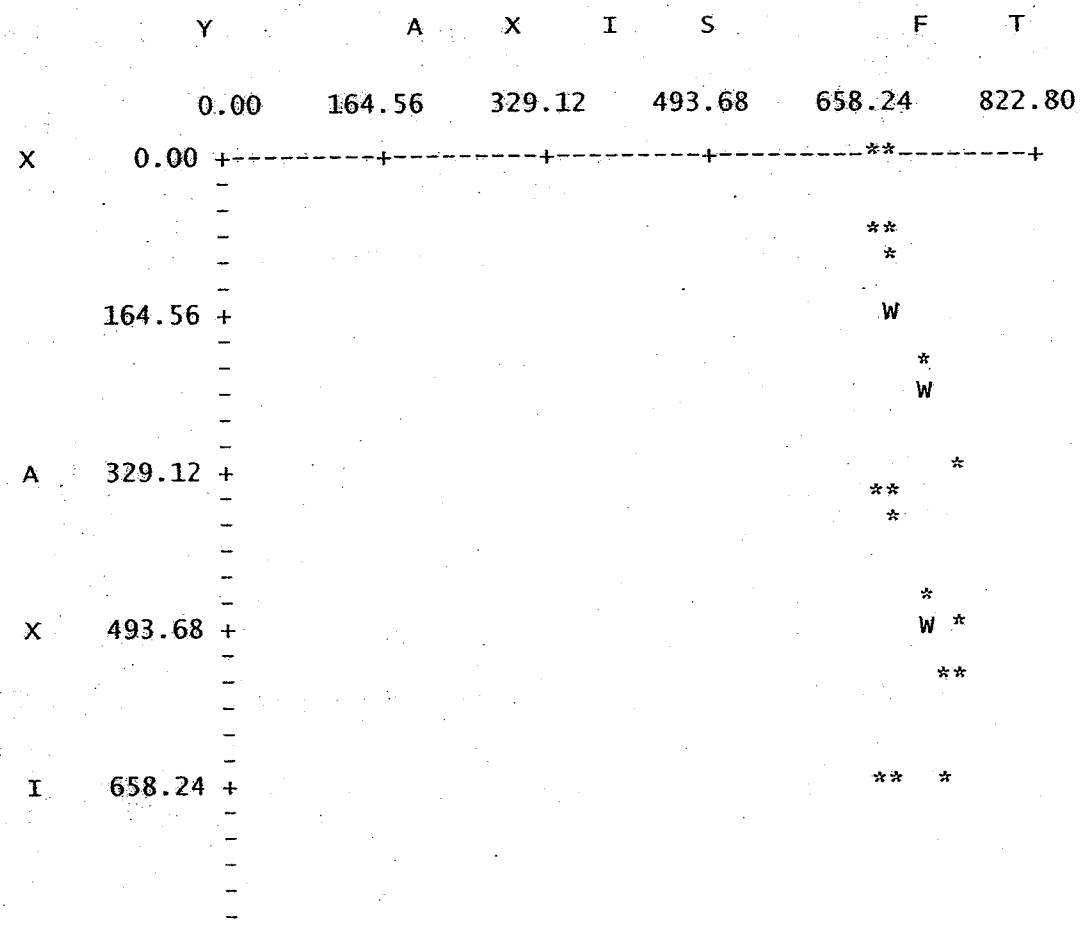
*** 2.555 ***

Failure Surface Specified By 5 Coordinate Points

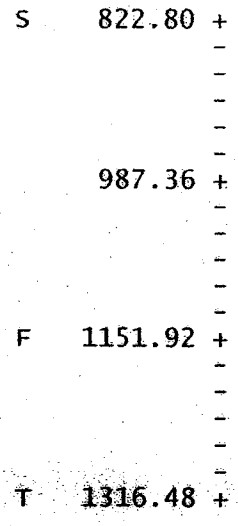
Point No.	X-Surf (ft)	Y-Surf (ft)
1	106.12	673.00
2	114.07	668.04
3	355.16	668.97
4	546.22	729.66
5	547.28	732.59

*** 2.617 ***

1



result



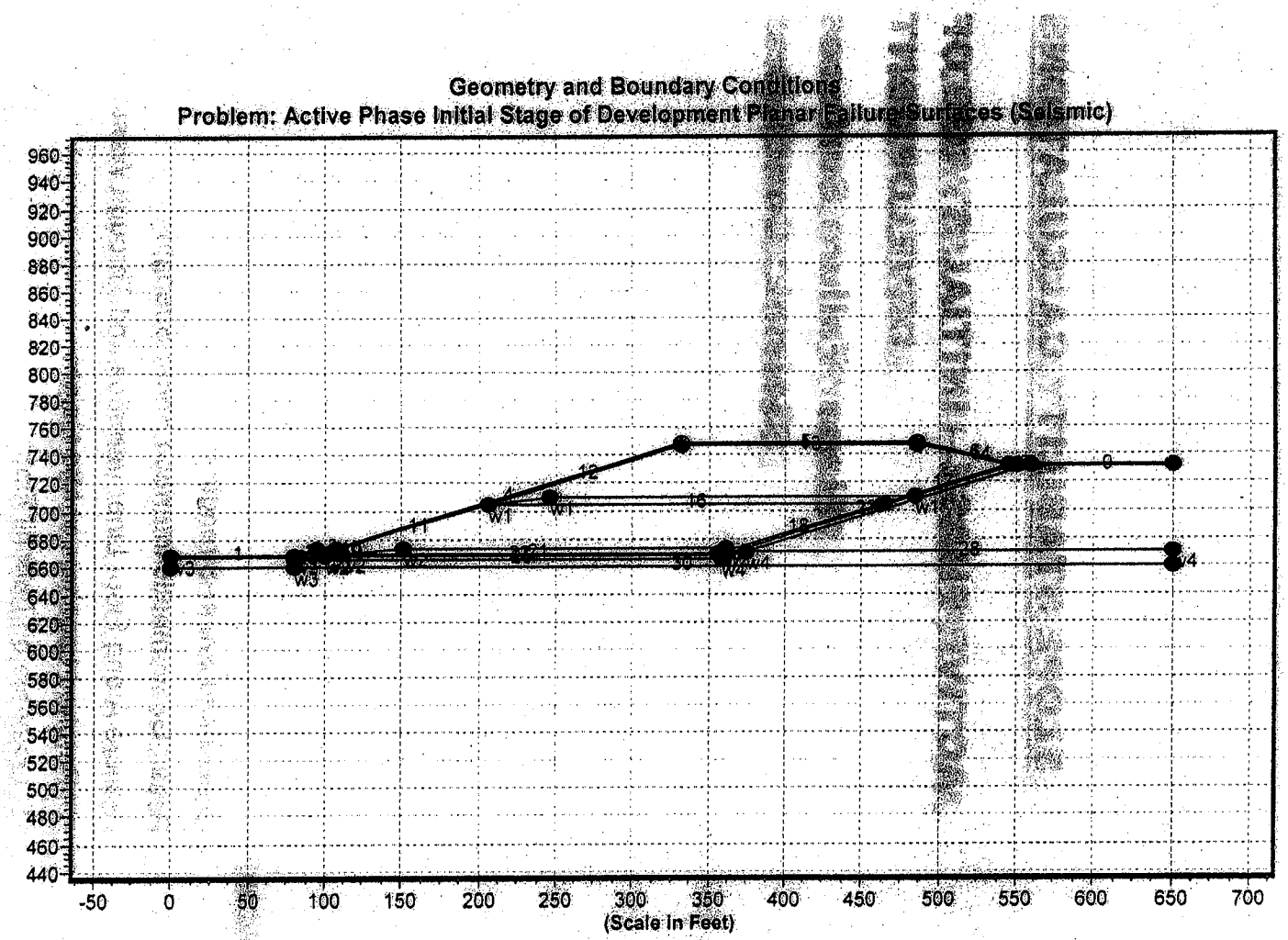
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

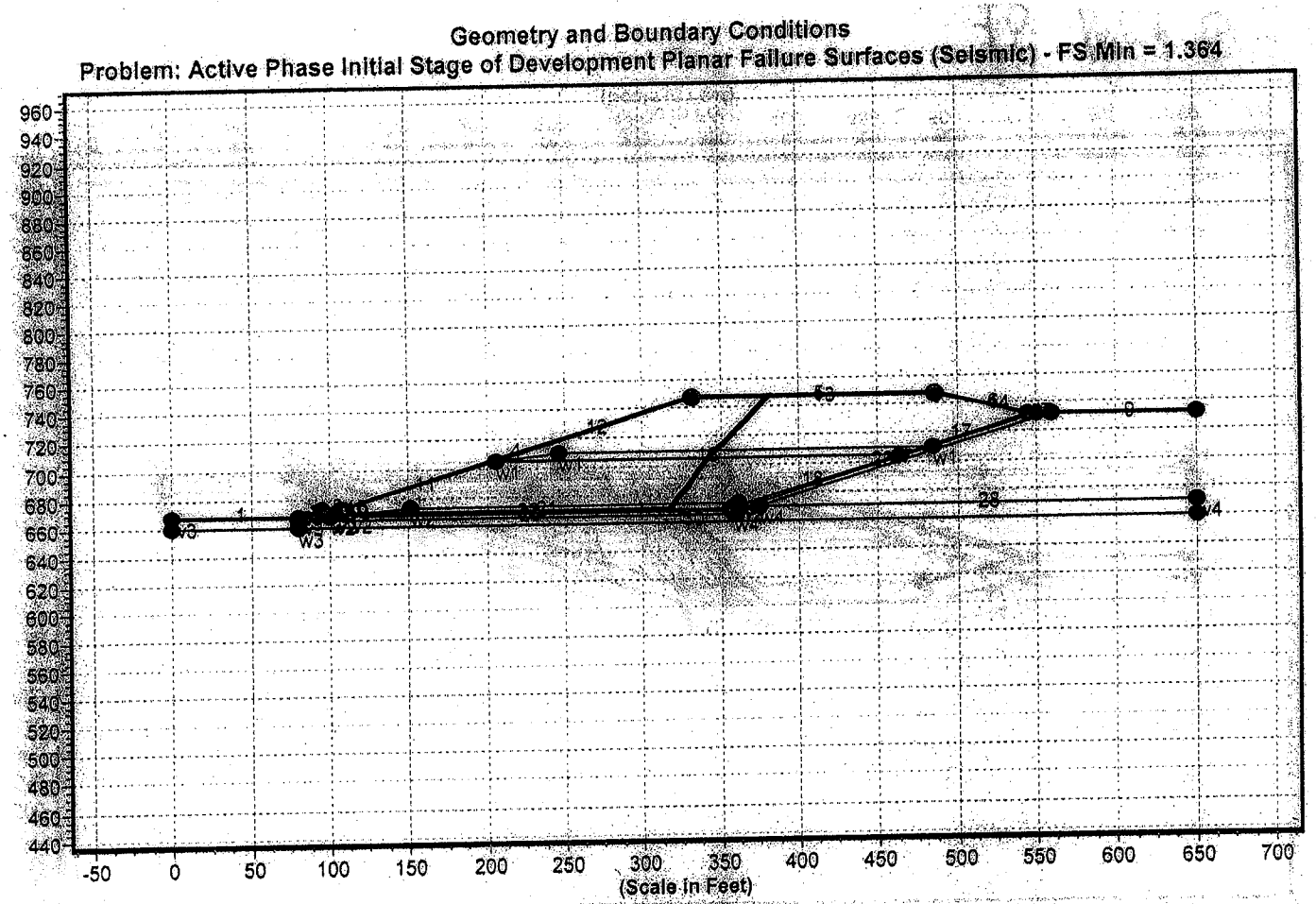
Planar Failure Surfaces
Seismic Conditions

Key Assumptions:

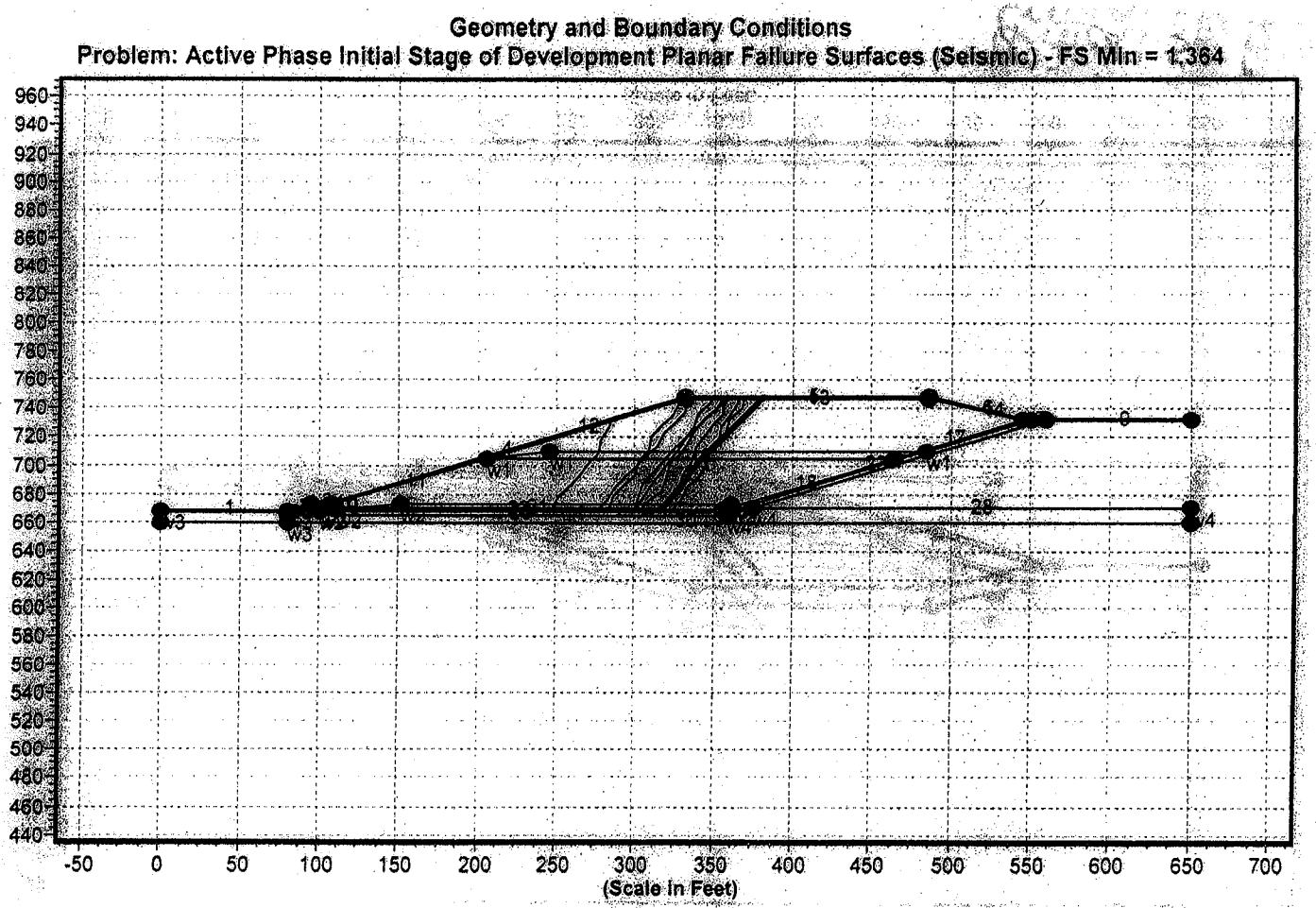
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
Failure Along Floor Liner Interface and Through Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
3:1 (Horizontal to Vertical) Waste Slope
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Planar Failure Surfaces (Seismic)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale In Feet)

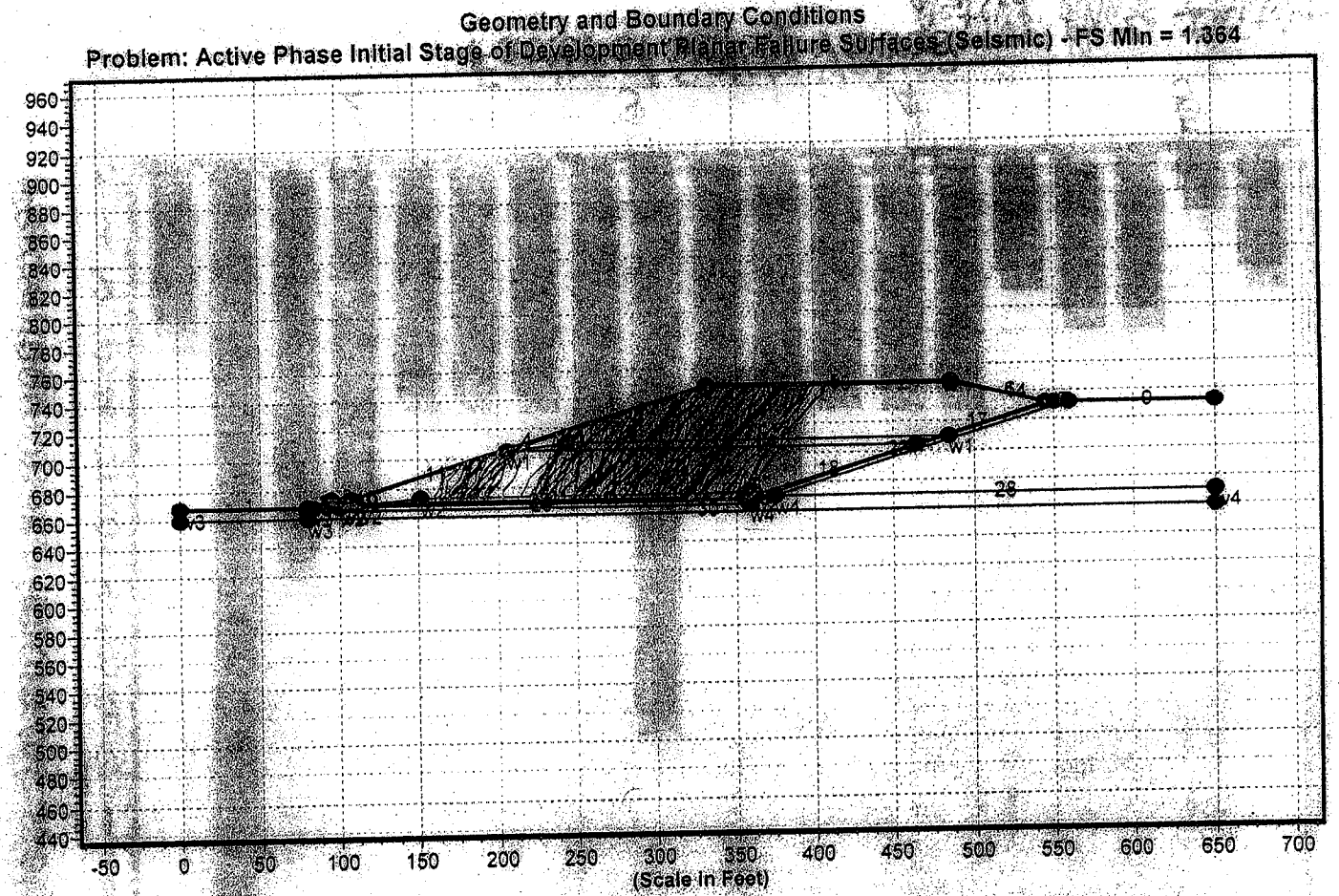
Profile



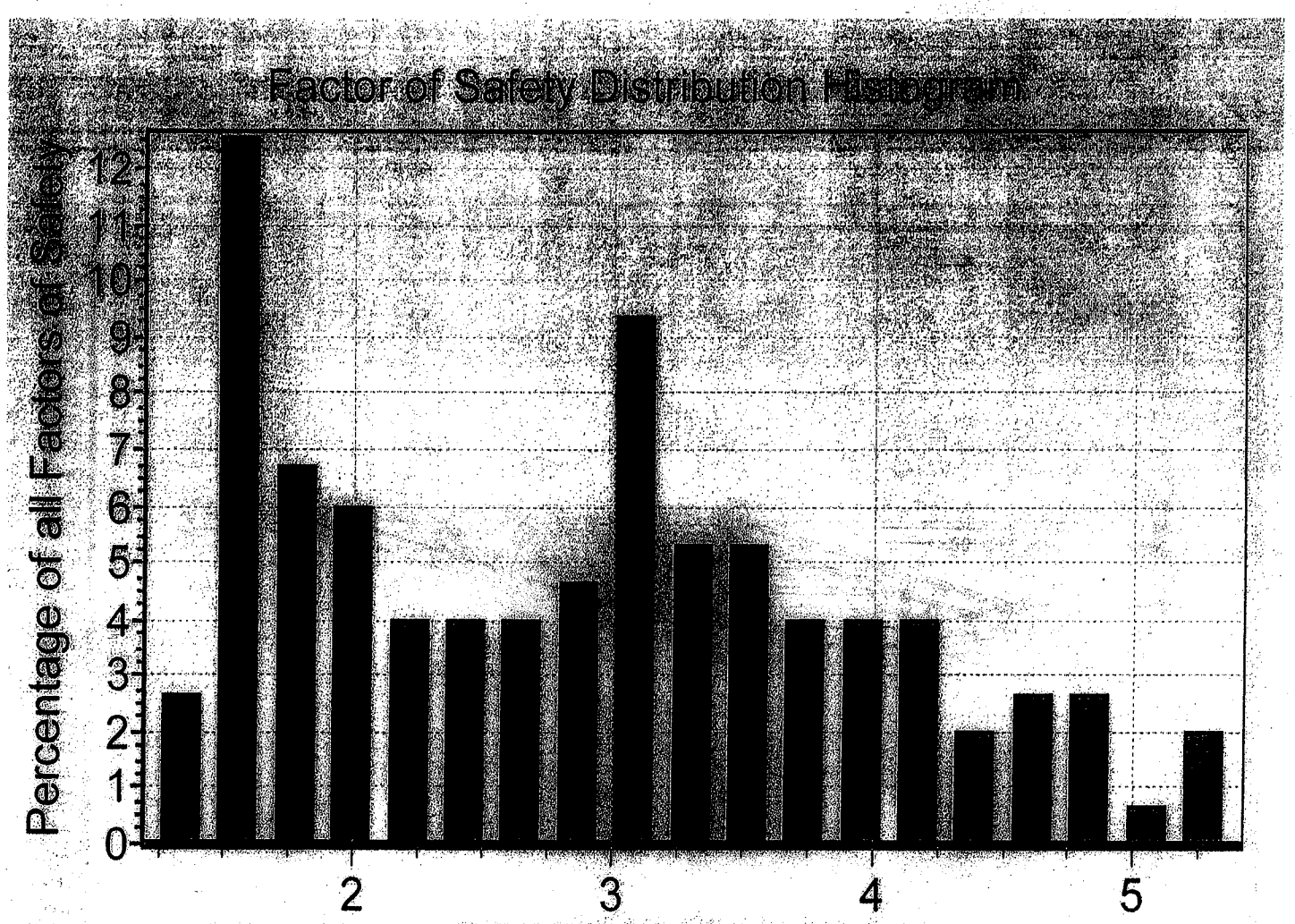
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase Initial Stage of Development Planar Failure Surfaces (seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Developmen
t Planar Failure Surfaces (Seismic)

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	107.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	15.0	0.00	0.0	1
9	128.0	134.0	0.0	15.0	0.00	0.0	2
10	135.0	140.0	0.0	16.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

1

4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

2 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	112.00	668.00	120.00	668.00	2.00
2	150.00	668.00	359.00	668.00	2.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical

result

First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.60	673.50
2	114.58	668.97
3	317.23	668.74
4	322.69	677.12
5	328.98	684.89
6	334.11	693.47
7	339.10	702.14
8	345.80	709.57
9	352.79	716.72
10	359.53	724.10
11	366.52	731.26
12	372.69	739.12
13	379.42	746.52
14	380.87	748.00

*** 1.364 ***

Individual data on the 26 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	0.9	58.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0
2	4.6	1465.1	0.0	0.0	0.0	0.0	146.5	0.0	0.0
3	0.4	210.0	0.0	5.4	0.0	0.0	21.0	0.0	0.0
4	0.0	21.4	0.0	1.1	0.0	0.0	2.1	0.0	0.0
5	36.5	36665.0	0.0	5044.5	0.0	0.0	3666.5	0.0	0.0
6	55.2	119115.5	0.0	14123.9	0.0	0.0	11911.6	0.0	0.0
7	40.0	134286.8	0.0	10374.8	0.0	0.0	13428.7	0.0	0.0
8	71.0	337305.7	0.0	18684.6	0.0	0.0	33730.6	0.0	0.0
9	0.2	952.5	0.0	79.8	0.0	0.0	95.2	0.0	0.0
10	2.6	14330.0	0.0	595.9	0.0	0.0	1433.0	0.0	0.0
11	2.7	14112.9	0.0	0.0	0.0	0.0	1411.3	0.0	0.0
12	6.3	30987.6	0.0	0.0	0.0	0.0	3098.8	0.0	0.0
13	3.1	14168.6	0.0	0.0	0.0	0.0	1416.9	0.0	0.0
14	0.2	745.8	0.0	0.0	0.0	0.0	74.6	0.0	0.0
15	1.9	7878.9	0.0	0.0	0.0	0.0	787.9	0.0	0.0
16	5.0	19064.4	0.0	0.0	0.0	0.0	1906.4	0.0	0.0
17	2.6	8733.4	0.0	0.0	0.0	0.0	873.3	0.0	0.0
18	4.1	12782.5	0.0	1042.1	0.0	0.0	1278.2	0.0	0.0
19	0.4	1238.5	0.0	8.2	0.0	0.0	123.9	0.0	0.0
20	6.6	17406.6	0.0	0.0	0.0	0.0	1740.7	0.0	0.0
21	6.7	14306.8	0.0	0.0	0.0	0.0	1430.7	0.0	0.0
22	7.0	11020.1	0.0	0.0	0.0	0.0	1102.0	0.0	0.0

					result				
23	6.2	6263.1	0.0	0.0	0.0	0.0	626.3	0.0	0.0
24	6.7	2971.9	0.0	0.0	0.0	0.0	297.2	0.0	0.0
25	0.5	68.8	0.0	0.0	0.0	0.0	6.9	0.0	0.0
26	1.0	62.4	0.0	0.0	0.0	0.0	6.2	0.0	0.0

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.02	673.64
2	115.82	668.00
3	298.93	668.98
4	304.38	677.36
5	310.01	685.62
6	316.11	693.54
7	320.36	702.60
8	326.64	710.38
9	331.20	719.28
10	337.73	726.85
11	339.83	736.63
12	346.86	743.74
13	351.01	748.00

*** 1.368 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.50	673.47
2	114.57	668.24
3	314.67	668.53
4	320.71	676.50
5	326.44	684.69
6	333.51	691.77
7	337.96	700.72
8	344.07	708.64
9	350.68	716.14
10	357.73	723.23
11	360.36	732.88
12	367.37	740.02
13	369.77	748.00

*** 1.381 ***

Failure Surface Specified By 15 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

result

1	107.65	673.19
2	109.95	671.66
3	119.50	668.70
4	302.41	668.13
5	309.47	675.21
6	316.52	682.30
7	320.20	691.60
8	322.21	701.40
9	329.28	708.47
10	333.76	717.41
11	338.19	726.38
12	345.25	733.45
13	352.26	740.59
14	359.32	747.67
15	359.65	748.00

*** 1.417 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.51	673.81
2	116.15	668.40
3	275.98	668.06
4	282.19	675.90
5	287.10	684.61
6	293.65	692.16
7	300.40	699.54
8	307.13	706.94
9	314.20	714.01
10	318.59	722.99
11	325.63	730.10
12	331.31	738.33
13	332.13	748.00

*** 1.463 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	111.15	674.35
2	118.33	668.70
3	299.96	668.39
4	301.91	678.20
5	305.12	687.67
6	311.89	695.03
7	318.06	702.90

		result
8	324.27	710.74
9	330.90	718.22
10	337.93	725.34
11	344.39	732.97
12	351.40	740.10
13	356.33	748.00

*** 1.464 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.88	673.60
2	116.03	668.02
3	316.06	668.57
4	323.05	675.71
5	327.75	684.54
6	330.18	694.24
7	336.24	702.19
8	338.14	712.01
9	343.11	720.69
10	349.49	728.40
11	355.96	736.02
12	356.42	746.01
13	358.41	748.00

*** 1.472 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	108.61	673.51
2	115.36	668.31
3	322.17	668.06
4	329.22	675.15
5	332.42	684.62
6	339.34	691.84
7	345.05	700.06
8	346.93	709.88
9	353.52	717.40
10	354.95	727.30
11	360.39	735.69
12	365.48	744.30
13	366.37	748.00

*** 1.488 ***

1

Failure Surface Specified By 11 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.69	673.20
2	112.22	668.71
3	247.25	668.44
4	251.25	677.60
5	257.57	685.36
6	264.58	692.49
7	270.33	700.67
8	276.11	708.83
9	278.64	718.50
10	283.14	727.44
11	285.41	732.44

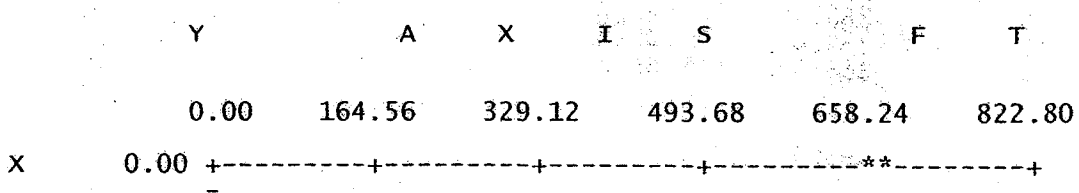
*** 1.513 ***

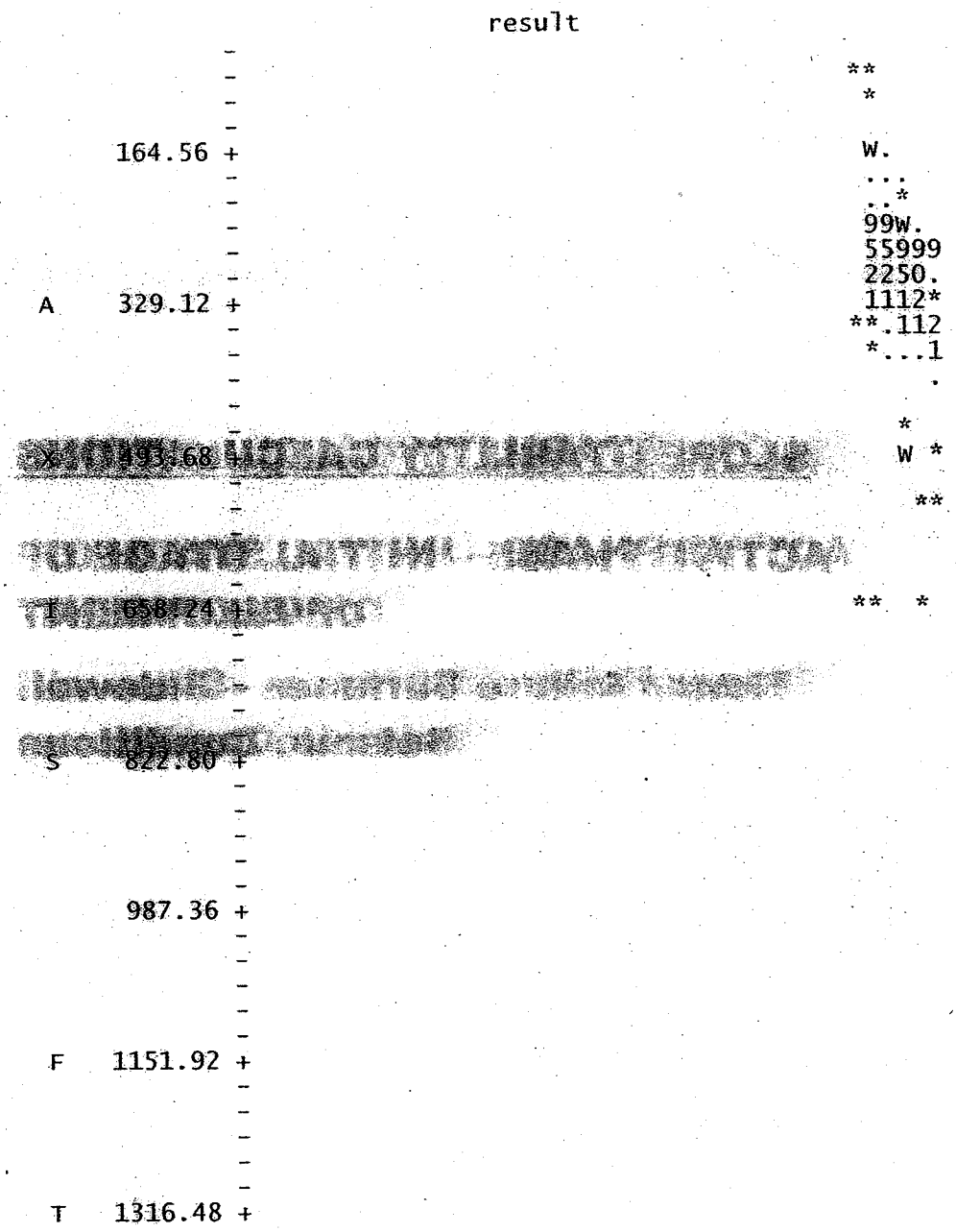
Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	106.03	673.00
2	109.44	671.88
3	118.67	668.02
4	283.49	668.79
5	286.32	678.38
6	292.90	685.91
7	299.94	693.02
8	302.38	702.71
9	308.41	710.69
10	310.37	720.50
11	316.69	728.24
12	323.68	735.40
13	327.57	744.61
14	330.04	747.32

*** 1.532 ***

1




result
164.56
A 329.12
T 658.24
S 822.80
987.36
F 1151.92
T 1316.48

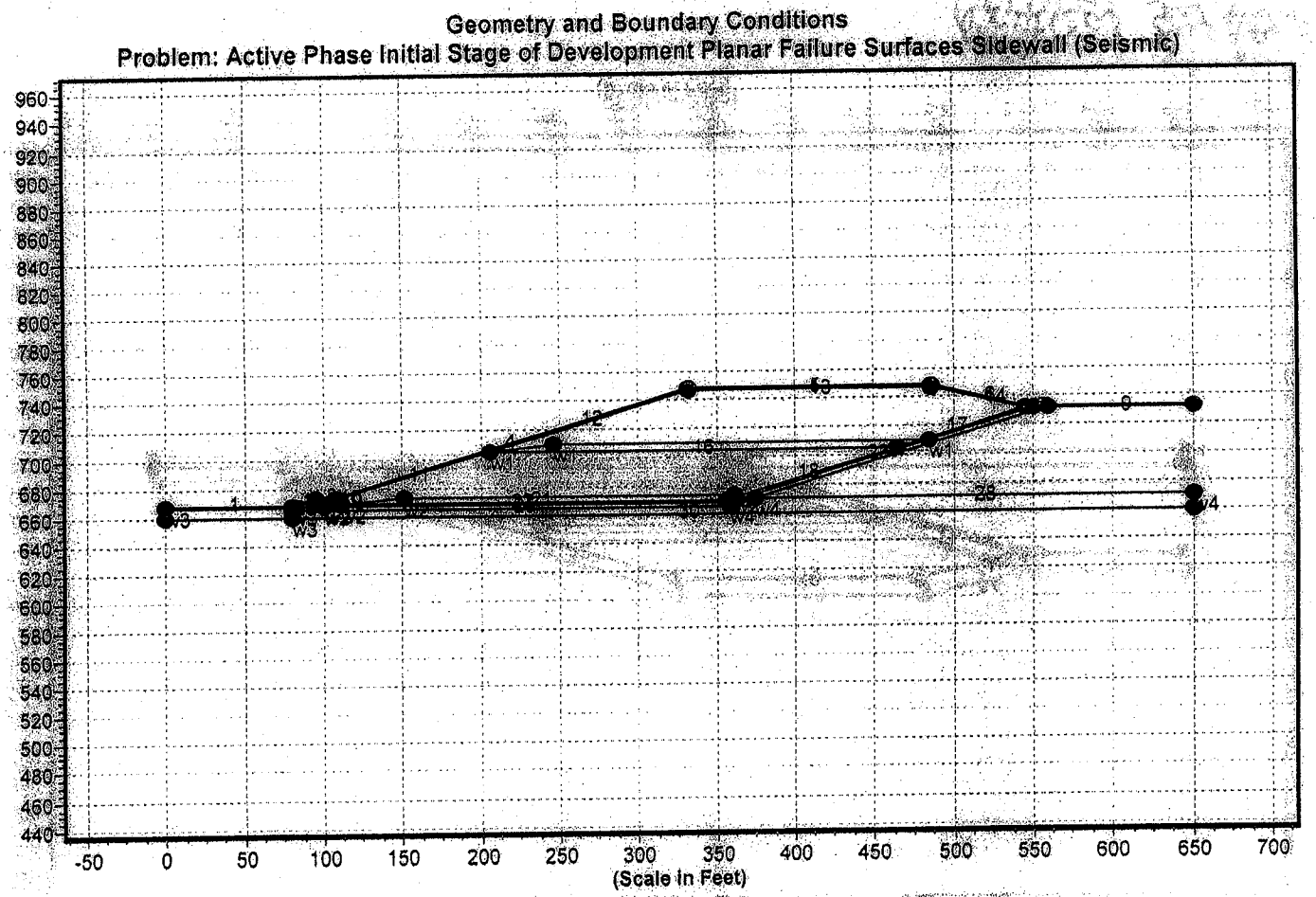
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – INITIAL STAGE OF DEVELOPMENT

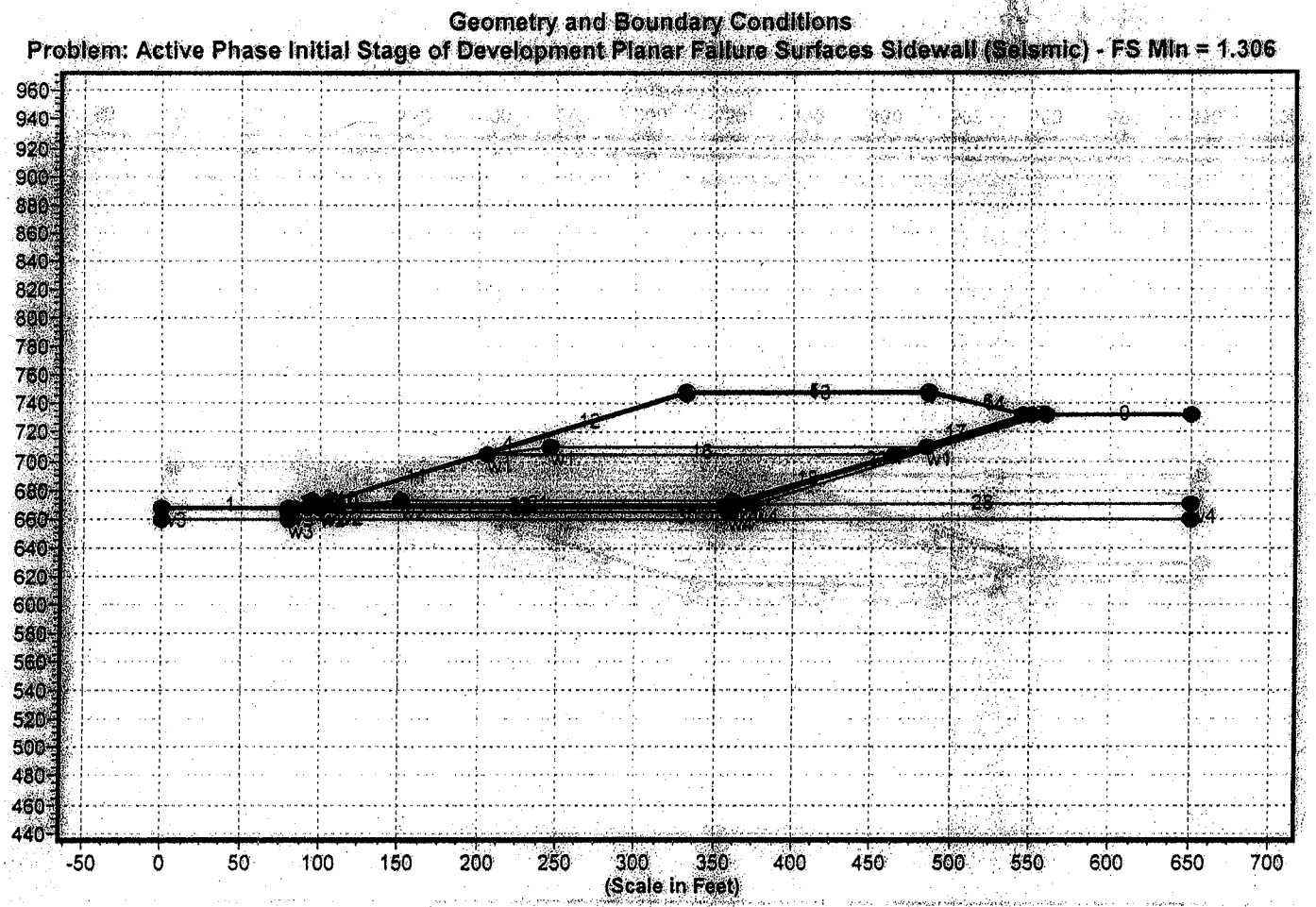
Planar Failure Surfaces – Sidewall Seismic Conditions

Key Assumptions:

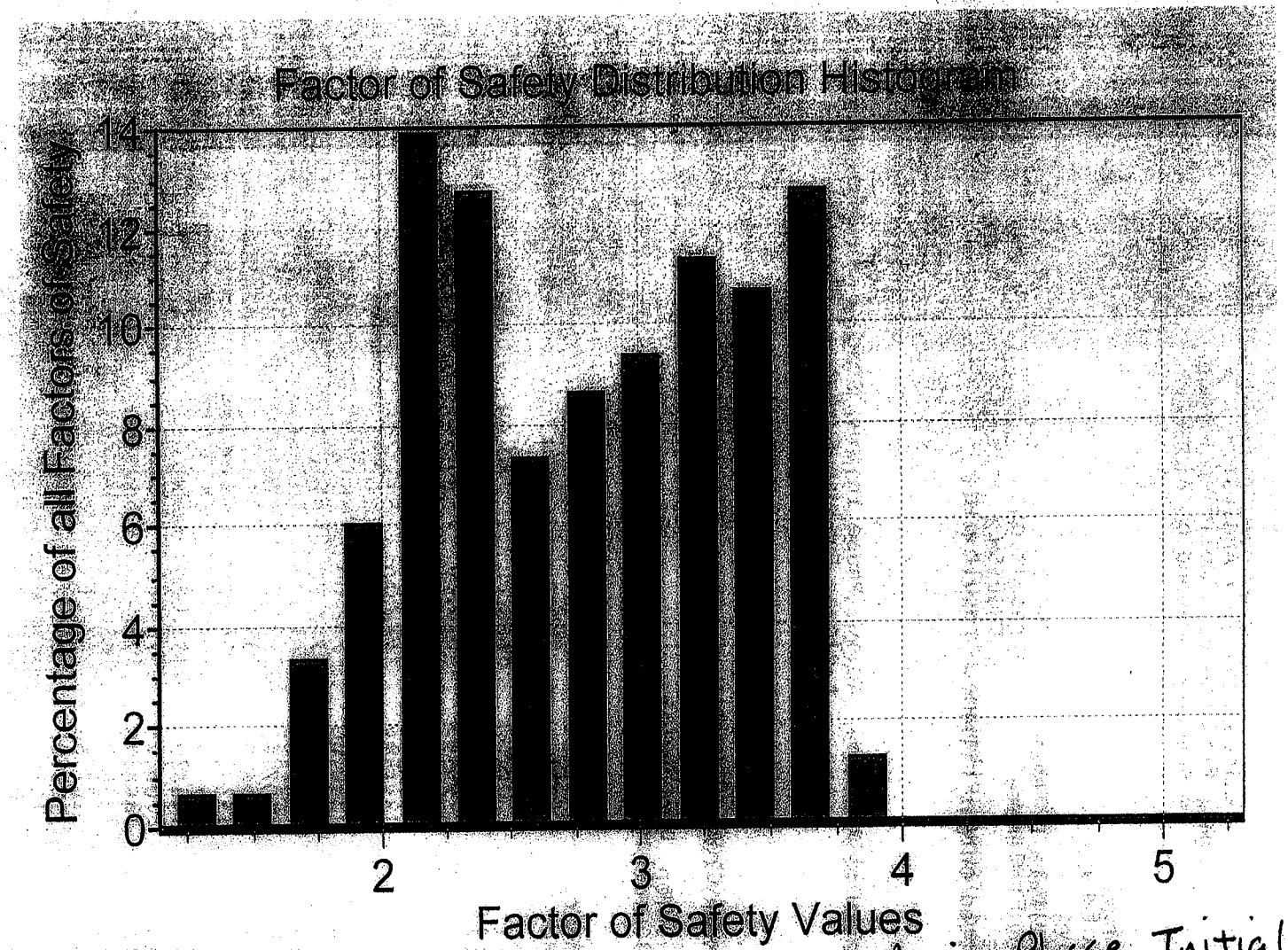
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
Failure Along Floor and Sidewall Liner Interfaces
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
3:1 (Horizontal to Vertical) Waste Slope
0.1 g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Active Phase Initial Stage of Development Planar Failure Surfaces Sidewall (Seismic)
960
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
-50
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
(Scale in Feet)

Profile



Critical Surface



Active Phase Initial Stage of Development Planar Failure Surfaces - Sidewall (Seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase Initial Stage of Developmen
t Planar Failure Surfaces Sidewall (Seis

BOUNDARY COORDINATES

9 Top Boundaries
30 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	668.00	80.09	668.00	1
2	80.09	668.00	95.09	673.00	2
3	95.09	673.00	107.09	673.00	2
4	107.09	673.00	332.09	748.00	3
5	332.09	748.00	485.38	748.00	3
6	485.38	748.00	545.26	733.03	3
7	545.26	733.03	550.00	732.00	3
8	550.00	732.00	560.00	732.00	4
9	560.00	732.00	650.00	732.00	5
10	107.09	673.00	107.88	672.27	2
11	107.88	672.27	206.26	705.00	7
12	206.26	705.00	332.26	747.00	6
13	332.26	747.00	485.26	747.00	6
14	485.26	747.00	545.26	732.00	6
15	545.26	732.00	550.00	732.00	8
16	206.26	705.00	464.26	705.00	7
17	464.26	705.00	545.26	732.00	8
18	356.26	669.00	464.26	705.00	9
19	107.88	672.21	111.09	669.00	2
20	100.09	668.00	101.09	669.00	10
21	101.09	669.00	361.00	669.00	10
22	80.09	668.00	358.00	668.00	4
23	358.00	668.00	550.00	732.00	4
24	80.09	668.00	80.13	665.00	1
25	80.13	665.00	359.00	665.00	2
26	359.00	665.00	374.00	670.00	12

			result		
27	374.00	670.00	560.00	732.00	5
28	374.00	670.00	650.00	670.00	12
29	80.13	665.00	80.19	660.00	1
30	0.00	660.00	650.00	660.00	11

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	135.0	140.0	3500.0	0.0	0.00	0.0	0
6	75.0	75.0	500.0	30.0	0.00	0.0	1
7	75.0	75.0	500.0	30.0	0.00	0.0	2
8	128.0	134.0	0.0	15.0	0.00	0.0	1
9	128.0	134.0	0.0	15.0	0.00	0.0	2
10	135.0	140.0	0.0	16.0	0.00	0.0	2
11	140.0	148.0	6000.0	0.0	0.00	0.0	0
12	100.0	110.0	1400.0	0.0	0.00	0.0	4

4 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	206.26	705.00
2	246.26	710.00
3	484.00	710.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	100.09	668.00
2	101.09	669.00
3	111.09	669.00
4	151.09	673.00
5	361.00	673.00

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	668.00
2	80.09	668.00
3	80.19	660.00

Piezometric Surface No. 4 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	359.00	665.00
2	374.00	670.00
3	650.00	670.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

3 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	112.00	668.00	120.00	668.00	2.00
2	350.00	668.00	359.00	668.00	2.00
3	545.00	730.00	560.00	730.00	1.00

1

Following Are Displayed The Ten Most Critical Of The Trial

result

Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.88	673.26
2	112.28	668.88
3	355.00	668.53
4	545.61	730.41
5	547.70	732.50

*** 1.306 ***

Individual data on the 24 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	0.7	47.5	0.0	0.0	0.0	0.0	4.8	0.0	0.0
2	3.4	1024.8	0.0	0.0	0.0	0.0	102.5	0.0	0.0
3	0.1	46.0	0.0	0.5	0.0	0.0	4.6	0.0	0.0
4	0.1	60.5	0.0	1.9	0.0	0.0	6.0	0.0	0.0
5	38.8	38402.1	0.0	5326.3	0.0	0.0	3840.2	0.0	0.0
6	55.2	120006.5	0.0	14521.0	0.0	0.0	12000.7	0.0	0.0
7	40.0	135012.1	0.0	10698.0	0.0	0.0	13501.2	0.0	0.0
8	85.8	425784.2	0.0	23437.5	0.0	0.0	42578.4	0.0	0.0
9	0.2	1027.0	0.0	47.1	0.0	0.0	102.7	0.0	0.0
10	22.7	137356.2	0.0	6318.8	0.0	0.0	13735.6	0.0	0.0
11	1.3	7607.7	0.0	353.9	0.0	0.0	760.8	0.0	0.0
12	0.2	1099.2	0.0	48.6	0.0	0.0	109.9	0.0	0.0
13	4.6	27006.7	0.0	974.6	0.0	0.0	2700.7	0.0	0.0
14	103.3	479041.9	0.0	0.0	0.0	0.0	47904.2	0.0	0.0
15	15.0	48498.0	0.0	3508.2	0.0	0.0	4849.8	0.0	0.0
16	3.5	10477.6	0.0	129.1	0.0	0.0	1047.8	0.0	0.0
17	2.5	7390.2	0.0	0.0	0.0	0.0	739.0	0.0	0.0
18	0.1	348.4	0.0	0.0	0.0	0.0	34.8	0.0	0.0
19	45.6	88011.2	0.0	0.0	0.0	0.0	8801.1	0.0	0.0
20	14.3	9393.5	0.0	0.0	0.0	0.0	939.4	0.0	0.0
21	0.4	119.8	0.0	0.0	0.0	0.0	12.0	0.0	0.0
22	0.2	59.5	0.0	0.0	0.0	0.0	6.0	0.0	0.0
23	1.4	260.9	0.0	0.0	0.0	0.0	26.1	0.0	0.0
24	0.5	19.4	0.0	0.0	0.0	0.0	1.9	0.0	0.0

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

result

1	111.80	674.57
2	117.40	668.99
3	356.45	668.84
4	546.66	730.41
5	548.01	732.43

*** 1.601 ***

1

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	106.96	673.00
2	112.22	668.71
3	354.19	668.44
4	546.17	730.19
5	548.31	732.37

*** 1.616 ***

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.05	673.65
2	114.34	668.36
3	357.59	668.95
4	546.75	730.44
5	548.60	732.30

*** 1.647 ***

1

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	110.69	674.20
2	110.83	674.15
3	118.94	668.30
4	355.59	668.87
5	545.82	729.69
6	547.58	732.53

result

*** 1.758 ***

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.50	673.14
2	112.36	668.32
3	354.15	668.76
4	545.43	729.69
5	547.88	732.46

*** 1.791 ***

1

Failure Surface Specified By 6 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.41	673.11
2	110.04	670.52
3	119.87	668.68
4	355.38	668.68
5	547.75	730.37
6	547.99	732.44

*** 1.799 ***

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	109.85	673.92
2	116.35	668.02
3	355.51	668.28
4	548.26	730.44
5	549.83	732.04

*** 1.863 ***

1

result

Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	110.49	674.13
2	117.57	667.98
3	357.14	668.34
4	546.57	730.43
5	547.23	732.60

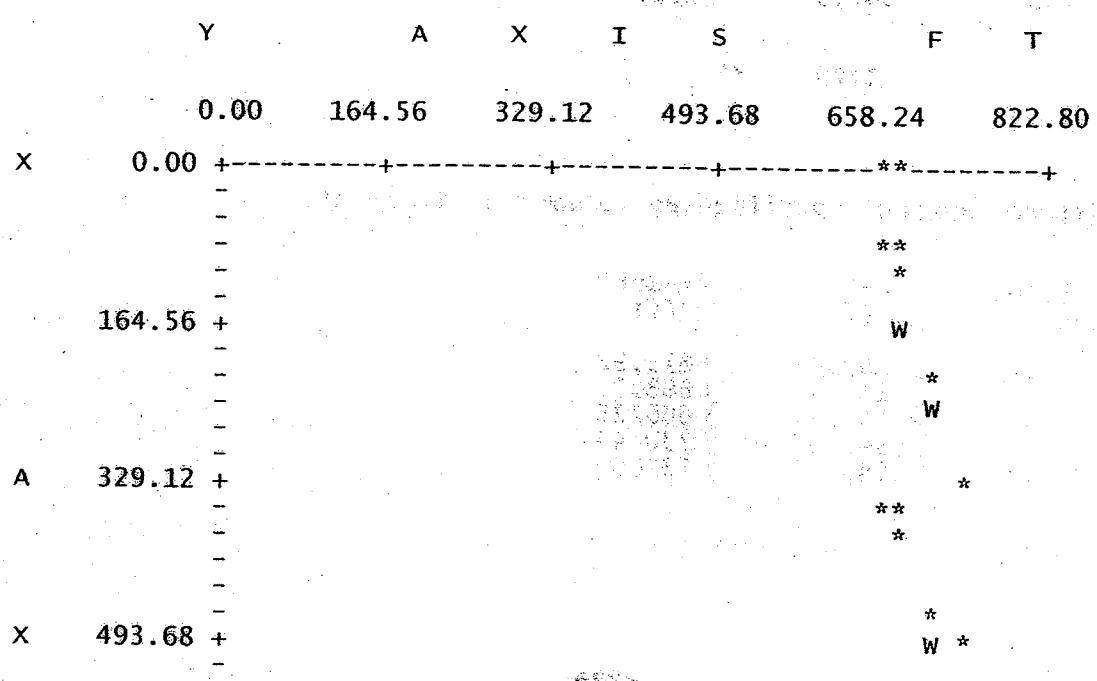
*** 1.873 ***

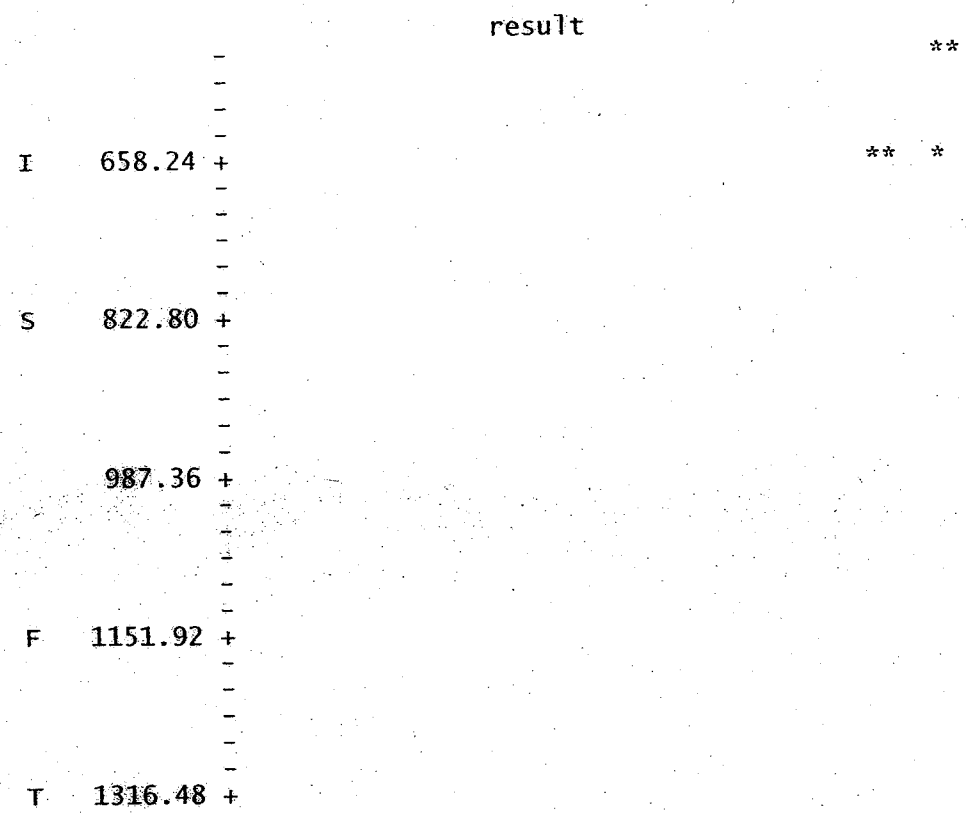
Failure Surface Specified By 5 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	107.26	673.06
2	115.90	668.72
3	352.33	668.55
4	546.52	730.01
5	548.64	732.29

*** 1.876 ***

1



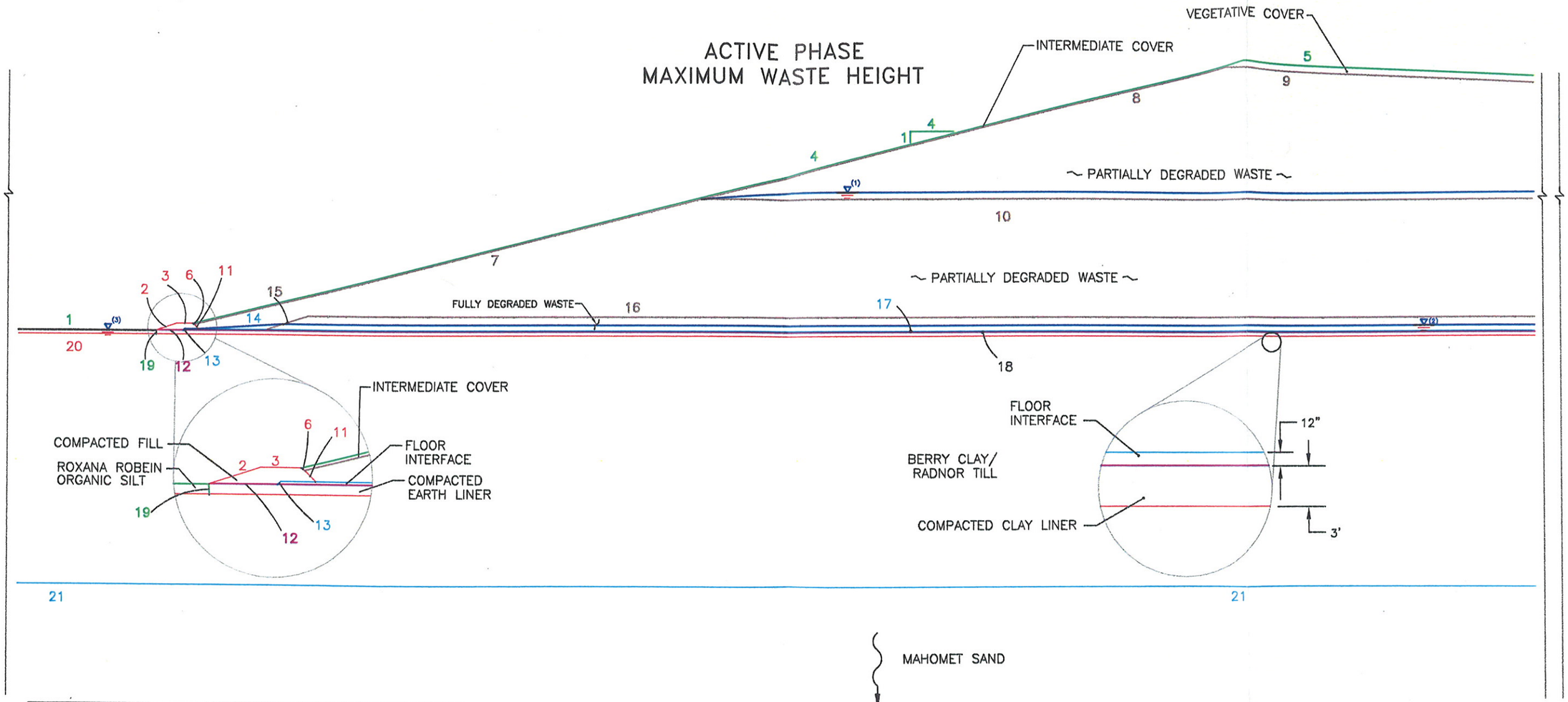

result
I
658.24
S
822.80
987.36
F
1151.92
T
1316.48

SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

CAD DWG NO:911181152G EMPLOYEE NO: 9834 DATE/TIME: 11/20/06 10:55 ACAD-16.

ACTIVE PHASE
MAXIMUM WASTE HEIGHT



SOIL IDENTITY	SOIL NUMBER
ROXANA ROBEIN:ORGANIC SILT	1
COMPACTED FILL	2
VEGETATIVE/INTERMEDIATE COVER	3
PARTIALLY DEGRADED WASTE	4, 5
COMPACTED CLAY LINER	6
FLOOR INTERFACE	7
FULLY DEGRADED WASTE	8
BERRY CLAY/RADNOR TILL	9
MAHOMET SAND	10

MAHOMET SAND

80' 40' 0 80' 160'

1"=80'

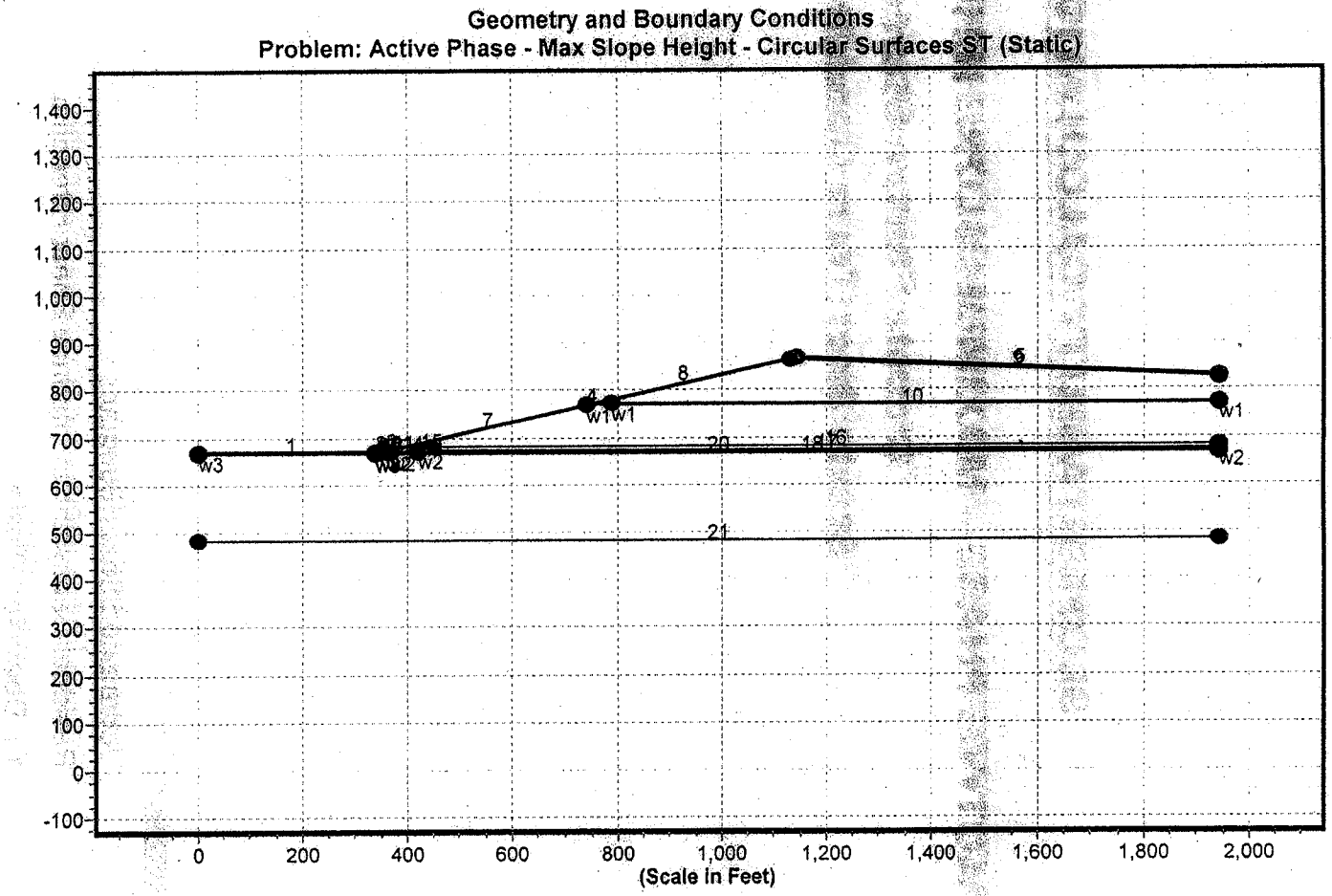
LEGEND

2 BOUNDARY NO.

PIEZOMETRIC SURFACE

PDC Technical Services, Inc.
Peoria, Illinois
Illinois Licensed Professional Design Firm 184-001145

APP. 812.305-E: FIGURE C
ACTIVE PHASE
MAXIMUM WASTE HEIGHT
CLINTON LANDFILL NO. 3
CLINTON, ILLINOIS
PROJECT NO. 91-118


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Circular Surfaces ST (Static)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
(Scale in Feet)
w1
w2
w3
1
7
8
10
20
21

Profile

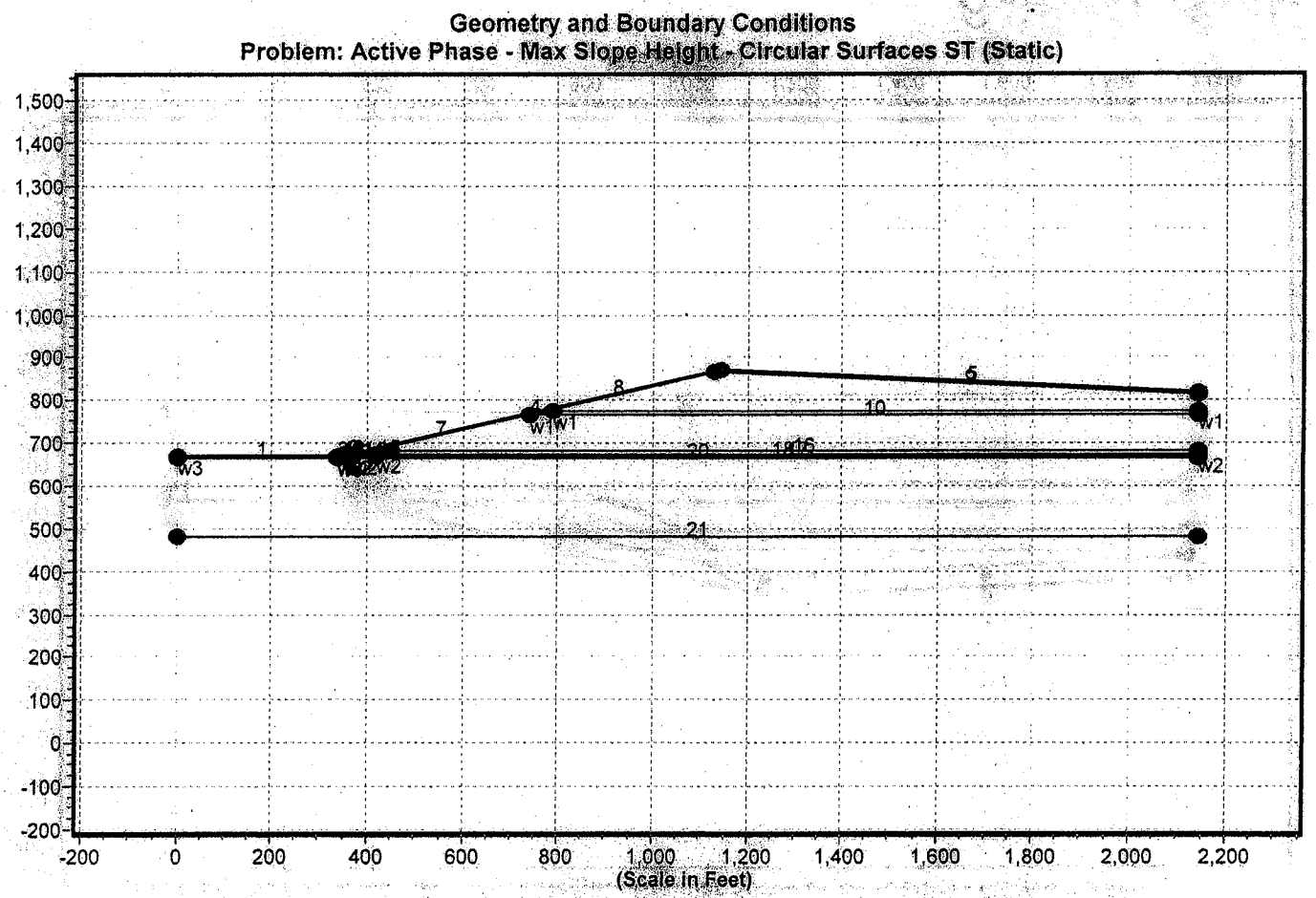
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

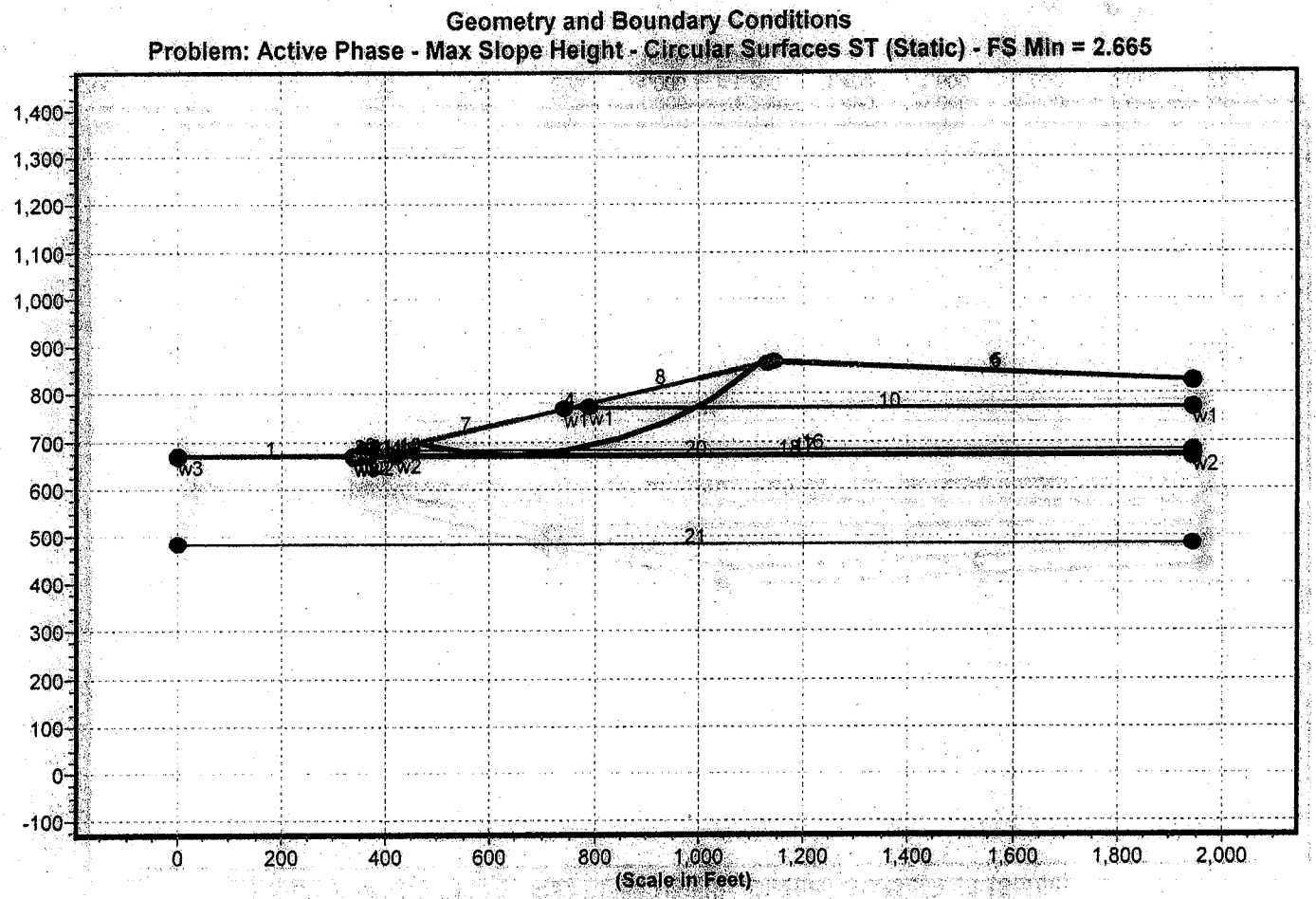
Circular Failure Surfaces
Static Short Term Conditions

Key Assumptions:

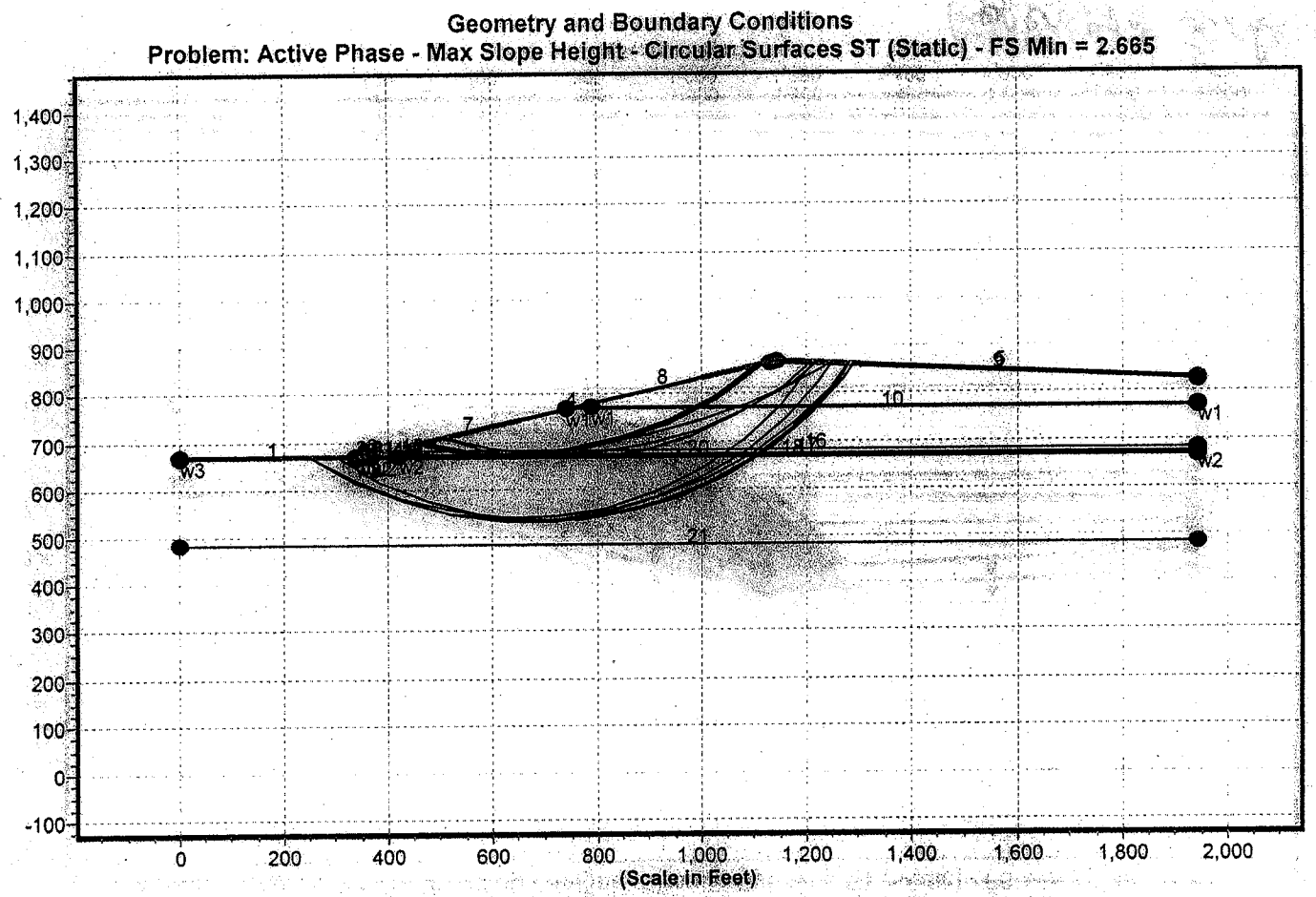
Undrained Shear Strengths
Residual Geosynthetic Interface Shear Strengths
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Circular Surfaces ST (Static)
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-200
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
(Scale in Feet)
1
5
7
8
10
21
W1
W2
W3

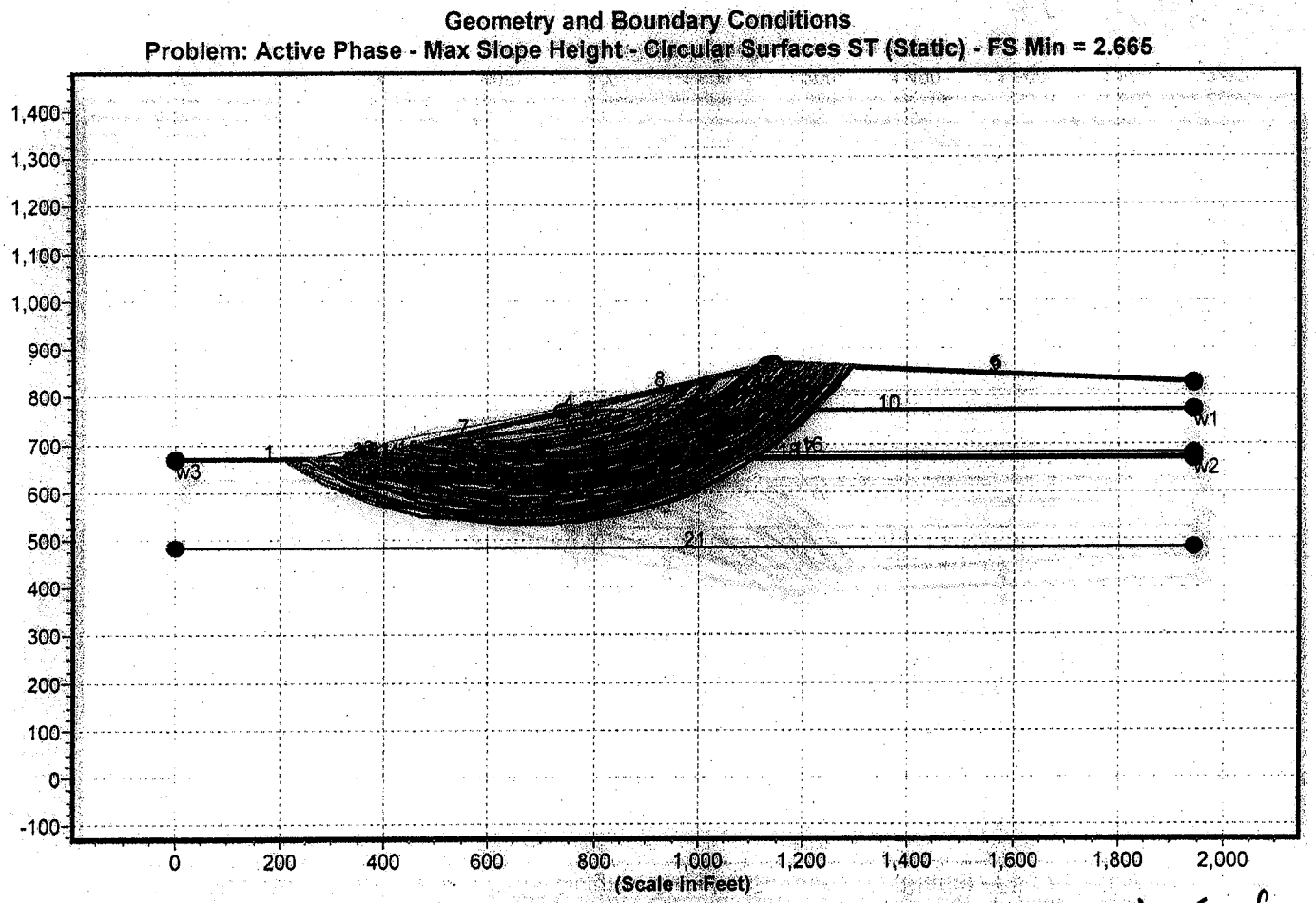
Profile



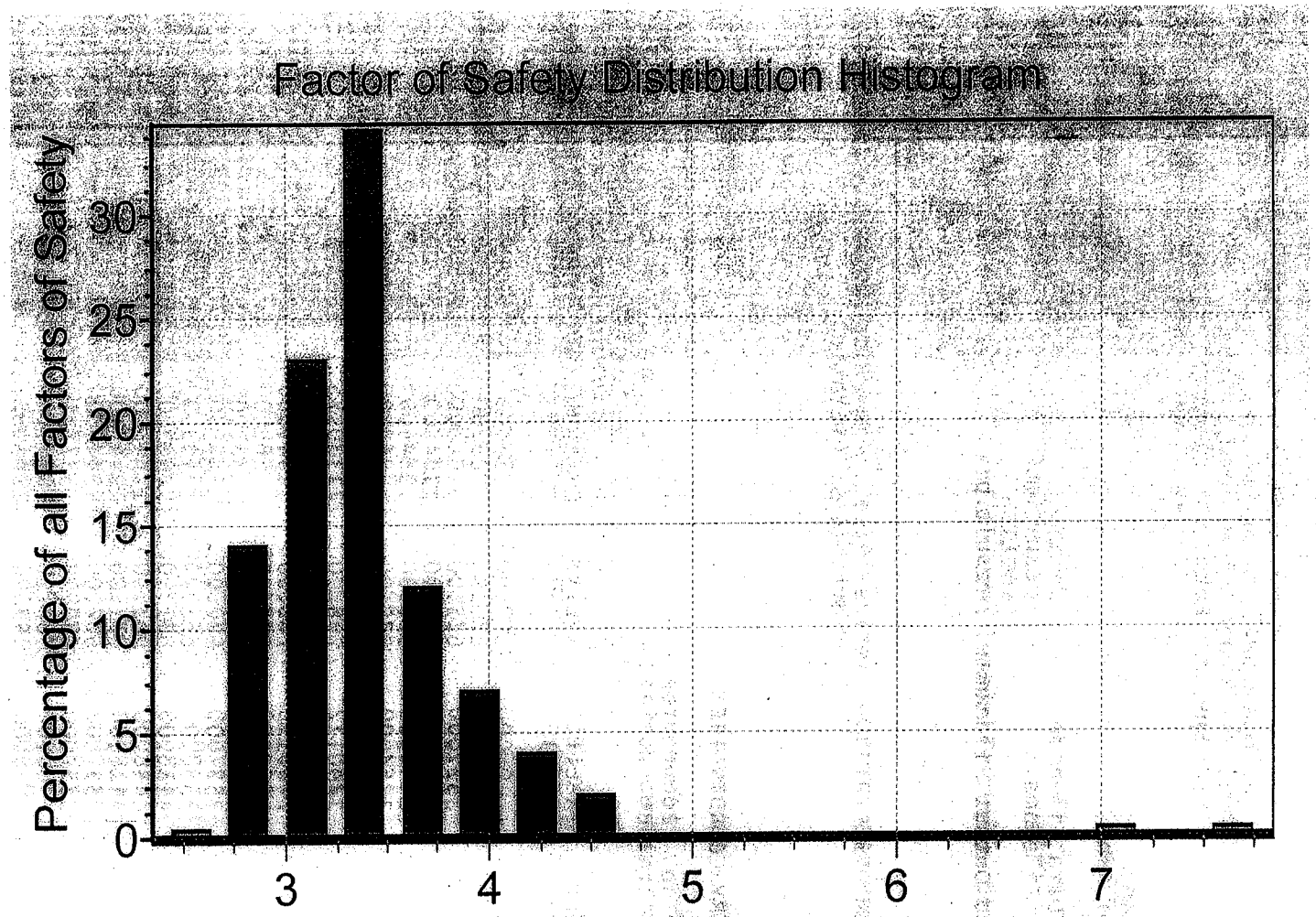
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase – Max. Slope Height

Circular Surfaces

Short Term (static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Circular Surfaces ST (Static)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
3	352.00	675.00	364.00	675.00	2
4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	3000.0	0.0	0.00	0.0	0
7	135.0	140.0	0.0	10.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	6000.0	0.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

result
3 337.10 667.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

200 Trial Surfaces Have Been Generated.

20 Surfaces Initiate From Each Of 10 Points Equally Spaced Along The Ground Surface Between X = 200.00 ft.
and X = 650.00 ft.

Each Surface Terminates Between X =1000.00 ft.
and X =1300.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =300.00 ft.

100.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -33.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	450.00	696.50
2	548.10	677.11
3	647.97	671.95
4	747.55	681.15
5	844.78	704.50
6	937.67	741.53
7	1024.30	791.48
8	1102.89	853.32
9	1110.89	861.72

Circle Center At X = 633.8 ; Y = 1368.6 and Radius, 696.8

*** 2.665 ***

result

Individual data on the 18 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	2.3	149.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	76.1	107236.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	19.7	60599.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	40.8	161491.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	59.1	305091.0	0.0	5624.2	0.0	0.0	0.0	0.0	0.0
6	33.0	198954.2	0.0	3151.6	0.0	0.0	0.0	0.0	0.0
7	59.1	381239.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	5.8	39258.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1.6	10841.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	43.5	295535.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	53.8	367677.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	92.9	588797.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	45.9	241392.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	8.7	39808.9	0.0	1561.6	0.0	0.0	0.0	0.0	0.0
15	32.1	131161.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	78.6	166379.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	6.7	2238.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.3	84.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	500.00	709.00
2	595.83	680.41
3	694.87	666.60
4	794.86	667.88
5	893.51	684.23
6	988.57	715.28
7	1077.86	760.30
8	1159.34	818.28
9	1209.32	866.73

Circle Center At X = 736.4 ; Y = 1326.4 and Radius, 661.1

*** 2.742 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	300.00	670.00
2	384.26	616.15

result

3	475.50	575.22
4	571.76	548.10
5	670.94	535.38
6	770.92	537.32
7	869.54	553.88
8	964.67	584.72
9	1054.25	629.15
10	1136.36	686.23
11	1209.22	754.73
12	1271.27	833.15
13	1288.32	862.78

Circle Center At X = 707.8 ; Y = 1215.2 and Radius, 680.8

*** 2.747 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	300.00	670.00
2	384.03	615.79
3	475.18	574.66
4	571.43	547.53
5	670.64	534.98
6	770.61	537.31
7	869.13	554.47
8	964.01	586.06
9	1053.15	631.39
10	1134.56	689.46
11	1206.45	758.97
12	1267.22	838.39
13	1280.88	863.16

Circle Center At X = 705.0 ; Y = 1205.6 and Radius, 671.5

*** 2.749 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	250.00	670.00
2	334.71	616.85
3	425.94	575.90
4	521.95	547.93
5	620.90	533.47
6	720.89	532.80
7	820.03	545.94
8	916.40	572.63

		result
9	1008.17	612.36
10	1093.58	664.37
11	1171.00	727.67
12	1238.94	801.04
13	1282.17	863.09

Circle Center At X = 675.7 ; Y = 1254.4 and Radius, 723.0

*** 2.755 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	400.00	684.00
2	499.59	675.00
3	599.59	673.61
4	699.39	679.84
5	798.43	693.65
6	896.14	714.95
7	991.94	743.63
8	1085.27	779.52
9	1175.61	822.41
10	1249.58	864.72

Circle Center At X = 567.9 ; Y = 1982.0 and Radius, 1308.8

*** 2.768 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	250.00	670.00
2	334.41	616.39
3	425.69	575.54
4	521.92	548.32
5	621.06	535.29
6	721.05	536.74
7	819.78	552.62
8	915.18	582.61
9	1005.24	626.07
10	1088.07	682.10
11	1161.94	749.51
12	1225.28	826.89
13	1248.05	864.80

Circle Center At X = 661.1 ; Y = 1224.1 and Radius, 689.9

result

*** 2.786 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	250.00	670.00
2	336.06	619.08
3	428.20	580.20
4	524.73	554.08
5	623.89	541.19
6	723.89	541.77
7	822.90	555.80
8	919.12	583.03
9	1010.80	622.97
10	1096.27	674.88
11	1173.97	737.83
12	1242.50	810.66
13	1279.99	863.20

Circle Center At X = 669.6 ; Y = 1281.0 and Radius, 741.2

*** 2.800 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	500.00	709.00
2	597.00	684.70
3	696.41	673.82
4	796.37	676.56
5	895.03	692.88
6	990.55	722.47
7	1081.16	764.79
8	1165.17	819.03
9	1220.06	866.20

Circle Center At X = 726.3 ; Y = 1406.5 and Radius, 733.3

*** 2.821 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

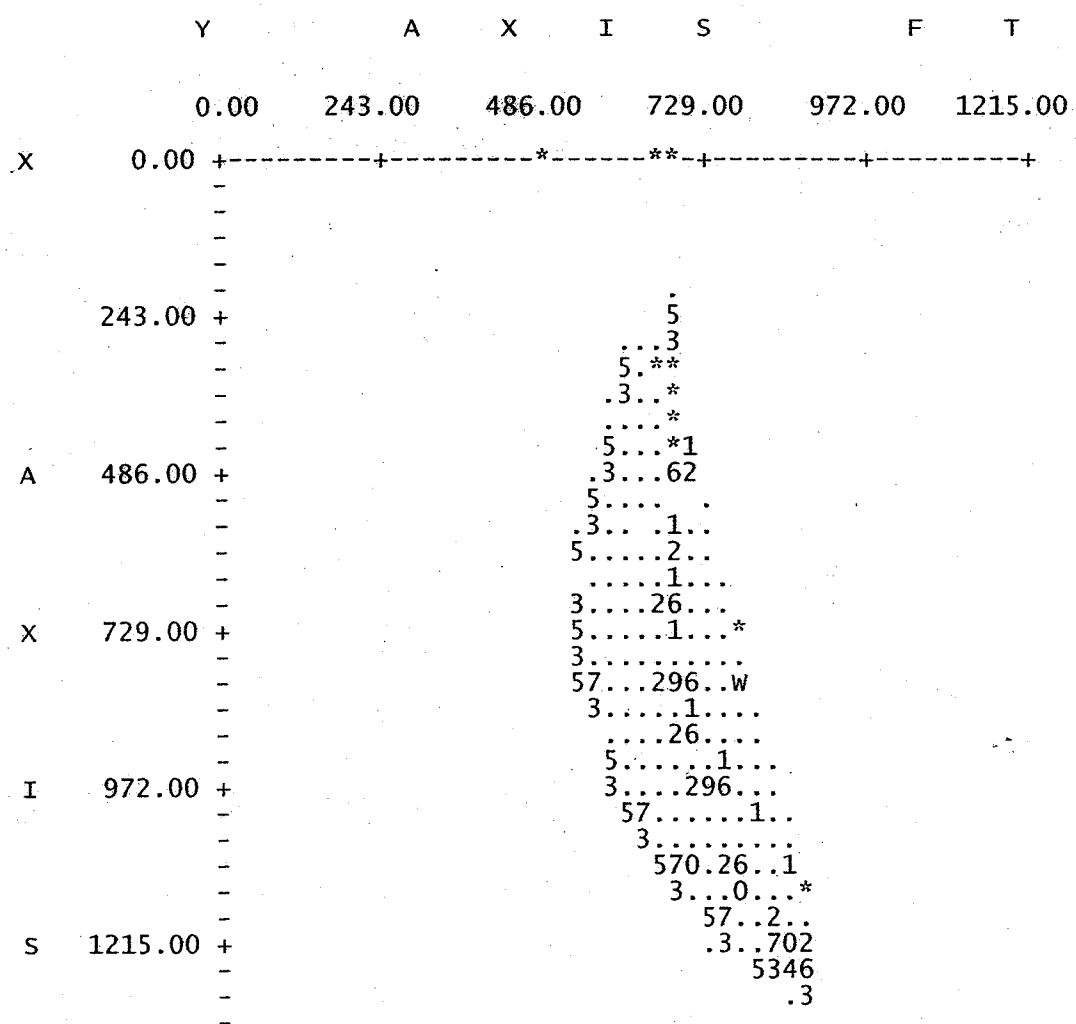
result

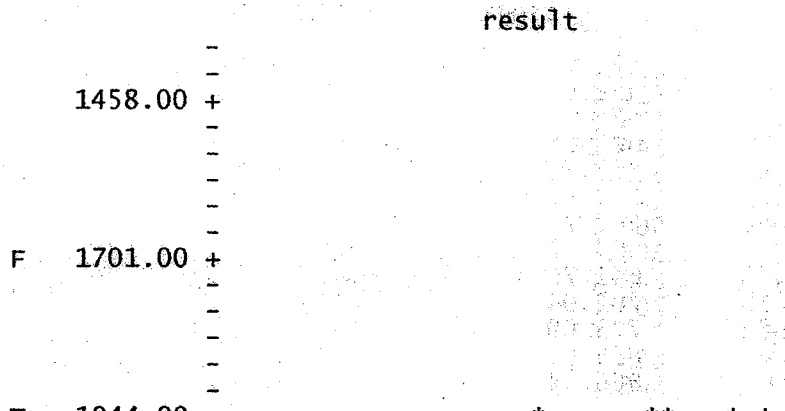
1	250.00	670.00
2	334.21	616.07
3	425.62	575.51
4	522.11	549.26
5	621.47	537.93
6	721.39	541.79
7	819.58	560.73
8	913.77	594.32
9	1001.78	641.79
10	1081.59	702.04
11	1151.36	773.69
12	1209.46	855.08
13	1215.21	866.44

Circle Center At X = 646.2 ; Y = 1195.8 and Radius, 658.4

*** 2.842 ***

1




result
1458.00 +
F 1701.00 +
T 1944.00 +

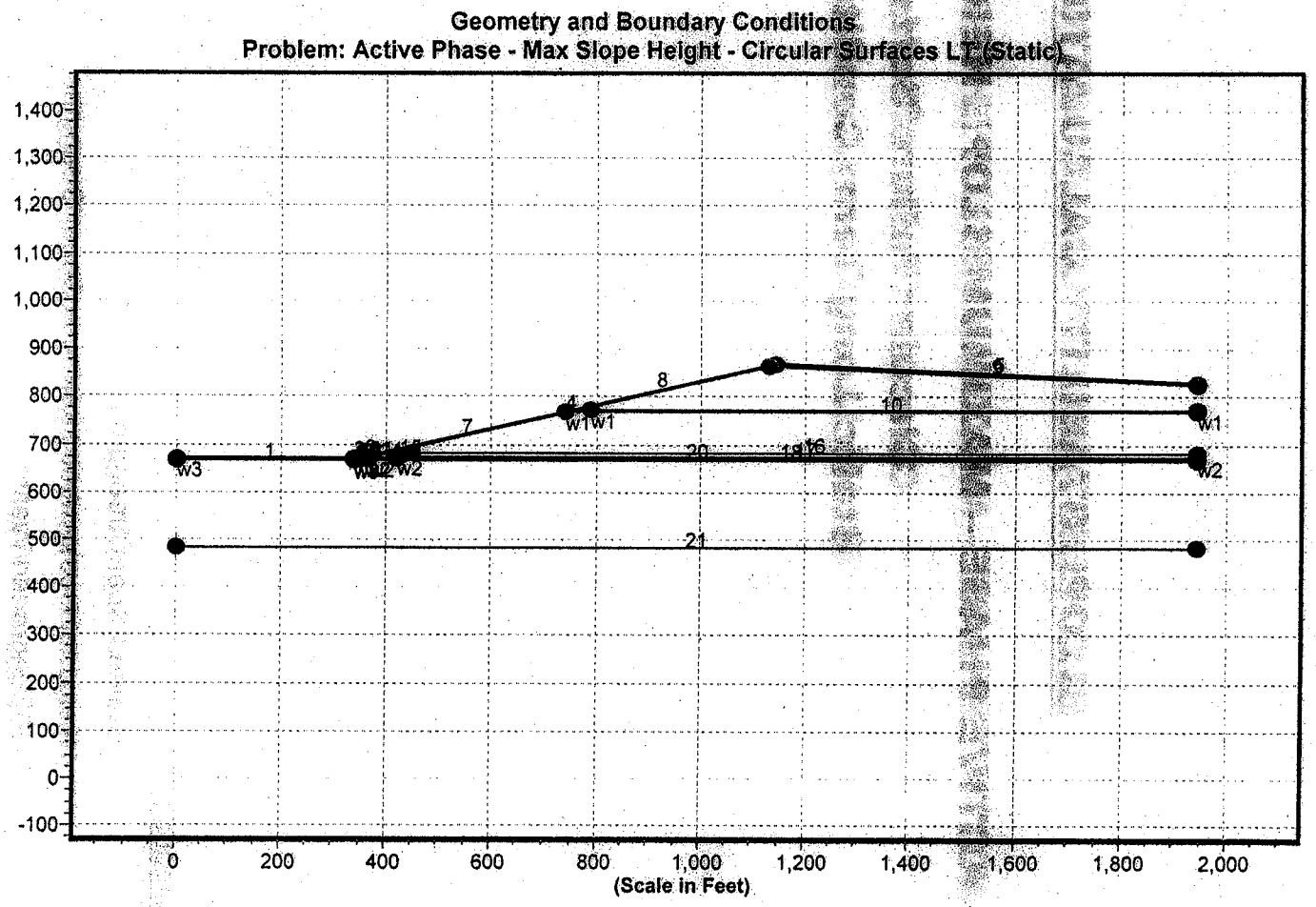
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

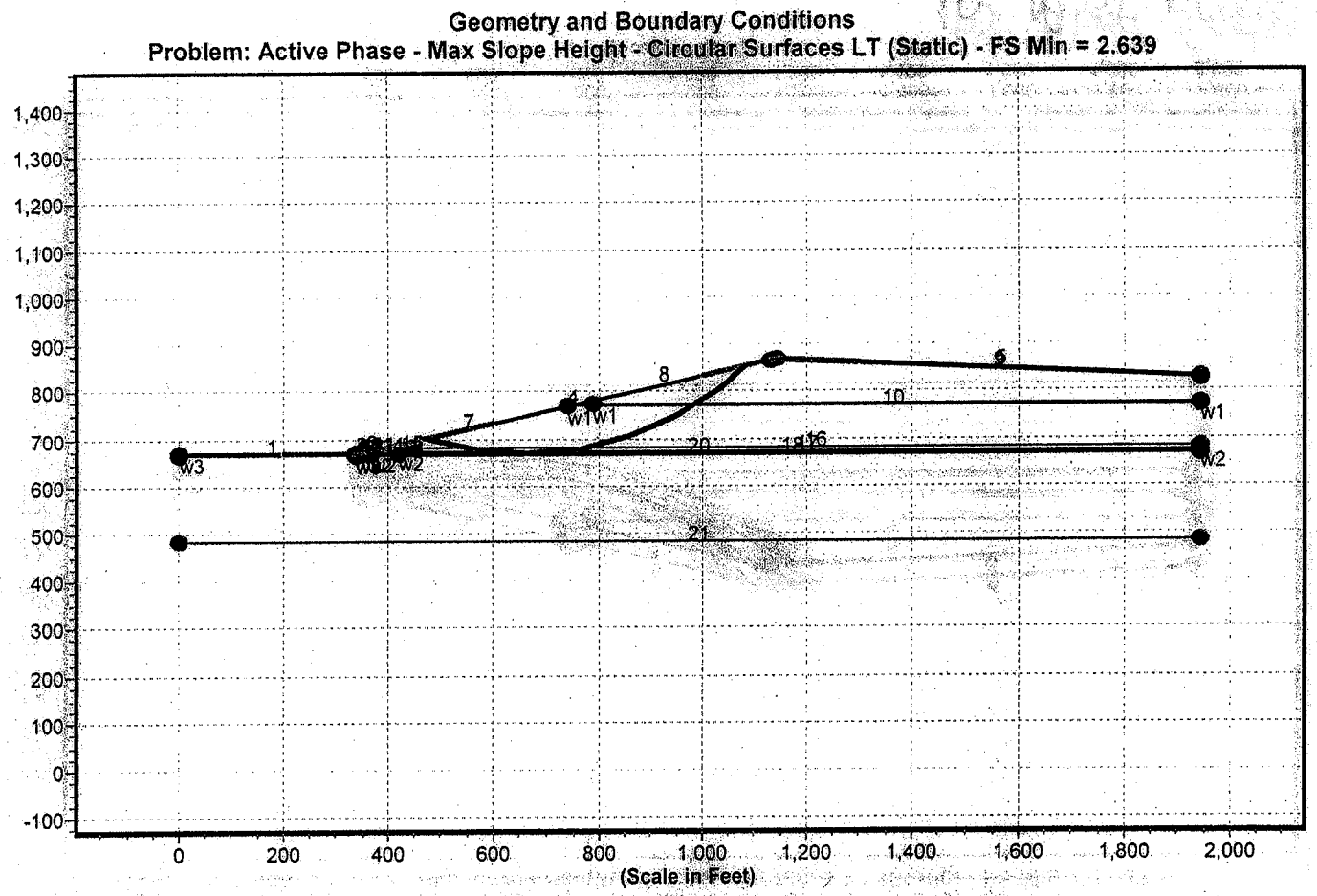
Circular Failure Surfaces
Static Long Term Conditions

Key Assumptions:

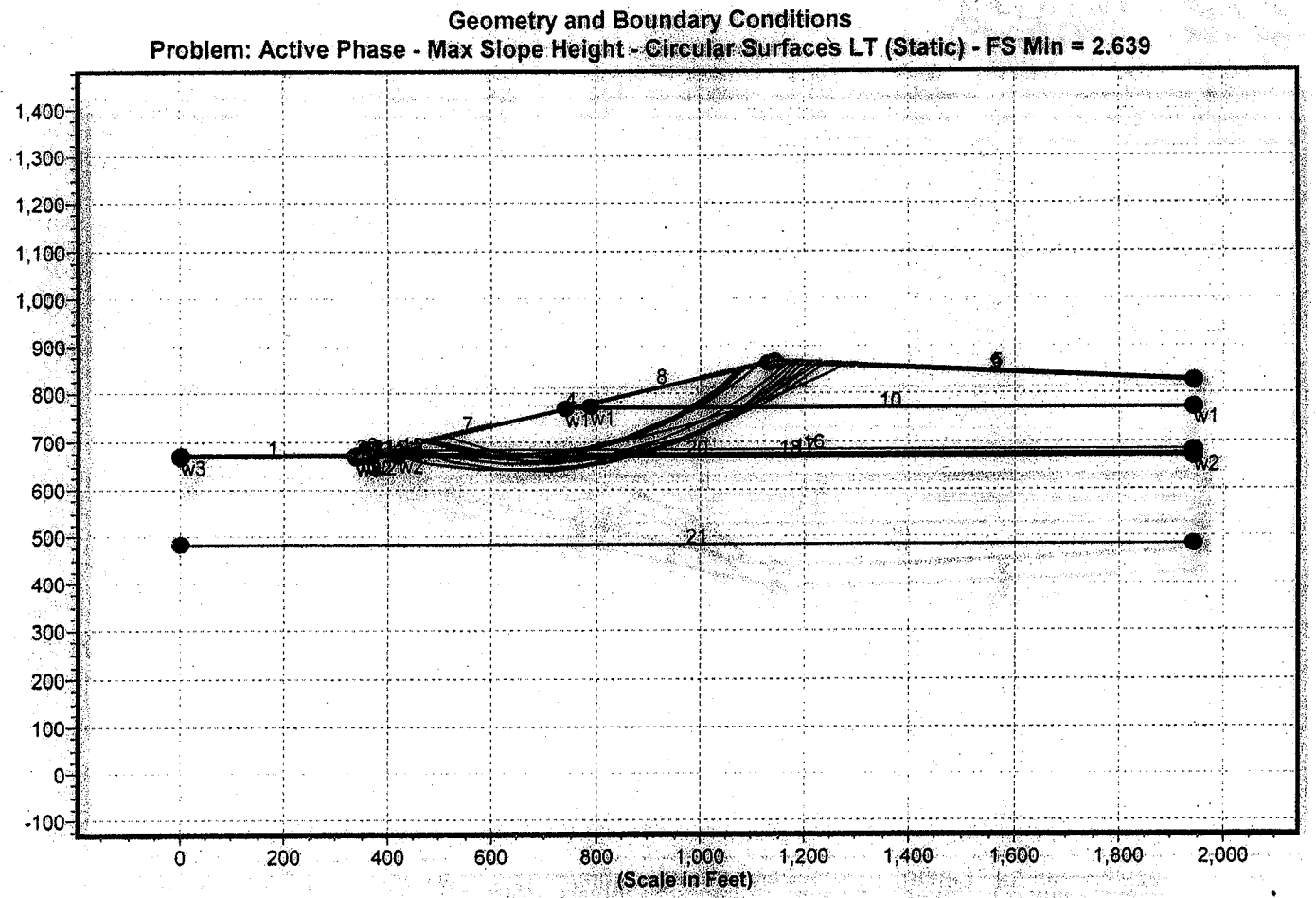
Drained Shear Strengths
Residual Geosynthetic Interface Shear Strengths
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Circular Surfaces LT (Static)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
(Scale in Feet)
w3
w2
w1
1
7
8
9
10
20
21

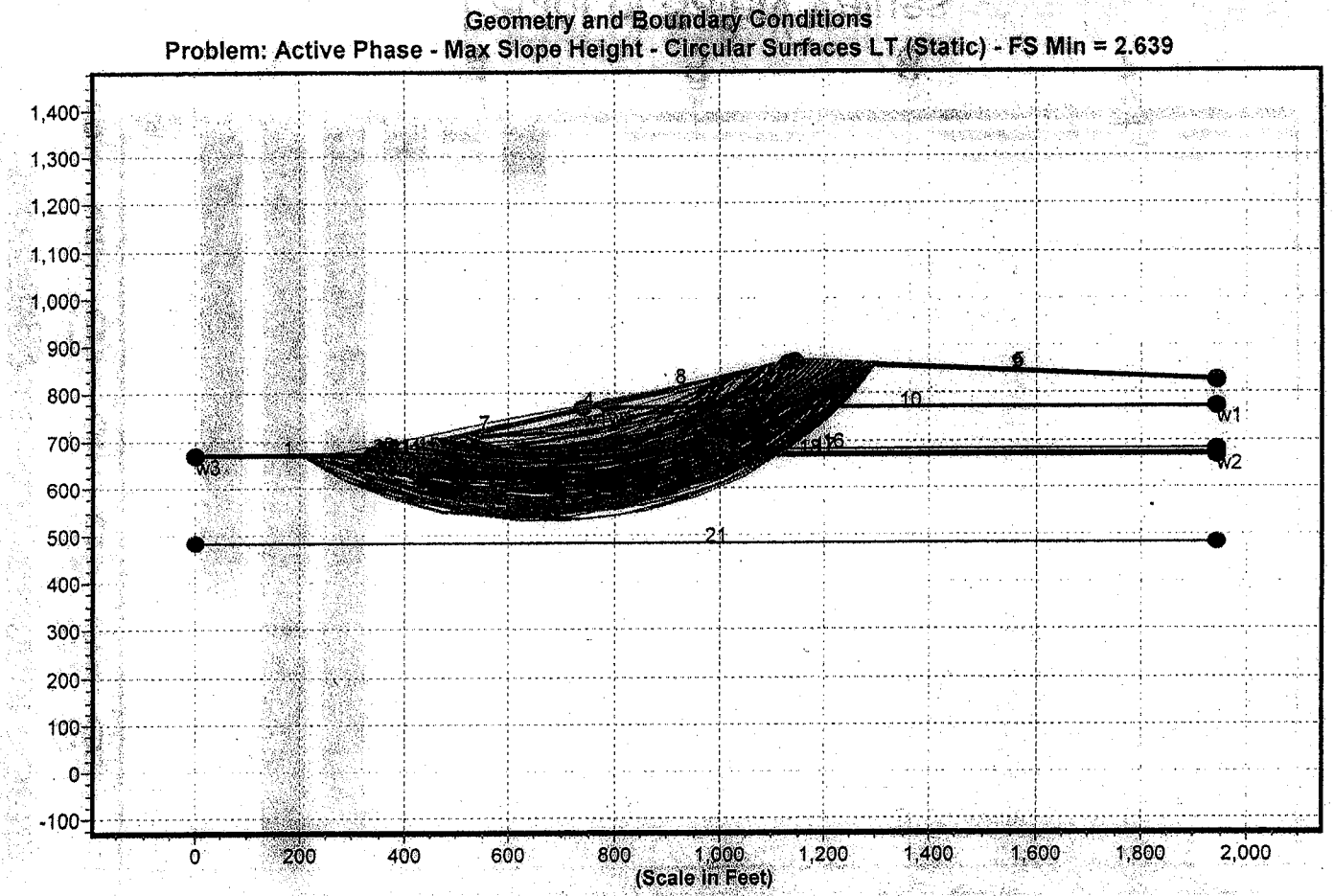
Profile



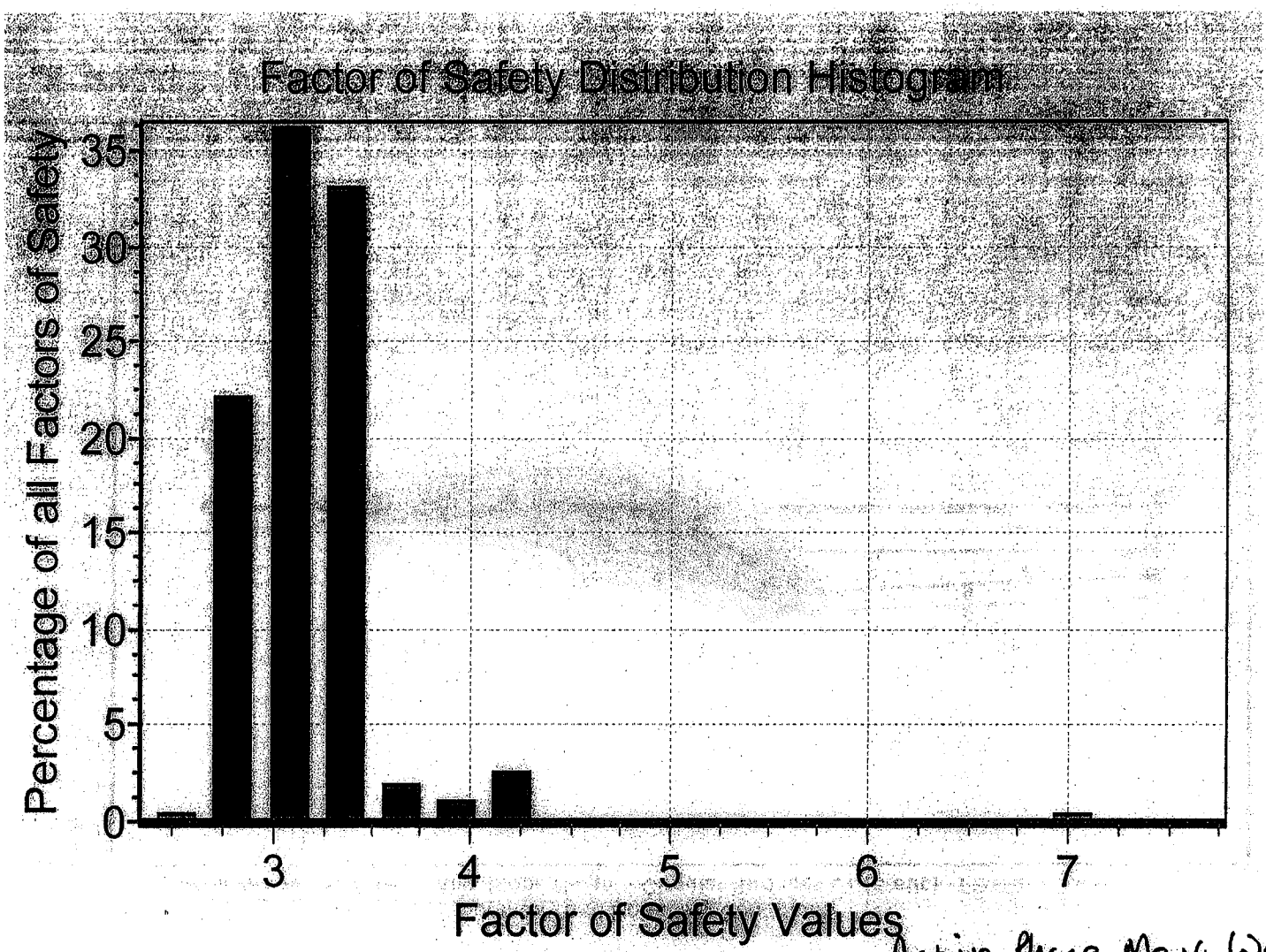
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase-Max Waste Height
Circular Surfaces
Long Term (Static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Circular Surfaces LT (Static)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
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4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1500.0	19.0	0.00	0.0	3
2	135.0	140.0	700.0	21.0	0.00	0.0	0
3	128.0	134.0	1300.0	22.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	700.0	21.0	0.00	0.0	0
7	135.0	140.0	0.0	10.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	1100.0	18.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

result
3 337.10 667.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

200 Trial Surfaces Have Been Generated.

20 Surfaces Initiate From Each Of 10 Points Equally Spaced Along The Ground Surface Between X = 200.00 ft.
and X = 600.00 ft.

Each Surface Terminates Between X =1000.00 ft.
and X =1300.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =300.00 ft.

100.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -33.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 8 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	466.67	700.67
2	563.86	677.14
3	663.63	670.30
4	763.12	680.34
5	859.51	706.98
6	950.04	749.45
7	1032.14	806.55
8	1080.56	854.14

Circle Center At X = 653.7 ; Y = 1256.9 and Radius, 586.9

*** 2.639 ***

result

Individual data on the 19 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	2.1	136.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	79.2	126028.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	15.9	54283.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	31.2	129978.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	58.3	310657.3	0.0	7298.7	0.0	0.0	0.0	0.0	0.0
6	10.2	63443.6	0.0	2772.1	0.0	0.0	0.0	0.0	0.0
7	6.9	44204.6	0.0	1888.1	0.0	0.0	0.0	0.0	0.0
8	39.6	260139.4	0.0	4971.2	0.0	0.0	0.0	0.0	0.0
9	29.9	205011.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	23.0	162462.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	2.4	16980.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	25.5	181257.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	68.5	480551.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	90.5	561554.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	26.7	133694.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	7.2	31975.1	0.0	1366.1	0.0	0.0	0.0	0.0	0.0
17	48.2	169884.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	47.0	66939.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1.4	92.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	422.22	689.56
2	520.32	670.16
3	620.15	664.30
4	719.85	672.09
5	817.56	693.38
6	911.46	727.77
7	999.80	774.63
8	1080.94	833.08
9	1111.08	861.77

Circle Center At X = 613.1 ; Y = 1397.1 and Radius, 732.8

*** 2.680 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	422.22	689.56
2	519.08	664.66

		result
3	618.42	653.20
4	718.39	655.38
5	817.14	671.17
6	912.81	700.26
7	1003.63	742.12
8	1087.90	795.96
9	1164.04	860.79
10	1171.06	868.65

Circle Center At X = 652.4 ; Y = 1382.4 and Radius, 730.0

*** 2.696 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	466.67	700.67
2	563.67	676.36
3	663.00	664.79
4	762.99	666.14
5	861.97	680.39
6	958.28	707.31
7	1050.31	746.43
8	1136.51	797.11
9	1215.45	858.50
10	1222.92	866.05

Circle Center At X = 702.5 ; Y = 1434.2 and Radius, 770.5

*** 2.702 ***

1

Failure Surface Specified By 11 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	377.78	678.44
2	477.49	670.85
3	577.49	669.90
4	677.32	675.59
5	776.56	687.90
6	874.76	706.77
7	971.50	732.13
8	1066.33	763.86
9	1158.85	801.81
10	1248.64	845.83
11	1278.91	863.25

Circle Center At X = 541.8 ; Y = 2174.1 and Radius, 1504.6

result

*** 2.705 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	466.67	700.67
2	562.49	672.08
3	661.42	657.48
4	761.42	657.18
5	860.44	671.18
6	956.43	699.19
7	1047.44	740.64
8	1131.58	794.68
9	1207.13	860.19
10	1212.64	866.57

Circle Center At X = 713.4 ; Y = 1351.4 and Radius, 695.9

*** 2.730 ***

1

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	422.22	689.56
2	517.68	659.75
3	616.36	643.59
4	716.34	641.39
5	815.64	653.20
6	912.31	678.78
7	1004.46	717.63
8	1090.26	768.99
9	1168.03	831.85
10	1200.97	867.15

Circle Center At X = 681.5 ; Y = 1348.7 and Radius, 708.3

*** 2.731 ***

Failure Surface Specified By 10 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

		result
1	422.22	689.56
2	517.25	658.43
3	615.87	641.84
4	715.86	640.17
5	814.97	653.46
6	910.98	681.41
7	1001.75	723.38
8	1085.22	778.44
9	1159.54	845.36
10	1178.38	868.28

Circle Center At X = 676.6 ; Y = 1302.4 and Radius, 663.5

*** 2.734 ***

1

Failure Surface Specified By 9 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	511.11	711.78
2	605.71	679.37
3	704.46	663.59
4	804.45	664.91
5	902.75	683.29
6	996.46	718.19
7	1082.83	768.58
8	1159.33	832.99
9	1188.58	867.77

Circle Center At X = 746.8 ; Y = 1245.3 and Radius, 583.3

*** 2.755 ***

Failure Surface Specified By 11 Coordinate Points

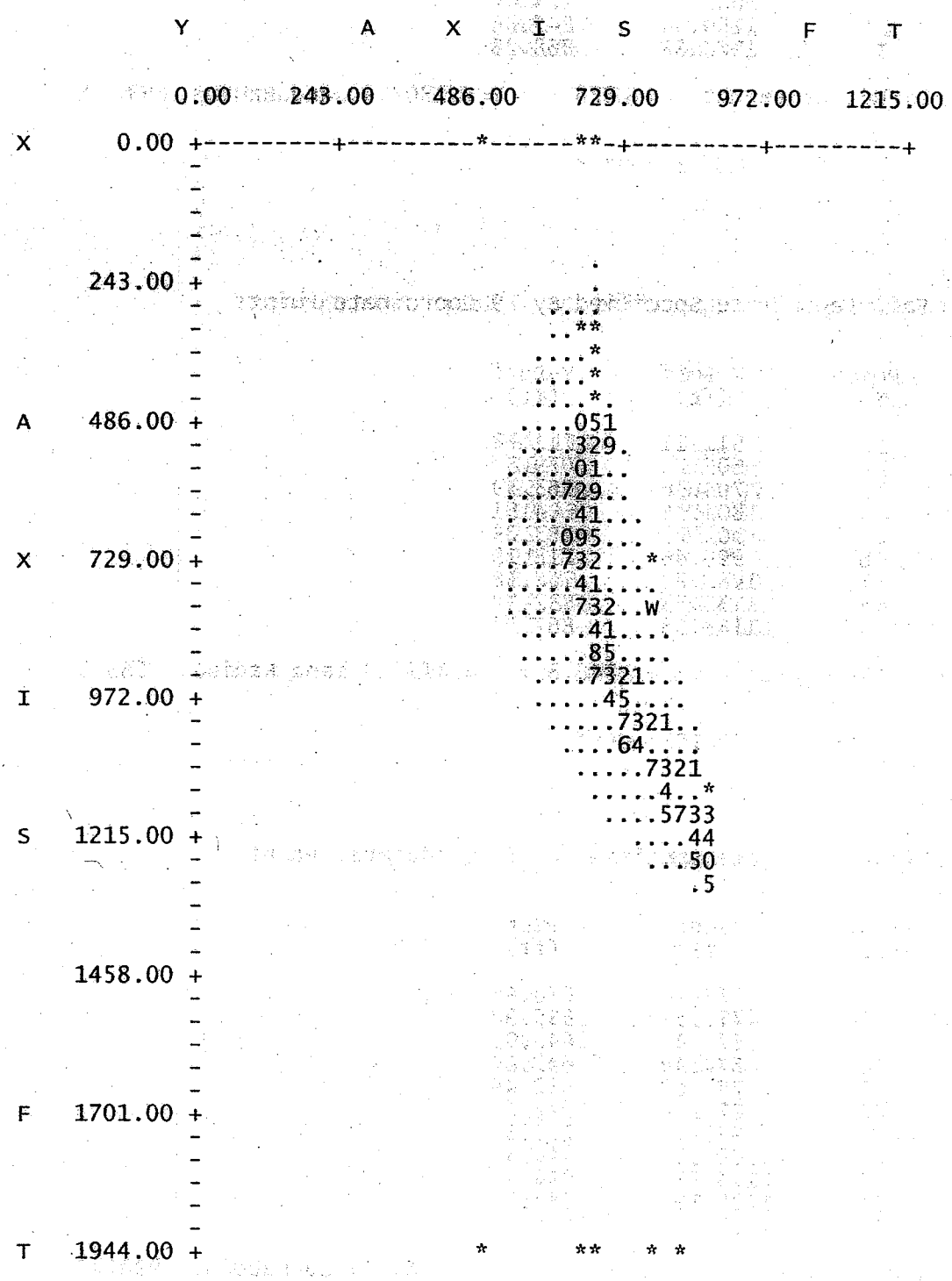
Point No.	X-Surf (ft)	Y-Surf (ft)
1	377.78	678.44
2	475.20	655.90
3	574.49	643.99
4	674.49	642.84
5	774.02	652.48
6	871.94	672.78
7	967.10	703.52
8	1058.39	744.34
9	1144.75	794.75
10	1225.18	854.17
11	1237.30	865.34

Circle Center At X = 635.1 ; Y = 1568.7 and Radius, 926.7

result

*** 2.763 ***

1



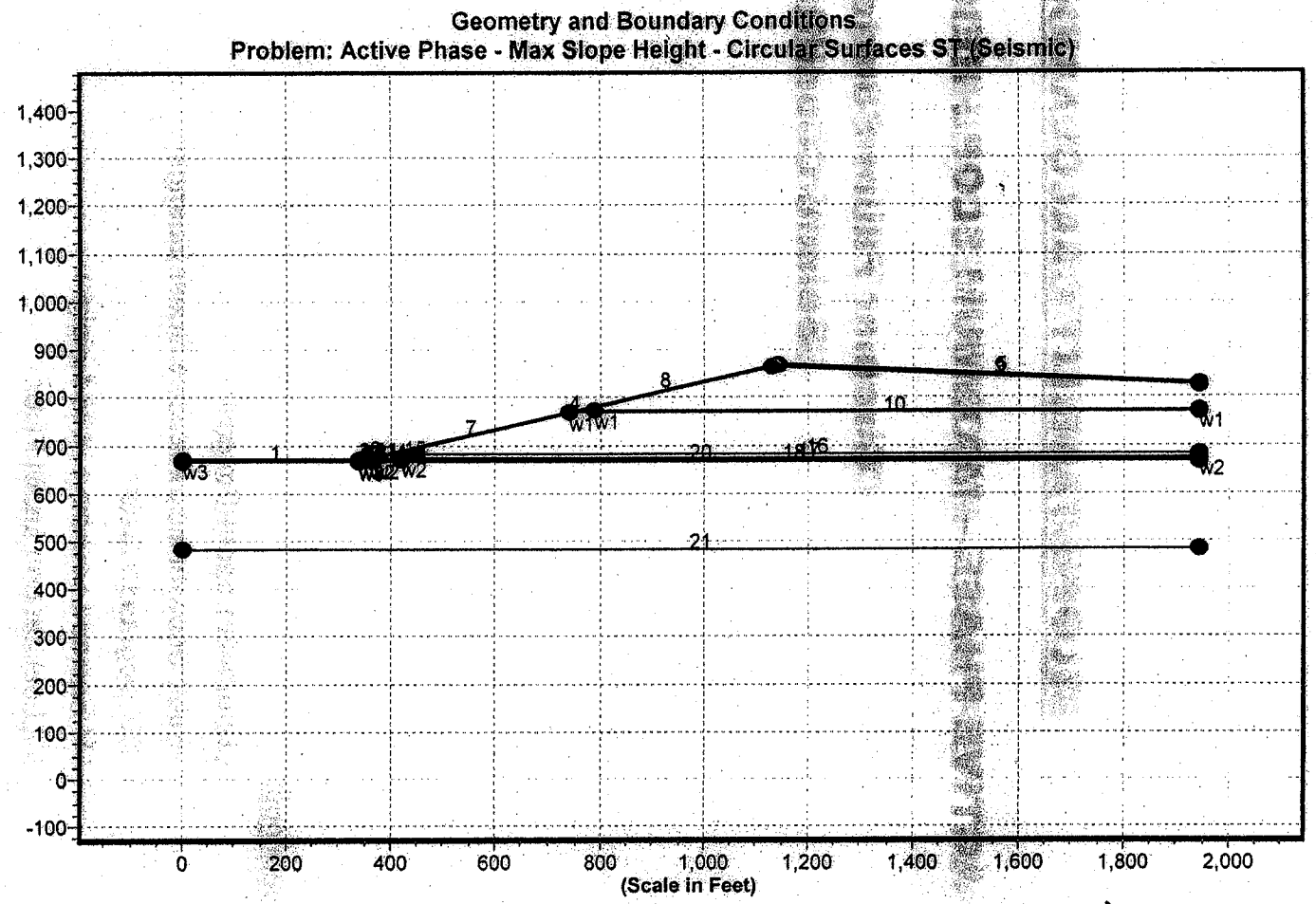
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

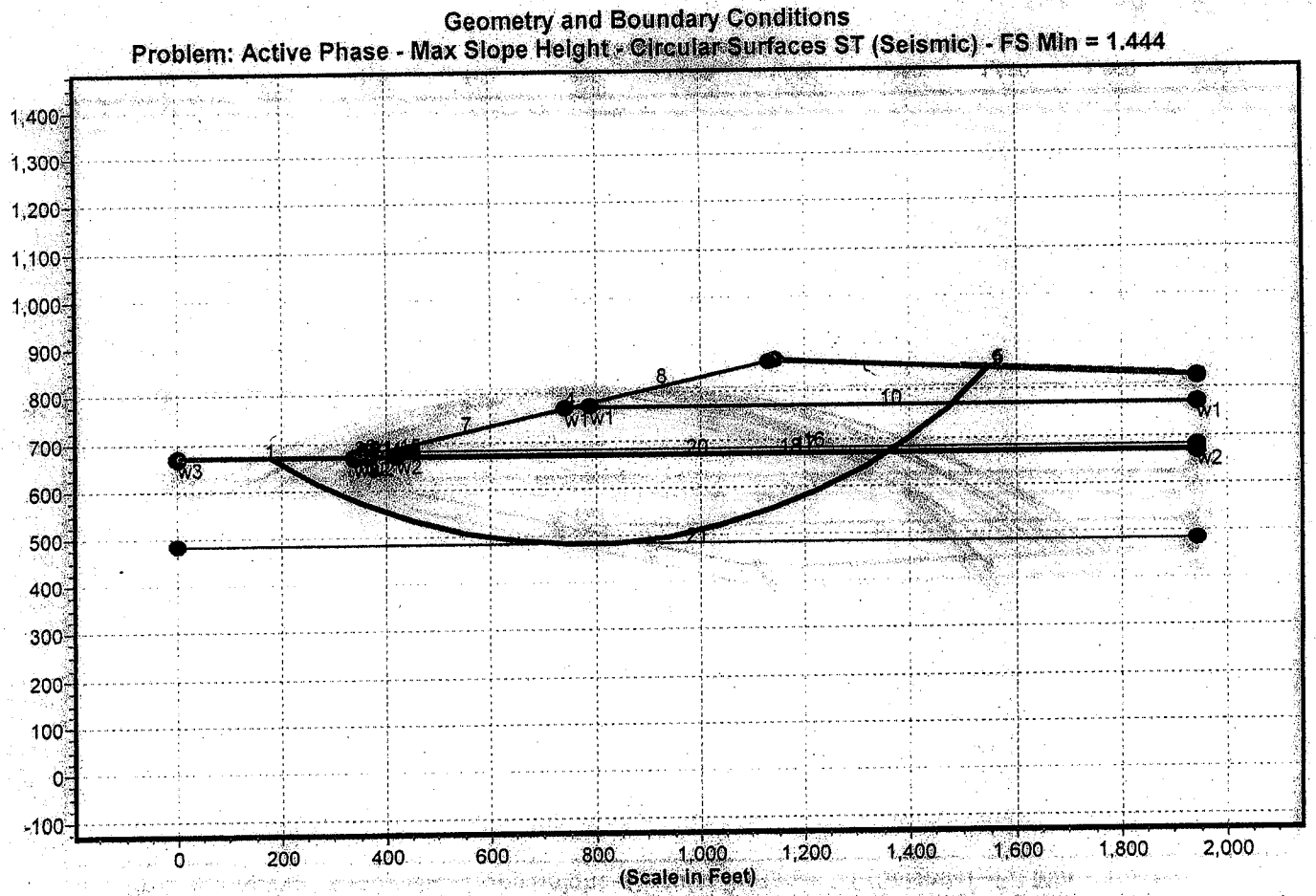
Circular Failure Surfaces
Seismic Conditions

Key Assumptions:

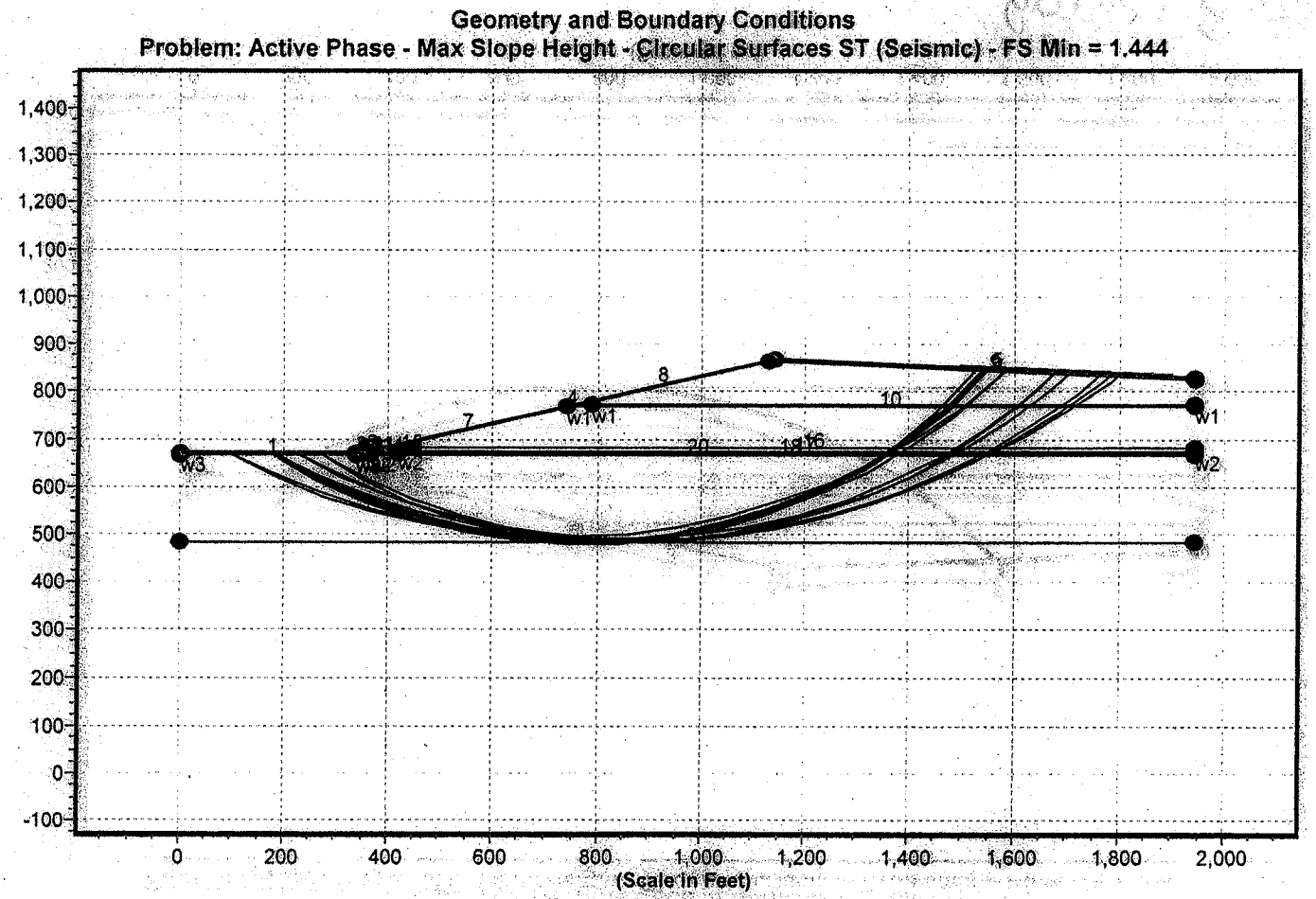
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Circular Surfaces ST (Seismic)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
(Scale in Feet)
W3
W2
W1
1
7
8
9
10
16
21

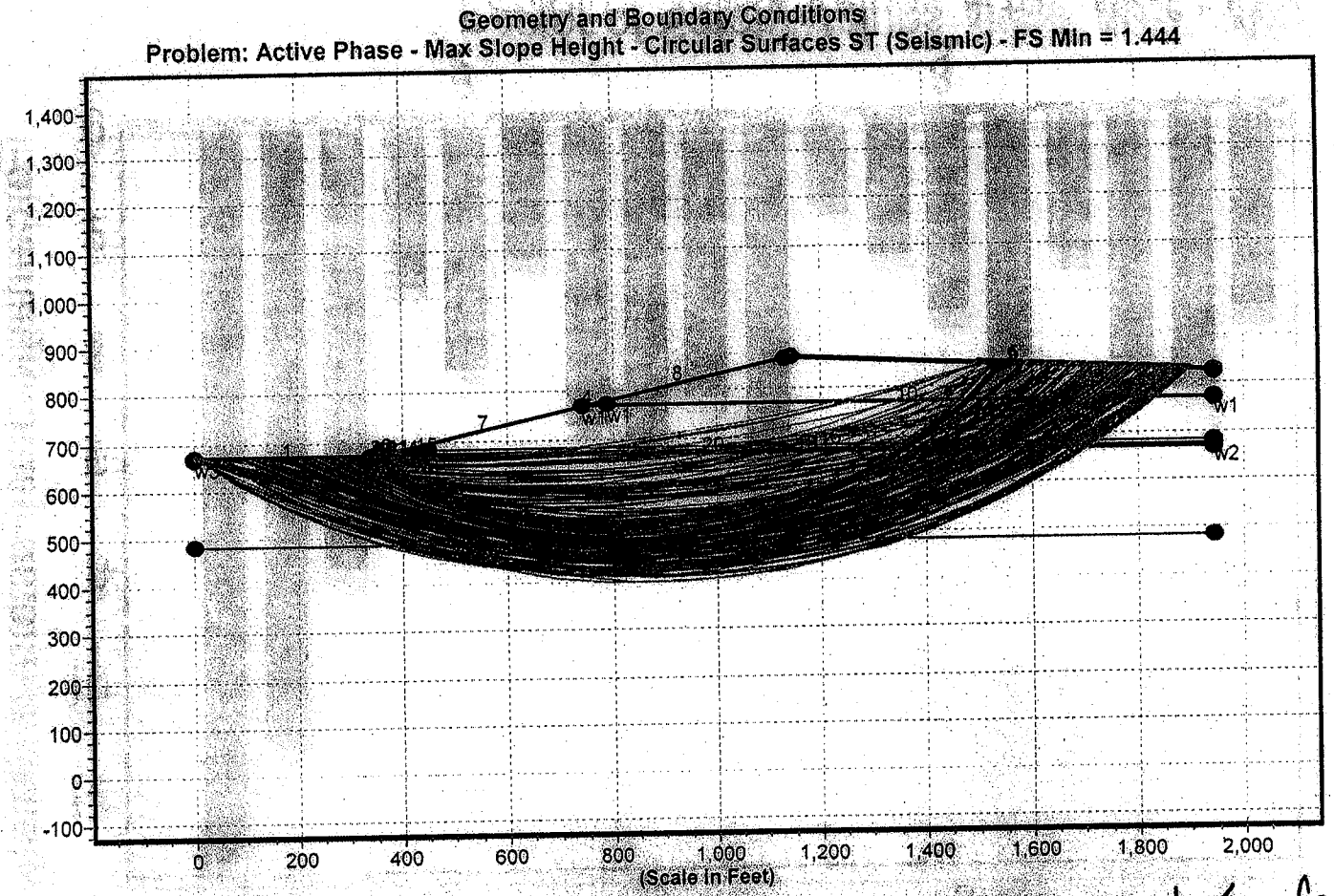
Profile



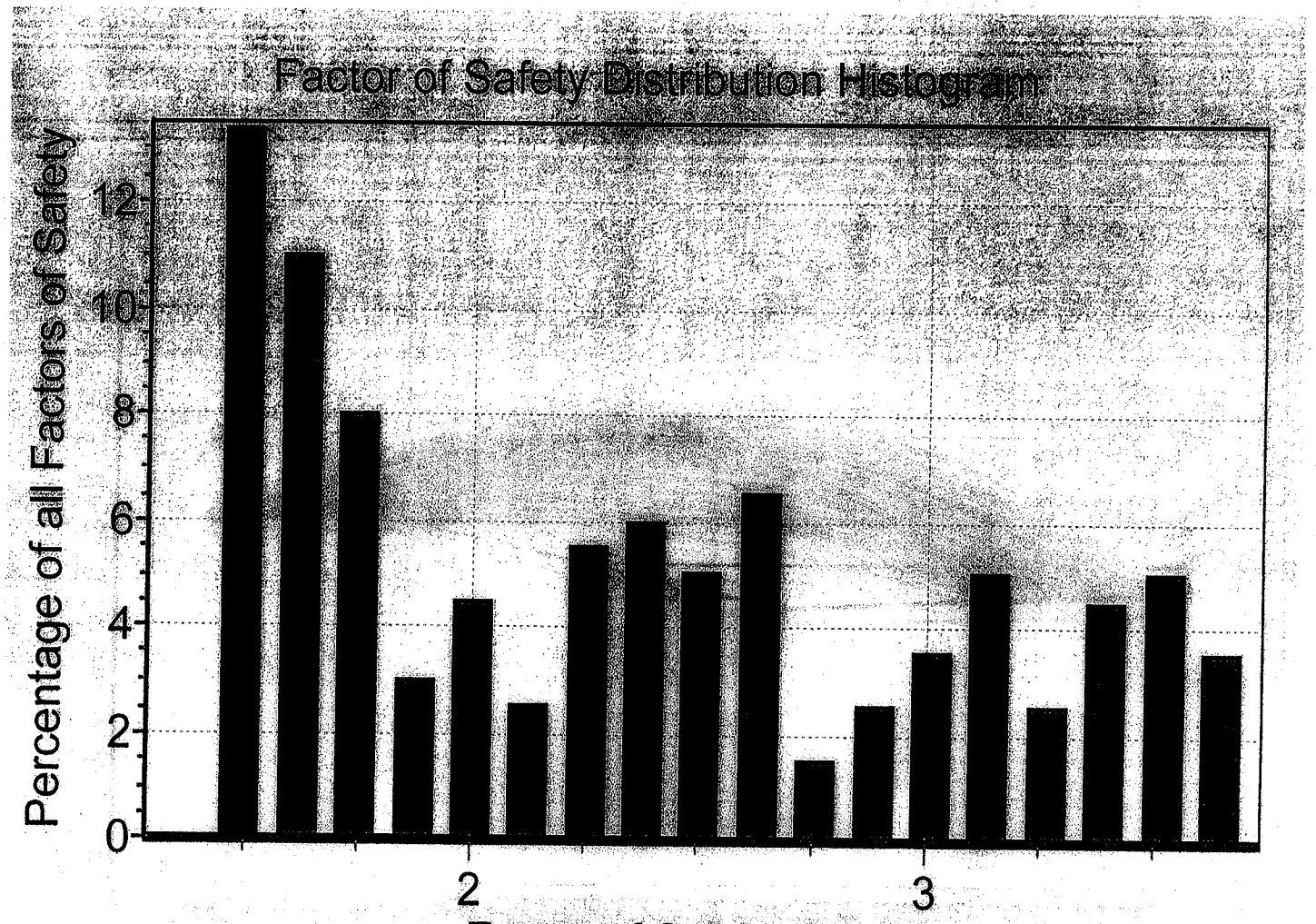
Critical Surface



10 Most Critical Surfaces



Generated surfaces



Active Phase - Max. Waste Height
Circular Surfaces
(Seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Circular Surfaces ST (Seismic)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
3	352.00	675.00	364.00	675.00	2
4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	3000.0	0.0	0.00	0.0	0
7	135.0	140.0	0.0	16.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	6000.0	0.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

		result
3	337.10	667.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

200 Trial Surfaces Have Been Generated.

20 Surfaces Initiate From Each Of 10 Points Equally Spaced Along The Ground Surface Between X = 5.00 ft.
and X = 400.00 ft.

Each Surface Terminates Between X =1500.00 ft.
and X =1900.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =300.00 ft.

100.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -35.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 17 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.56	670.00
2	264.92	616.31
3	354.14	571.15
4	447.37	534.97

		result
5	543.69	508.10
6	642.19	490.82
7	741.90	483.29
8	841.88	485.57
9	941.14	497.65
10	1038.75	519.42
11	1133.74	550.65
12	1225.21	591.06
13	1312.28	640.25
14	1394.10	697.74
15	1469.89	762.98
16	1538.91	835.35
17	1550.12	849.69

Circle Center At X = 768.7 ; Y = 1500.9 and Radius, 1018.0

*** 1.444 ***

Individual data on the 40 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.7	777.7	0.0	523.0	0.0	0.0	77.8	0.0	0.0
2	79.6	308920.0	0.0	0.0	0.0	0.0	30892.0	0.0	0.0
3	72.1	719423.0	0.0	0.0	0.0	0.0	71942.3	0.0	0.0
4	0.1	1256.3	0.0	0.0	0.0	0.0	125.6	0.0	0.0
5	14.9	200912.6	0.0	0.0	0.0	0.0	20091.3	0.0	0.0
6	2.1	30898.6	0.0	0.0	0.0	0.0	3089.9	0.0	0.0
7	2.9	41655.6	0.0	0.0	0.0	0.0	4165.6	0.0	0.0
8	1.0	14683.9	0.0	0.0	0.0	0.0	1468.4	0.0	0.0
9	6.0	89259.8	0.0	0.0	0.0	0.0	8926.0	0.0	0.0
10	0.8	12056.9	0.0	0.0	0.0	0.0	1205.7	0.0	0.0
11	3.2	48398.7	0.0	0.0	0.0	0.0	4839.9	0.0	0.0
12	50.0	848669.1	0.0	0.0	0.0	0.0	84866.9	0.0	0.0
13	12.0	231590.8	0.0	0.0	0.0	0.0	23159.1	0.0	0.0
14	17.4	356340.9	0.0	0.0	0.0	0.0	35634.1	0.0	0.0
15	0.6	13477.1	0.0	0.0	0.0	0.0	1347.7	0.0	0.0
16	95.7	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
17	98.5	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
18	97.9	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
19	1.8	60533.7	0.0	0.0	0.0	0.0	6053.4	0.0	0.0
20	49.1	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
21	50.9	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
22	99.3	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
23	97.6	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
24	92.0	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
25	3.0	95689.6	0.0	0.0	0.0	0.0	9569.0	0.0	0.0
26	10.3	326506.8	0.0	0.0	0.0	0.0	32650.7	0.0	0.0
27	81.2	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
28	87.1	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
29	38.1	655069.1	0.0	0.0	0.0	0.0	65506.9	0.0	0.0
30	4.3	64259.7	0.0	0.0	0.0	0.0	6426.0	0.0	0.0
31	1.4	21015.7	0.0	488.4	0.0	0.0	2101.6	0.0	0.0
32	5.7	82398.2	0.0	868.3	0.0	0.0	8239.8	0.0	0.0
33	8.5	118885.6	0.0	0.0	0.0	0.0	11888.6	0.0	0.0
34	23.8	307772.8	0.0	0.0	0.0	0.0	30777.3	0.0	0.0

					result				
35	75.8	731940.0	0.0	0.0	0.0	0.0	73194.0	0.0	0.0
36	4.8	32892.1	0.0	0.0	0.0	0.0	3289.2	0.0	0.0
37	4.8	30895.9	0.0	1077.9	0.0	0.0	3089.6	0.0	0.0
38	59.5	227905.3	0.0	0.0	0.0	0.0	22790.5	0.0	0.0
39	7.5	7541.0	0.0	0.0	0.0	0.0	754.1	0.0	0.0
40	3.8	1204.2	0.0	0.0	0.0	0.0	120.4	0.0	0.0

Failure Surface Specified By 16 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	268.33	670.00
2	350.57	613.10
3	438.70	565.84
4	531.60	528.84
5	628.09	502.57
6	726.92	487.36
7	826.85	483.42
8	926.57	490.78
9	1024.83	509.35
10	1120.37	538.90
11	1211.95	579.05
12	1298.42	629.29
13	1378.66	688.97
14	1451.65	757.33
15	1516.45	833.49
16	1528.08	850.80

Circle Center At X = 811.3 ; Y = 1365.8 and Radius, 882.6

*** 1.451 ***

1

Failure Surface Specified By 17 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.56	670.00
2	266.21	618.39
3	356.27	574.93
4	449.96	539.97
5	546.48	513.82
6	645.01	496.70
7	744.69	488.77
8	844.68	490.08
9	944.12	500.62
10	1042.17	520.32
11	1137.97	548.99
12	1230.71	586.39
13	1319.60	632.20
14	1403.87	686.04
15	1482.81	747.43
16	1555.73	815.86
17	1584.18	847.99

result

Circle Center At X = 780.5 ; Y = 1569.0 and Radius, 1080.8

*** 1.462 ***

Failure Surface Specified By 18 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.56	670.00
2	267.71	620.97
3	358.51	579.07
4	452.37	544.57
5	548.69	517.70
6	646.86	498.62
7	746.23	487.46
8	846.18	484.29
9	946.06	489.13
10	1045.24	501.95
11	1143.07	522.66
12	1238.93	551.14
13	1332.20	587.20
14	1422.29	630.61
15	1508.61	681.09
16	1590.62	738.32
17	1667.78	801.93
18	1708.89	841.76

Circle Center At X = 835.2 ; Y = 1730.4 and Radius, 1246.2

*** 1.469 ***

1

Failure Surface Specified By 17 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	268.33	670.00
2	353.64	617.82
3	443.40	573.74
4	536.85	538.13
5	633.18	511.31
6	731.58	493.49
7	831.21	484.83
8	931.20	485.40
9	1030.72	495.21
10	1128.91	514.16
11	1224.93	542.10
12	1317.96	578.78
13	1407.20	623.89
14	1491.90	677.05
15	1571.33	737.80

		result
16	1644.82	805.63
17	1678.70	843.27

Circle Center At X = 875.0 ; Y = 1566.0 and Radius, 1082.0

*** 1.471 ***

Failure Surface Specified By 17 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	224.44	670.00
2	311.16	620.20
3	401.83	578.01
4	495.78	543.75
5	592.32	517.68
6	690.74	499.98
7	790.31	490.78
8	890.31	490.16
9	989.99	498.11
10	1088.63	514.58
11	1185.49	539.45
12	1279.86	572.53
13	1371.04	613.58
14	1458.37	662.30
15	1541.21	718.32
16	1618.93	781.24
17	1683.12	843.04

Circle Center At X = 847.6 ; Y = 1654.5 and Radius, 1165.2

*** 1.483 ***

1

Failure Surface Specified By 19 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.56	670.00
2	268.86	623.06
3	360.34	582.68
4	454.52	549.08
5	550.91	522.42
6	648.98	502.86
7	748.21	490.50
8	848.08	485.40
9	948.05	487.60
10	1047.60	497.07
11	1146.20	513.77
12	1243.32	537.61
13	1338.44	568.47

		result
14	1431.06	606.17
15	1520.68	650.53
16	1606.84	701.29
17	1689.07	758.20
18	1766.93	820.95
19	1785.12	837.94

Circle Center At X = 868.0 ; Y = 1856.7 and Radius, 1371.4

*** 1.491 ***

Failure Surface Specified By 20 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	92.78	670.00
2	182.12	625.07
3	274.20	586.06
4	368.62	553.15
5	465.00	526.47
6	562.91	506.14
7	661.94	492.24
8	761.67	484.84
9	861.66	483.96
10	961.50	489.60
11	1060.76	501.76
12	1159.02	520.36
13	1255.85	545.33
14	1350.84	576.58
15	1443.59	613.95
16	1533.71	657.30
17	1620.80	706.44
18	1704.51	761.16
19	1784.46	821.22
20	1802.89	837.06

Circle Center At X = 824.8 ; Y = 2013.2 and Radius, 1529.7

*** 1.494 ***

1

Failure Surface Specified By 18 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	92.78	670.00
2	180.48	621.95
3	271.79	581.19
4	366.12	547.99
5	462.84	522.57
6	561.30	505.10

		result
7	660.86	495.70
8	760.85	494.42
9	860.61	501.28
10	959.49	516.23
11	1056.82	539.17
12	1151.97	569.95
13	1244.29	608.36
14	1333.19	654.16
15	1418.07	707.04
16	1498.36	766.64
17	1573.55	832.57
18	1588.28	847.79

Circle Center At X = 726.2 ; Y = 1720.9 and Radius, 1227.0

*** 1.497 ***

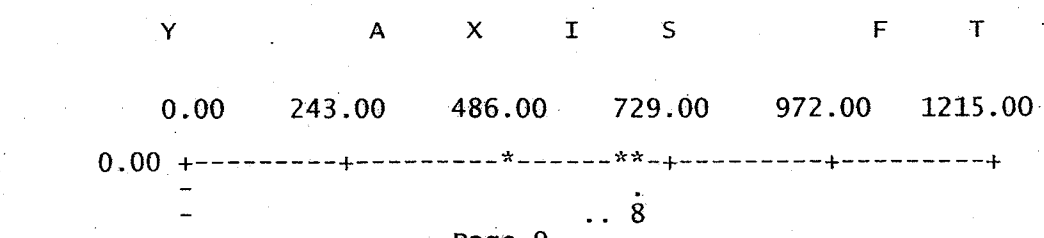
Failure Surface Specified By 18 Coordinate Points

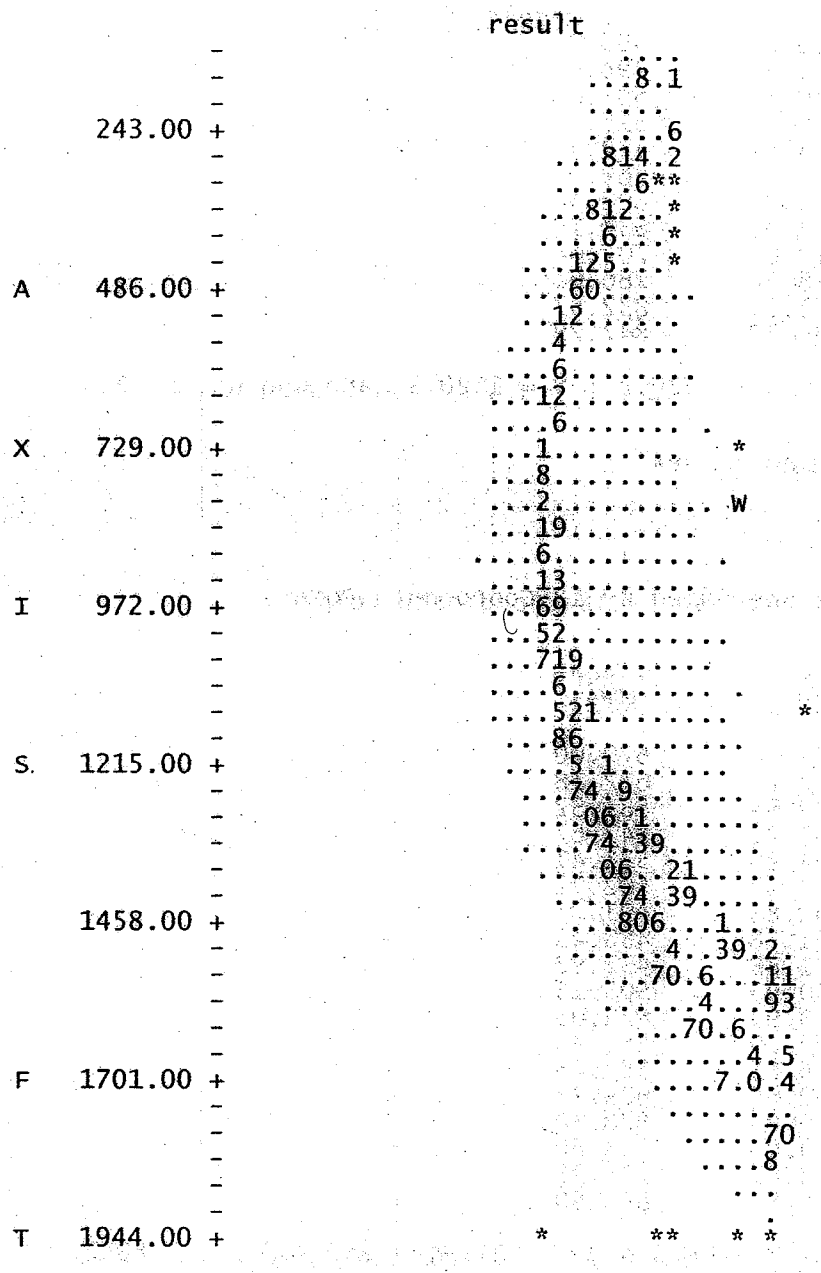
Point No.	X-Surf (ft)	Y-Surf (ft)
1	224.44	670.00
2	312.27	622.18
3	403.54	581.32
4	497.71	547.67
5	594.20	521.41
6	692.44	502.72
7	791.83	491.71
8	891.78	488.43
9	991.68	492.92
10	1090.93	505.15
11	1188.93	525.03
12	1285.10	552.45
13	1378.85	587.25
14	1469.61	629.22
15	1556.85	678.10
16	1640.04	733.60
17	1718.67	795.38
18	1765.98	838.90

Circle Center At X = 883.4 ; Y = 1774.6 and Radius, 1286.2

*** 1.499 ***

1




result
A
X
I
S.
F
T
243.00
486.00
729.00
972.00
1215.00
1458.00
1701.00
1944.00

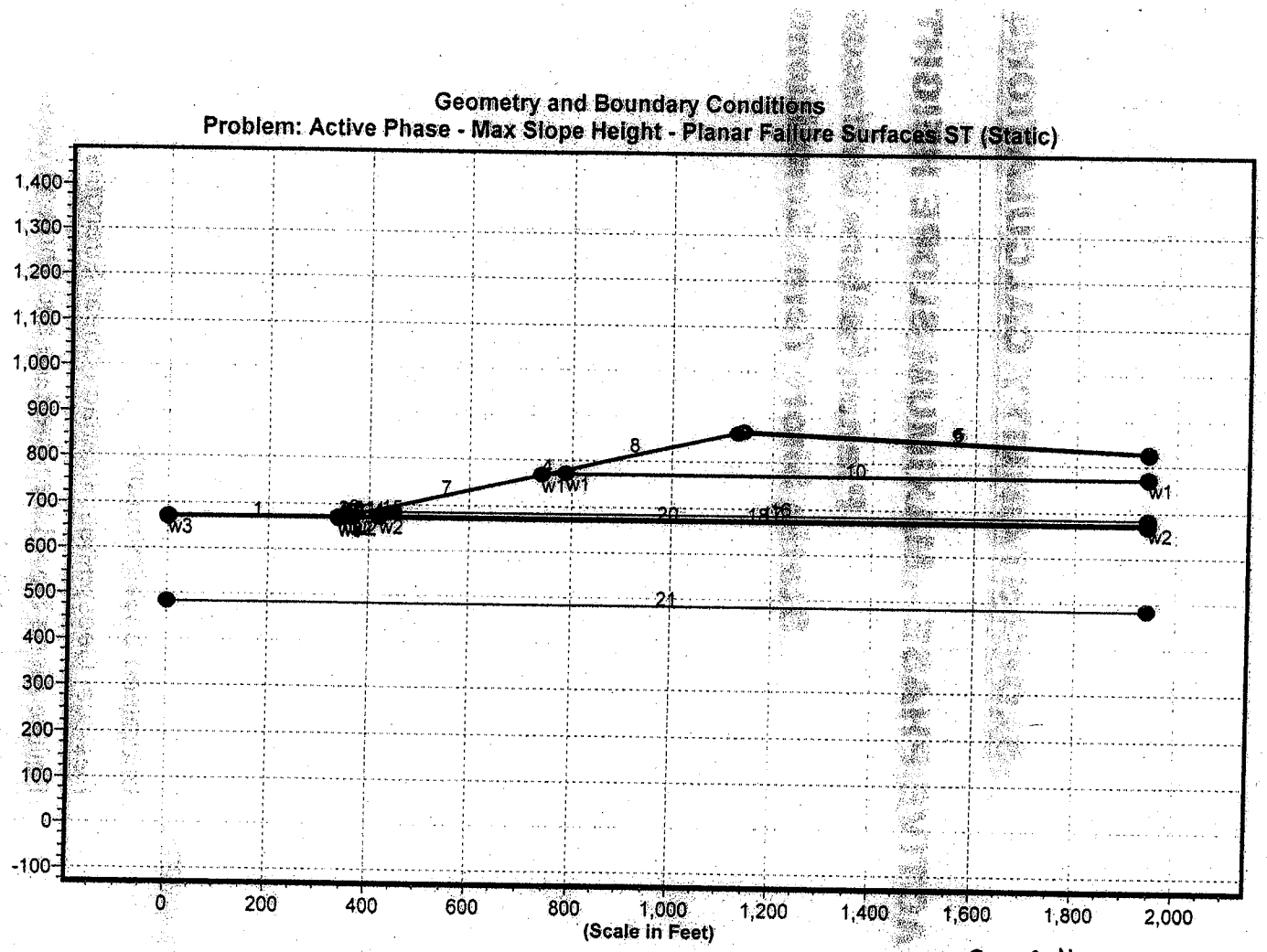
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

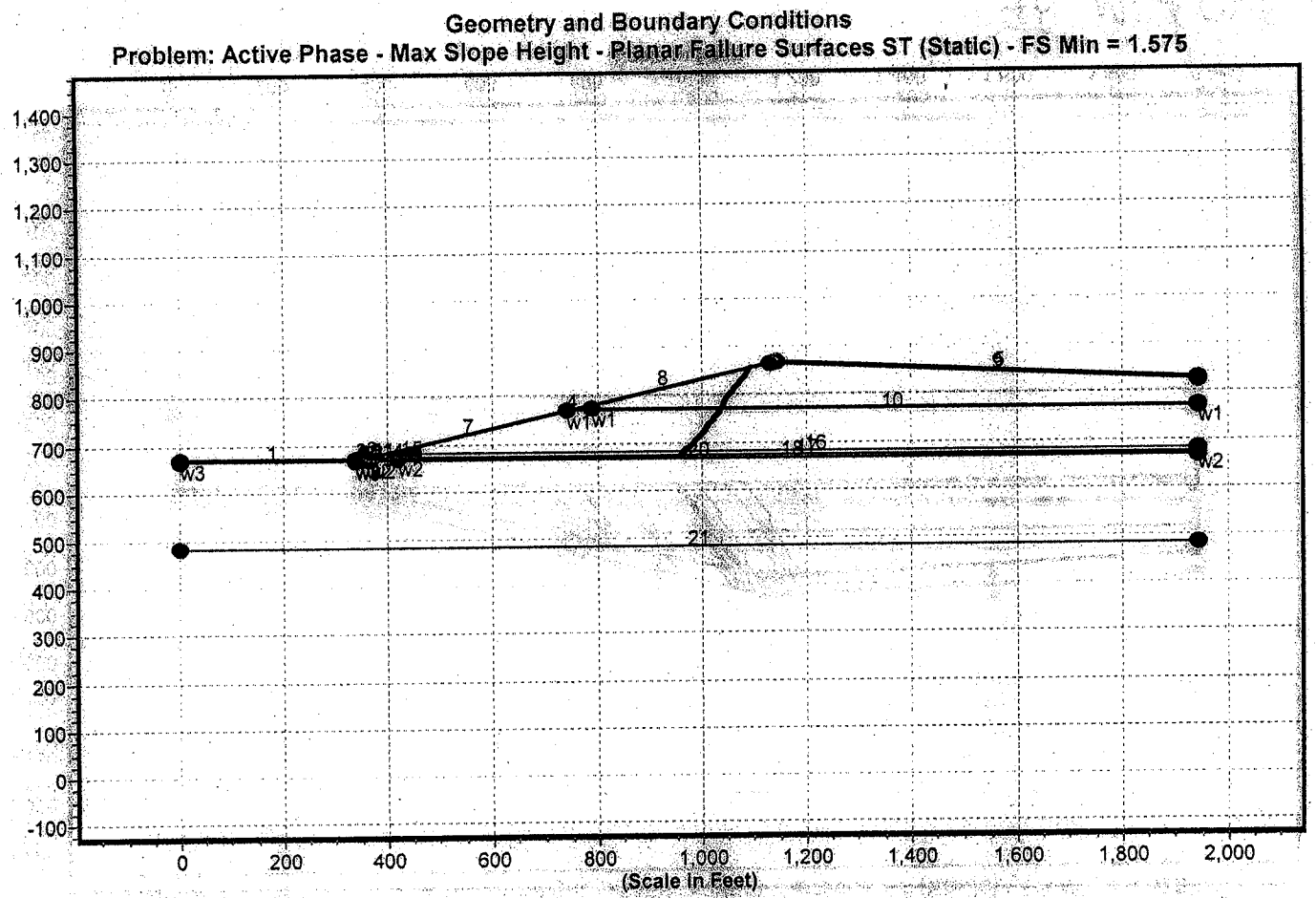
Planar Failure Surfaces
Static Short Term Conditions

Key Assumptions:

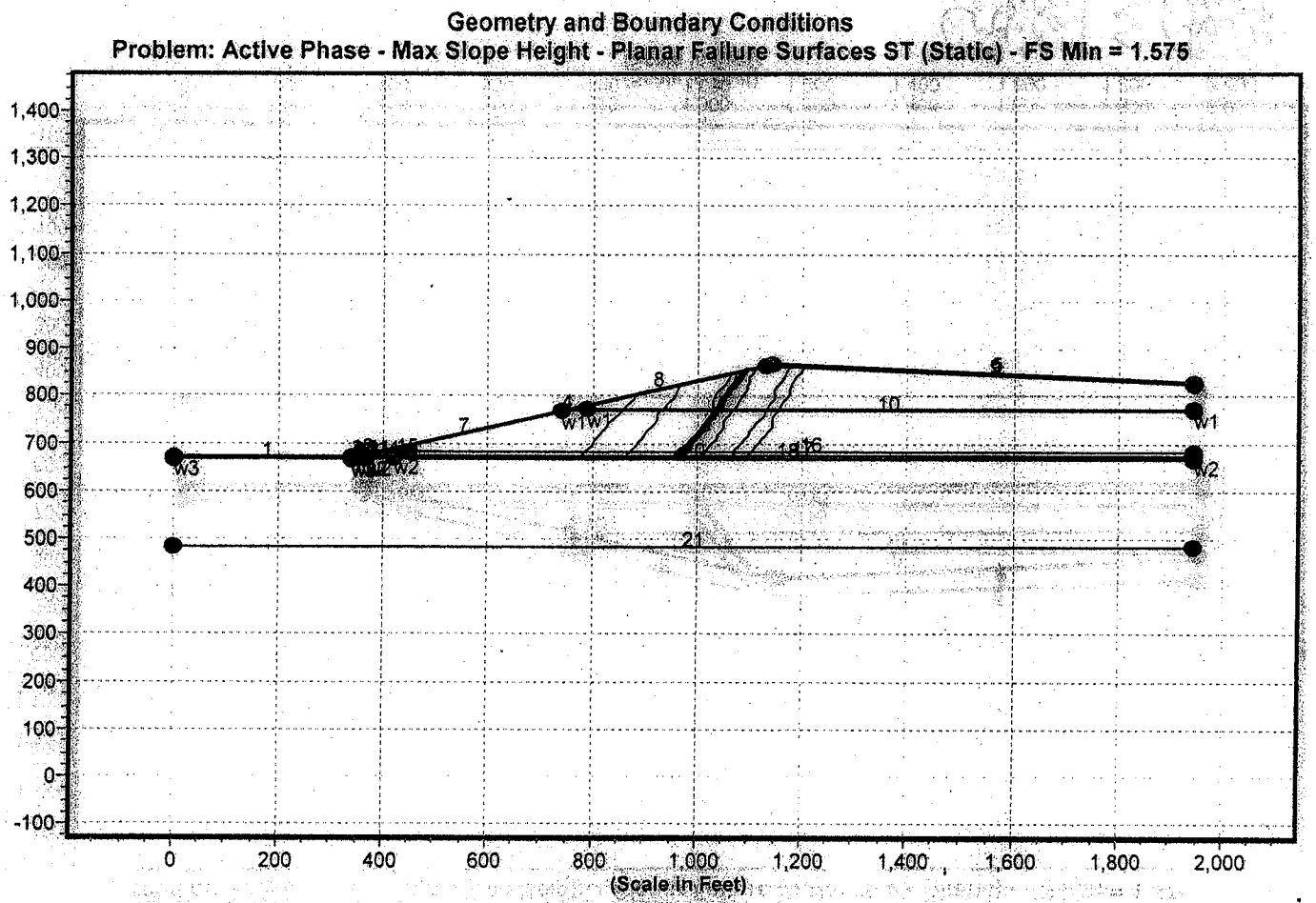
Undrained Shear Strengths
Residual Geosynthetic Interface Shear Strengths
Failure Along Floor Liner Interface and Through Waste
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Planar Failure Surfaces: ST (Static)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
(Scale in Feet)
w3
w2
w1
1
7
8
10
21

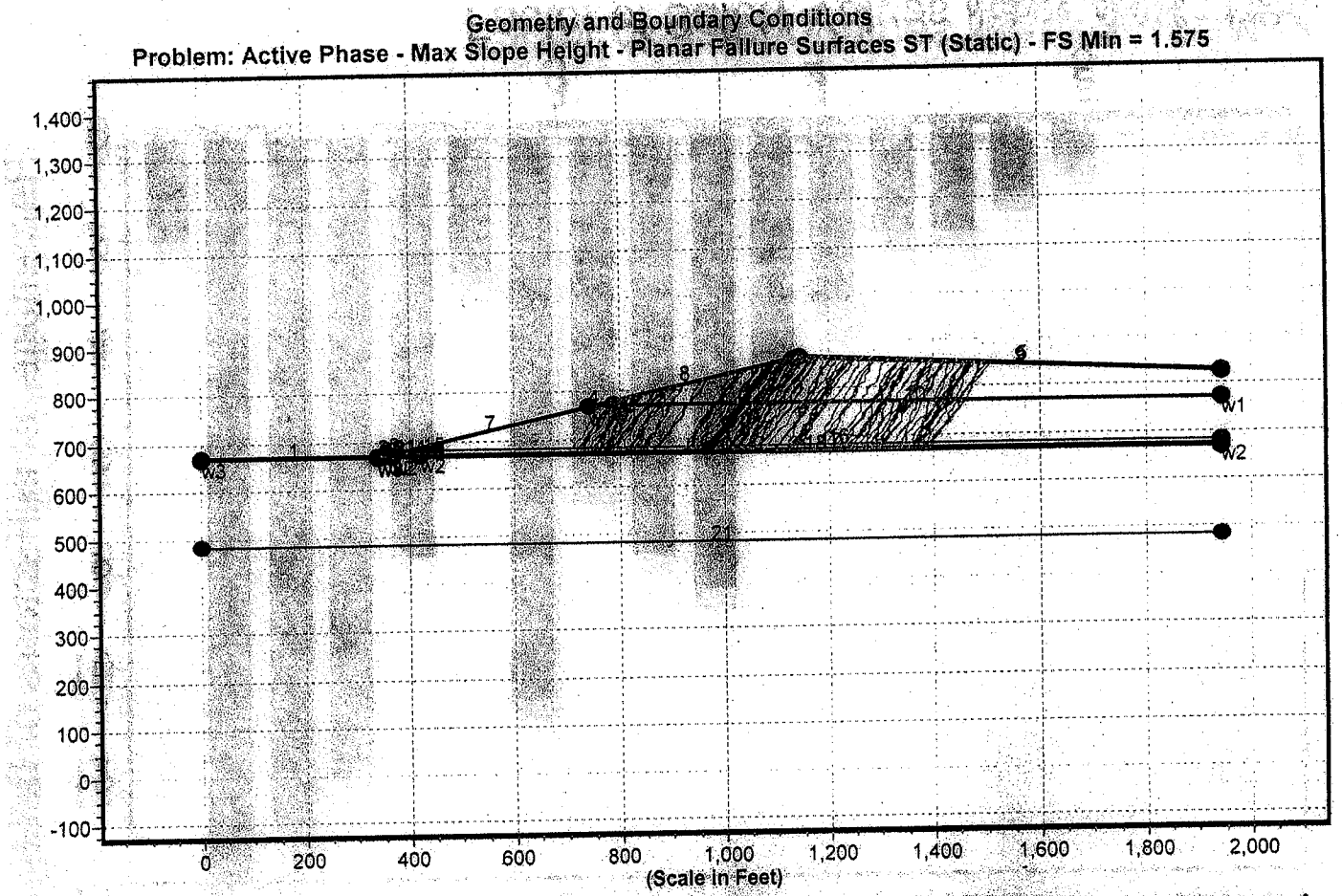
Profile



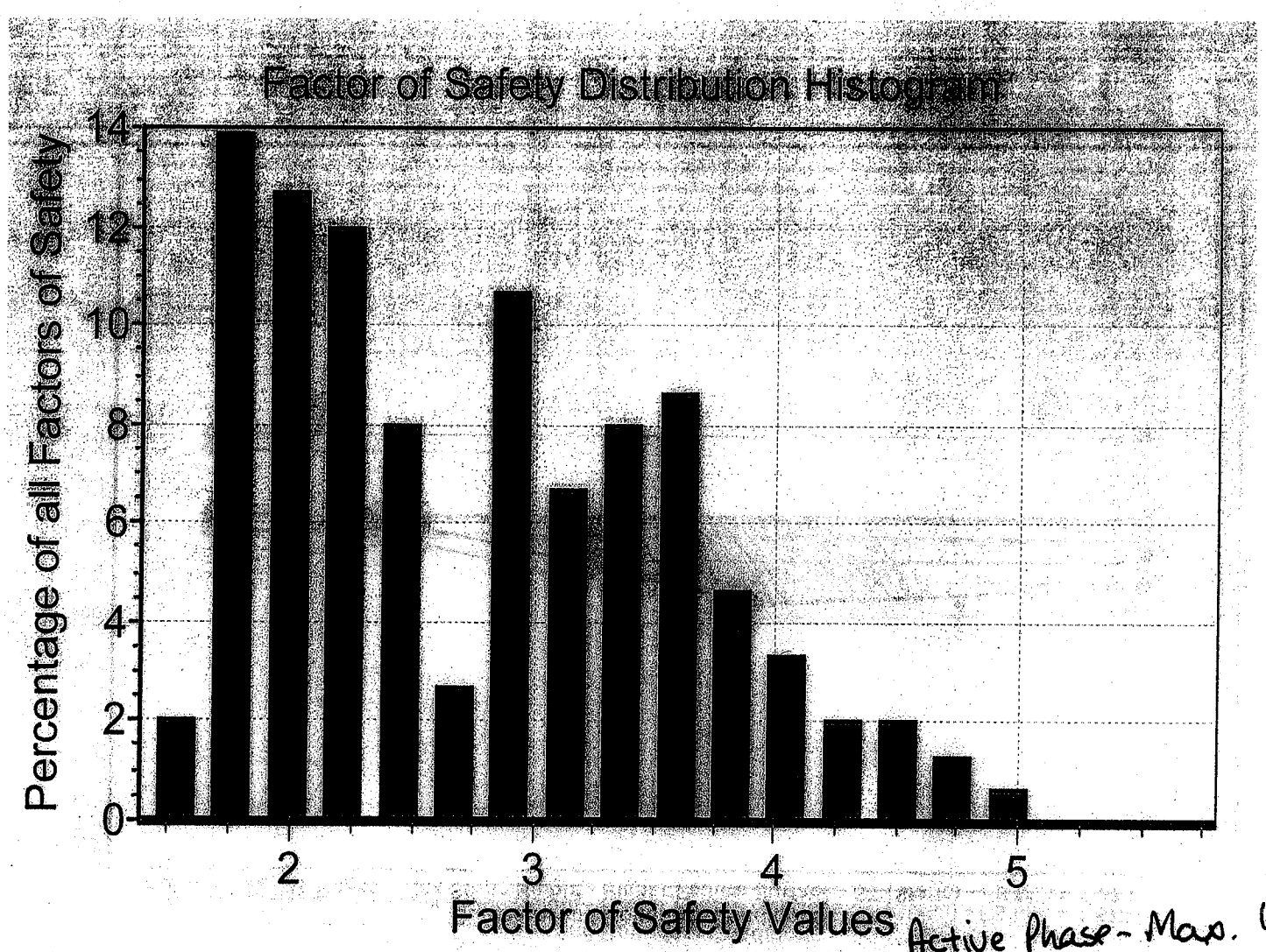
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase - Max. Waste Height
Planar Failure Surfaces
Short Term (static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Planar
Failure Surfaces ST (Static)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
3	352.00	675.00	364.00	675.00	2
4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	3000.0	0.0	0.00	0.0	0
7	135.0	140.0	0.0	10.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	6000.0	0.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

result

3	337.10	667.00

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

2 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	364.00	670.00	370.00	670.00	1.00
2	700.00	670.00	1400.00	670.00	1.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.85	675.00
2	366.50	670.01
3	955.67	670.06
4	962.36	677.49
5	969.35	684.64
6	976.09	692.03
7	983.08	699.18
8	989.26	707.04
9	995.99	714.44
10	1002.97	721.60
11	1007.64	730.44
12	1013.27	738.71
13	1019.38	746.62
14	1025.97	754.14
15	1032.88	761.37
16	1037.52	770.23
17	1041.23	779.52
18	1044.08	789.10
19	1051.14	796.19
20	1056.63	804.55

		result
21	1062.36	812.74
22	1069.37	819.87
23	1073.03	829.18
24	1080.01	836.33
25	1085.29	844.82
26	1090.49	853.37
27	1094.79	857.70

*** 1.575 ***

Individual data on the 41 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	6.1	1470.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.8	410.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1.7	1011.6	0.0	60.7	0.0	0.0	0.0	0.0	0.0
5	1.5	895.4	0.0	92.1	0.0	0.0	0.0	0.0	0.0
6	50.0	51778.0	0.0	9279.4	0.0	0.0	0.0	0.0	0.0
7	12.0	20118.2	0.0	3729.9	0.0	0.0	0.0	0.0	0.0
8	18.0	37937.2	0.0	5593.6	0.0	0.0	0.0	0.0	0.0
9	292.1	********	0.0	90556.2	0.0	0.0	0.0	0.0	0.0
10	50.9	423192.3	0.0	15730.0	0.0	0.0	0.0	0.0	0.0
11	164.7	********	0.0	50822.3	0.0	0.0	0.0	0.0	0.0
12	0.8	10008.8	0.0	352.8	0.0	0.0	0.0	0.0	0.0
13	3.6	41768.1	0.0	672.0	0.0	0.0	0.0	0.0	0.0
14	2.2	25351.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	3.4	37885.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	3.6	38378.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	6.7	70569.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	7.0	70240.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	6.2	59376.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	6.7	61648.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	7.0	61045.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	4.7	38528.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	5.6	43379.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	6.1	44087.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	6.6	44501.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	6.9	43690.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	3.5	20459.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	1.2	6554.7	0.0	610.6	0.0	0.0	0.0	0.0	0.0
29	1.1	6020.2	0.0	257.2	0.0	0.0	0.0	0.0	0.0
30	2.6	13368.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	2.9	13091.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	7.1	28577.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	5.5	19693.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	5.7	17581.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	7.0	18361.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	3.7	7671.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	7.0	11057.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	5.3	5865.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	5.2	2964.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	2.9	633.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1.4	89.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

result

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	353.31	675.00
2	359.75	671.80
3	369.63	670.24
4	960.79	670.00
5	967.10	677.75
6	972.99	685.84
7	978.72	694.03
8	984.96	701.85
9	990.67	710.05
10	995.98	718.53
11	1002.24	726.33
12	1008.84	733.84
13	1012.56	743.12
14	1017.85	751.61
15	1023.06	760.14
16	1028.46	768.56
17	1034.94	776.18
18	1041.79	783.46
19	1043.48	793.32
20	1049.73	801.12
21	1055.37	809.38
22	1058.74	818.79
23	1064.83	826.73
24	1071.71	833.99
25	1077.17	842.36
26	1083.70	849.94
27	1086.22	855.55

*** 1.607 ***

1

Failure Surface Specified By 21 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	356.68	675.00
2	364.37	670.31
3	776.78	670.29
4	782.51	678.49
5	789.39	685.74
6	795.69	693.52
7	802.75	700.59
8	806.95	709.67
9	813.53	717.20
10	818.98	725.58
11	825.06	733.52
12	831.60	741.08
13	838.34	748.47
14	844.76	756.14
15	851.77	763.27
16	858.50	770.67

		result
17	864.28	778.83
18	871.13	786.11
19	877.93	793.44
20	884.61	800.89
21	888.25	806.06

*** 1.640 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	358.54	675.00
2	365.17	670.39
3	1063.20	669.95
4	1068.55	678.40
5	1071.49	687.96
6	1078.15	695.42
7	1083.87	703.62
8	1090.60	711.02
9	1097.49	718.27
10	1099.63	728.04
11	1105.79	735.91
12	1111.99	743.76
13	1119.03	750.86
14	1124.77	759.05
15	1129.65	767.77
16	1133.33	777.07
17	1139.71	784.77
18	1146.78	791.84
19	1147.63	801.81
20	1148.28	811.78
21	1152.41	820.89
22	1157.18	829.68
23	1162.82	837.93
24	1168.86	845.91
25	1173.12	854.96
26	1178.69	863.26
27	1183.42	868.03

*** 1.673 ***

1

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	362.13	675.00
2	366.83	670.49
3	969.24	669.99
4	973.35	679.11

		result
5	980.20	686.39
6	986.91	693.81
7	991.94	702.45
8	998.54	709.97
9	1005.60	717.05
10	1011.85	724.85
11	1018.91	731.93
12	1021.80	741.50
13	1025.33	750.86
14	1032.40	757.93
15	1033.27	767.89
16	1040.18	775.12
17	1046.38	782.97
18	1047.88	792.86
19	1051.18	802.30
20	1057.91	809.69
21	1064.62	817.11
22	1068.17	826.45
23	1075.06	833.70
24	1080.07	842.36
25	1085.78	850.57
26	1091.46	856.86

*** 1.675 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.60	675.00
2	359.77	673.57
3	369.24	670.36
4	1003.71	670.03
5	1010.11	677.72
6	1016.60	685.33
7	1022.68	693.27
8	1028.86	701.12
9	1035.53	708.57
10	1038.48	718.13
11	1044.29	726.27
12	1049.11	735.03
13	1050.04	744.99
14	1053.63	754.32
15	1060.68	761.40
16	1066.43	769.59
17	1072.04	777.87
18	1077.99	785.90
19	1082.52	794.82
20	1087.70	803.37
21	1093.54	811.49
22	1095.68	821.26
23	1099.23	830.60
24	1099.27	840.60
25	1105.79	848.18
26	1109.15	857.60
27	1111.15	861.79

result

*** 1.682 ***

1

Failure Surface Specified By 23 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.43	675.00
2	364.86	670.30
3	865.44	670.20
4	868.28	679.79
5	875.29	686.91
6	882.26	694.09
7	888.02	702.26
8	894.88	709.54
9	897.53	719.18
10	904.58	726.28
11	910.35	734.45
12	917.42	741.52
13	921.61	750.60
14	923.04	760.50
15	929.50	768.14
16	936.35	775.42
17	941.97	783.69
18	948.69	791.10
19	955.18	798.71
20	958.13	808.26
21	963.53	816.68
22	969.16	824.94
23	970.71	826.68

*** 1.704 ***

Failure Surface Specified By 24 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	362.08	675.00
2	366.95	670.48
3	967.85	670.12
4	973.32	678.49
5	979.20	686.58
6	983.58	695.57
7	990.60	702.69
8	994.03	712.08
9	998.69	720.93
10	1005.12	728.59
11	1011.99	735.85
12	1016.29	744.88
13	1021.57	753.38
14	1026.94	761.81

		result
15	1029.36	771.51
16	1029.83	781.50
17	1030.64	791.47
18	1033.36	801.09
19	1038.65	809.58
20	1045.28	817.07
21	1051.59	824.83
22	1057.37	832.99
23	1062.24	841.72
24	1066.38	850.59

*** 1.714 ***

1

Failure Surface Specified By 25 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	361.71	675.00
2	368.62	670.27
3	967.37	670.15
4	974.03	677.61
5	979.88	685.73
6	985.37	694.08
7	992.34	701.26
8	993.20	711.22
9	1000.23	718.33
10	1007.28	725.43
11	1013.55	733.22
12	1019.78	741.04
13	1024.61	749.80
14	1029.82	758.33
15	1036.08	766.13
16	1043.01	773.34
17	1049.44	781.00
18	1051.09	790.86
19	1051.81	800.83
20	1058.75	808.03
21	1059.66	817.99
22	1066.39	825.39
23	1070.66	834.43
24	1073.49	844.02
25	1075.57	852.89

*** 1.718 ***

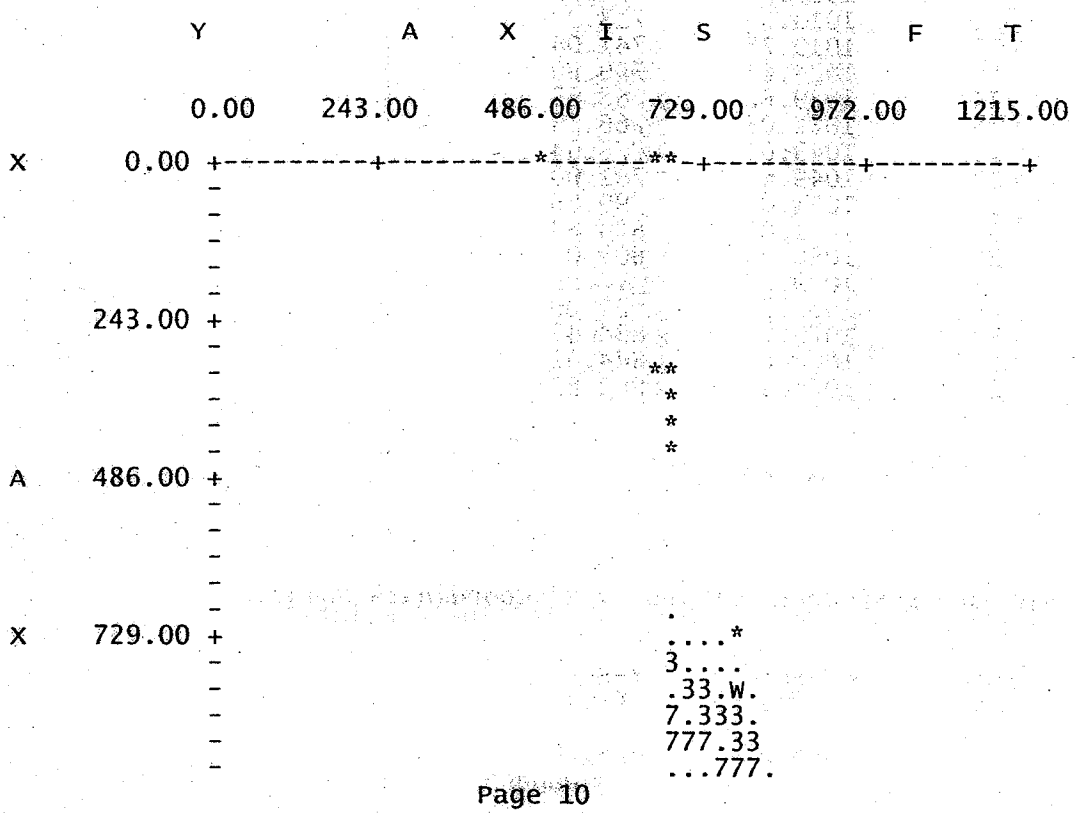
Failure Surface Specified By 27 Coordinate Points

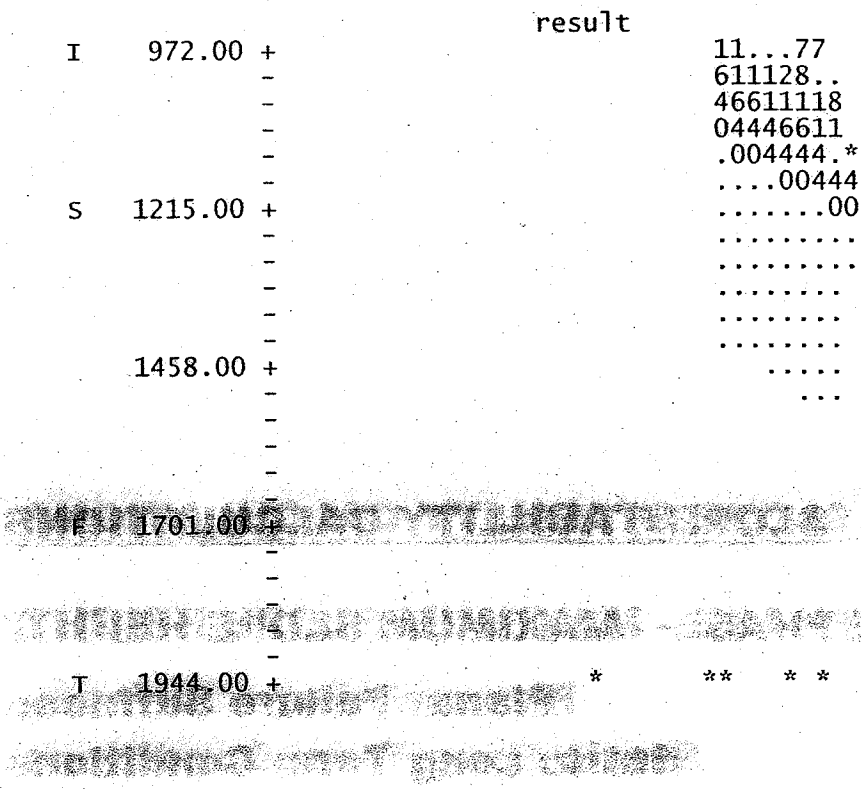
Point No.	X-Surf (ft)	Y-Surf (ft)
1	364.62	675.16

		result
2	369.74	670.43
3	1094.33	670.22
4	1097.46	679.72
5	1104.52	686.80
6	1111.27	694.18
7	1117.28	702.17
8	1121.88	711.05
9	1128.95	718.13
10	1134.56	726.40
11	1141.25	733.84
12	1143.04	743.68
13	1143.67	753.66
14	1148.15	762.60
15	1153.36	771.14
16	1156.97	780.46
17	1162.46	788.82
18	1169.21	796.20
19	1174.72	804.54
20	1175.59	814.50
21	1177.50	824.32
22	1183.78	832.10
23	1189.12	840.55
24	1194.36	849.07
25	1200.26	857.15
26	1207.04	864.49
27	1207.91	866.80

*** 1.722 ***

1




result
I 972.00
S 1215.00
1458.00
1701.00
T 1944.00
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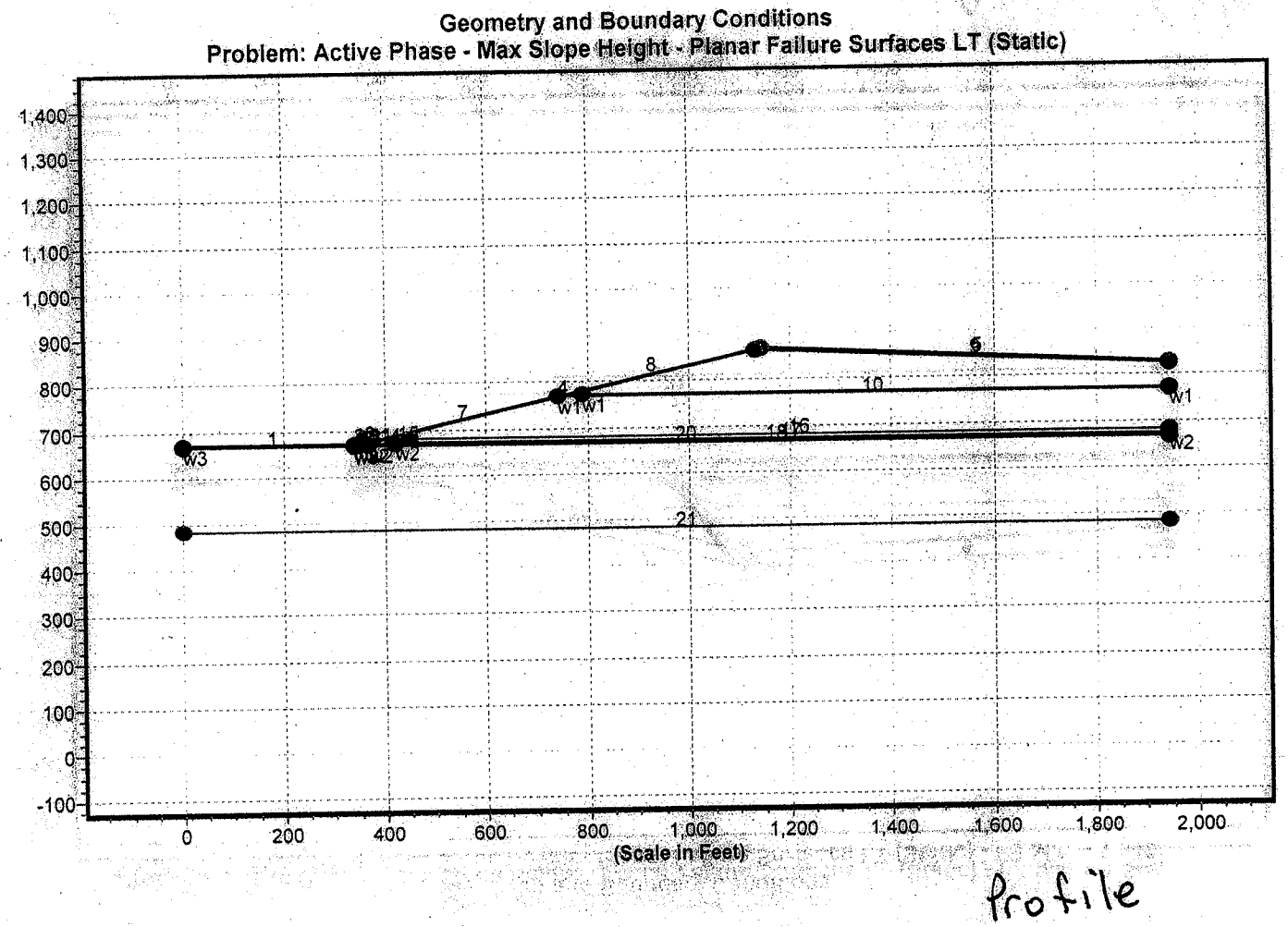
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

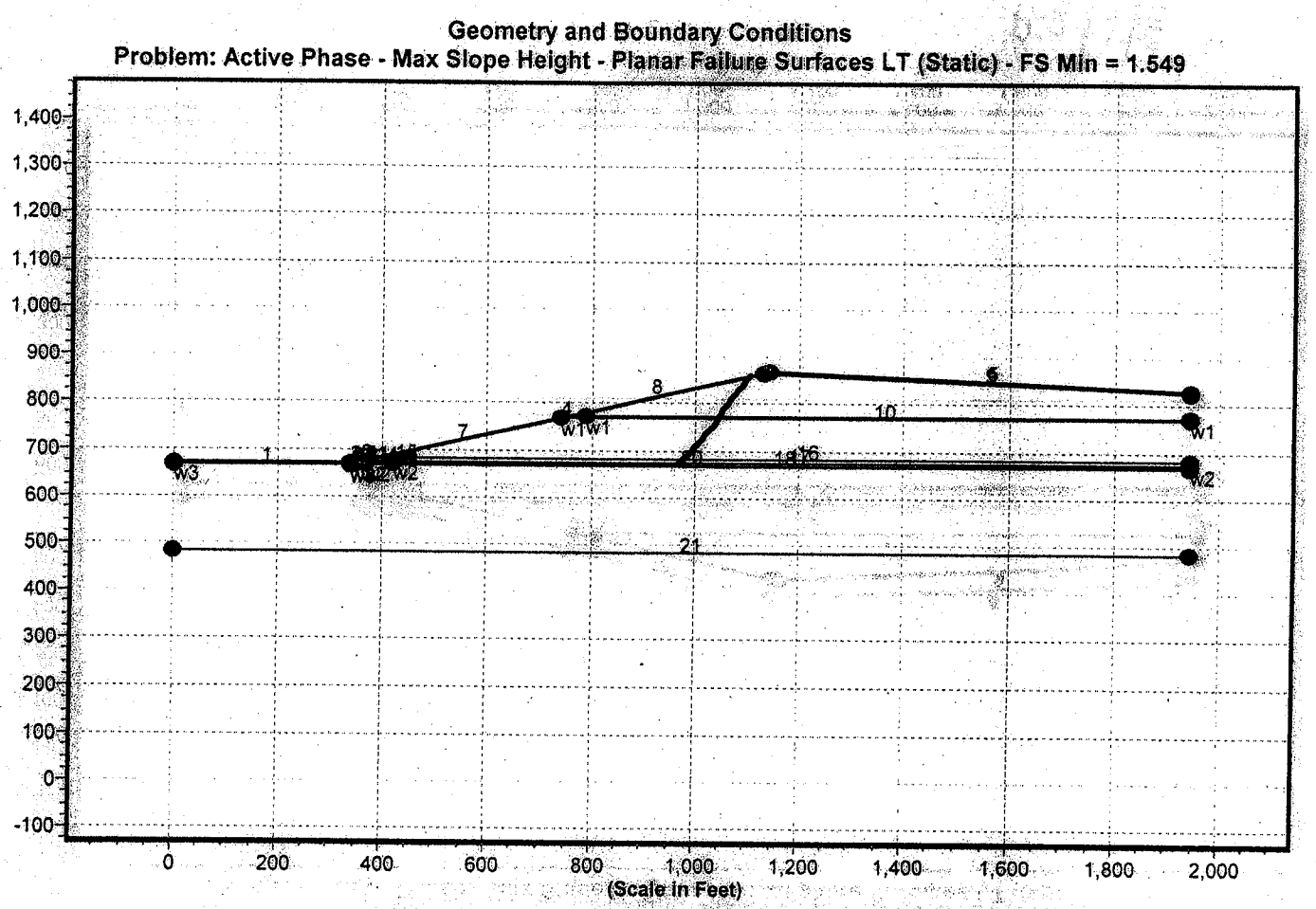
Planar Failure Surfaces
Static Long Term Conditions

Key Assumptions:

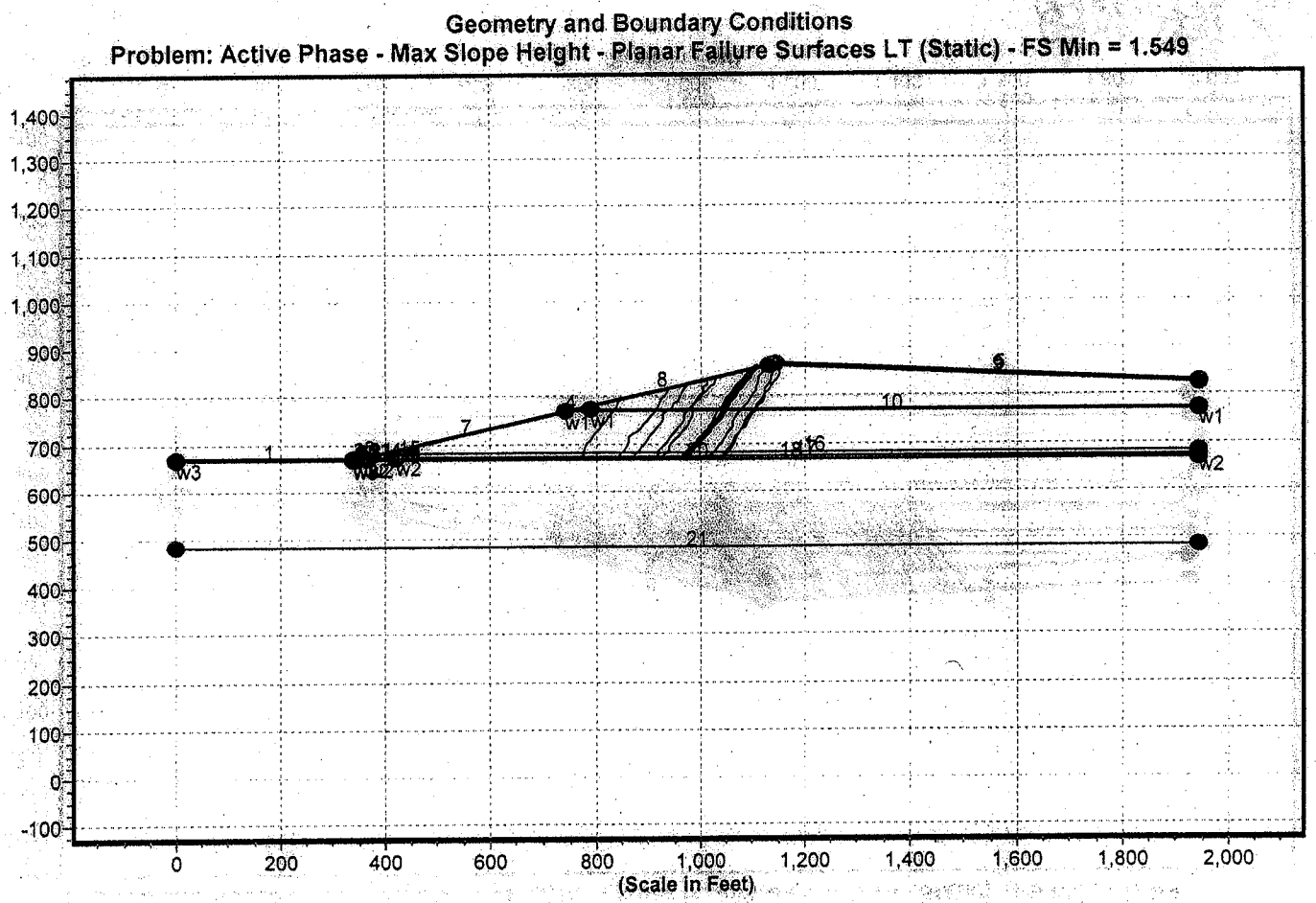
Drained Shear Strengths
Residual Geosynthetic Interface Shear Strengths
Failure Along Floor Liner Interface and Through Waste
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Planar Failure Surfaces LT (Static)
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
(Scale in Feet)
W3
W1
W2
1
7
8
9
10
21

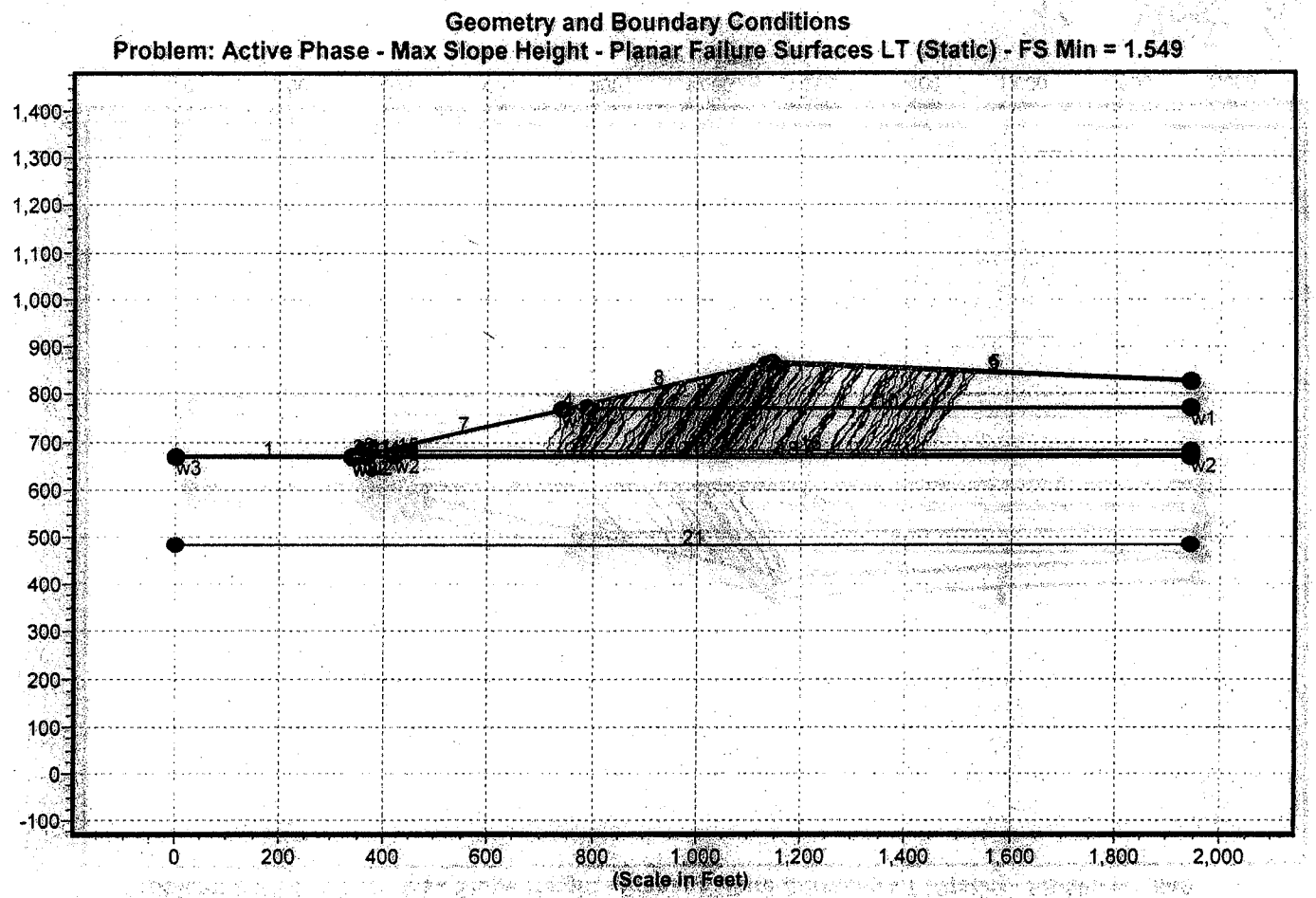
Profile



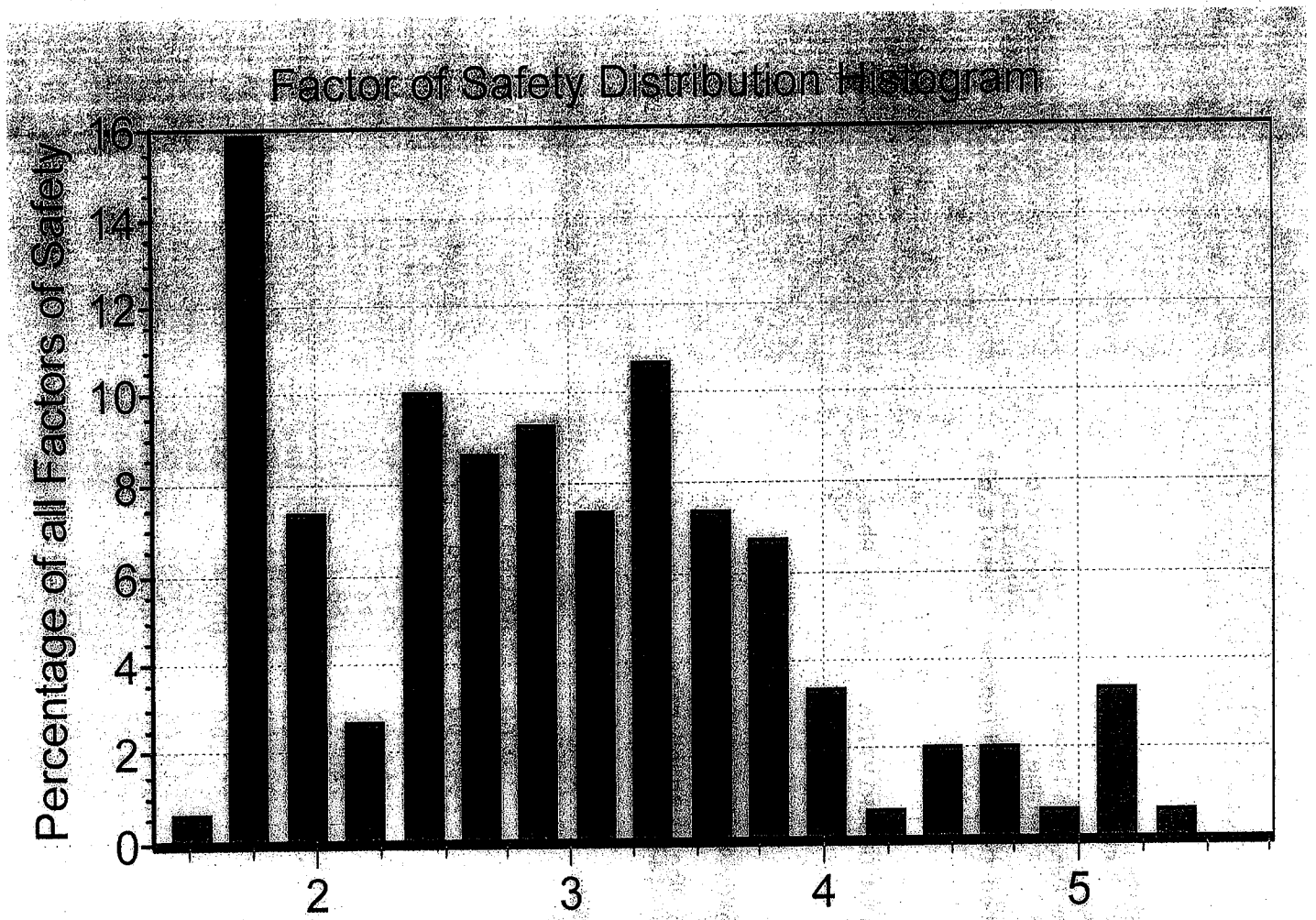
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase - Max Waste Height

Planar Failure Surfaces

Long Term (Static)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Planar Failure Surfaces LT (Static)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
3	352.00	675.00	364.00	675.00	2
4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1500.0	19.0	0.00	0.0	3
2	135.0	140.0	700.0	21.0	0.00	0.0	0
3	128.0	134.0	1300.0	22.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	700.0	21.0	0.00	0.0	0
7	135.0	140.0	0.0	10.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	1100.0	18.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

result
3 337.10 667.00

Janbus Empirical Coef is being used for the case of C=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

2 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	364.00	670.00	370.00	670.00	1.00
2	700.00	670.00	1425.00	670.00	1.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.85	675.00
2	366.50	670.01
3	964.80	670.06
4	971.49	677.49
5	978.48	684.64
6	985.23	692.03
7	992.21	699.18
8	998.39	707.04
9	1005.12	714.44
10	1012.10	721.60
11	1016.77	730.44
12	1022.40	738.71
13	1028.51	746.62
14	1035.11	754.14
15	1042.01	761.37
16	1046.65	770.23
17	1050.36	779.52
18	1053.22	789.10
19	1060.27	796.19
20	1065.76	804.55

		result
21	1071.49	812.74
22	1078.50	819.87
23	1082.16	829.18
24	1089.14	836.33
25	1094.42	844.82
26	1099.62	853.37
27	1106.67	860.46
28	1106.91	860.73

*** 1.549 ***

Individual data on the 42 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	6.1	1470.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.8	410.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1.7	1011.6	0.0	60.7	0.0	0.0	0.0	0.0	0.0
5	1.5	895.4	0.0	92.1	0.0	0.0	0.0	0.0	0.0
6	50.0	51778.4	0.0	9279.6	0.0	0.0	0.0	0.0	0.0
7	12.0	20118.3	0.0	3730.0	0.0	0.0	0.0	0.0	0.0
8	18.0	37937.3	0.0	5593.7	0.0	0.0	0.0	0.0	0.0
9	292.1	********	0.0	90560.7	0.0	0.0	0.0	0.0	0.0
10	50.9	423195.8	0.0	15731.6	0.0	0.0	0.0	0.0	0.0
11	173.8	********	0.0	53643.1	0.0	0.0	0.0	0.0	0.0
12	0.8	10153.7	0.0	352.7	0.0	0.0	0.0	0.0	0.0
13	3.6	42385.2	0.0	672.0	0.0	0.0	0.0	0.0	0.0
14	2.2	25735.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	3.4	38473.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	3.6	38987.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	6.7	71723.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	7.0	71436.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	6.2	60434.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	6.7	62800.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	7.0	62240.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	4.7	39327.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	5.6	44342.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	6.1	45134.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	6.6	45630.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	6.9	44873.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	3.5	21053.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	1.2	6754.6	0.0	610.6	0.0	0.0	0.0	0.0	0.0
29	1.1	6209.5	0.0	257.2	0.0	0.0	0.0	0.0	0.0
30	2.6	13814.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	2.9	13580.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	7.1	29785.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	5.5	20633.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	5.7	18561.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	7.0	19563.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	3.7	8296.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	7.0	12253.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	5.3	6769.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	5.2	3854.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	6.0	1791.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1.1	85.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0

result

42	0.2	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.60	675.00
2	359.77	673.57
3	369.24	670.36
4	1014.56	670.03
5	1020.96	677.72
6	1027.45	685.33
7	1033.53	693.27
8	1039.71	701.12
9	1046.38	708.57
10	1049.32	718.13
11	1055.13	726.27
12	1059.96	735.03
13	1060.88	744.99
14	1064.47	754.32
15	1071.53	761.40
16	1077.28	769.59
17	1082.89	777.87
18	1088.84	785.90
19	1093.37	794.82
20	1098.55	803.37
21	1104.39	811.49
22	1106.52	821.26
23	1110.08	830.60
24	1110.11	840.60
25	1116.64	848.18
26	1119.99	857.60
27	1123.48	864.87

*** 1.651 ***

1

Failure Surface Specified By 23 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.43	675.00
2	364.86	670.30
3	871.35	670.20
4	874.19	679.79
5	881.20	686.91
6	888.17	694.09
7	893.93	702.26
8	900.78	709.54
9	903.44	719.18
10	910.49	726.28
11	916.26	734.45
12	923.33	741.52
13	927.52	750.60
14	928.95	760.50

		result
15	935.41	768.14
16	942.26	775.42
17	947.88	783.69
18	954.60	791.10
19	961.09	798.71
20	964.04	808.26
21	969.44	816.68
22	975.07	824.94
23	978.31	828.58

*** 1.669 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	359.66	675.00
2	364.68	670.47
3	1041.00	670.38
4	1043.94	679.93
5	1050.76	687.25
6	1057.48	694.66
7	1061.90	703.63
8	1066.57	712.47
9	1071.59	721.12
10	1078.48	728.37
11	1085.27	735.71
12	1088.95	745.01
13	1093.58	753.87
14	1098.08	762.80
15	1104.96	770.06
16	1107.64	779.69
17	1112.71	788.31
18	1119.70	795.46
19	1120.66	805.42
20	1121.38	815.39
21	1128.01	822.88
22	1132.73	831.70
23	1133.62	841.66
24	1138.45	850.41
25	1141.87	859.81
26	1148.78	867.03
27	1151.37	869.63

*** 1.673 ***

1

Failure Surface Specified By 19 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

		result
1	362.73	675.00
2	367.52	670.21
3	768.89	670.37
4	775.59	677.80
5	778.86	687.25
6	782.38	696.60
7	788.65	704.39
8	793.10	713.35
9	798.64	721.68
10	804.35	729.88
11	810.99	737.37
12	817.20	745.20
13	822.31	753.80
14	824.93	763.45
15	831.98	770.54
16	836.97	779.21
17	842.22	787.72
18	849.18	794.90
19	850.47	796.62

*** 1.675 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	356.39	675.00
2	356.61	674.82
3	365.46	670.16
4	974.72	670.35
5	981.55	677.65
6	988.48	684.87
7	988.76	694.86
8	993.75	703.53
9	1000.17	711.19
10	1003.85	720.49
11	1010.53	727.93
12	1016.98	735.57
13	1022.60	743.84
14	1026.06	753.23
15	1029.37	762.66
16	1033.32	771.85
17	1040.30	779.01
18	1044.82	787.93
19	1051.13	795.69
20	1056.03	804.41
21	1062.35	812.15
22	1066.65	821.18
23	1073.69	828.28
24	1080.75	835.36
25	1087.08	843.10
26	1091.92	851.86
27	1092.26	857.07

*** 1.688 ***

1

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	356.34	675.00
2	359.48	671.87
3	369.38	670.43
4	1046.11	669.97
5	1049.84	679.25
6	1056.91	686.32
7	1062.04	694.91
8	1067.40	703.35
9	1068.73	713.26
10	1074.02	721.74
11	1079.16	730.32
12	1082.19	739.85
13	1084.40	749.60
14	1091.35	756.80
15	1097.41	764.76
16	1104.31	771.99
17	1110.05	780.18
18	1116.86	787.50
19	1121.51	796.36
20	1122.45	806.31
21	1129.21	813.68
22	1132.74	823.04
23	1139.52	830.39
24	1146.22	837.82
25	1151.05	846.57
26	1152.48	856.47
27	1154.14	866.33
28	1156.75	869.36

*** 1.693 ***

Failure Surface Specified By 24 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	360.39	675.00
2	367.32	670.37
3	925.18	670.29
4	931.23	678.25
5	937.97	685.63
6	940.31	695.36
7	945.47	703.92
8	952.31	711.21
9	959.30	718.37
10	963.46	727.46
11	970.44	734.63
12	977.30	741.90

		result
13	981.16	751.13
14	983.10	760.93
15	985.67	770.60
16	986.22	780.58
17	991.66	788.97
18	998.68	796.10
19	1004.41	804.29
20	1011.44	811.40
21	1017.23	819.56
22	1024.30	826.64
23	1027.39	836.14
24	1032.63	842.16

*** 1.696 ***

1

Failure Surface Specified By 22 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	358.06	675.00
2	366.14	670.32
3	841.81	670.16
4	845.66	679.39
5	852.45	686.74
6	858.23	694.89
7	863.32	703.51
8	863.96	713.49
9	871.00	720.59
10	878.07	727.66
11	884.90	734.97
12	891.14	742.78
13	897.70	750.32
14	904.27	757.86
15	911.24	765.04
16	917.01	773.20
17	921.03	782.36
18	923.43	792.07
19	929.78	799.80
20	934.10	808.82
21	940.42	816.56
22	943.66	819.91

*** 1.697 ***

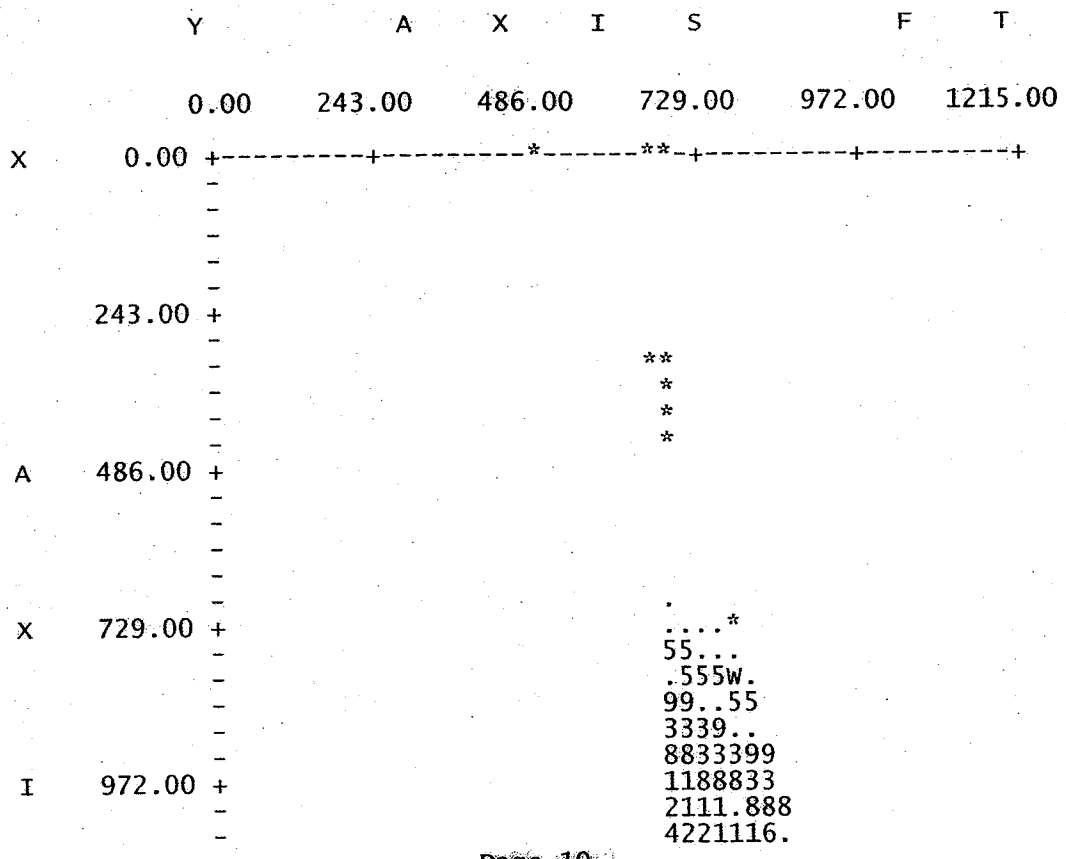
Failure Surface Specified By 25 Coordinate Points

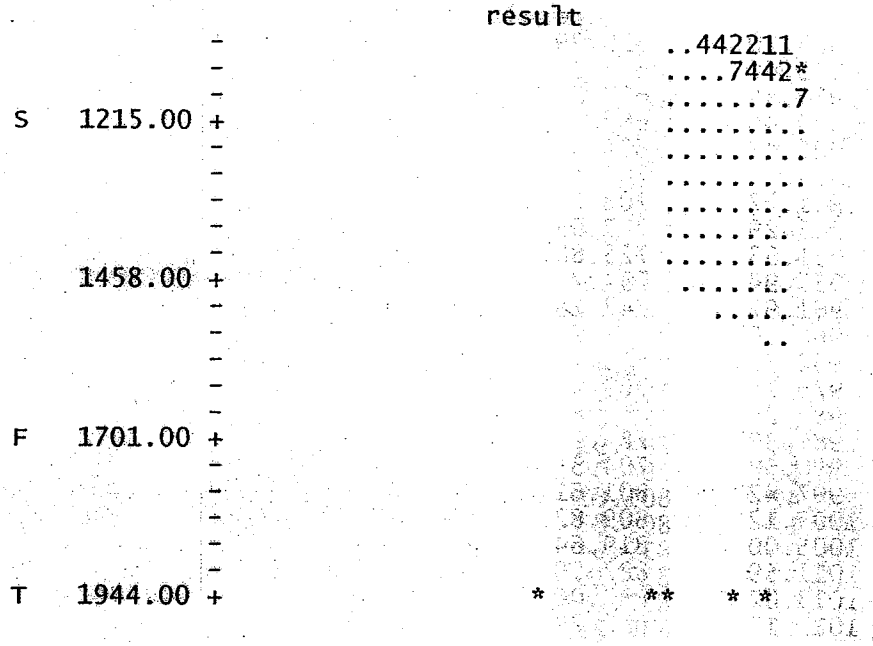
Point No.	X-Surf (ft)	Y-Surf (ft)
1	345.68	672.89
2	355.36	672.54

		result
3	365.10	670.29
4	912.46	670.18
5	919.45	677.33
6	920.40	687.28
7	927.47	694.35
8	934.52	701.45
9	941.27	708.82
10	945.29	717.98
11	951.53	725.80
12	955.94	734.77
13	961.97	742.75
14	966.30	751.77
15	968.79	761.45
16	974.15	769.90
17	980.24	777.82
18	987.30	784.91
19	990.50	794.39
20	997.42	801.61
21	1003.12	809.82
22	1005.00	819.64
23	1011.59	827.16
24	1013.02	837.06
25	1013.17	837.29

*** 1.704 ***

1




result
S
1215.00
1458.00
F
1701.00
T
1944.00

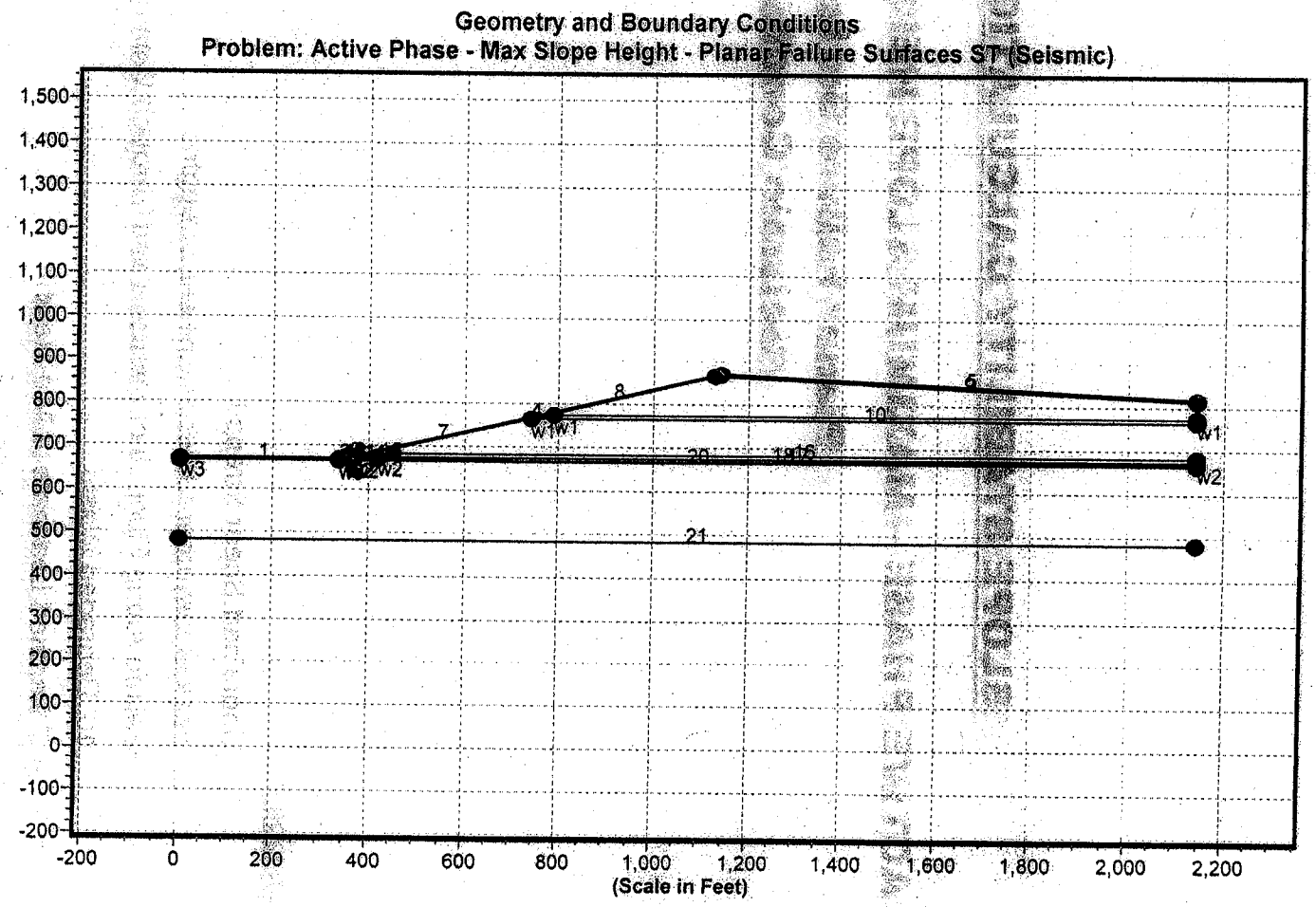
SLOPE STABILITY CALCULATIONS

ACTIVE PHASE – MAXIMUM SLOPE HEIGHT

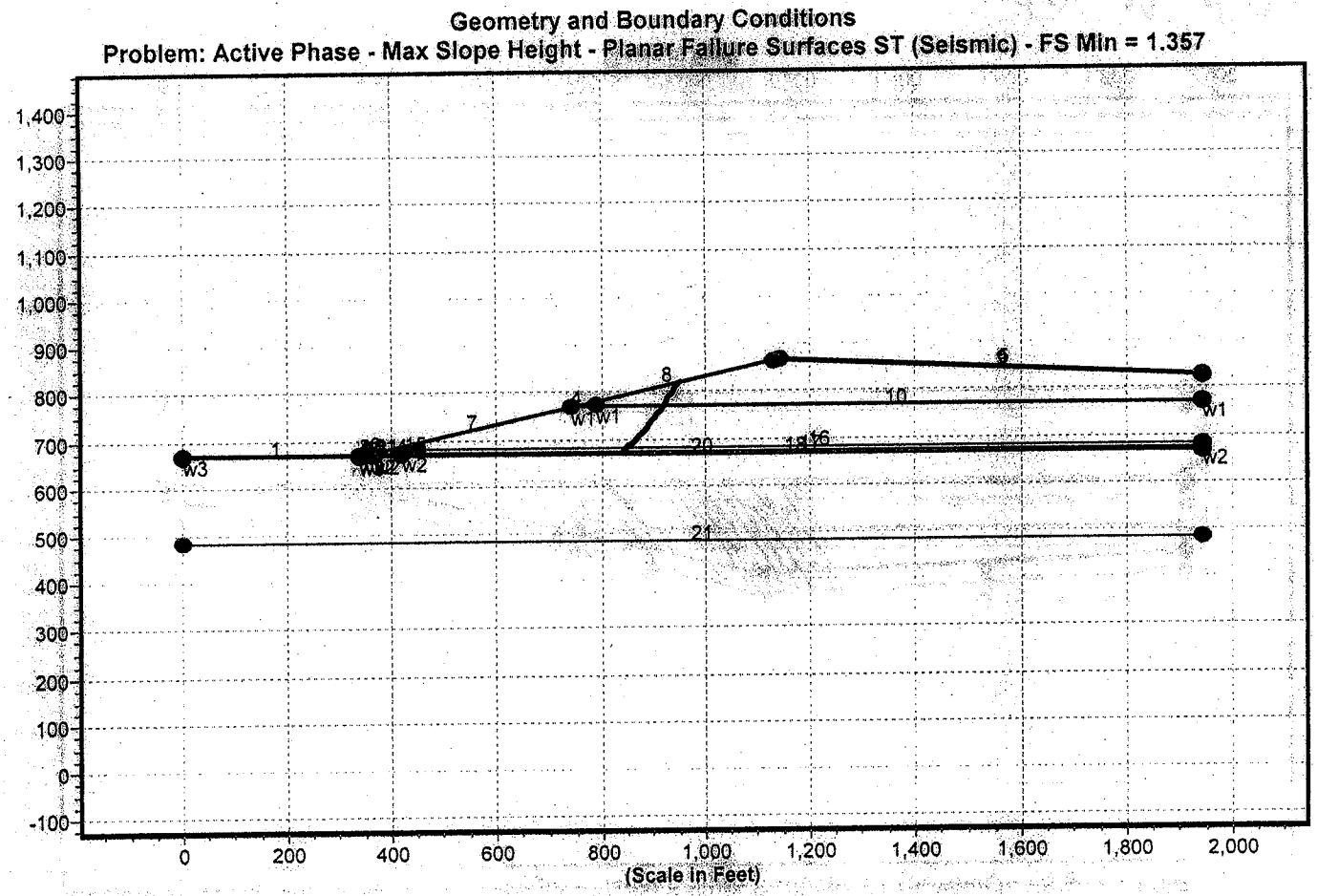
Planar Failure Surfaces
Seismic Conditions

Key Assumptions:

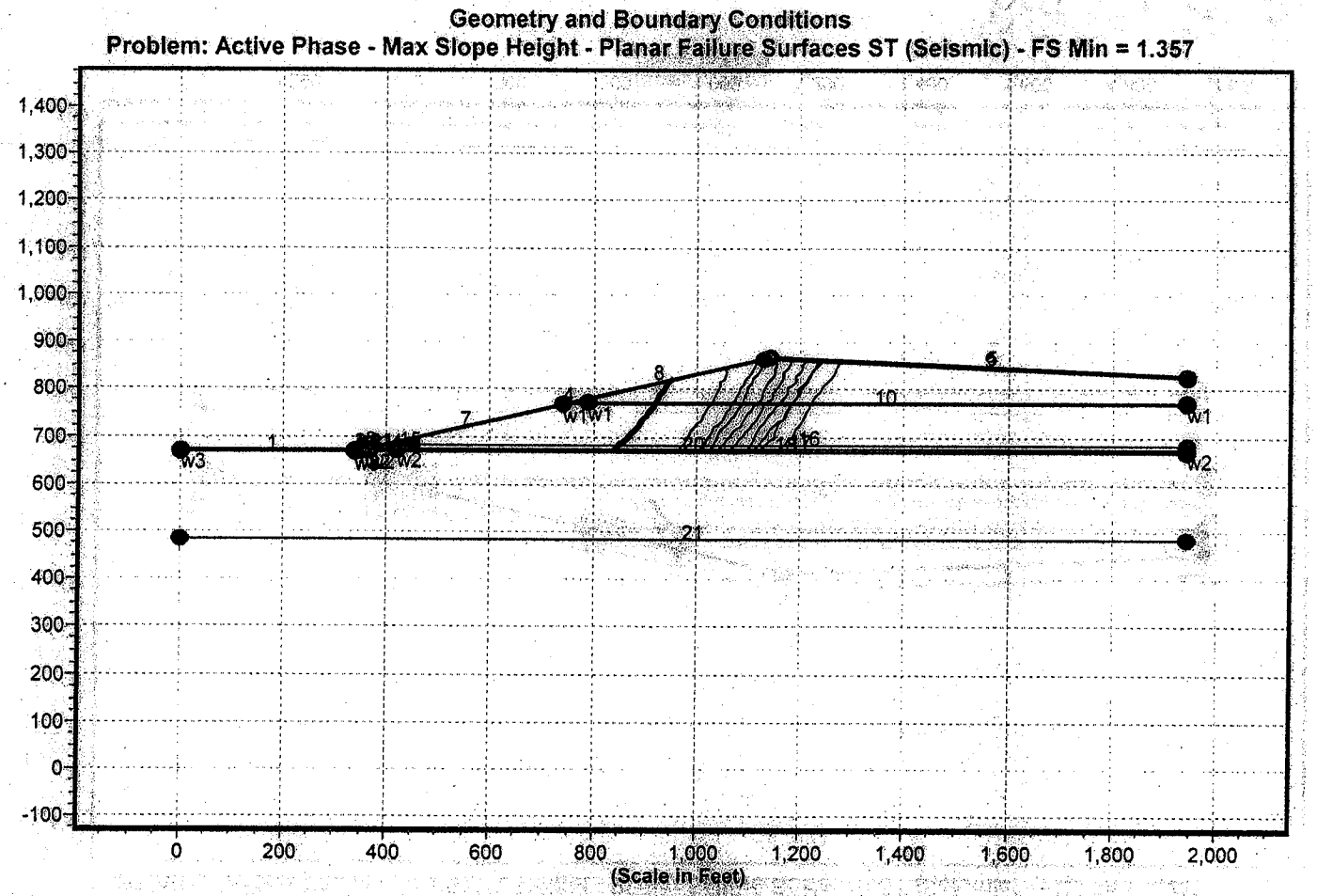
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
Failure Along Floor Liner Interface and Through Waste
10' Degraded Waste
5' Perched Leachate at Mid-Height
5' Leachate on Landfill Floor
4:1 (Horizontal to Vertical) Waste Slope
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: Active Phase - Max Slope Height - Planar Failure Surfaces ST (Seismic)
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-200
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
(Scale in Feet)
W3
W2
W1
1
7
8
9
10
21

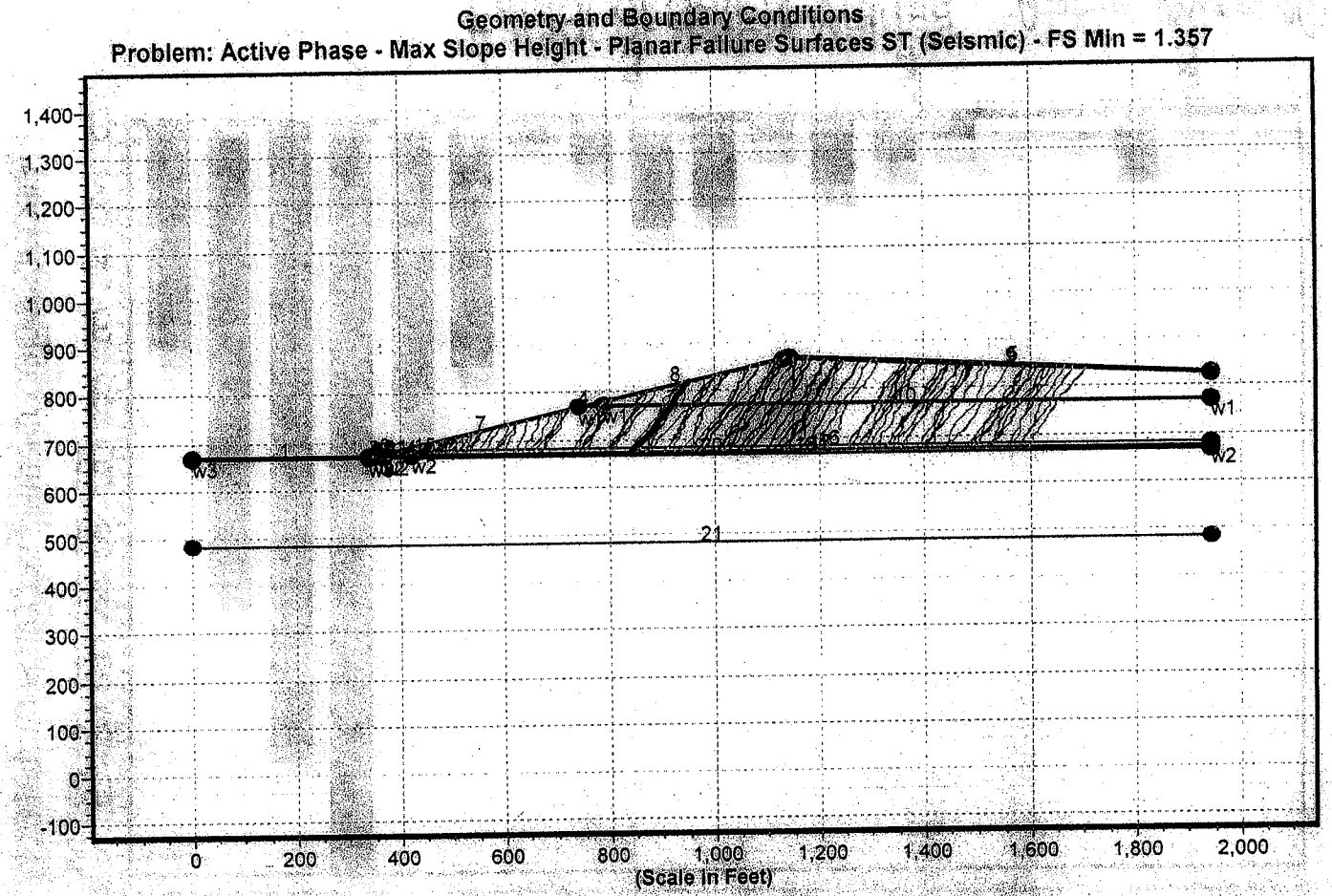
Profile



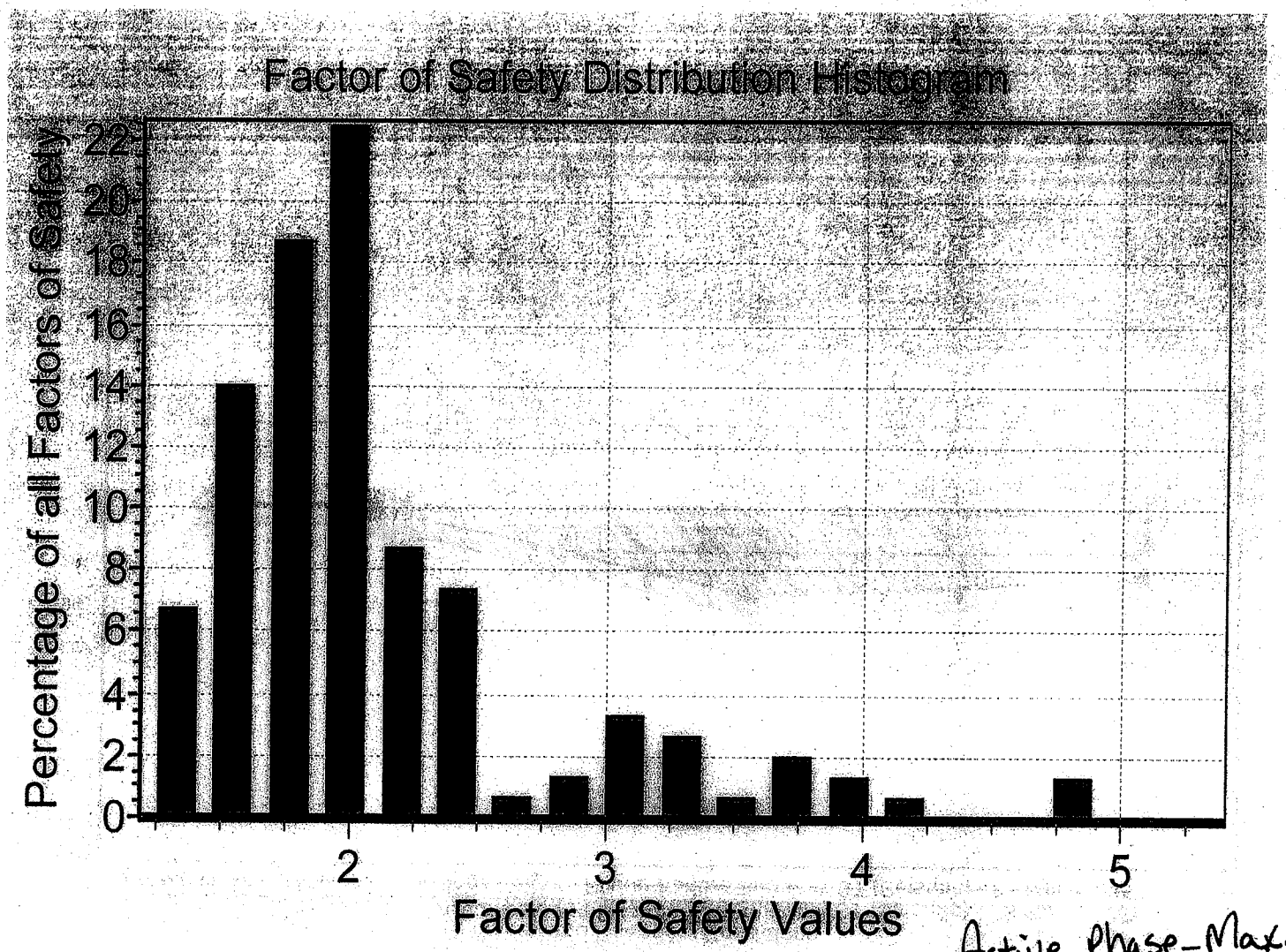
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



Active Phase_Max. Slope Height
Planar Failure surfaces
(Seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION Active Phase - Max Slope Height - Planar Failure Surfaces ST (Seismic)

BOUNDARY COORDINATES

5 Top Boundaries
21 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	670.00	337.00	670.00	1
2	337.00	670.00	352.00	675.00	2
3	352.00	675.00	364.00	675.00	2
4	364.00	675.00	1144.00	870.00	3
5	1144.00	870.00	1944.00	830.00	3
6	364.00	675.00	364.80	674.18	2
7	364.80	674.18	740.12	768.00	5
8	740.12	768.00	1130.75	865.66	4
9	1130.75	865.66	1944.00	825.00	4
10	740.12	768.00	1944.00	768.00	5
11	364.80	674.18	368.00	671.00	2
12	337.00	670.00	357.00	670.00	6
13	357.00	670.00	358.00	671.00	7
14	358.00	671.00	418.00	671.00	7
15	418.00	671.00	448.00	681.00	8
16	448.00	681.00	1944.00	681.00	8
17	418.00	671.00	1944.00	671.00	7
18	357.00	670.00	1944.00	670.00	6
19	337.00	670.00	337.10	667.00	1
20	0.00	667.00	1944.00	667.00	9
21	0.00	483.00	1944.00	483.00	10

1

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	100.0	110.0	1400.0	0.0	0.00	0.0	3
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	75.0	75.0	500.0	30.0	0.00	0.0	1
5	75.0	75.0	500.0	30.0	0.00	0.0	2
6	135.0	140.0	3000.0	0.0	0.00	0.0	0
7	135.0	140.0	0.0	16.0	0.00	0.0	2
8	105.0	105.0	0.0	22.0	0.00	0.0	2
9	140.0	148.0	6000.0	0.0	0.00	0.0	0
10	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	740.12	768.00
2	791.00	773.00
3	1944.00	773.00

Piezometric Surface No. 2 Specified by 5 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	357.00	670.00
2	358.00	671.00
3	368.00	671.00
4	418.00	675.00
5	1944.00	675.00

1

Piezometric Surface No. 3 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	0.00	670.00
2	337.00	670.00

result

3	337.10	667.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

2 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	364.00	670.00	370.00	670.00	1.00
2	400.00	670.00	1600.00	670.00	1.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 23 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	357.85	675.00
2	366.50	670.01
3	838.29	670.06
4	844.98	677.49
5	851.97	684.64
6	858.72	692.03
7	865.70	699.18
8	871.88	707.04
9	878.61	714.44
10	885.59	721.60

		result
11	890.26	730.44
12	895.89	738.71
13	902.00	746.62
14	908.60	754.14
15	915.50	761.37
16	920.14	770.23
17	923.85	779.52
18	926.70	789.10
19	933.76	796.19
20	939.25	804.55
21	944.98	812.74
22	951.99	819.87
23	952.92	822.23

*** 1.357 ***

Individual data on the 37 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	6.1	1470.6	0.0	0.0	0.0	0.0	147.1	0.0	0.0
2	0.8	410.9	0.0	0.0	0.0	0.0	41.1	0.0	0.0
3	0.0	4.6	0.0	0.0	0.0	0.0	0.5	0.0	0.0
4	1.7	1011.6	0.0	60.7	0.0	0.0	101.2	0.0	0.0
5	1.5	895.4	0.0	92.1	0.0	0.0	89.5	0.0	0.0
6	50.0	51774.6	0.0	9277.9	0.0	0.0	5177.5	0.0	0.0
7	12.0	20116.3	0.0	3729.1	0.0	0.0	2011.6	0.0	0.0
8	18.0	37933.6	0.0	5592.0	0.0	0.0	3793.4	0.0	0.0
9	292.1	********	0.0	90475.0	0.0	0.0	*******	0.0	0.0
10	50.9	423137.1	0.0	15705.4	0.0	0.0	42313.7	0.0	0.0
11	47.3	436766.7	0.0	14582.9	0.0	0.0	43676.7	0.0	0.0
12	0.8	8145.5	0.0	352.8	0.0	0.0	814.5	0.0	0.0
13	3.6	33835.4	0.0	672.0	0.0	0.0	3383.5	0.0	0.0
14	2.2	20415.1	0.0	0.0	0.0	0.0	2041.5	0.0	0.0
15	3.4	30333.4	0.0	0.0	0.0	0.0	3033.3	0.0	0.0
16	3.6	30546.6	0.0	0.0	0.0	0.0	3054.7	0.0	0.0
17	6.7	55732.7	0.0	0.0	0.0	0.0	5573.3	0.0	0.0
18	7.0	54860.7	0.0	0.0	0.0	0.0	5486.1	0.0	0.0
19	6.2	45781.0	0.0	0.0	0.0	0.0	4578.1	0.0	0.0
20	6.7	46837.3	0.0	0.0	0.0	0.0	4683.7	0.0	0.0
21	7.0	45679.4	0.0	0.0	0.0	0.0	4567.9	0.0	0.0
22	4.7	28253.5	0.0	0.0	0.0	0.0	2825.3	0.0	0.0
23	5.6	30992.5	0.0	0.0	0.0	0.0	3099.2	0.0	0.0
24	6.1	30631.6	0.0	0.0	0.0	0.0	3063.2	0.0	0.0
25	6.6	29994.7	0.0	0.0	0.0	0.0	2999.5	0.0	0.0
26	6.9	28487.1	0.0	0.0	0.0	0.0	2848.7	0.0	0.0
27	3.5	12830.5	0.0	0.0	0.0	0.0	1283.0	0.0	0.0
28	1.2	3985.0	0.0	610.7	0.0	0.0	398.5	0.0	0.0
29	1.1	3587.8	0.0	257.2	0.0	0.0	358.8	0.0	0.0
30	2.6	7637.1	0.0	0.0	0.0	0.0	763.7	0.0	0.0
31	2.9	6801.9	0.0	0.0	0.0	0.0	680.2	0.0	0.0
32	7.1	13043.6	0.0	0.0	0.0	0.0	1304.4	0.0	0.0
33	5.5	7611.8	0.0	0.0	0.0	0.0	761.2	0.0	0.0
34	5.7	4984.5	0.0	0.0	0.0	0.0	498.5	0.0	0.0
35	7.0	2916.8	0.0	0.0	0.0	0.0	291.7	0.0	0.0
36	0.5	82.9	0.0	0.0	0.0	0.0	8.3	0.0	0.0

result

37	0.4	29.5	0.0	0.0	0.0	0.0	2.9	0.0	0.0

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	354.71	675.00
2	355.66	674.15
3	364.96	670.48
4	1094.39	669.83
5	1100.84	677.47
6	1106.46	685.74
7	1109.92	695.13
8	1113.24	704.56
9	1117.18	713.75
10	1124.16	720.91
11	1128.69	729.83
12	1134.99	737.59
13	1139.89	746.31
14	1146.21	754.05
15	1150.51	763.08
16	1157.55	770.18
17	1164.62	777.26
18	1170.95	785.00
19	1175.78	793.76
20	1176.44	803.73
21	1183.51	810.81
22	1189.85	818.54
23	1191.54	828.40
24	1198.48	835.60
25	1203.56	844.21
26	1204.46	854.17
27	1211.38	861.39
28	1215.21	866.44

*** 1.368 ***

1

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	359.91	675.00
2	365.87	670.21
3	1108.64	670.14
4	1115.44	677.47
5	1122.02	685.00
6	1127.79	693.17
7	1133.18	701.60
8	1139.66	709.21
9	1144.34	718.05
10	1151.21	725.32
11	1158.27	732.40
12	1165.26	739.55
13	1170.14	748.28

		result
14	1175.08	756.98
15	1179.06	766.15
16	1184.09	774.79
17	1189.48	783.21
18	1196.33	790.50
19	1196.83	800.49
20	1202.80	808.51
21	1209.83	815.62
22	1215.90	823.57
23	1218.98	833.08
24	1225.41	840.74
25	1232.39	847.90
26	1238.77	855.60
27	1245.45	863.05
28	1246.38	864.88

*** 1.390 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	362.60	675.00
2	367.40	670.34
3	1041.09	669.87
4	1045.01	679.07
5	1051.54	686.64
6	1058.37	693.95
7	1063.76	702.37
8	1070.83	709.45
9	1077.83	716.59
10	1084.47	724.07
11	1088.64	733.16
12	1093.44	741.93
13	1099.26	750.06
14	1105.67	757.74
15	1111.01	766.19
16	1117.70	773.63
17	1124.44	781.01
18	1124.71	791.01
19	1129.73	799.66
20	1135.01	808.15
21	1139.30	817.18
22	1145.39	825.12
23	1151.38	833.12
24	1151.45	843.12
25	1154.32	852.70
26	1155.37	862.65
27	1156.34	869.38

*** 1.391 ***

1

result

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	359.08	675.00
2	364.16	670.15
3	1123.42	669.81
4	1128.17	678.61
5	1135.10	685.82
6	1141.93	693.13
7	1149.00	700.20
8	1151.86	709.78
9	1153.03	719.71
10	1157.91	728.44
11	1164.97	735.52
12	1170.80	743.64
13	1175.44	752.50
14	1178.09	762.15
15	1183.76	770.38
16	1188.81	779.02
17	1195.69	786.27
18	1200.78	794.88
19	1204.55	804.14
20	1210.19	812.39
21	1215.60	820.81
22	1219.33	830.08
23	1222.66	839.51
24	1229.73	846.59
25	1231.88	856.35
26	1237.94	864.31
27	1238.64	865.27

*** 1.396 ***

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	356.89	675.00
2	359.29	673.19
3	368.80	670.13
4	1157.23	669.79
5	1162.77	678.11
6	1169.24	685.74
7	1176.26	692.86
8	1183.21	700.06
9	1189.22	708.05
10	1192.11	717.62
11	1199.05	724.82
12	1203.76	733.64
13	1208.43	742.48
14	1210.19	752.33
15	1217.26	759.40
16	1219.33	769.19
17	1225.10	777.35

		result
18	1228.80	786.64
19	1235.84	793.75
20	1239.84	802.91
21	1246.15	810.67
22	1253.16	817.80
23	1258.92	825.98
24	1264.70	834.14
25	1267.23	843.81
26	1271.72	852.74
27	1275.86	861.85
28	1277.34	863.33

*** 1.411 ***

1

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	359.51	675.00
2	366.40	670.15
3	1023.30	670.43
4	1027.98	679.27
5	1033.74	687.44
6	1038.66	696.15
7	1040.11	706.04
8	1047.02	713.27
9	1054.09	720.34
10	1059.42	728.80
11	1066.32	736.04
12	1072.21	744.13
13	1077.31	752.73
14	1081.59	761.77
15	1088.16	769.30
16	1090.06	779.11
17	1095.10	787.76
18	1096.94	797.58
19	1099.77	807.18
20	1106.77	814.31
21	1109.41	823.96
22	1116.31	831.20
23	1121.43	839.79
24	1125.85	848.76
25	1129.74	857.97
26	1136.80	865.06
27	1140.94	869.24

*** 1.414 ***

Failure Surface Specified By 26 Coordinate Points

Point	X-Surf	Y-Surf

No.	(ft)	result (ft)
1	360.74	675.00
2	366.22	670.14
3	1003.53	669.97
4	1009.74	677.81
5	1014.85	686.40
6	1017.47	696.06
7	1024.52	703.15
8	1029.51	711.82
9	1034.76	720.33
10	1041.72	727.51
11	1047.72	735.51
12	1054.26	743.07
13	1058.03	752.33
14	1064.37	760.06
15	1065.94	769.94
16	1072.53	777.46
17	1079.36	784.77
18	1080.31	794.72
19	1084.44	803.83
20	1091.33	811.07
21	1094.78	820.46
22	1101.30	828.04
23	1107.79	835.65
24	1108.17	845.64
25	1113.80	853.90
26	1114.33	862.58

*** 1.423 ***

1

Failure Surface Specified By 24 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	359.66	675.00
2	364.68	670.47
3	964.41	670.38
4	967.36	679.93
5	974.17	687.25
6	980.89	694.66
7	985.31	703.63
8	989.98	712.47
9	995.00	721.12
10	1001.89	728.37
11	1008.68	735.71
12	1012.36	745.01
13	1016.99	753.87
14	1021.49	762.80
15	1028.37	770.06
16	1031.05	779.69
17	1036.12	788.31
18	1043.11	795.46
19	1044.07	805.42
20	1044.80	815.39
21	1051.42	822.88

		result
22	1056.14	831.70
23	1057.03	841.66
24	1061.26	849.32

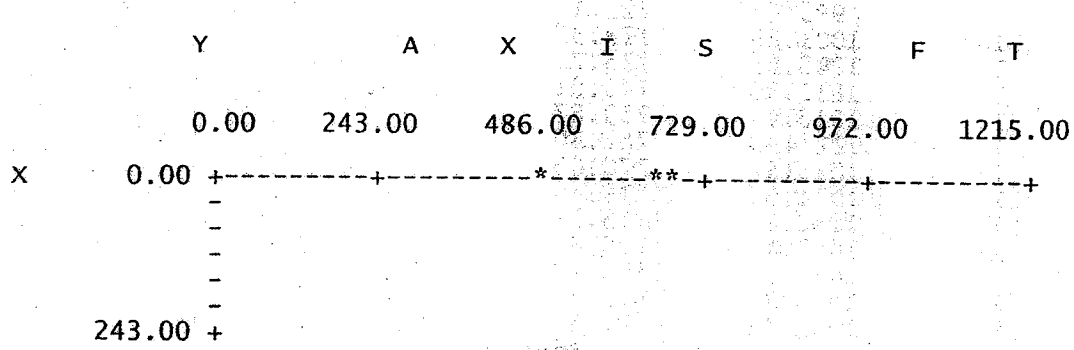
*** 1.424 ***

Failure Surface Specified By 27 Coordinate Points

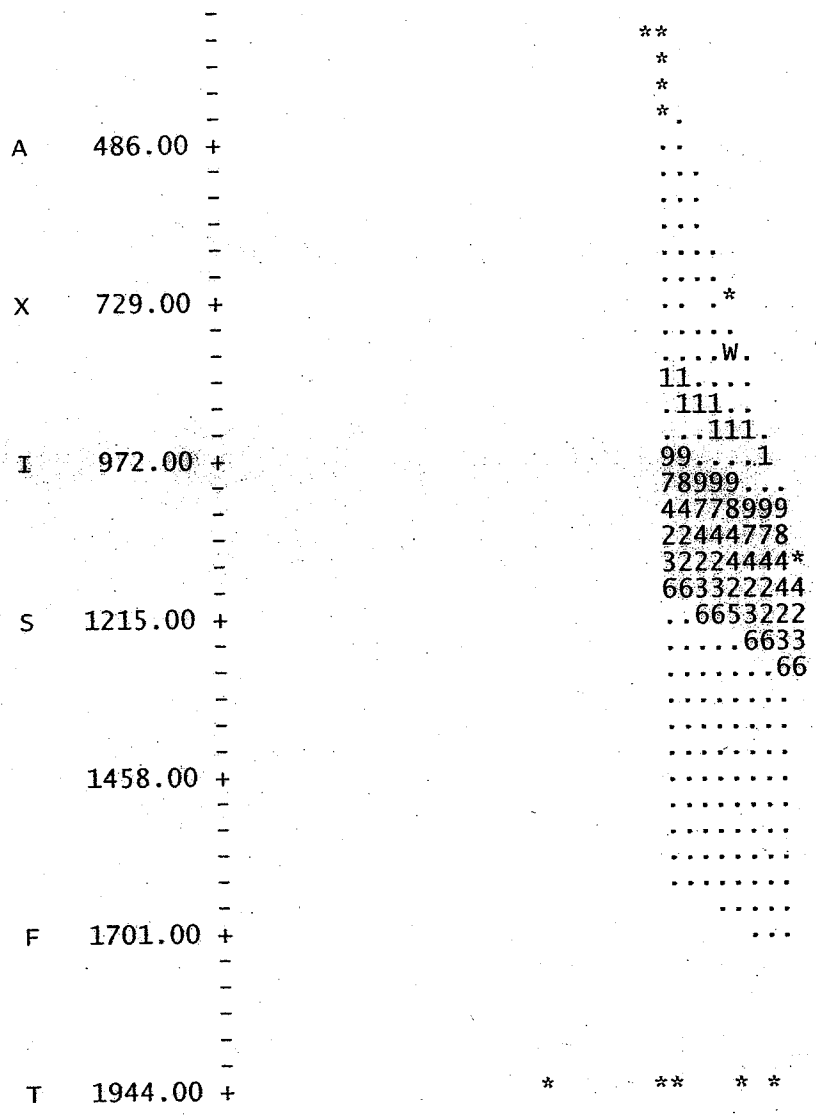
Point No.	X-Surf (ft)	Y-Surf (ft)
1	360.50	675.00
2	365.62	670.17
3	1066.55	669.88
4	1068.96	679.58
5	1076.01	686.68
6	1083.01	693.82
7	1090.08	700.89
8	1094.26	709.98
9	1100.50	717.79
10	1107.29	725.14
11	1113.15	733.24
12	1116.49	742.66
13	1121.89	751.08
14	1127.45	759.39
15	1131.33	768.61
16	1138.40	775.68
17	1145.29	782.93
18	1146.03	792.90
19	1153.06	800.00
20	1159.75	807.44
21	1162.43	817.07
22	1168.19	825.24
23	1168.39	835.24
24	1174.26	843.34
25	1180.68	851.00
26	1185.27	859.89
27	1185.81	867.91

*** 1.435 ***

1



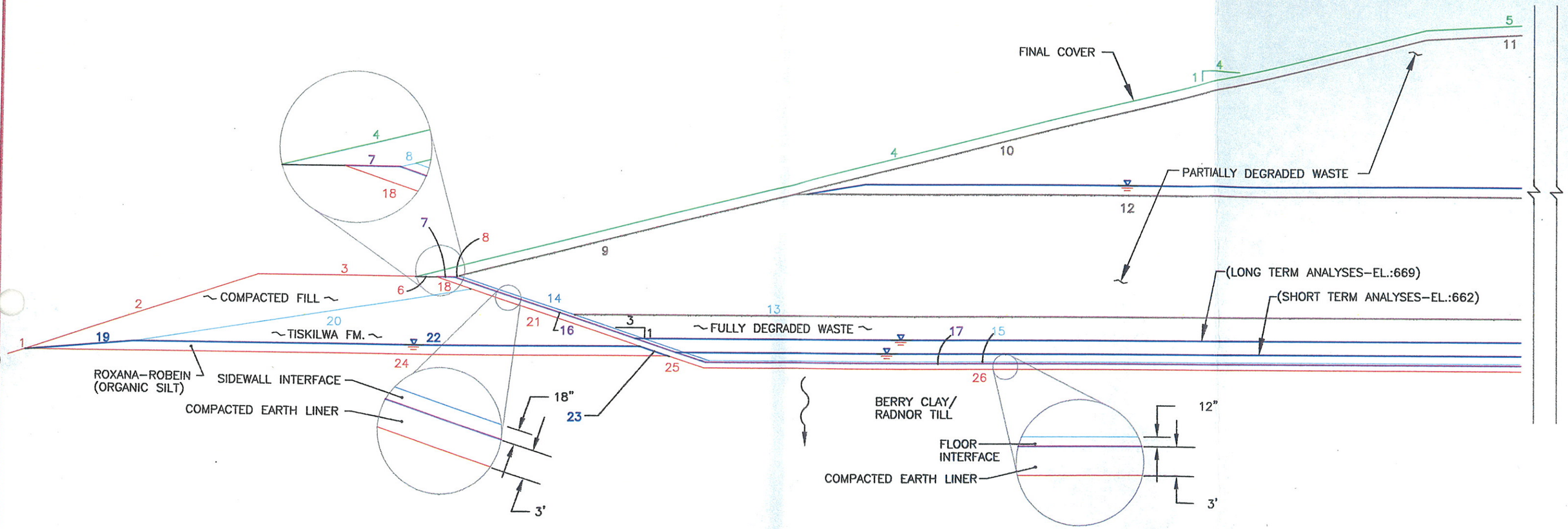
result



SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD

SLOPE STABILITY MODEL – SOUTH EXTERIOR SLOPE
POST – DESIGN PERIOD



SOIL IDENTITY	SOIL TYPE NO.
BERRY CLAY/RADNOR TILL	1
COMPACTED FILL	2
FINAL COVER	3
COMPACTED EARTH LINER	4
SIDEWALL INTERFACE	5
PARTIALLY DEGRADED WASTE	6, 7
FLOOR INTERFACE	8
ROXANA ROBEIN: ORGANIC SILT	9
TISKILWA FORMATION	10
FULLY DEGRADED WASTE	11

50' 25' 0 50' 100'

1"=50'

LEGEND

2 BOUNDARY NO.

PIEZOMETRIC SURFACE

Illinois Licensed Professional Design Firm 184–001145

PDC Technical Services, Inc.

Peoria, Illinois

APP. 812.305-E: FIGURE D

POST DESIGN PERIOD SLOPE STABILITY MODEL

CLINTON LANDFILL NO. 3

CLINTON, ILLINOIS

SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD
Circular Failure Surfaces
Static Short Term Conditions

Key Assumptions:

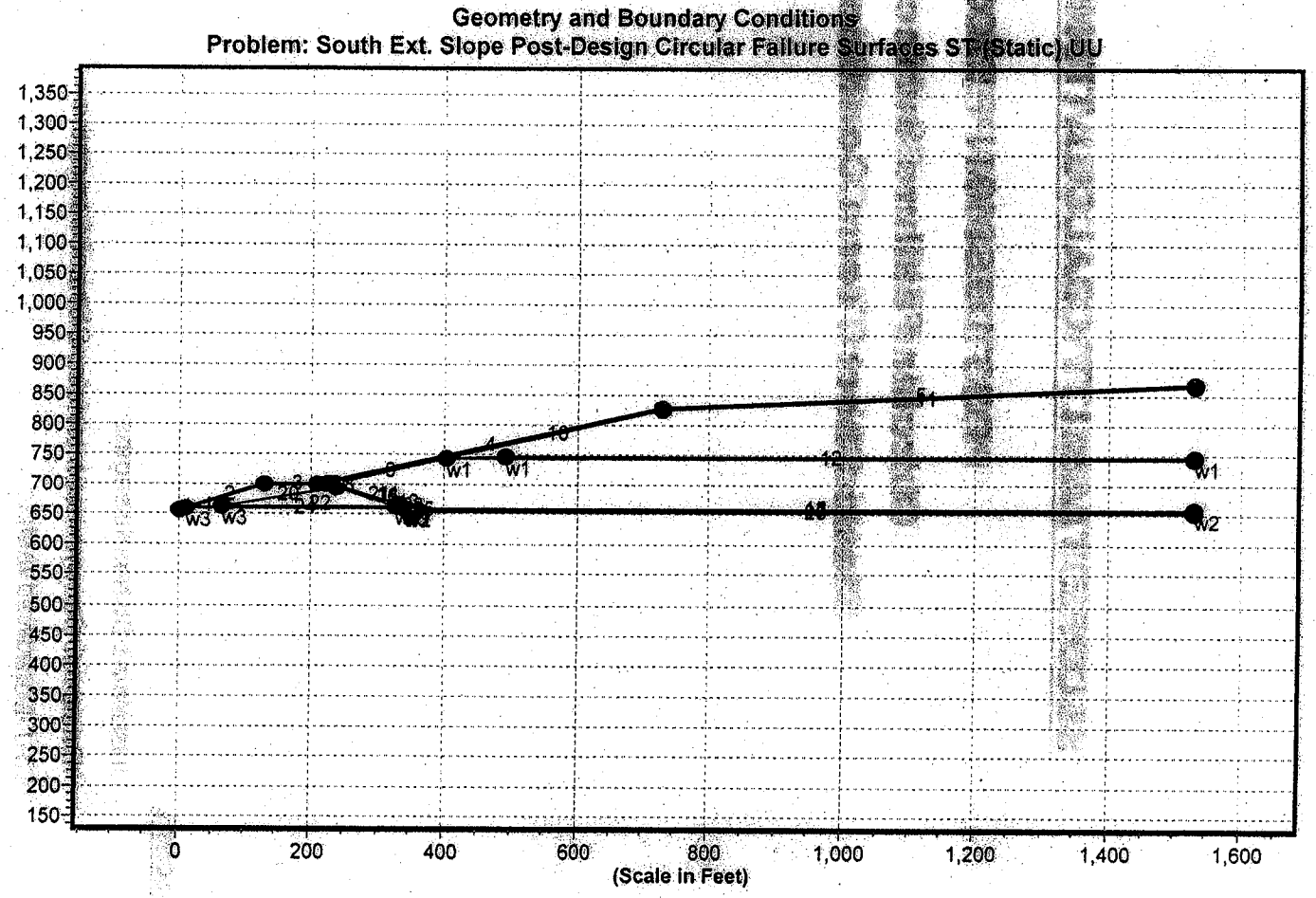
Undrained Shear Strengths

Residual Geosynthetic Interface Shear Strengths

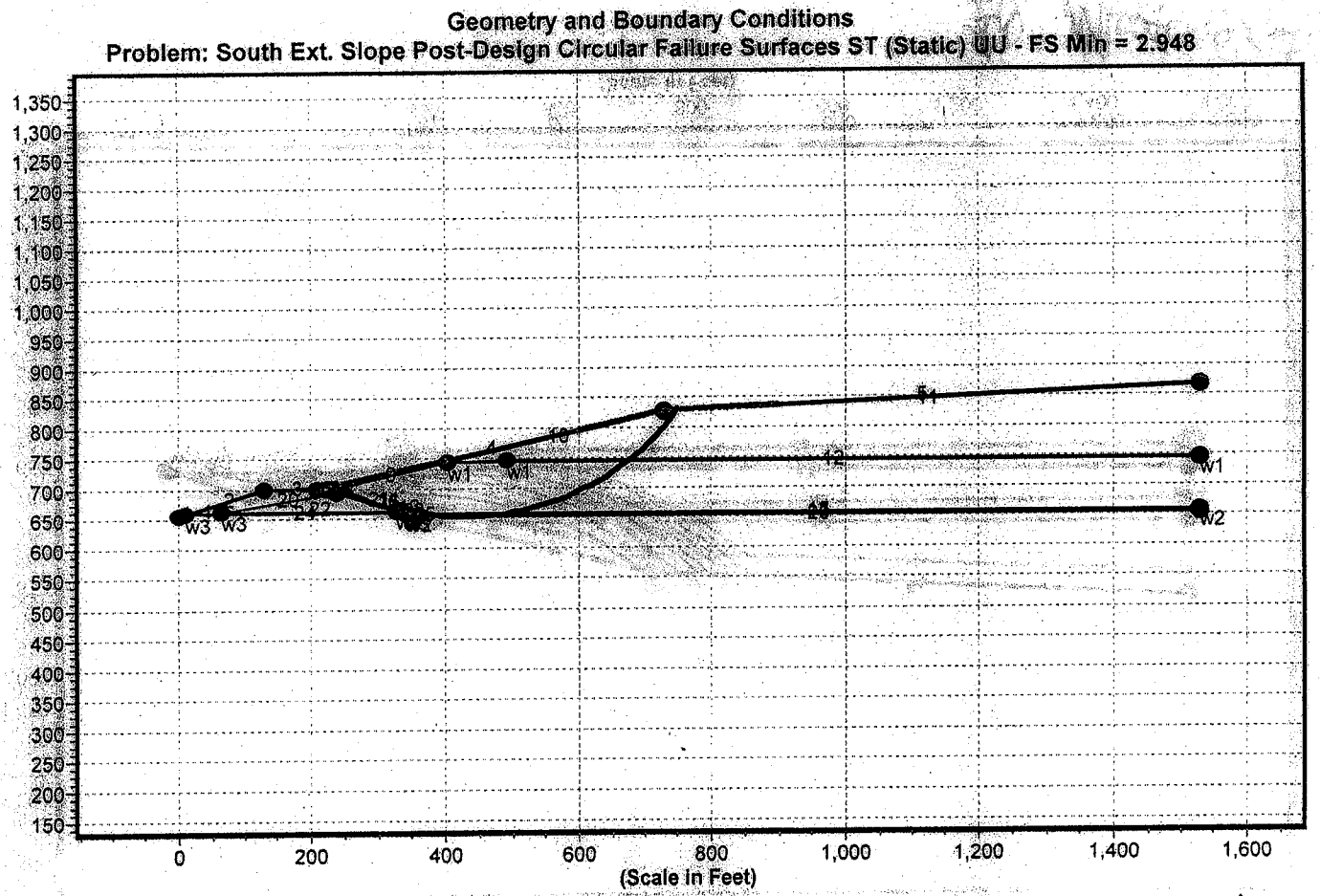
10' Degraded Waste

5' Perched Leachate at Mid-Height

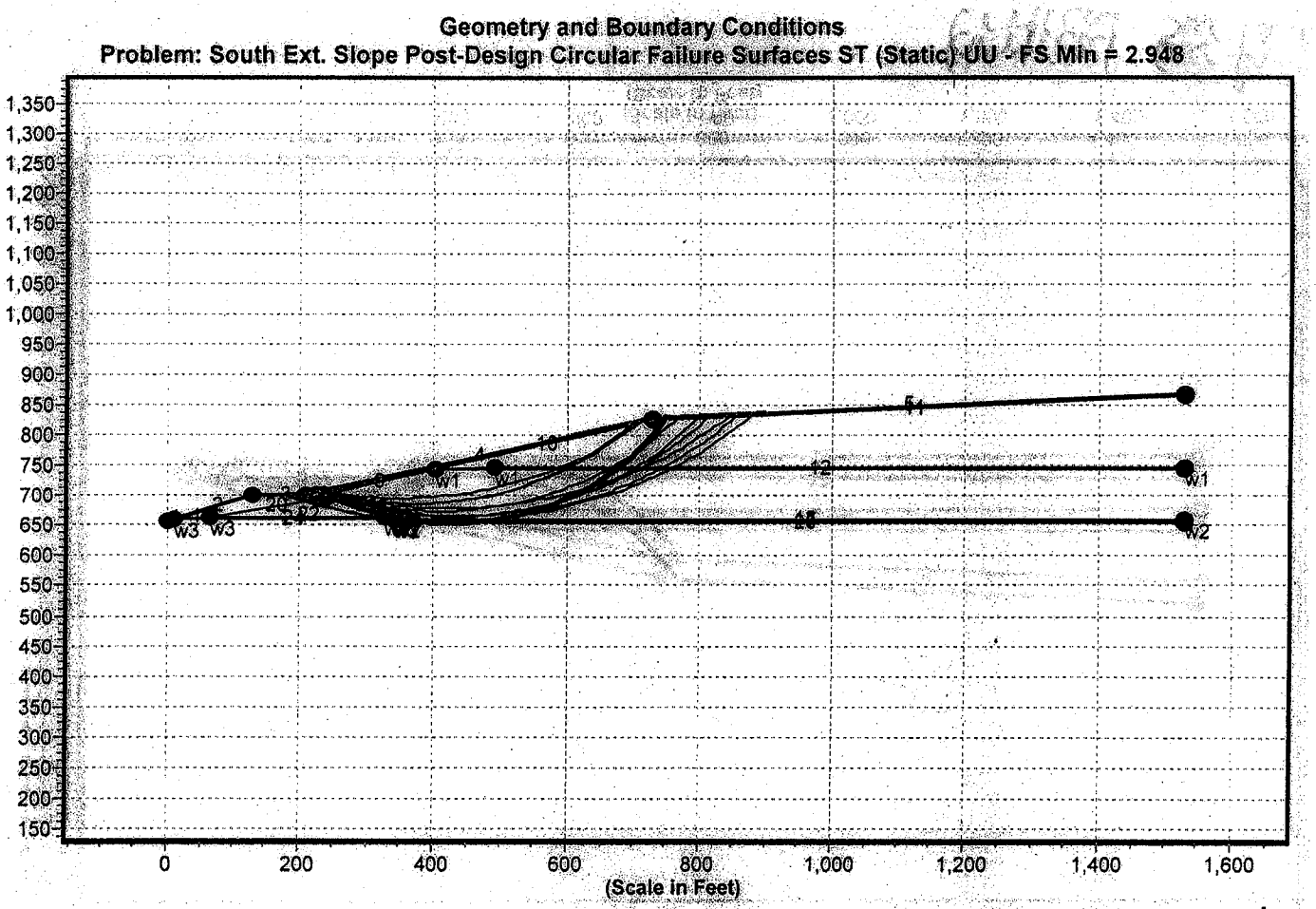
5' Leachate on Landfill Floor


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Circular Failure Surfaces ST (Static) UU
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1,000
1,200
1,400
1,600
(Scale in Feet)
W1
W2
W3

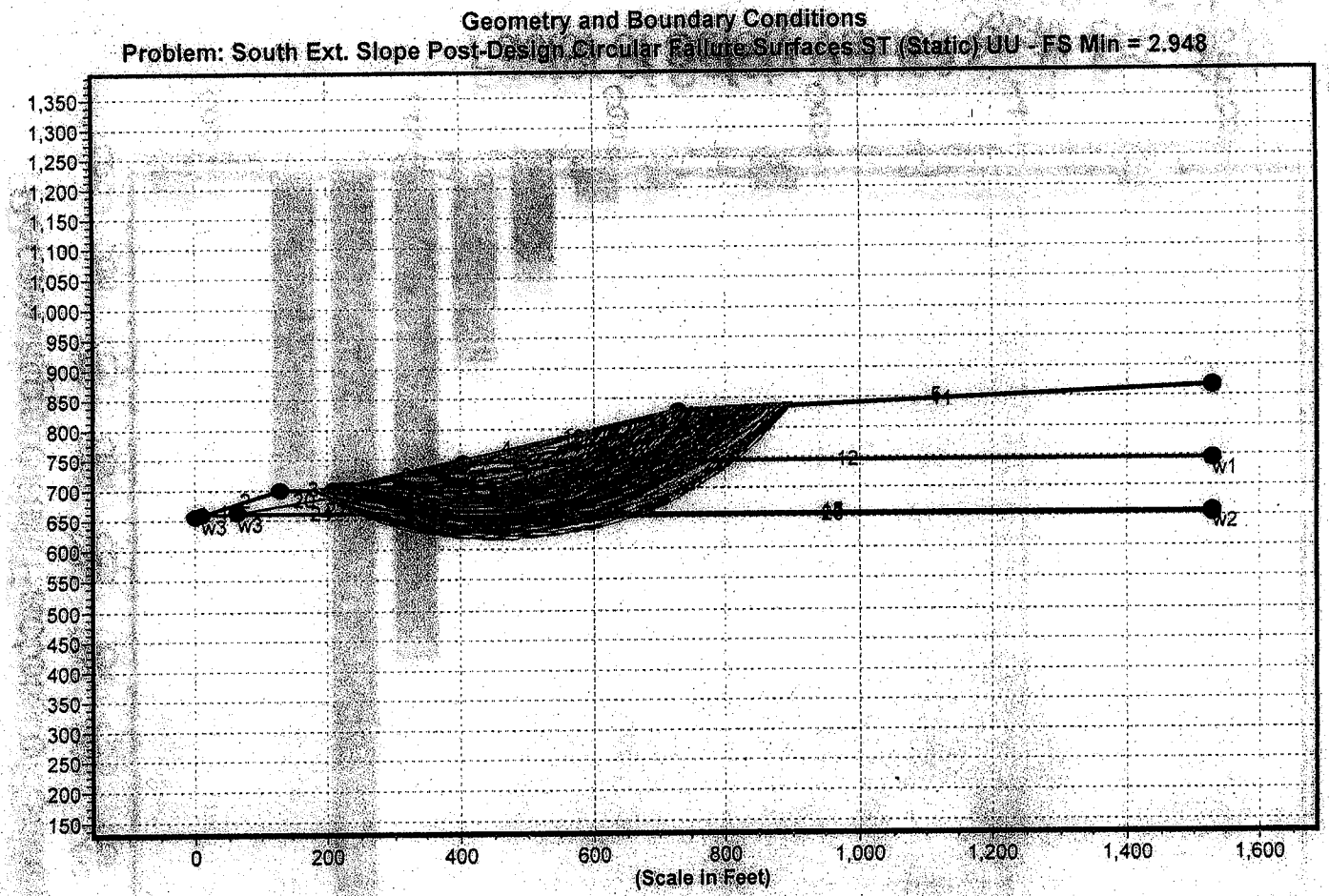
Profile



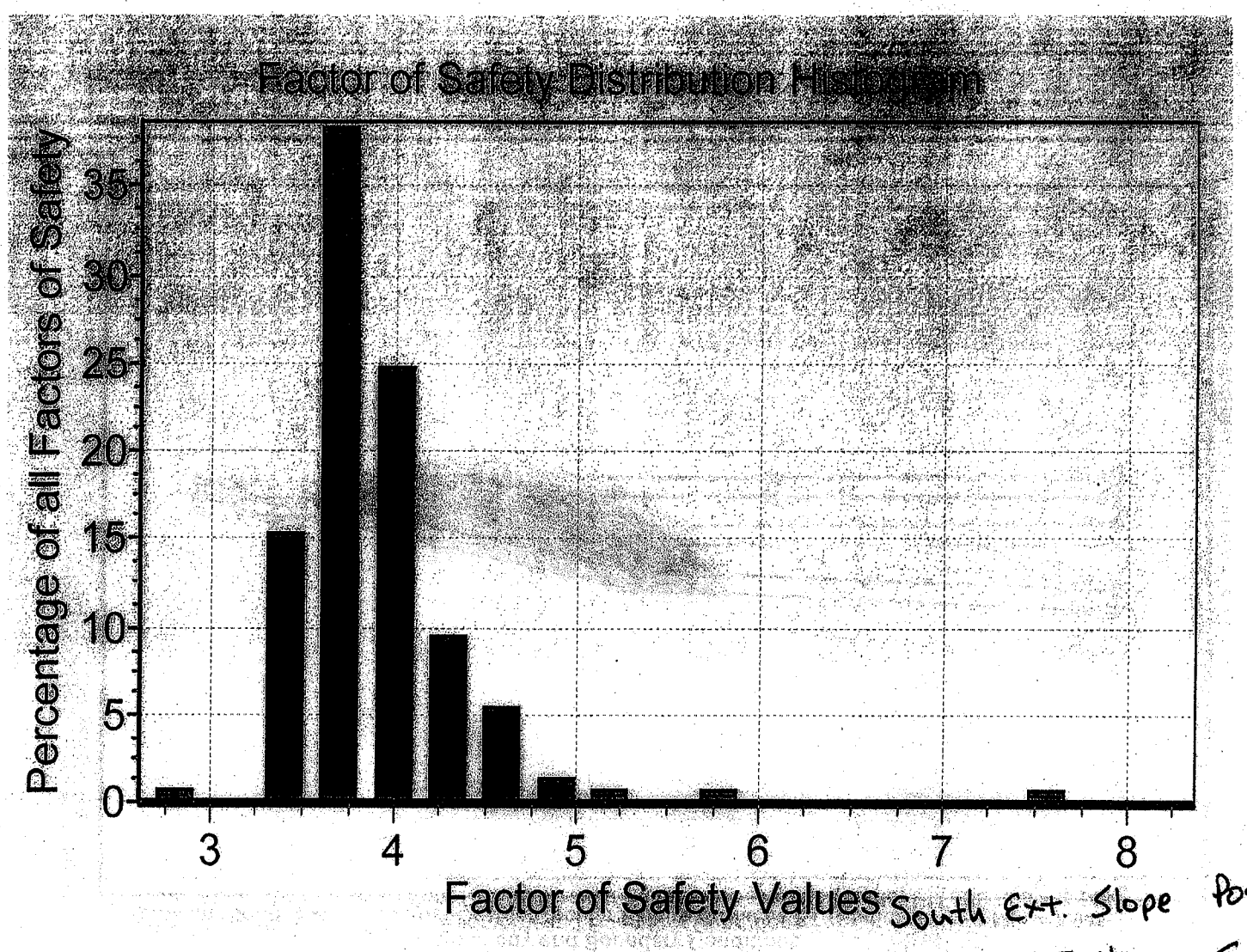
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



South Ext. Slope Post-Design

Circular Failure Surfaces

Short Term (Static)

Unconsolidated / Undrained Soils

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Circular Failure Surfaces ST (Static) UU

BOUNDARY COORDINATES

5 Top Boundaries
26 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	657.00	9.00	660.00	1
2	9.00	660.00	129.00	700.00	2
3	129.00	700.00	209.00	700.00	2
4	209.00	700.00	729.00	830.00	3
5	729.00	830.00	1529.00	870.00	3
6	209.00	700.00	220.00	700.00	2
7	220.00	700.00	229.49	700.00	4
8	229.49	700.00	232.25	700.66	5
9	232.25	700.66	403.62	743.50	6
10	403.62	743.50	729.00	825.00	7
11	729.00	825.00	1529.00	865.00	7
12	403.62	743.50	1529.00	743.50	6
13	330.23	668.00	330.23	668.00	11
14	232.25	700.66	360.23	658.00	5
15	355.49	658.00	1529.00	658.00	8
16	229.49	700.00	358.49	657.00	4
17	358.49	657.00	1529.00	657.00	4
18	220.00	700.00	238.00	694.00	2
19	9.00	660.00	66.00	665.00	9
20	66.00	665.00	238.00	694.00	10
21	238.00	694.00	325.00	665.00	10
22	66.00	665.00	325.00	665.00	9
23	325.00	665.00	340.00	660.00	9
24	9.00	660.00	340.00	660.00	1
25	340.00	660.00	358.00	654.00	1
26	358.00	654.00	1529.00	654.00	1

1

ISOTROPIC SOIL PARAMETERS

11 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	6000.0	0.0	0.00	0.0	0
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	128.0	134.0	0.0	10.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	10.0	0.00	0.0	2
9	100.0	110.0	1400.0	0.0	0.00	0.0	3
10	135.0	140.0	3500.0	0.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	403.62	743.50
2	493.62	748.50
3	1529.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	343.49	662.00
2	1529.00	662.00

1

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)

result

1	9.00	660.00
2	66.00	665.00
3	325.00	665.00
4	340.00	660.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

30 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 180.00 ft.
and X = 400.00 ft.

Each Surface Terminates Between X = 600.00 ft.
and X = 900.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =400.00 ft.

10.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -35.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 60 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	243.70	701.57
3	252.52	696.86
4	261.47	692.39
5	270.53	688.16
6	279.69	684.16
7	288.96	680.41
8	298.33	676.90
9	307.78	673.63
10	317.31	670.62

		result
11	326.92	667.85
12	336.60	665.34
13	346.34	663.08
14	356.14	661.08
15	365.99	659.34
16	375.88	657.85
17	385.80	656.63
18	395.76	655.66
19	405.73	654.96
20	415.72	654.52
21	425.72	654.34
22	435.72	654.42
23	445.71	654.76
24	455.70	655.37
25	465.66	656.23
26	475.59	657.36
27	485.50	658.75
28	495.36	660.39
29	505.18	662.30
30	514.94	664.46
31	524.65	666.88
32	534.28	669.55
33	543.85	672.47
34	553.33	675.64
35	562.73	679.05
36	572.03	682.72
37	581.24	686.62
38	590.34	690.77
39	599.33	695.15
40	608.20	699.77
41	616.94	704.62
42	625.56	709.69
43	634.04	714.99
44	642.38	720.51
45	650.57	726.24
46	658.61	732.19
47	666.49	738.35
48	674.21	744.71
49	681.75	751.27
50	689.12	758.03
51	696.32	764.98
52	703.32	772.11
53	710.14	779.43
54	716.77	786.92
55	723.19	794.58
56	729.42	802.41
57	735.43	810.40
58	741.23	818.54
59	746.82	826.83
60	749.49	831.02

Circle Center At X = 427.6 ; Y = 1035.9 and Radius, 381.6

*** 2.948 ***

Individual data on the 77 slices

Water Water Earthquake

result

slice No.	Width (ft)	Weight (lbs)	Force Top (lbs)	Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Force Hor (lbs)	Force Ver (lbs)	Surcharge Load (lbs)
1	6.3	2079.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.4	1753.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	8.8	9401.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	8.9	14096.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	9.1	18763.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	2.5	5929.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	6.7	17574.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	9.3	28437.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	5.5	19052.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	3.8	14127.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	9.5	37701.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	9.5	41957.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	2.4	11184.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	7.2	34749.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	3.3	16595.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	6.4	33037.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	5.3	28353.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	4.5	24729.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	5.3	30250.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	4.5	26420.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	9.8	60151.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	8.9	57009.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1.0	6432.1	0.0	252.3	0.0	0.0	0.0	0.0	0.0
24	6.9	46243.8	0.0	1985.6	0.0	0.0	0.0	0.0	0.0
25	3.0	20760.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	10.0	70539.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	7.9	57852.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	2.1	15829.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	10.0	76434.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	10.0	78787.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	10.0	80736.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	10.0	82275.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	10.0	83400.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	10.0	84109.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	6.8	57367.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	3.2	27031.9	0.0	962.0	0.0	0.0	0.0	0.0	0.0
37	4.6	38823.8	0.0	1242.1	0.0	0.0	0.0	0.0	0.0
38	5.3	45534.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	8.1	69650.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1.7	14978.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	8.3	71406.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1.5	13325.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	9.8	84573.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	9.7	84156.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	9.6	83486.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	9.6	82565.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	9.5	81401.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	9.4	79999.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	9.3	78368.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	9.2	76515.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	9.1	74451.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	9.0	72184.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	8.9	69727.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	8.7	67090.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	8.6	64288.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	8.5	61332.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	8.3	58237.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58	8.2	55017.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	8.0	51688.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	7.9	48266.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

				result					
61	6.2	36435.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	1.5	8330.4	0.0	522.4	0.0	0.0	0.0	0.0	0.0
63	4.4	24111.0	0.0	682.3	0.0	0.0	0.0	0.0	0.0
64	3.2	17093.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65	7.4	37599.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
66	7.2	33967.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67	7.0	30327.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68	6.8	26696.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
69	6.6	23092.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70	6.4	19533.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71	5.8	15060.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
72	0.4	977.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
73	6.0	12317.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
74	5.8	8502.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75	4.9	4464.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76	0.7	380.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
77	2.7	693.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 60 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.37	703.01
3	253.81	699.71
4	263.32	696.60
5	272.88	693.69
6	282.51	690.98
7	292.19	688.47
8	301.92	686.15
9	311.69	684.04
10	321.51	682.13
11	331.36	680.42
12	341.25	678.92
13	351.16	677.62
14	361.10	676.52
15	371.06	675.63
16	381.04	674.94
17	391.03	674.46
18	401.02	674.18
19	411.02	674.11
20	421.02	674.25
21	431.01	674.59
22	441.00	675.14
23	450.97	675.89
24	460.92	676.85
25	470.86	678.01
26	480.76	679.38
27	490.64	680.95
28	500.48	682.72
29	510.28	684.70
30	520.04	686.87
31	529.76	689.25
32	539.42	691.83
33	549.03	694.60
34	558.57	697.58
35	568.06	700.74
36	577.48	704.11
37	586.82	707.66
38	596.09	711.41
39	605.29	715.35

		result
40	614.40	719.47
41	623.42	723.79
42	632.35	728.28
43	641.19	732.96
44	649.93	737.82
45	658.56	742.86
46	667.09	748.08
47	675.52	753.47
48	683.83	759.04
49	692.02	764.77
50	700.09	770.67
51	708.04	776.74
52	715.87	782.96
53	723.56	789.35
54	731.12	795.90
55	738.55	802.59
56	745.83	809.45
57	752.97	816.44
58	759.97	823.59
59	766.82	830.88
60	767.78	831.94

Circle Center At X = 409.4 ; Y = 1159.9 and Radius, 485.8

*** 3.305 ***

1

Failure Surface Specified By 53 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.84	704.71
3	254.71	703.08
4	264.60	701.62
5	274.51	700.33
6	284.45	699.21
7	294.41	698.25
8	304.37	697.46
9	314.35	696.84
10	324.34	696.39
11	334.34	696.10
12	344.34	695.99
13	354.34	696.04
14	364.34	696.26
15	374.33	696.66
16	384.31	697.22
17	394.29	697.94
18	404.25	698.84
19	414.19	699.90
20	424.11	701.14
21	434.02	702.53
22	443.89	704.10
23	453.74	705.83
24	463.56	707.73
25	473.34	709.79
26	483.09	712.02

		result
27	492.80	714.41
28	502.47	716.97
29	512.09	719.69
30	521.67	722.57
31	531.20	725.61
32	540.67	728.81
33	550.09	732.17
34	559.45	735.69
35	568.75	739.37
36	577.98	743.20
37	587.16	747.19
38	596.26	751.33
39	605.29	755.63
40	614.24	760.07
41	623.12	764.67
42	631.93	769.42
43	640.65	774.31
44	649.28	779.35
45	657.83	784.54
46	666.29	789.87
47	674.66	795.34
48	682.94	800.95
49	691.12	806.70
50	699.21	812.59
51	707.19	818.61
52	715.07	824.77
53	718.19	827.30

Circle Center At X = 346.2 ; Y = 1288.8 and Radius, 592.8

*** 3.307 ***

Failure Surface Specified By 52 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.60	703.71
3	254.26	701.12
4	263.97	698.74
5	273.73	696.56
6	283.54	694.60
7	293.38	692.84
8	303.26	691.29
9	313.17	689.95
10	323.11	688.82
11	333.07	687.90
12	343.04	687.19
13	353.03	686.70
14	363.03	686.42
15	373.02	686.34
16	383.02	686.49
17	393.02	686.84
18	403.00	687.41
19	412.97	688.18
20	422.92	689.17
21	432.85	690.37

		result
22	442.75	691.78
23	452.62	693.40
24	462.45	695.23
25	472.24	697.27
26	481.98	699.52
27	491.68	701.97
28	501.32	704.62
29	510.90	707.48
30	520.42	710.55
31	529.87	713.81
32	539.25	717.28
33	548.56	720.94
34	557.78	724.80
35	566.93	728.85
36	575.98	733.10
37	584.94	737.54
38	593.80	742.17
39	602.57	746.98
40	611.23	751.98
41	619.78	757.16
42	628.22	762.52
43	636.55	768.07
44	644.75	773.78
45	652.84	779.67
46	660.79	785.73
47	668.62	791.96
48	676.31	798.35
49	683.86	804.90
50	691.27	811.61
51	698.54	818.48
52	703.85	823.71

Circle Center At X = 371.3 ; Y = 1157.4 and Radius, 471.1

*** 3.315 ***

1

Failure Surface Specified By 52 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.60	703.71
3	254.27	701.13
4	263.98	698.76
5	273.74	696.59
6	283.55	694.63
7	293.39	692.89
8	303.28	691.35
9	313.19	690.03
10	323.13	688.91
11	333.09	688.02
12	343.06	687.33
13	353.05	686.86
14	363.05	686.60
15	373.05	686.55
16	383.05	686.72

		result
17	393.04	687.10
18	403.02	687.70
19	412.99	688.51
20	422.94	689.53
21	432.86	690.77
22	442.75	692.21
23	452.62	693.87
24	462.44	695.74
25	472.22	697.82
26	481.96	700.11
27	491.64	702.60
28	501.27	705.30
29	510.84	708.21
30	520.34	711.32
31	529.78	714.63
32	539.14	718.15
33	548.42	721.86
34	557.63	725.77
35	566.74	729.88
36	575.77	734.18
37	584.71	738.67
38	593.54	743.35
39	602.28	748.22
40	610.90	753.28
41	619.42	758.52
42	627.82	763.94
43	636.11	769.54
44	644.27	775.32
45	652.31	781.26
46	660.22	787.38
47	668.00	793.67
48	675.64	800.12
49	683.14	806.73
50	690.50	813.51
51	697.71	820.43
52	700.02	822.76

Circle Center At X = 370.1 ; Y = 1154.1 and Radius, 467.5

*** 3.320 ***

Failure Surface Specified By 75 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.35	696.45
3	198.75	693.04
4	208.20	689.77
5	217.70	686.66
6	227.25	683.69
7	236.85	680.88
8	246.49	678.21
9	256.16	675.69
10	265.88	673.32
11	275.63	671.11
12	285.42	669.05

		result
13	295.23	667.14
14	305.08	665.38
15	314.95	663.78
16	324.84	662.33
17	334.76	661.03
18	344.69	659.89
19	354.64	658.90
20	364.61	658.07
21	374.59	657.40
22	384.57	656.87
23	394.57	656.51
24	404.56	656.30
25	414.56	656.25
26	424.56	656.35
27	434.56	656.61
28	444.55	657.02
29	454.53	657.59
30	464.51	658.31
31	474.47	659.19
32	484.42	660.22
33	494.35	661.41
34	504.25	662.76
35	514.14	664.25
36	524.00	665.90
37	533.84	667.71
38	543.65	669.66
39	553.42	671.77
40	563.16	674.04
41	572.87	676.45
42	582.53	679.01
43	592.16	681.73
44	601.74	684.59
45	611.28	687.60
46	620.76	690.76
47	630.20	694.07
48	639.58	697.52
49	648.91	701.12
50	658.19	704.87
51	667.40	708.76
52	676.55	712.79
53	685.64	716.96
54	694.66	721.27
55	703.61	725.73
56	712.50	730.32
57	721.31	735.05
58	730.04	739.92
59	738.70	744.92
60	747.28	750.06
61	755.78	755.33
62	764.20	760.73
63	772.53	766.26
64	780.77	771.92
65	788.92	777.71
66	796.99	783.63
67	804.96	789.67
68	812.83	795.83
69	820.61	802.11
70	828.29	808.52
71	835.87	815.04
72	843.35	821.68
73	850.72	828.44
74	857.98	835.31
75	859.22	836.51

result

Circle Center At X = 413.0 ; Y = 1298.6 and Radius, 642.4

*** 3.340 ***

1

Failure Surface Specified By 77 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.40	696.59
3	198.85	693.31
4	208.34	690.17
5	217.88	687.17
6	227.46	684.31
7	237.09	681.59
8	246.75	679.01
9	256.45	676.57
10	266.18	674.27
11	275.94	672.12
12	285.74	670.10
13	295.56	668.23
14	305.41	666.50
15	315.29	664.92
16	325.18	663.48
17	335.10	662.18
18	345.03	661.03
19	354.98	660.02
20	364.94	659.16
21	374.92	658.44
22	384.90	657.87
23	394.89	657.44
24	404.89	657.16
25	414.89	657.03
26	424.89	657.04
27	434.88	657.19
28	444.88	657.49
29	454.87	657.94
30	464.85	658.53
31	474.83	659.27
32	484.79	660.15
33	494.73	661.18
34	504.66	662.35
35	514.58	663.66
36	524.47	665.12
37	534.34	666.73
38	544.19	668.48
39	554.01	670.37
40	563.80	672.40
41	573.56	674.57
42	583.29	676.89
43	592.98	679.35
44	602.64	681.95
45	612.25	684.69
46	621.83	687.57
47	631.36	690.59

		result
48	640.85	693.74
49	650.29	697.04
50	659.69	700.47
51	669.03	704.04
52	678.32	707.74
53	687.55	711.58
54	696.73	715.55
55	705.85	719.66
56	714.90	723.90
57	723.90	728.27
58	732.83	732.77
59	741.69	737.39
60	750.49	742.15
61	759.21	747.04
62	767.87	752.05
63	776.45	757.19
64	784.95	762.45
65	793.38	767.83
66	801.73	773.34
67	809.99	778.97
68	818.17	784.71
69	826.27	790.58
70	834.29	796.56
71	842.21	802.66
72	850.05	808.88
73	857.79	815.20
74	865.44	821.64
75	873.00	828.19
76	880.46	834.85
77	883.59	837.73

Circle Center At X = 419.2 ; Y = 1344.1 and Radius, 687.1

*** 3.383 ***

Failure Surface Specified By 67 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.60	703.70
3	254.24	701.04
4	263.92	698.54
5	273.64	696.18
6	283.39	693.97
7	293.18	691.91
8	302.99	690.00
9	312.84	688.24
10	322.71	686.63
11	332.60	685.18
12	342.52	683.87
13	352.45	682.72
14	362.40	681.71
15	372.36	680.87
16	382.34	680.17
17	392.32	679.62
18	402.32	679.23

result

19	412.31	679.00
20	422.31	678.91
21	432.31	678.98
22	442.31	679.20
23	452.30	679.57
24	462.29	680.10
25	472.27	680.78
26	482.23	681.61
27	492.18	682.60
28	502.12	683.73
29	512.03	685.02
30	521.93	686.46
31	531.80	688.06
32	541.65	689.80
33	551.47	691.69
34	561.26	693.73
35	571.01	695.93
36	580.74	698.27
37	590.42	700.76
38	600.07	703.40
39	609.67	706.18
40	619.23	709.11
41	628.75	712.19
42	638.21	715.42
43	647.63	718.78
44	656.99	722.29
45	666.30	725.95
46	675.55	729.75
47	684.74	733.68
48	693.87	737.76
49	702.94	741.98
50	711.94	746.33
51	720.88	750.83
52	729.74	755.45
53	738.53	760.22
54	747.25	765.12
55	755.90	770.15
56	764.46	775.31
57	772.94	780.60
58	781.35	786.02
59	789.66	791.57
60	797.90	797.25
61	806.04	803.05
62	814.10	808.98
63	822.06	815.03
64	829.93	821.20
65	837.71	827.49
66	845.38	833.89
67	847.76	835.94

Circle Center At X = 422.9 ; Y = 1332.3 and Radius, 653.4

*** 3.394 ***

1

Failure Surface Specified By 63 Coordinate Points

Point	X-Surf	Y-Surf

No.	(ft)	result (ft)
1	235.00	706.50
2	244.16	702.49
3	253.40	698.67
4	262.72	695.04
5	272.11	691.61
6	281.58	688.38
7	291.10	685.34
8	300.69	682.50
9	310.34	679.86
10	320.04	677.42
11	329.78	675.18
12	339.57	673.15
13	349.41	671.32
14	359.27	669.70
15	369.17	668.28
16	379.10	667.07
17	389.05	666.06
18	399.01	665.26
19	409.00	664.67
20	418.99	664.29
21	428.99	664.11
22	438.99	664.15
23	448.99	664.39
24	458.98	664.83
25	468.95	665.49
26	478.92	666.35
27	488.86	667.42
28	498.78	668.70
29	508.67	670.18
30	518.52	671.87
31	528.34	673.77
32	538.12	675.86
33	547.85	678.16
34	557.53	680.66
35	567.16	683.37
36	576.73	686.27
37	586.24	689.37
38	595.68	692.67
39	605.05	696.16
40	614.35	699.85
41	623.56	703.72
42	632.70	707.80
43	641.74	712.05
44	650.70	716.50
45	659.56	721.13
46	668.33	725.95
47	676.99	730.95
48	685.55	736.12
49	693.99	741.47
50	702.33	747.00
51	710.54	752.70
52	718.64	758.57
53	726.61	764.60
54	734.46	770.80
55	742.17	777.17
56	749.76	783.69
57	757.20	790.37
58	764.50	797.20
59	771.66	804.18
60	778.68	811.31
61	785.54	818.58

		result
62	792.25	825.99
63	798.75	833.49

Circle Center At X = 432.4 ; Y = 1144.9 and Radius, 480.8

*** 3.401 ***

Failure Surface Specified By 65 Coordinate Points

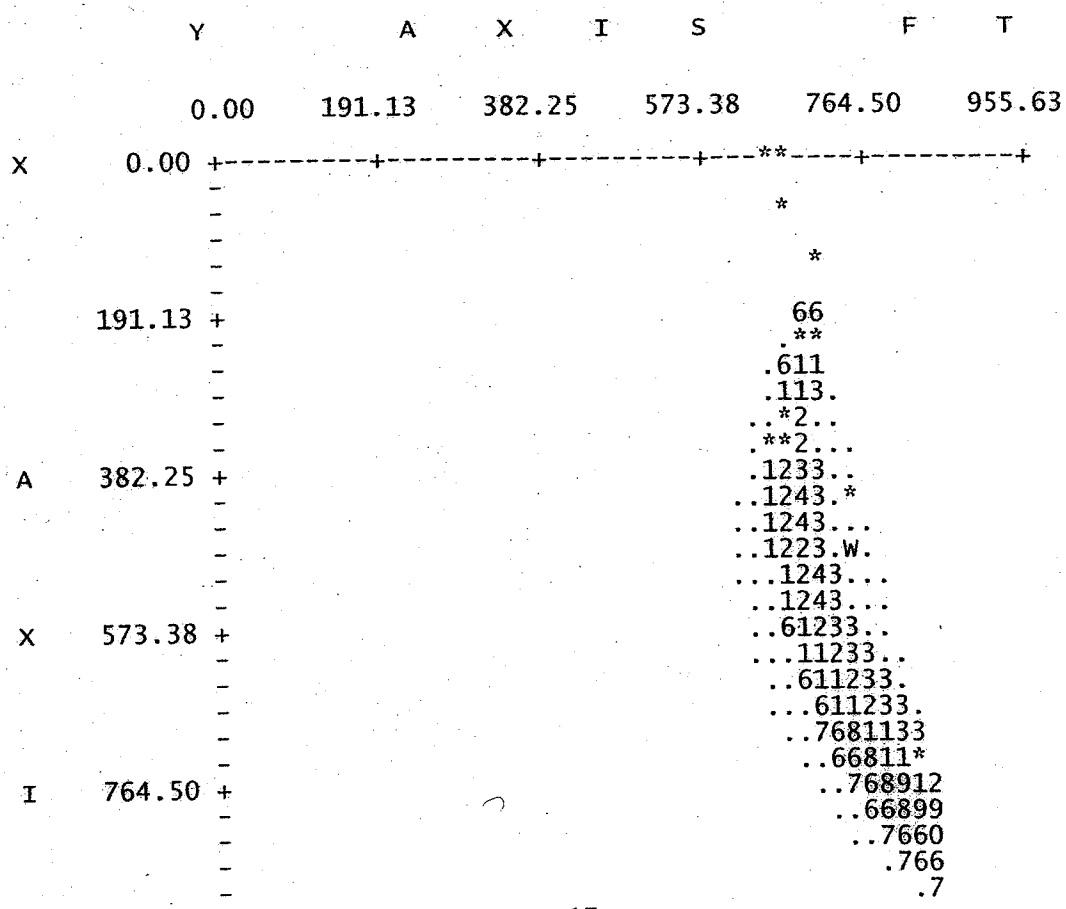
Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.25	702.71
3	253.58	699.10
4	262.97	695.67
5	272.43	692.43
6	281.95	689.37
7	291.53	686.49
8	301.16	683.80
9	310.85	681.31
10	320.58	679.00
11	330.35	676.88
12	340.16	674.95
13	350.01	673.21
14	359.89	671.66
15	369.80	670.31
16	379.73	669.15
17	389.68	668.18
18	399.65	667.41
19	409.63	666.83
20	419.63	666.45
21	429.63	666.26
22	439.63	666.26
23	449.62	666.46
24	459.62	666.86
25	469.60	667.45
26	479.57	668.23
27	489.52	669.21
28	499.45	670.38
29	509.36	671.74
30	519.24	673.30
31	529.08	675.05
32	538.89	676.99
33	548.66	679.12
34	558.39	681.44
35	568.07	683.95
36	577.70	686.65
37	587.27	689.53
38	596.79	692.60
39	606.25	695.86
40	615.64	699.30
41	624.96	702.92
42	634.21	706.72
43	643.38	710.70
44	652.47	714.86
45	661.49	719.19
46	670.41	723.70

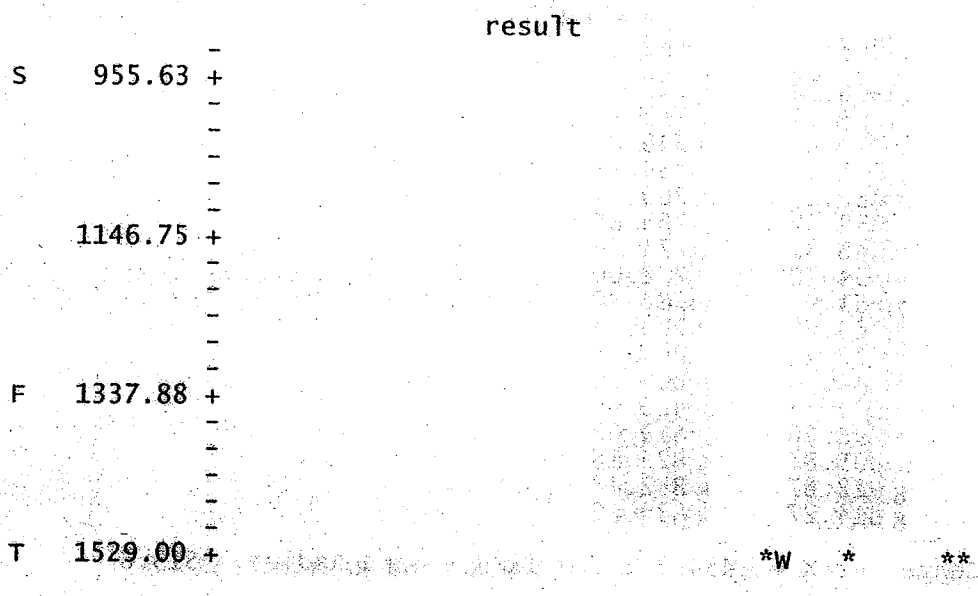
		result
47	679.25	728.39
48	687.99	733.24
49	696.64	738.26
50	705.18	743.45
51	713.63	748.81
52	721.97	754.33
53	730.20	760.01
54	738.32	765.85
55	746.32	771.84
56	754.20	778.00
57	761.97	784.30
58	769.60	790.75
59	777.12	797.35
60	784.50	804.10
61	791.75	810.99
62	798.86	818.02
63	805.84	825.18
64	812.67	832.48
65	814.27	834.26

Circle Center At X = 434.3 ; Y = 1179.8 and Radius, 513.6

*** 3.402 ***

1




result
S
955.63
1146.75
F
1337.88
T
1529.00
*W
*
**

SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD

Circular Failure Surfaces

Static Long Term Conditions

Key Assumptions:

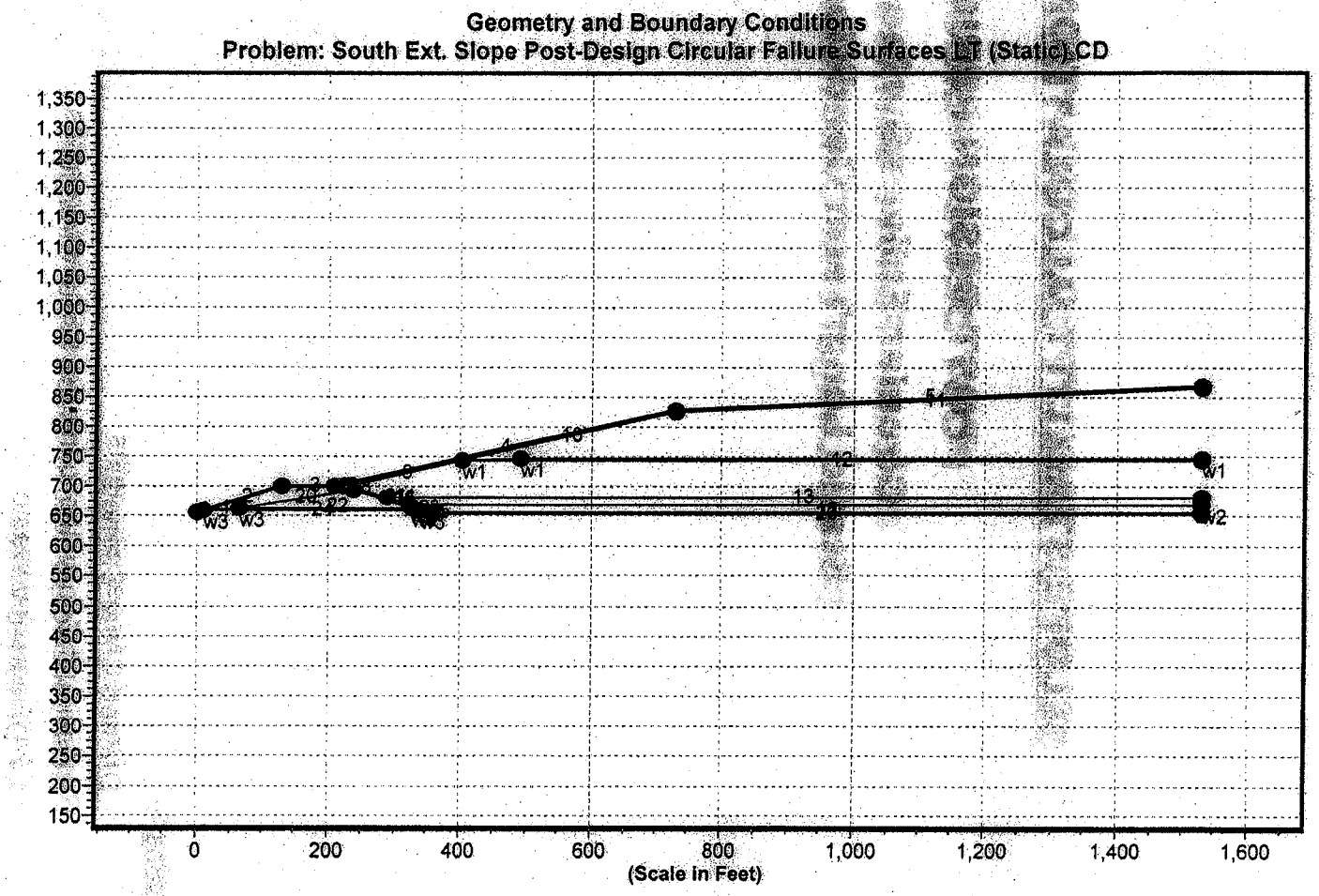
Drained Shear Strengths

Residual Geosynthetic Interface Shear Strengths

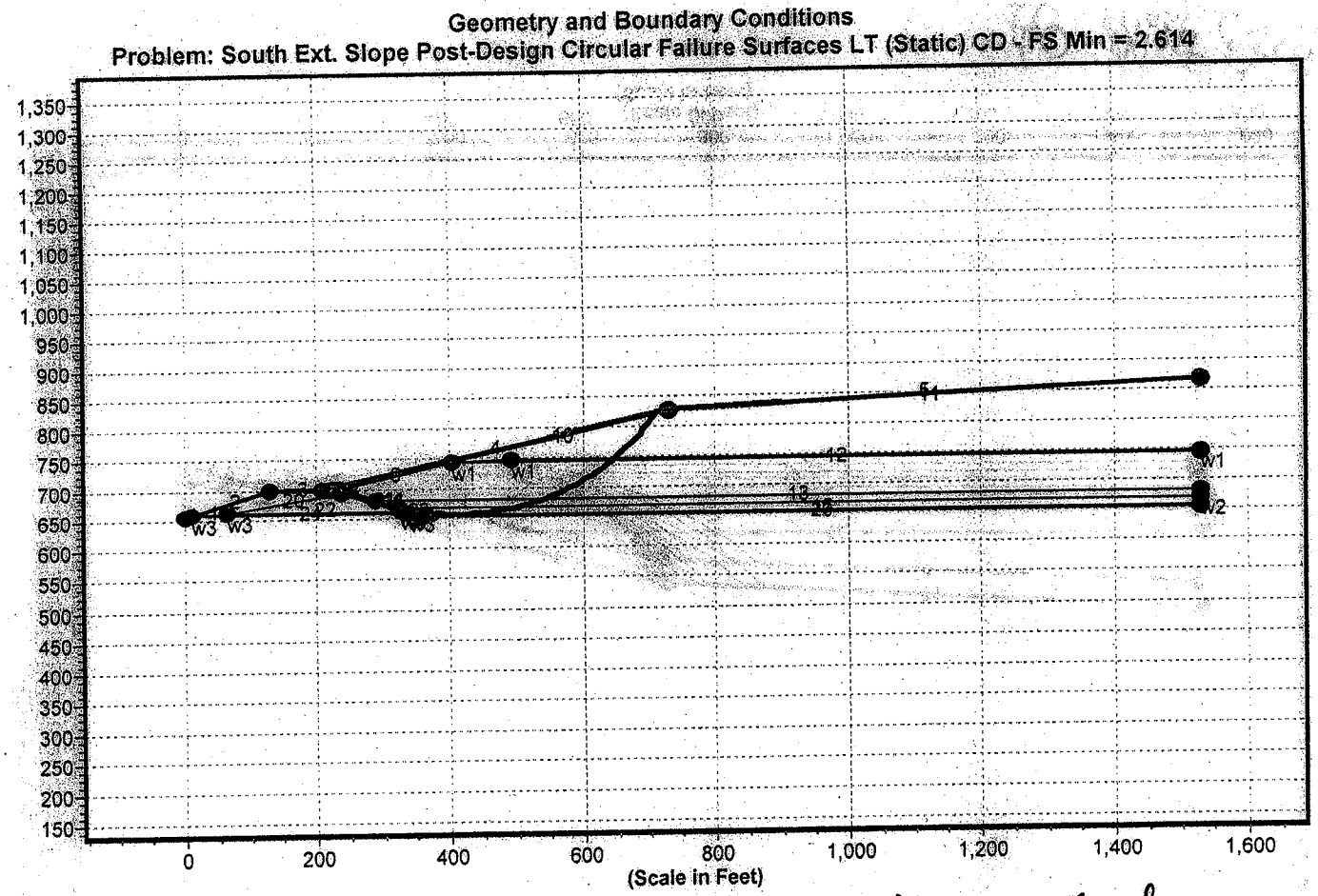
24' Degraded Waste

5' Perched Leachate at Mid-Height

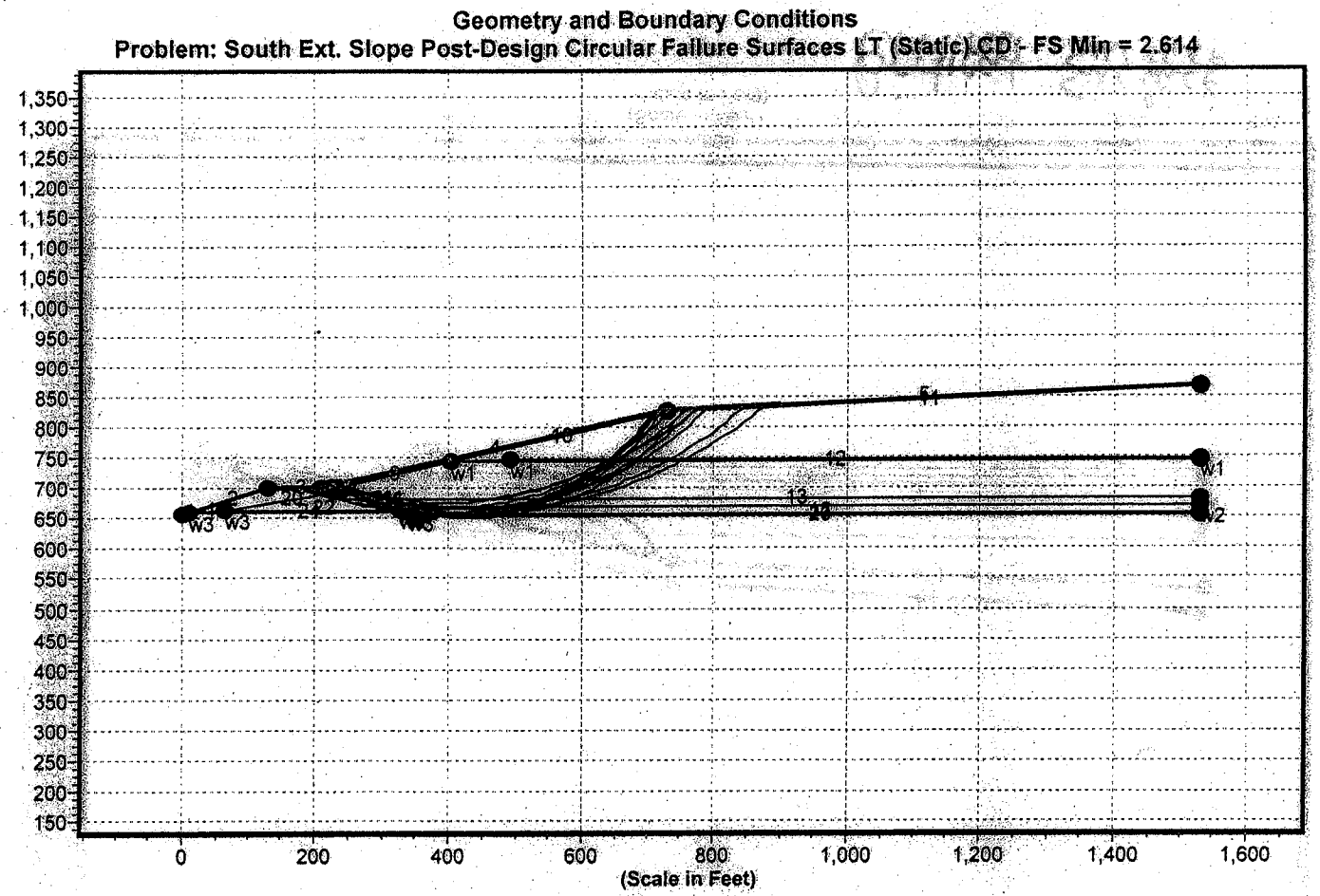
12' Leachate on Landfill Floor


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Circular Failure Surfaces LT (Static).CD
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1,000
1,200
1,400
1,600
(Scale in Feet)
W1
W2
W3

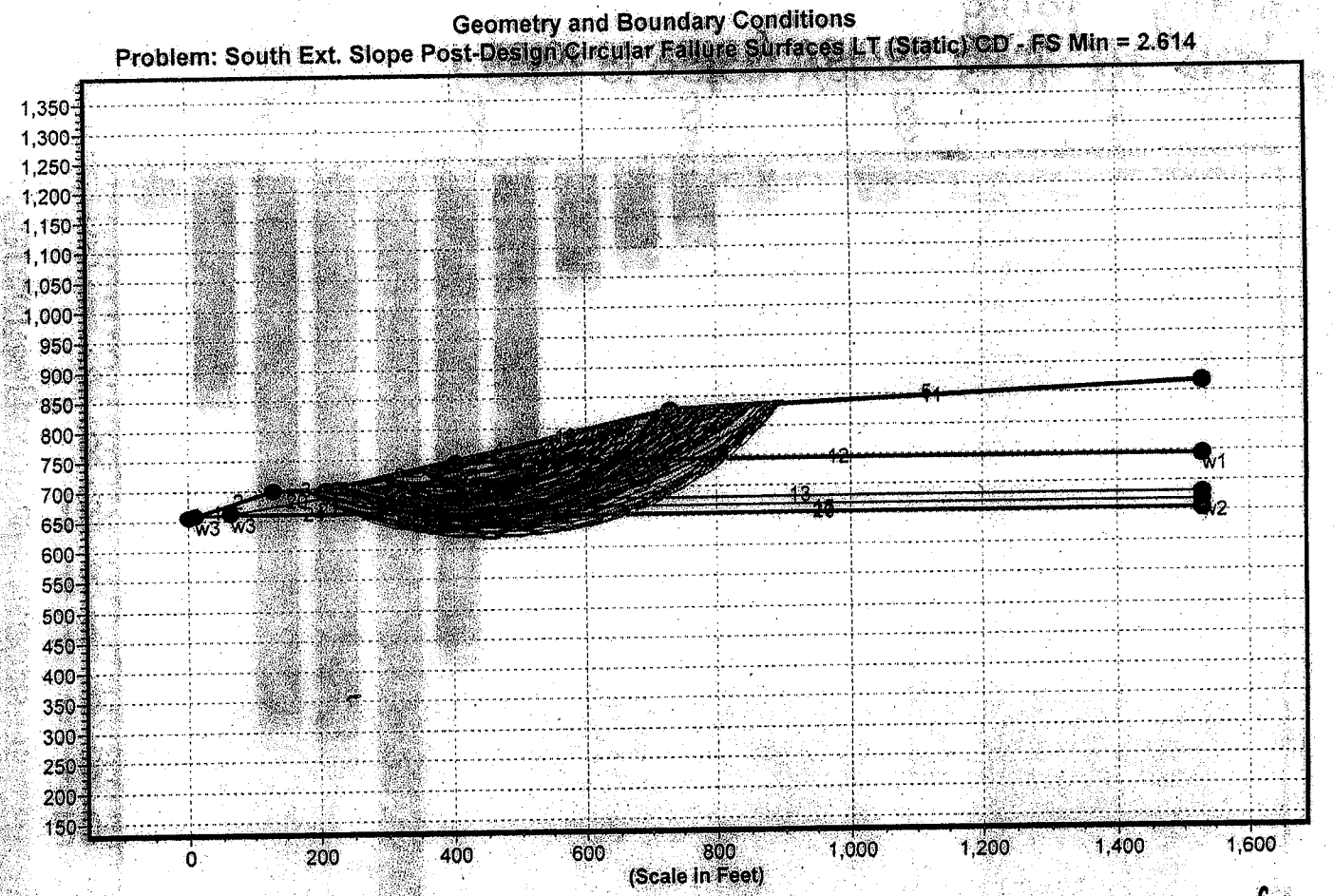
Profile



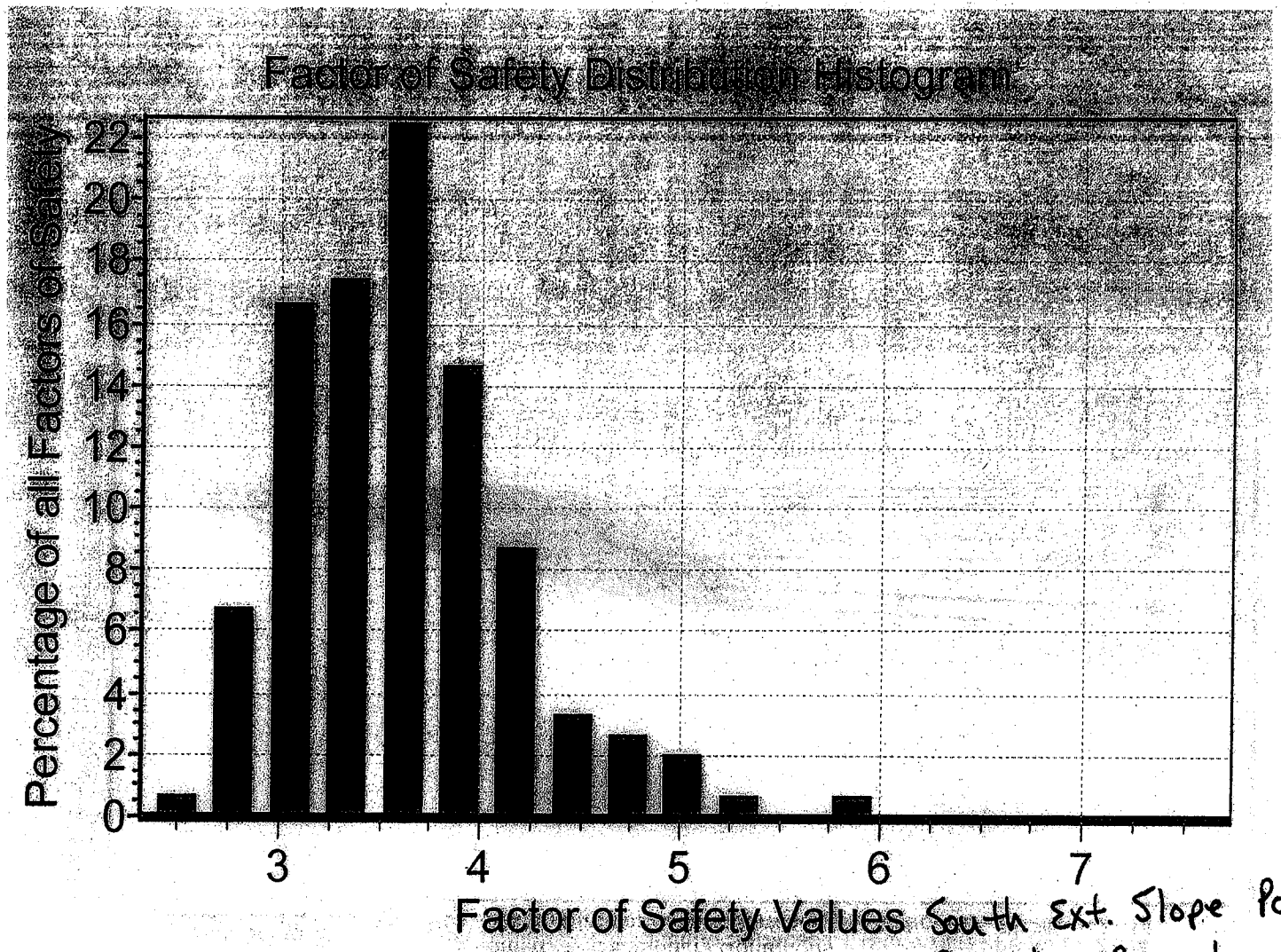
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



South Ext. Slope Post-Design Period Circular Failure Surfaces Long Term (Static)
Consolidated / Drained $\bar{c}$'s

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Circular Failure Surfaces LT (Static) CD

BOUNDARY COORDINATES

5 Top Boundaries
26 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	657.00	9.00	660.00	1
2	9.00	660.00	129.00	700.00	2
3	129.00	700.00	209.00	700.00	2
4	209.00	700.00	729.00	830.00	3
5	729.00	830.00	1529.00	870.00	3
6	209.00	700.00	220.00	700.00	2
7	220.00	700.00	229.49	700.00	4
8	229.49	700.00	232.25	700.66	5
9	232.25	700.66	403.62	743.50	6
10	403.62	743.50	729.00	825.00	7
11	729.00	825.00	1529.00	865.00	7
12	403.62	743.50	1529.00	743.50	6
13	288.23	682.00	1529.00	682.00	11
14	232.25	700.66	360.23	658.00	5
15	355.49	658.00	1529.00	658.00	8
16	229.49	700.00	358.49	657.00	4
17	358.49	657.00	1529.00	657.00	4
18	220.00	700.00	238.00	694.00	2
19	9.00	660.00	66.00	665.00	9
20	66.00	665.00	238.00	694.00	10
21	238.00	694.00	325.00	665.00	10
22	66.00	665.00	325.00	665.00	9
23	325.00	665.00	340.00	660.00	9
24	9.00	660.00	340.00	660.00	1
25	340.00	660.00	358.00	654.00	1
26	358.00	654.00	1529.00	654.00	1

ISOTROPIC SOIL PARAMETERS

11 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	1100.0	18.0	0.00	0.0	0
2	135.0	140.0	700.0	21.0	0.00	0.0	0
3	128.0	134.0	1300.0	22.0	0.00	0.0	0
4	135.0	140.0	700.0	21.0	0.00	0.0	0
5	128.0	134.0	0.0	10.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	10.0	0.00	0.0	2
9	100.0	110.0	1500.0	19.0	0.00	0.0	3
10	135.0	140.0	600.0	26.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	403.62	743.50
2	493.62	748.50
3	1529.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	322.49	669.00
2	1529.00	669.00

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)

result

1	9.00	660.00
2	66.00	665.00
3	325.00	665.00
4	340.00	660.00

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

30 Surfaces Initiate From Each Of 5 Points Equally Spaced Along The Ground Surface Between X = 180.00 ft.
and X = 400.00 ft.

Each Surface Terminates Between X = 550.00 ft.
and X = 900.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y =500.00 ft.

10.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation. The Angle Has Been Restricted Between The Angles Of -35.0 And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 56 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	243.70	701.57
3	252.53	696.88
4	261.50	692.45
5	270.59	688.28
6	279.79	684.37
7	289.10	680.72
8	298.51	677.34
9	308.01	674.22
10	317.60	671.38

		result
11	327.27	668.82
12	337.00	666.52
13	346.80	664.51
14	356.65	662.78
15	366.54	661.33
16	376.47	660.16
17	386.43	659.27
18	396.41	658.67
19	406.41	658.35
20	416.41	658.32
21	426.40	658.57
22	436.39	659.11
23	446.36	659.93
24	456.30	661.04
25	466.20	662.42
26	476.06	664.09
27	485.87	666.04
28	495.62	668.27
29	505.30	670.77
30	514.90	673.55
31	524.43	676.60
32	533.86	679.92
33	543.19	683.51
34	552.42	687.37
35	561.54	691.48
36	570.53	695.85
37	579.39	700.48
38	588.12	705.36
39	596.71	710.48
40	605.15	715.85
41	613.43	721.45
42	621.55	727.29
43	629.50	733.35
44	637.27	739.65
45	644.87	746.15
46	652.27	752.88
47	659.48	759.81
48	666.48	766.94
49	673.29	774.27
50	679.88	781.79
51	686.25	789.50
52	692.40	797.38
53	698.33	805.44
54	704.02	813.66
55	709.48	822.04
56	711.70	825.67

Circle Center At X = 412.5 ; Y = 1009.3 and Radius, 351.0

*** 2.614 ***

Individual data on the 68 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	6.3	2079.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

result

2	2.4	1753.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	8.8	9406.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	9.0	14105.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	9.1	18767.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	4.3	10491.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	4.9	12940.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	8.4	25429.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.9	2833.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	9.4	33417.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	9.5	38692.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	9.6	43705.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	9.0	44801.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.7	3439.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
15	0.0	192.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0
16	1.8	9278.1	0.0	44.3	0.0	0.0	0.0	0.0	0.0
17	8.0	43646.8	0.0	785.8	0.0	0.0	0.0	0.0	0.0
18	9.8	57260.2	0.0	2172.6	0.0	0.0	0.0	0.0	0.0
19	9.8	61322.1	0.0	3341.0	0.0	0.0	0.0	0.0	0.0
20	9.9	65089.8	0.0	4334.4	0.0	0.0	0.0	0.0	0.0
21	9.9	68547.5	0.0	5152.0	0.0	0.0	0.0	0.0	0.0
22	10.0	71681.8	0.0	5793.1	0.0	0.0	0.0	0.0	0.0
23	10.0	74480.0	0.0	6257.2	0.0	0.0	0.0	0.0	0.0
24	7.2	55248.7	0.0	4698.5	0.0	0.0	0.0	0.0	0.0
25	2.8	21683.0	0.0	1845.4	0.0	0.0	0.0	0.0	0.0
26	10.0	79026.2	0.0	6653.0	0.0	0.0	0.0	0.0	0.0
27	10.0	80757.7	0.0	6584.4	0.0	0.0	0.0	0.0	0.0
28	10.0	82121.0	0.0	6338.1	0.0	0.0	0.0	0.0	0.0
29	10.0	83112.9	0.0	5914.3	0.0	0.0	0.0	0.0	0.0
30	9.9	83731.7	0.0	5313.5	0.0	0.0	0.0	0.0	0.0
31	9.9	83976.8	0.0	4536.0	0.0	0.0	0.0	0.0	0.0
32	9.9	83850.0	0.0	3582.5	0.0	0.0	0.0	0.0	0.0
33	9.8	83355.1	0.0	2453.8	0.0	0.0	0.0	0.0	0.0
34	7.8	65649.4	0.0	1028.3	0.0	0.0	0.0	0.0	0.0
35	2.0	16847.7	0.0	122.4	0.0	0.0	0.0	0.0	0.0
36	2.8	23794.3	0.0	66.5	0.0	0.0	0.0	0.0	0.0
37	6.9	57488.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	9.6	79721.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	9.5	77823.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	9.4	75600.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	5.4	42480.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	3.9	30674.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	9.2	71186.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	9.1	69153.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	9.0	66899.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	8.9	64436.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	8.7	61779.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	8.6	58943.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	8.4	55943.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	8.3	52797.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	8.1	49521.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	7.9	46134.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	7.8	42654.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	4.5	23473.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	3.1	15629.5	0.0	934.6	0.0	0.0	0.0	0.0	0.0
56	2.6	12690.8	0.0	255.3	0.0	0.0	0.0	0.0	0.0
57	4.8	22807.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58	7.2	31860.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	7.0	28211.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	6.8	24572.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
61	6.6	20964.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	6.4	17408.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
63	6.2	13927.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
64	5.9	10541.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

					result				
65	5.7	7273.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
66	4.0	3289.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67	1.5	777.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68	2.2	437.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 61 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.16	702.49
3	253.41	698.68
4	262.74	695.08
5	272.14	691.68
6	281.62	688.49
7	291.17	685.51
8	300.77	682.75
9	310.44	680.19
10	320.16	677.85
11	329.94	675.72
12	339.75	673.81
13	349.61	672.12
14	359.50	670.64
15	369.42	669.38
16	379.36	668.35
17	389.33	667.53
18	399.31	666.93
19	409.31	666.55
20	419.30	666.39
21	429.30	666.45
22	439.30	666.73
23	449.29	667.23
24	459.26	667.96
25	469.22	668.90
26	479.15	670.06
27	489.05	671.44
28	498.92	673.04
29	508.76	674.85
30	518.55	676.88
31	528.29	679.13
32	537.99	681.59
33	547.62	684.27
34	557.20	687.15
35	566.71	690.25
36	576.14	693.55
37	585.51	697.07
38	594.79	700.78
39	603.99	704.70
40	613.10	708.83
41	622.12	713.15
42	631.04	717.67
43	639.85	722.39
44	648.57	727.30
45	657.17	732.40
46	665.65	737.69
47	674.02	743.16
48	682.27	748.82
49	690.39	754.66
50	698.38	760.67
51	706.23	766.86
52	713.94	773.23

result

53	721.52	779.76
54	728.94	786.45
55	736.22	793.31
56	743.35	800.33
57	750.32	807.50
58	757.12	814.82
59	763.77	822.30
60	770.25	829.91
61	772.07	832.15

Circle Center At X = 421.5 ; Y = 1120.0 and Radius, 453.6

*** 2.754 ***

1

Failure Surface Specified By 74 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.35	696.45
3	198.75	693.04
4	208.20	689.78
5	217.71	686.68
6	227.26	683.72
7	236.86	680.92
8	246.51	678.27
9	256.19	675.78
10	265.91	673.43
11	275.67	671.25
12	285.46	669.22
13	295.28	667.34
14	305.13	665.62
15	315.01	664.06
16	324.91	662.65
17	334.83	661.40
18	344.77	660.31
19	354.73	659.38
20	364.70	658.61
21	374.68	657.99
22	384.67	657.53
23	394.67	657.23
24	404.67	657.09
25	414.67	657.11
26	424.66	657.29
27	434.66	657.63
28	444.65	658.12
29	454.62	658.78
30	464.59	659.59
31	474.54	660.56
32	484.48	661.69
33	494.40	662.98
34	504.29	664.42
35	514.16	666.02
36	524.01	667.78
37	533.82	669.69
38	543.61	671.76

result

39	553.36	673.99
40	563.07	676.36
41	572.74	678.90
42	582.38	681.58
43	591.96	684.42
44	601.51	687.41
45	611.00	690.56
46	620.44	693.85
47	629.83	697.29
48	639.16	700.88
49	648.44	704.62
50	657.65	708.50
51	666.80	712.54
52	675.89	716.71
53	684.91	721.03
54	693.86	725.49
55	702.74	730.10
56	711.54	734.84
57	720.26	739.73
58	728.91	744.75
59	737.48	749.91
60	745.96	755.20
61	754.36	760.63
62	762.67	766.19
63	770.89	771.88
64	779.02	777.71
65	787.06	783.66
66	795.00	789.73
67	802.85	795.94
68	810.59	802.26
69	818.23	808.71
70	825.77	815.28
71	833.21	821.97
72	840.53	828.77
73	847.75	835.70
74	848.01	835.95

Circle Center At X = 408.5 ; Y = 1286.6 and Radius, 629.5

*** 2.779 ***

Failure Surface Specified By 62 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.25	702.71
3	253.58	699.11
4	262.98	695.70
5	272.45	692.48
6	281.98	689.46
7	291.58	686.63
8	301.23	684.00
9	310.93	681.57
10	320.67	679.34
11	330.46	677.31
12	340.29	675.48

		result
13	350.16	673.85
14	360.06	672.42
15	369.98	671.19
16	379.93	670.17
17	389.90	669.35
18	399.88	668.74
19	409.87	668.33
20	419.87	668.13
21	429.87	668.13
22	439.87	668.33
23	449.86	668.74
24	459.84	669.35
25	469.81	670.17
26	479.75	671.19
27	489.68	672.42
28	499.58	673.84
29	509.44	675.47
30	519.27	677.31
31	529.06	679.34
32	538.81	681.57
33	548.51	684.00
34	558.16	686.63
35	567.75	689.46
36	577.28	692.48
37	586.75	695.69
38	596.15	699.10
39	605.48	702.70
40	614.74	706.50
41	623.91	710.48
42	633.00	714.64
43	642.00	718.99
44	650.92	723.53
45	659.73	728.25
46	668.45	733.14
47	677.07	738.22
48	685.58	743.46
49	693.99	748.89
50	702.28	754.48
51	710.45	760.24
52	718.50	766.17
53	726.43	772.26
54	734.24	778.51
55	741.91	784.92
56	749.46	791.49
57	756.86	798.21
58	764.13	805.07
59	771.26	812.09
60	778.24	819.25
61	785.07	826.55
62	790.94	833.10

Circle Center At X = 424.9 ; Y = 1156.7 and Radius, 488.6

*** 2.784 ***

1

Failure Surface Specified By 76 Coordinate Points

result

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.40	696.59
3	198.85	693.31
4	208.34	690.18
5	217.88	687.18
6	227.47	684.32
7	237.09	681.61
8	246.76	679.03
9	256.46	676.60
10	266.19	674.31
11	275.96	672.17
12	285.75	670.17
13	295.58	668.31
14	305.43	666.59
15	315.31	665.03
16	325.21	663.60
17	335.12	662.32
18	345.06	661.19
19	355.01	660.20
20	364.98	659.36
21	374.95	658.67
22	384.94	658.12
23	394.93	657.72
24	404.93	657.46
25	414.92	657.35
26	424.92	657.39
27	434.92	657.58
28	444.92	657.91
29	454.91	658.39
30	464.89	659.01
31	474.86	659.79
32	484.81	660.70
33	494.76	661.77
34	504.68	662.98
35	514.59	664.33
36	524.48	665.83
37	534.34	667.48
38	544.18	669.27
39	553.99	671.20
40	563.77	673.28
41	573.52	675.50
42	583.24	677.86
43	592.92	680.37
44	602.56	683.02
45	612.17	685.81
46	621.73	688.74
47	631.25	691.81
48	640.72	695.02
49	650.14	698.37
50	659.51	701.85
51	668.83	705.47
52	678.10	709.23
53	687.31	713.13
54	696.46	717.16
55	705.55	721.32
56	714.58	725.62
57	723.55	730.05
58	732.45	734.61
59	741.28	739.30
60	750.05	744.11

		result
61	758.74	749.06
62	767.35	754.13
63	775.89	759.33
64	784.36	764.66
65	792.74	770.11
66	801.05	775.68
67	809.27	781.37
68	817.41	787.18
69	825.46	793.11
70	833.42	799.16
71	841.30	805.33
72	849.08	811.60
73	856.77	818.00
74	864.37	824.50
75	871.86	831.12
76	878.88	837.49

Circle Center At X = 417.3 ; Y = 1338.8 and Radius, 681.4

*** 2.831 ***

Failure Surface Specified By 58 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	243.56	701.33
3	252.26	696.40
4	261.10	691.72
5	270.07	687.31
6	279.16	683.14
7	288.37	679.25
8	297.69	675.61
9	307.11	672.25
10	316.62	669.16
11	326.21	666.34
12	335.88	663.80
13	345.62	661.53
14	355.42	659.55
15	365.28	657.84
16	375.18	656.42
17	385.11	655.29
18	395.08	654.44
19	405.06	653.88
20	415.06	653.60
21	425.06	653.61
22	435.05	653.90
23	445.03	654.49
24	455.00	655.35
25	464.93	656.51
26	474.83	657.95
27	484.68	659.67
28	494.47	661.67
29	504.21	663.95
30	513.88	666.51
31	523.47	669.35
32	532.97	672.46

		result
33	542.38	675.84
34	551.69	679.49
35	560.89	683.41
36	569.98	687.58
37	578.94	692.02
38	587.77	696.71
39	596.47	701.65
40	605.01	706.84
41	613.41	712.28
42	621.65	717.95
43	629.72	723.85
44	637.61	729.99
45	645.33	736.34
46	652.87	742.92
47	660.21	749.71
48	667.35	756.71
49	674.29	763.91
50	681.02	771.30
51	687.54	778.89
52	693.84	786.66
53	699.91	794.60
54	705.75	802.72
55	711.36	811.00
56	716.72	819.44
57	721.84	828.03
58	721.96	828.24

Circle Center At X = 419.7 ; Y = 1002.4 and Radius, 348.8

*** 2.855 ***

1

Failure Surface Specified By 61 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	243.60	701.40
3	252.34	696.53
4	261.20	691.89
5	270.18	687.49
6	279.27	683.33
7	288.47	679.41
8	297.77	675.74
9	307.16	672.31
10	316.65	669.13
11	326.21	666.21
12	335.85	663.54
13	345.55	661.12
14	355.31	658.96
15	365.13	657.06
16	375.00	655.43
17	384.90	654.05
18	394.84	652.94
19	404.80	652.08
20	414.79	651.50
21	424.78	651.18

		result
22	434.78	651.12
23	444.78	651.32
24	454.77	651.80
25	464.74	652.53
26	474.69	653.53
27	484.61	654.79
28	494.49	656.32
29	504.33	658.10
30	514.12	660.14
31	523.85	662.45
32	533.52	665.01
33	543.12	667.82
34	552.63	670.89
35	562.07	674.21
36	571.41	677.77
37	580.65	681.59
38	589.79	685.64
39	598.82	689.94
40	607.74	694.47
41	616.53	699.24
42	625.19	704.24
43	633.71	709.47
44	642.10	714.92
45	650.34	720.59
46	658.42	726.47
47	666.34	732.57
48	674.11	738.88
49	681.70	745.38
50	689.12	752.09
51	696.35	758.99
52	703.40	766.08
53	710.27	773.36
54	716.93	780.81
55	723.40	788.44
56	729.66	796.23
57	735.72	804.19
58	741.56	812.31
59	747.19	820.58
60	752.59	828.99
61	753.96	831.25

Circle Center At X = 432.0 ; Y = 1029.0 and Radius, 377.9

*** 2.858 ***

Failure Surface Specified By 65 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.61	697.23
3	199.26	694.62
4	208.96	692.16
5	218.69	689.85
6	228.45	687.70
7	238.25	685.71
8	248.08	683.87

		result
9	257.94	682.19
10	267.82	680.66
11	277.73	679.29
12	287.65	678.08
13	297.60	677.03
14	307.56	676.14
15	317.53	675.40
16	327.51	674.82
17	337.50	674.40
18	347.50	674.14
19	357.50	674.04
20	367.50	674.10
21	377.50	674.32
22	387.49	674.70
23	397.48	675.23
24	407.45	675.93
25	417.42	676.78
26	427.37	677.79
27	437.30	678.96
28	447.21	680.29
29	457.10	681.77
30	466.96	683.41
31	476.80	685.21
32	486.61	687.16
33	496.38	689.27
34	506.12	691.54
35	515.82	693.96
36	525.49	696.53
37	535.11	699.26
38	544.68	702.14
39	554.21	705.17
40	563.69	708.35
41	573.12	711.69
42	582.50	715.17
43	591.81	718.80
44	601.07	722.58
45	610.27	726.50
46	619.40	730.58
47	628.47	734.79
48	637.47	739.15
49	646.40	743.65
50	655.26	748.30
51	664.04	753.08
52	672.74	758.00
53	681.37	763.07
54	689.91	768.26
55	698.37	773.59
56	706.74	779.06
57	715.03	784.66
58	723.22	790.39
59	731.33	796.25
60	739.34	802.24
61	747.25	808.35
62	755.07	814.59
63	762.78	820.95
64	770.39	827.44
65	775.98	832.35

Circle Center At X = 358.8 ; Y = 1302.9 and Radius, 628.9

*** 2.886 ***

1

Failure Surface Specified By 56 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	235.00	706.50
2	244.37	703.01
3	253.82	699.72
4	263.33	696.65
5	272.91	693.78
6	282.56	691.14
7	292.25	688.70
8	302.01	686.48
9	311.80	684.48
10	321.64	682.70
11	331.52	681.14
12	341.43	679.79
13	351.37	678.67
14	361.33	677.77
15	371.30	677.08
16	381.29	676.62
17	391.29	676.39
18	401.29	676.37
19	411.29	676.58
20	421.28	677.01
21	431.26	677.66
22	441.22	678.53
23	451.16	679.62
24	461.07	680.93
25	470.95	682.47
26	480.80	684.22
27	490.60	686.19
28	500.36	688.38
29	510.07	690.78
30	519.72	693.40
31	529.31	696.23
32	538.83	699.28
33	548.29	702.53
34	557.67	706.00
35	566.97	709.67
36	576.19	713.55
37	585.32	717.63
38	594.35	721.92
39	603.29	726.40
40	612.13	731.08
41	620.86	735.95
42	629.48	741.02
43	637.99	746.28
44	646.37	751.73
45	654.64	757.36
46	662.77	763.17
47	670.78	769.17
48	678.65	775.33
49	686.38	781.68
50	693.97	788.19
51	701.41	794.87
52	708.70	801.71
53	715.84	808.71

		result
54	722.82	815.87
55	729.64	823.19
56	736.03	830.35

Circle Center At X = 397.0 ; Y = 1126.6 and Radius, 450.2

*** 2.890 ***

Failure Surface Specified By 65 Coordinate Points

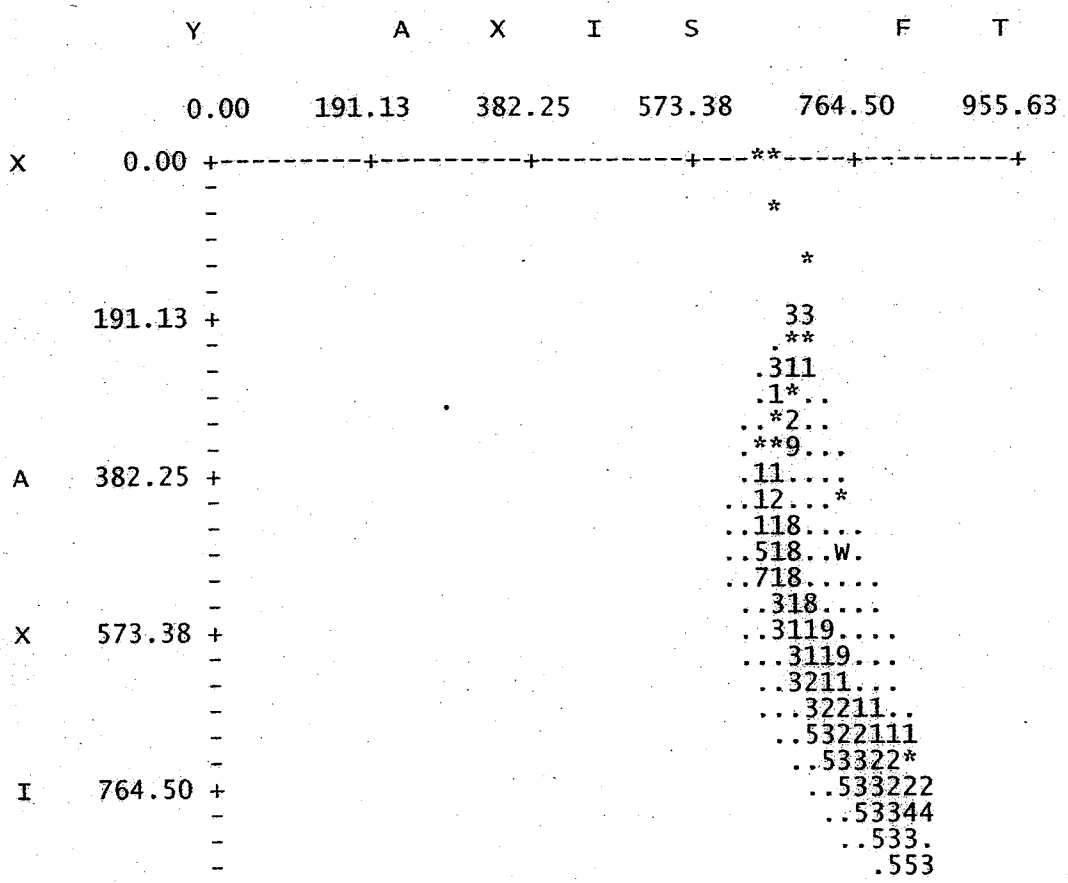
Point No.	X-Surf (ft)	Y-Surf (ft)
1	180.00	700.00
2	189.39	696.55
3	198.84	693.28
4	208.34	690.18
5	217.91	687.26
6	227.52	684.51
7	237.19	681.95
8	246.90	679.56
9	256.65	677.36
10	266.45	675.33
11	276.28	673.49
12	286.14	671.83
13	296.03	670.35
14	305.94	669.06
15	315.88	667.95
16	325.84	667.02
17	335.81	666.28
18	345.80	665.73
19	355.79	665.36
20	365.79	665.17
21	375.79	665.17
22	385.79	665.36
23	395.78	665.73
24	405.76	666.28
25	415.74	667.02
26	425.69	667.95
27	435.63	669.06
28	445.55	670.35
29	455.44	671.83
30	465.30	673.49
31	475.13	675.33
32	484.92	677.36
33	494.67	679.56
34	504.39	681.95
35	514.05	684.51
36	523.67	687.26
37	533.23	690.18
38	542.74	693.28
39	552.19	696.55
40	561.57	700.00
41	570.89	703.62
42	580.15	707.42
43	589.33	711.38
44	598.43	715.52
45	607.46	719.82

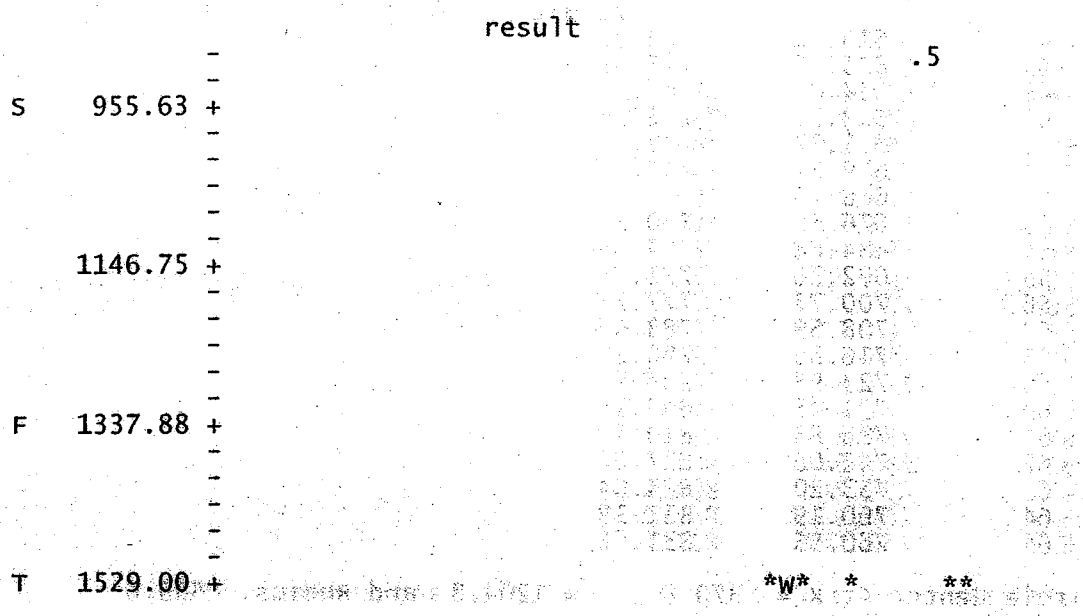
		result
46	616.41	724.29
47	625.27	728.92
48	634.04	733.72
49	642.72	738.68
50	651.32	743.80
51	659.81	749.08
52	668.20	754.51
53	676.50	760.10
54	684.68	765.84
55	692.76	771.73
56	700.73	777.77
57	708.59	783.96
58	716.33	790.29
59	723.95	796.77
60	731.45	803.38
61	738.83	810.13
62	746.08	817.02
63	753.20	824.04
64	760.19	831.19
65	760.55	831.58

Circle Center At X = 370.8 ; Y = 1204.8 and Radius, 539.6

*** 2.897 ***

1



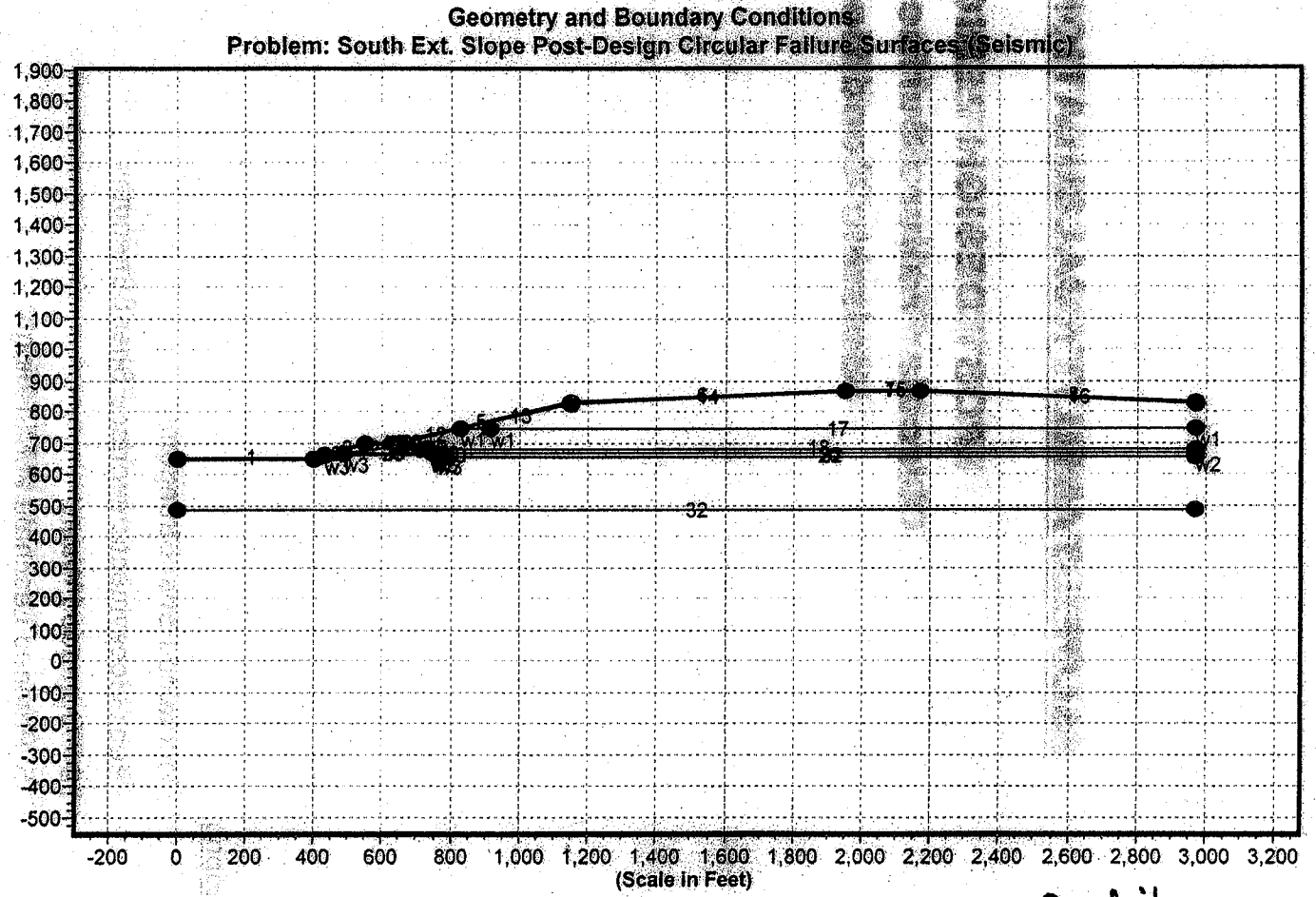

result
.5
S
955.63
1146.75
F
1337.88
T
1529.00
W
*
**

SLOPE STABILITY CALCULATIONS

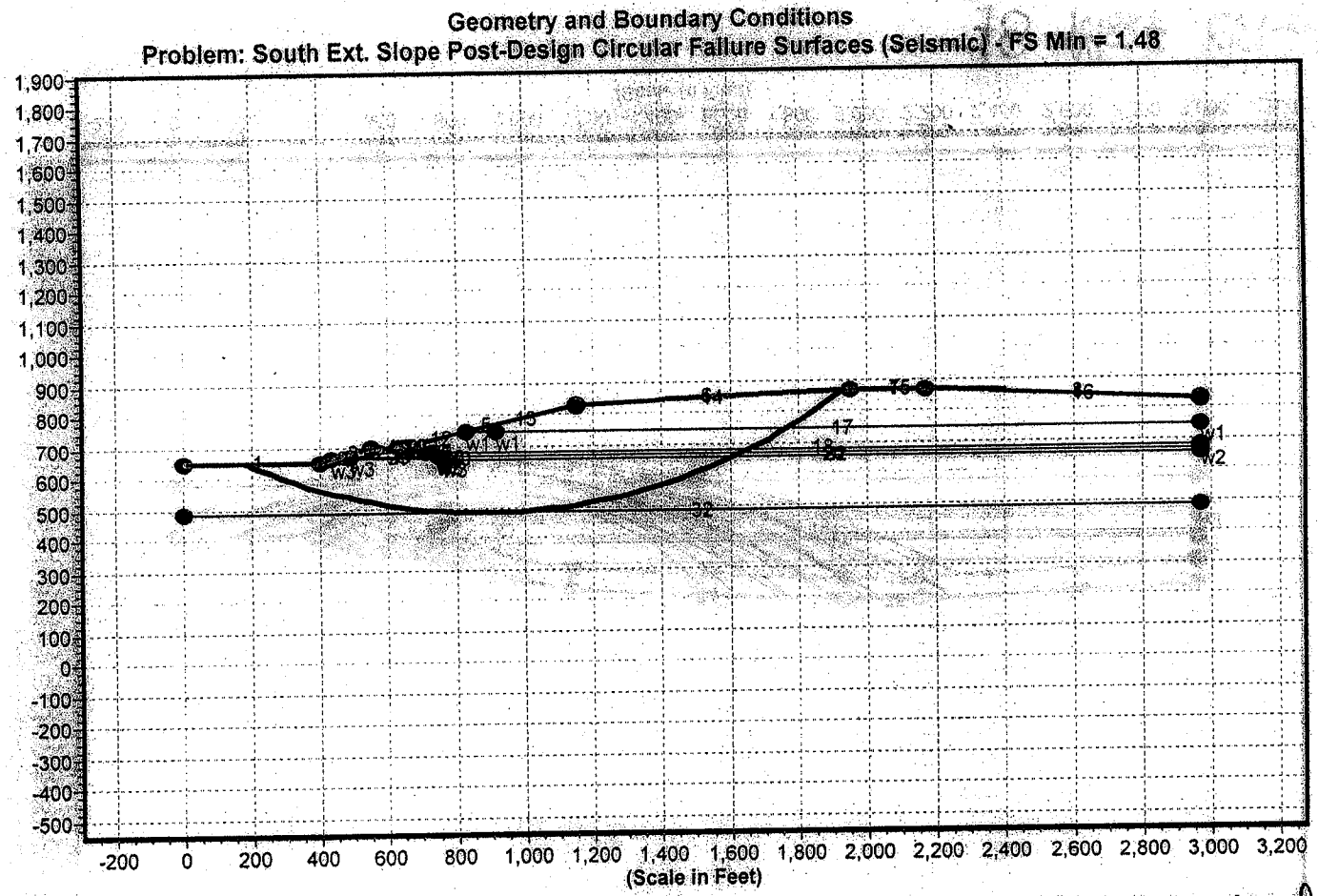
POST DESIGN PERIOD
Circular Failure Surfaces
Seismic Conditions

Key Assumptions:

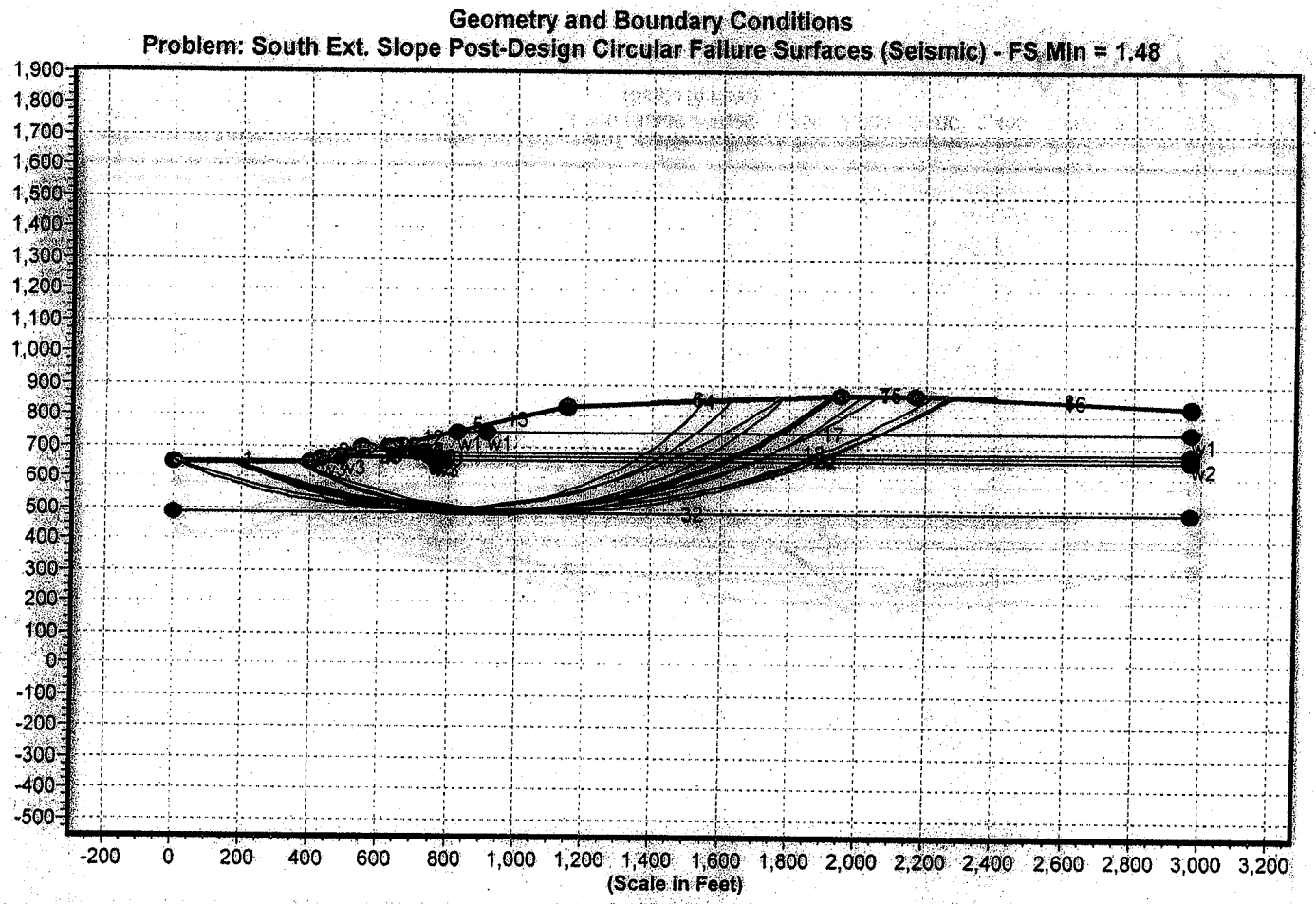
Undrained Shear Strengths
Peak Geosynthetic Interface Shear Strengths
24' Degraded Waste
5' Perched Leachate at Mid-Height
12' Leachate on Landfill Floor
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Circular Failure Surfaces (Seismic)
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-200
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
2,600
2,800
3,000
3,200
(Scale in Feet)
1
32
17
W1
W2
W3

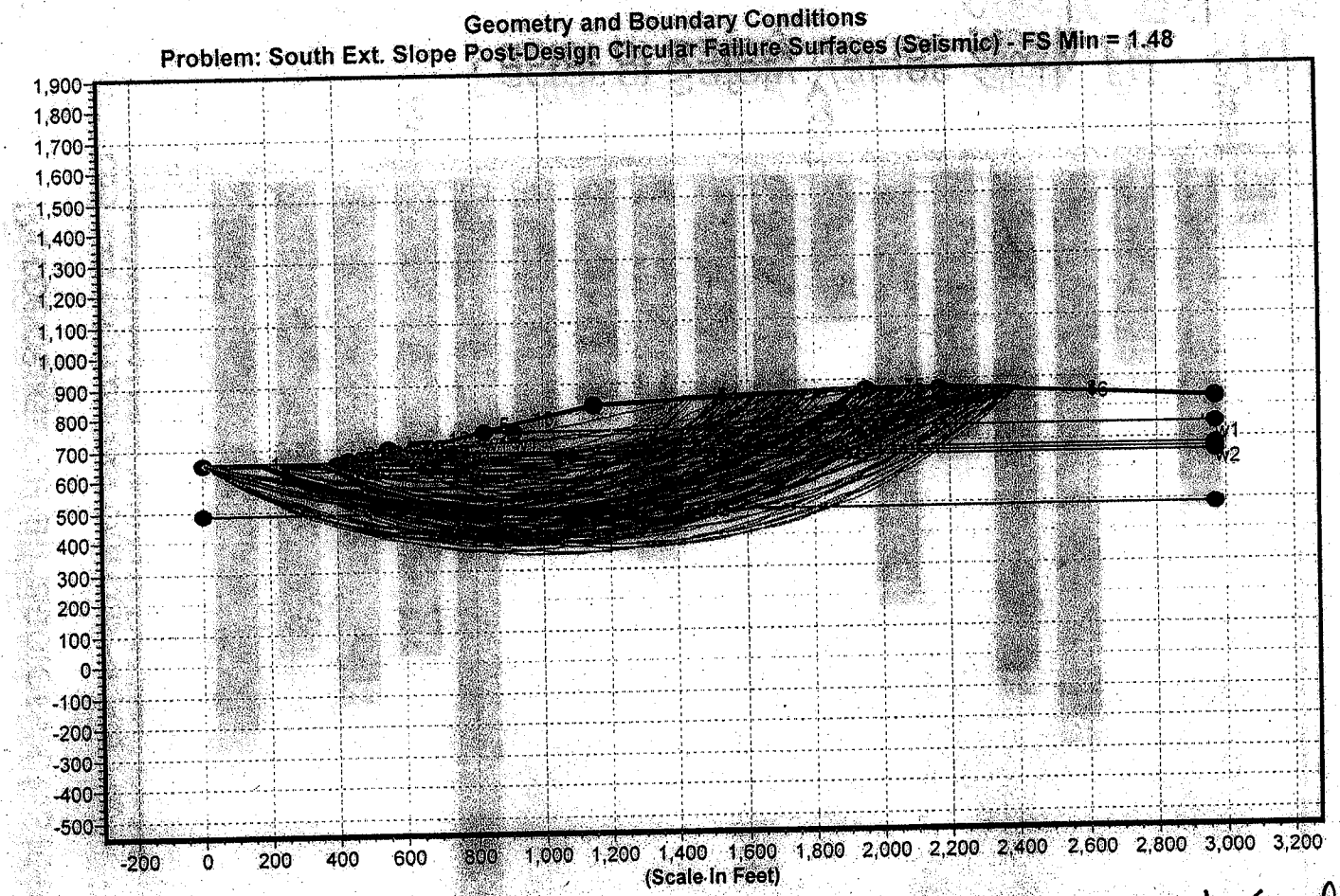
Profile



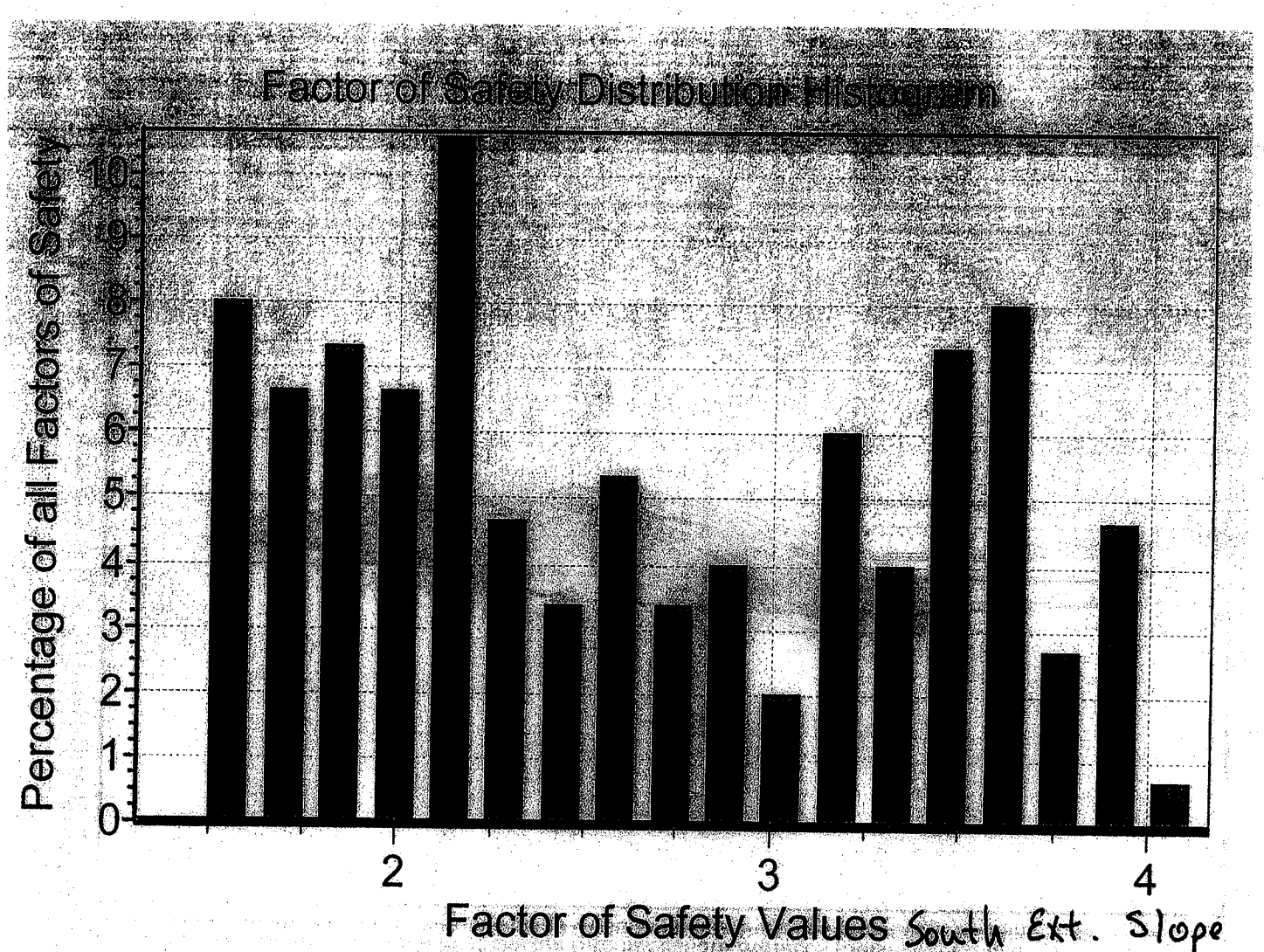
Critical Surfaces



10 Most Critical Surfaces



Generated Surfaces



South Ext. Slope Post-Design
Circular Failure Surfaces
(Seismic)
Unconsolidated/Undrained

s

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Circular Fa
ilure Surfaces (Seismic)

BOUNDARY COORDINATES

8 Top Boundaries
32 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	650.00	400.00	650.00	1
2	400.00	650.00	430.00	660.00	1
3	430.00	660.00	550.00	700.00	2
4	550.00	700.00	630.00	700.00	2
5	630.00	700.00	1150.00	830.00	3
6	1150.00	830.00	1950.00	870.00	3
7	1950.00	870.00	2170.00	870.00	3
8	2170.00	870.00	2970.00	830.00	3
9	630.00	700.00	641.00	700.00	2
10	641.00	700.00	650.49	700.00	4
11	650.49	700.00	653.25	700.66	5
12	653.25	700.66	824.62	743.50	6
13	824.62	743.50	1150.00	825.00	7
14	1150.00	825.00	1950.12	865.00	7
15	1950.12	865.00	2169.87	865.00	7
16	2169.87	865.00	2970.00	825.00	7
17	824.62	743.50	2970.00	743.50	6
18	709.23	682.00	2970.00	682.00	11
19	653.25	700.66	781.23	658.00	5
20	776.49	658.00	2970.00	658.00	8
21	650.49	700.00	779.49	657.00	4
22	779.49	657.00	2970.00	657.00	4
23	641.00	700.00	659.00	694.00	2
24	430.00	660.00	487.00	665.00	9
25	487.00	665.00	659.00	694.00	10
26	659.00	694.00	746.00	665.00	10

			result		
27	487.00	665.00	746.00	665.00	9
28	746.00	665.00	761.00	660.00	9
29	430.00	660.00	761.00	660.00	1
30	761.00	660.00	779.00	654.00	1
31	779.00	654.00	2970.00	654.00	1
32	0.00	483.00	2970.00	483.00	12

1

ISOTROPIC SOIL PARAMETERS

12 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	6000.0	0.0	0.00	0.0	0
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	128.0	134.0	0.0	15.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	16.0	0.00	0.0	2
9	100.0	110.0	1400.0	0.0	0.00	0.0	3
10	135.0	140.0	3500.0	0.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2
12	135.0	140.0	0.0	35.0	0.00	0.0	0

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	824.62	743.50
2	914.62	748.50
3	2970.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	743.49	669.00
2	2970.00	669.00

1

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	430.00	660.00
2	487.00	665.00
3	746.00	665.00
4	761.00	660.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

30 Surfaces Initiate From Each Of 5 Points Equally Spaced
Along The Ground Surface Between X = 5.00 ft.
and X = 700.00 ft.

Each Surface Terminates Between X =1400.00 ft.
and X =2400.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y =300.00 ft.

40.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -35.0
And 30.0 deg.

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 48 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	178.75	650.00
2	214.85	632.77
3	251.36	616.44
4	288.27	601.03
5	325.56	586.54
6	363.19	572.98
7	401.15	560.36
8	439.41	548.70
9	477.95	537.99
10	516.74	528.24
11	555.77	519.46
12	595.00	511.66
13	634.41	504.84
14	673.99	499.00
15	713.69	494.14
16	753.50	490.28
17	793.40	487.41
18	833.36	485.54
19	873.35	484.66
20	913.35	484.77
21	953.33	485.89
22	993.28	487.99
23	1033.15	491.10
24	1072.94	495.19
25	1112.62	500.28
26	1152.16	506.35
27	1191.53	513.40
28	1230.72	521.43
29	1269.69	530.44
30	1308.43	540.41
31	1346.90	551.34
32	1385.09	563.23
33	1422.98	576.07
34	1460.53	589.84
35	1497.73	604.55
36	1534.55	620.18
37	1570.97	636.72
38	1606.97	654.16
39	1642.52	672.50
40	1677.60	691.71
41	1712.20	711.79
42	1746.28	732.73
43	1779.83	754.51
44	1812.83	777.11
45	1845.25	800.54
46	1877.09	824.76
47	1908.31	849.77
48	1931.20	869.06

Circle Center At X = 888.6 ; Y = 2090.4 and Radius, 1605.8

*** 1.480 ***

result

Individual data on the 76 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	36.1	43543.5	0.0	0.0	0.0	0.0	4354.4	0.0	0.0
2	36.5	129831.9	0.0	0.0	0.0	0.0	12983.2	0.0	0.0
3	36.9	213251.1	0.0	0.0	0.0	0.0	21325.1	0.0	0.0
4	37.3	293446.3	0.0	0.0	0.0	0.0	29344.6	0.0	0.0
5	37.6	370078.0	0.0	0.0	0.0	0.0	37007.8	0.0	0.0
6	36.8	428435.3	0.0	0.0	0.0	0.0	42843.5	0.0	0.0
7	1.1	14420.8	0.0	0.0	0.0	0.0	1442.1	0.0	0.0
8	28.9	400787.8	0.0	0.0	0.0	0.0	40078.8	0.0	0.0
9	9.4	146636.4	0.0	0.0	0.0	0.0	14663.6	0.0	0.0
10	38.5	676746.3	0.0	0.0	0.0	0.0	67674.6	0.0	0.0
11	9.1	176365.5	0.0	0.0	0.0	0.0	17636.6	0.0	0.0
12	29.7	625588.7	0.0	0.0	0.0	0.0	62558.9	0.0	0.0
13	33.3	781403.2	0.0	0.0	0.0	0.0	78140.3	0.0	0.0
14	5.8	143414.4	0.0	0.0	0.0	0.0	14341.4	0.0	0.0
15	39.2	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
16	35.0	926318.5	0.0	0.0	0.0	0.0	92631.9	0.0	0.0
17	4.4	119252.4	0.0	0.0	0.0	0.0	11925.2	0.0	0.0
18	6.6	179871.8	0.0	0.0	0.0	0.0	17987.2	0.0	0.0
19	9.5	263212.5	0.0	0.0	0.0	0.0	26321.2	0.0	0.0
20	2.8	77432.4	0.0	0.0	0.0	0.0	7743.2	0.0	0.0
21	5.8	162037.2	0.0	0.0	0.0	0.0	16203.7	0.0	0.0
22	15.0	425319.3	0.0	0.0	0.0	0.0	42531.9	0.0	0.0
23	35.2	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
24	4.5	129989.0	0.0	0.0	0.0	0.0	12998.9	0.0	0.0
25	29.8	879187.6	0.0	0.0	0.0	0.0	87918.8	0.0	0.0
26	2.5	74917.5	0.0	0.0	0.0	0.0	7491.8	0.0	0.0
27	2.2	66716.9	0.0	0.0	0.0	0.0	6671.7	0.0	0.0
28	5.3	158454.2	0.0	0.0	0.0	0.0	15845.4	0.0	0.0
29	7.5	226787.5	0.0	0.0	0.0	0.0	22678.8	0.0	0.0
30	15.5	472429.5	0.0	0.0	0.0	0.0	47242.9	0.0	0.0
31	2.5	76946.6	0.0	0.0	0.0	0.0	7694.7	0.0	0.0
32	0.5	15035.4	0.0	0.0	0.0	0.0	1503.5	0.0	0.0
33	1.7	53429.5	0.0	0.0	0.0	0.0	5343.0	0.0	0.0
34	12.2	376048.0	0.0	0.0	0.0	0.0	37604.8	0.0	0.0
35	31.2	982469.0	0.0	0.0	0.0	0.0	98246.9	0.0	0.0
36	8.7	279344.3	0.0	0.0	0.0	0.0	27934.4	0.0	0.0
37	40.0	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
38	40.0	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
39	1.3	42918.7	0.0	0.0	0.0	0.0	4291.9	0.0	0.0
40	38.7	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
41	39.9	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
42	39.9	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
43	39.8	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
44	39.7	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
45	37.4	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
46	2.2	75776.5	0.0	0.0	0.0	0.0	7577.7	0.0	0.0
47	39.4	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
48	39.2	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
49	39.0	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
50	38.7	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
51	38.5	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
52	38.2	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
53	37.9	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
54	37.6	956488.9	0.0	0.0	0.0	0.0	95648.9	0.0	0.0
55	37.2	878501.8	0.0	0.0	0.0	0.0	87850.2	0.0	0.0

					result				
56	36.8	796502.3	0.0	0.0	0.0	0.0	79650.2	0.0	0.0
57	36.4	710825.5	0.0	0.0	0.0	0.0	71082.6	0.0	0.0
58	35.7	616406.4	0.0	0.0	0.0	0.0	61640.6	0.0	0.0
59	0.3	5417.4	0.0	0.0	0.0	0.0	541.7	0.0	0.0
60	5.5	87702.7	0.0	0.0	0.0	0.0	8770.3	0.0	0.0
61	1.9	30430.2	0.0	1565.6	0.0	0.0	3043.0	0.0	0.0
62	21.3	321855.9	0.0	8236.6	0.0	0.0	32185.6	0.0	0.0
63	6.8	97500.9	0.0	0.0	0.0	0.0	9750.1	0.0	0.0
64	17.4	238500.2	0.0	0.0	0.0	0.0	23850.0	0.0	0.0
65	17.7	229538.6	0.0	0.0	0.0	0.0	22953.9	0.0	0.0
66	34.6	412614.9	0.0	0.0	0.0	0.0	41261.5	0.0	0.0
67	34.1	358486.0	0.0	0.0	0.0	0.0	35848.6	0.0	0.0
68	16.6	156401.8	0.0	0.0	0.0	0.0	15640.2	0.0	0.0
69	7.7	68384.9	0.0	1432.6	0.0	0.0	6838.5	0.0	0.0
70	9.3	78616.3	0.0	0.0	0.0	0.0	7861.6	0.0	0.0
71	33.0	247597.3	0.0	0.0	0.0	0.0	24759.7	0.0	0.0
72	32.4	191304.8	0.0	0.0	0.0	0.0	19130.5	0.0	0.0
73	31.8	134766.4	0.0	0.0	0.0	0.0	13476.6	0.0	0.0
74	31.2	78227.8	0.0	0.0	0.0	0.0	7822.8	0.0	0.0
75	16.6	18795.7	0.0	0.0	0.0	0.0	1879.6	0.0	0.0
76	6.3	2023.0	0.0	0.0	0.0	0.0	202.3	0.0	0.0

Failure Surface Specified By 56 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	178.75	650.00
2	215.95	635.28
3	253.40	621.24
4	291.10	607.86
5	329.03	595.16
6	367.18	583.15
7	405.54	571.81
8	444.10	561.17
9	482.84	551.22
10	521.75	541.96
11	560.83	533.41
12	600.05	525.55
13	639.40	518.39
14	678.88	511.95
15	718.47	506.20
16	758.15	501.17
17	797.91	496.85
18	837.75	493.25
19	877.65	490.35
20	917.59	488.17
21	957.56	486.71
22	997.55	485.96
23	1037.55	485.93
24	1077.55	486.61
25	1117.52	488.01
26	1157.47	490.13
27	1197.37	492.96
28	1237.21	496.50
29	1276.98	500.76
30	1316.67	505.73
31	1356.27	511.40
32	1395.75	517.79
33	1435.12	524.88
34	1474.35	532.68
35	1513.44	541.17

		result
36	1552.37	550.37
37	1591.13	560.26
38	1629.70	570.84
39	1668.08	582.11
40	1706.25	594.06
41	1744.21	606.70
42	1781.92	620.02
43	1819.40	634.00
44	1856.62	648.66
45	1893.57	663.98
46	1930.24	679.96
47	1966.61	696.59
48	2002.69	713.88
49	2038.45	731.80
50	2073.88	750.36
51	2108.97	769.56
52	2143.72	789.37
53	2178.10	809.81
54	2212.12	830.86
55	2245.75	852.52
56	2264.78	865.26

Circle Center At X = 1019.3 ; Y = 2719.9 and Radius, 2234.0

*** 1.505 ***

1

Failure Surface Specified By 41 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	352.50	650.00
2	387.46	630.55
3	423.06	612.32
4	459.26	595.32
5	496.03	579.57
6	533.32	565.09
7	571.09	551.91
8	609.28	540.03
9	647.86	529.46
10	686.78	520.23
11	726.00	512.34
12	765.46	505.81
13	805.12	500.63
14	844.94	496.82
15	884.87	494.37
16	924.85	493.30
17	964.85	493.61
18	1004.81	495.28
19	1044.70	498.33
20	1084.45	502.75
21	1124.03	508.53
22	1163.39	515.67
23	1202.48	524.15
24	1241.26	533.97
25	1279.67	545.12
26	1317.68	557.58

		result
27	1355.24	571.34
28	1392.31	586.38
29	1428.83	602.68
30	1464.78	620.23
31	1500.10	639.00
32	1534.75	658.98
33	1568.70	680.13
34	1601.90	702.44
35	1634.32	725.88
36	1665.91	750.41
37	1696.64	776.02
38	1726.48	802.66
39	1755.38	830.32
40	1783.31	858.95
41	1785.91	861.80

Circle Center At X = 936.0 ; Y = 1657.7 and Radius, 1164.4

*** 1.514 ***

Failure Surface Specified By 46 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	352.50	650.00
2	388.63	632.83
3	425.20	616.63
4	462.19	601.39
5	499.56	587.14
6	537.30	573.89
7	575.38	561.63
8	613.76	550.39
9	652.43	540.16
10	691.36	530.96
11	730.52	522.79
12	769.88	515.66
13	809.41	509.57
14	849.09	504.53
15	888.89	500.54
16	928.79	497.60
17	968.74	495.72
18	1008.73	494.90
19	1048.73	495.13
20	1088.71	496.42
21	1128.64	498.77
22	1168.50	502.17
23	1208.25	506.62
24	1247.87	512.12
25	1287.33	518.67
26	1326.60	526.26
27	1365.66	534.88
28	1404.48	544.53
29	1443.03	555.21
30	1481.28	566.90
31	1519.21	579.59
32	1556.80	593.29
33	1594.00	607.97

		result
34	1630.81	623.64
35	1667.19	640.27
36	1703.12	657.85
37	1738.57	676.38
38	1773.51	695.84
39	1807.93	716.22
40	1841.80	737.50
41	1875.10	759.66
42	1907.80	782.70
43	1939.88	806.60
44	1971.31	831.33
45	2002.08	856.89
46	2017.05	870.00

Circle Center At X = 1019.9 ; Y = 2007.7 and Radius, 1512.9

*** 1.519 ***

1

Failure Surface Specified By 55 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	178.75	650.00
2	215.94	635.27
3	253.40	621.23
4	291.10	607.88
5	329.05	595.23
6	367.22	583.28
7	405.61	572.04
8	444.20	561.51
9	482.97	551.69
10	521.92	542.58
11	561.04	534.20
12	600.29	526.53
13	639.69	519.59
14	679.20	513.38
15	718.83	507.90
16	758.54	503.15
17	798.34	499.13
18	838.20	495.85
19	878.12	493.30
20	918.08	491.48
21	958.07	490.41
22	998.07	490.07
23	1038.06	490.47
24	1078.05	491.60
25	1118.00	493.47
26	1157.92	496.08
27	1197.78	499.42
28	1237.57	503.50
29	1277.28	508.31
30	1316.90	513.85
31	1356.40	520.12
32	1395.78	527.12
33	1435.03	534.84
34	1474.13	543.28

result

35	1513.07	552.44
36	1551.83	562.32
37	1590.40	572.91
38	1628.77	584.21
39	1666.93	596.22
40	1704.86	608.92
41	1742.54	622.33
42	1779.98	636.42
43	1817.15	651.20
44	1854.04	666.67
45	1890.63	682.81
46	1926.93	699.62
47	1962.91	717.10
48	1998.56	735.24
49	2033.87	754.04
50	2068.82	773.48
51	2103.42	793.56
52	2137.64	814.28
53	2171.47	835.62
54	2204.90	857.59
55	2219.44	867.53

Circle Center At X = 996.5 ; Y = 2660.5 and Radius, 2170.4

*** 1.520 ***

Failure Surface Specified By 51 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	178.75	650.00
2	215.65	634.56
3	252.87	619.91
4	290.39	606.05
5	328.20	592.98
6	366.27	580.72
7	404.59	569.26
8	443.15	558.61
9	481.92	548.78
10	520.90	539.77
11	560.05	531.58
12	599.37	524.22
13	638.83	517.70
14	678.42	512.01
15	718.13	507.15
16	757.93	503.14
17	797.80	499.97
18	837.73	497.64
19	877.71	496.15
20	917.70	495.51
21	957.70	495.72
22	997.69	496.77
23	1037.64	498.66
24	1077.55	501.39
25	1117.39	504.97
26	1157.14	509.39
27	1196.80	514.65

		result
28	1236.33	520.74
29	1275.72	527.66
30	1314.97	535.42
31	1354.03	544.00
32	1392.91	553.41
33	1431.58	563.64
34	1470.03	574.68
35	1508.23	586.53
36	1546.18	599.18
37	1583.85	612.63
38	1621.23	626.87
39	1658.30	641.90
40	1695.04	657.71
41	1731.44	674.30
42	1767.48	691.64
43	1803.15	709.75
44	1838.43	728.60
45	1873.30	748.20
46	1907.75	768.52
47	1941.77	789.57
48	1975.33	811.33
49	2008.42	833.80
50	2041.04	856.96
51	2058.60	870.00

Circle Center At X = 928.1 ; Y = 2389.6 and Radius, 1894.1

*** 1.532 ***

Failure Surface Specified By 61 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	5.00	650.00
2	42.60	636.36
3	80.41	623.29
4	118.40	610.79
5	156.59	598.88
6	194.95	587.54
7	233.48	576.79
8	272.16	566.63
9	311.00	557.05
10	349.98	548.07
11	389.09	539.68
12	428.32	531.89
13	467.67	524.69
14	507.12	518.10
15	546.67	512.10
16	586.31	506.70
17	626.02	501.91
18	665.80	497.72
19	705.64	494.14
20	745.53	491.16
21	785.46	488.79
22	825.42	487.03
23	865.40	485.87

		result
24	905.40	485.32
25	945.40	485.38
26	985.39	486.05
27	1025.37	487.32
28	1065.33	489.21
29	1105.25	491.70
30	1145.13	494.79
31	1184.96	498.49
32	1224.72	502.80
33	1264.42	507.71
34	1304.04	513.23
35	1343.57	519.34
36	1383.00	526.06
37	1422.33	533.37
38	1461.54	541.28
39	1500.62	549.78
40	1539.58	558.88
41	1578.38	568.57
42	1617.04	578.85
43	1655.54	589.71
44	1693.86	601.16
45	1732.01	613.19
46	1769.97	625.80
47	1807.74	638.98
48	1845.30	652.74
49	1882.65	667.06
50	1919.77	681.95
51	1956.67	697.41
52	1993.32	713.42
53	2029.73	729.99
54	2065.88	747.10
55	2101.77	764.77
56	2137.38	782.98
57	2172.72	801.73
58	2207.76	821.01
59	2242.51	840.83
60	2276.95	861.17
61	2282.22	864.39

Circle Center At X = 921.5 ; Y = 3117.1 and Radius, 2631.8

*** 1.539 ***

Failure Surface Specified By 37 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	352.50	650.00
2	387.16	630.04
3	422.59	611.46
4	458.73	594.31
5	495.51	578.61
6	532.90	564.38
7	570.82	551.65
8	609.21	540.43
9	648.02	530.75
10	687.19	522.61

result

11	726.64	516.04
12	766.33	511.04
13	806.18	507.62
14	846.14	505.78
15	886.14	505.53
16	926.12	506.87
17	966.01	509.80
18	1005.75	514.31
19	1045.29	520.40
20	1084.55	528.05
21	1123.48	537.25
22	1162.01	547.99
23	1200.08	560.25
24	1237.64	574.02
25	1274.62	589.27
26	1310.96	605.97
27	1346.62	624.10
28	1381.52	643.64
29	1415.63	664.54
30	1448.87	686.79
31	1481.21	710.33
32	1512.58	735.14
33	1542.95	761.18
34	1572.25	788.41
35	1600.46	816.77
36	1627.51	846.23
37	1634.27	854.21

Circle Center At X = 872.4 ; Y = 1512.5 and Radius, 1007.0

*** 1.568 ***

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Failure Surface Specified By 35 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	352.50	650.00
2	386.57	629.03
3	421.52	609.59
4	457.31	591.72
5	493.85	575.44
6	531.07	560.80
7	568.90	547.82
8	607.28	536.52
9	646.11	526.92
10	685.33	519.06
11	724.86	512.93
12	764.62	508.56
13	804.53	505.95
14	844.52	505.11
15	884.51	506.04
16	924.42	508.73
17	964.17	513.19
18	1003.69	519.40
19	1042.89	527.35
20	1081.70	537.02

		result
21	1120.05	548.40
22	1157.85	561.47
23	1195.05	576.19
24	1231.55	592.55
25	1267.30	610.50
26	1302.21	630.01
27	1336.23	651.05
28	1369.29	673.57
29	1401.32	697.53
30	1432.26	722.89
31	1462.04	749.58
32	1490.62	777.57
33	1517.94	806.79
34	1543.93	837.20
35	1554.09	850.20

Circle Center At X = 843.6 ; Y = 1409.7 and Radius, 904.6

*** 1.579 ***

Failure Surface Specified By 48 Coordinate Points

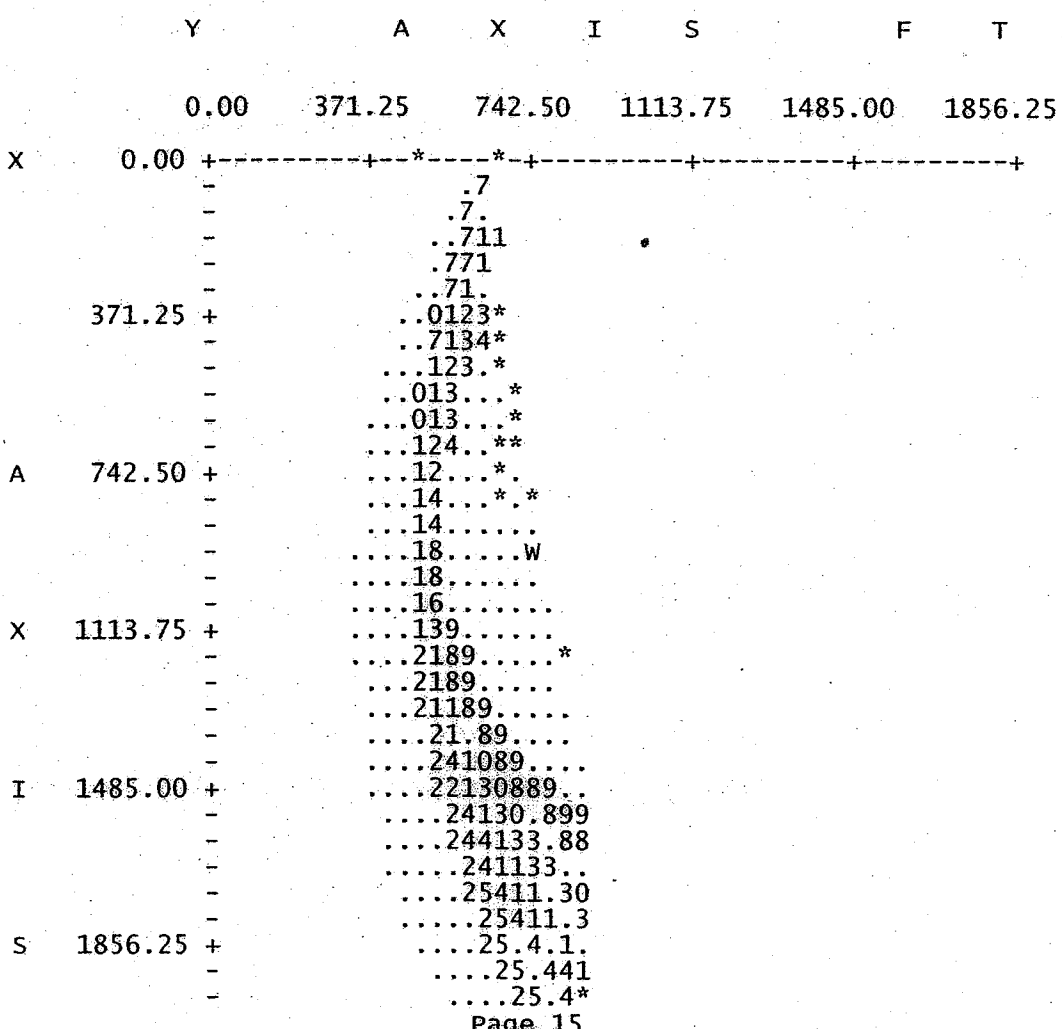
Point No.	X-Surf (ft)	Y-Surf (ft)
1	5.00	650.00
2	41.54	633.73
3	78.46	618.32
4	115.72	603.78
5	153.31	590.12
6	191.22	577.35
7	229.41	565.46
8	267.87	554.48
9	306.58	544.39
10	345.52	535.22
11	384.66	526.97
12	423.98	519.63
13	463.46	513.22
14	503.08	507.73
15	542.82	503.17
16	582.66	499.55
17	622.57	496.86
18	662.53	495.11
19	702.52	494.29
20	742.52	494.42
21	782.51	495.48
22	822.46	497.47
23	862.35	500.40
24	902.16	504.27
25	941.87	509.07
26	981.46	514.80
27	1020.90	521.45
28	1060.18	529.03
29	1099.27	537.52
30	1138.14	546.93
31	1176.79	557.25
32	1215.18	568.47
33	1253.30	580.59

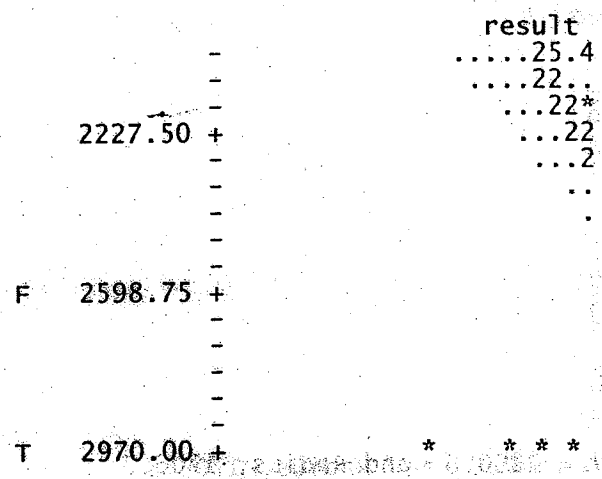
		result
34	1291.13	593.60
35	1328.64	607.49
36	1365.82	622.26
37	1402.63	637.89
38	1439.08	654.38
39	1475.12	671.72
40	1510.75	689.90
41	1545.94	708.92
42	1580.68	728.75
43	1614.94	749.39
44	1648.71	770.83
45	1681.97	793.05
46	1714.70	816.05
47	1746.88	839.80
48	1774.52	861.23

Circle Center At X = 717.3 ; Y = 2200.6 and Radius, 1706.3

*** 1.581 ***

1




result
.....25.4
....22..
...22*
2227.50 +
...22
...2
..
.
F 2598.75 +
T 2970.00 +
* * * *

SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD
Planar Failure Surfaces
Static Short Term Conditions

Key Assumptions:

Undrained Shear Strengths

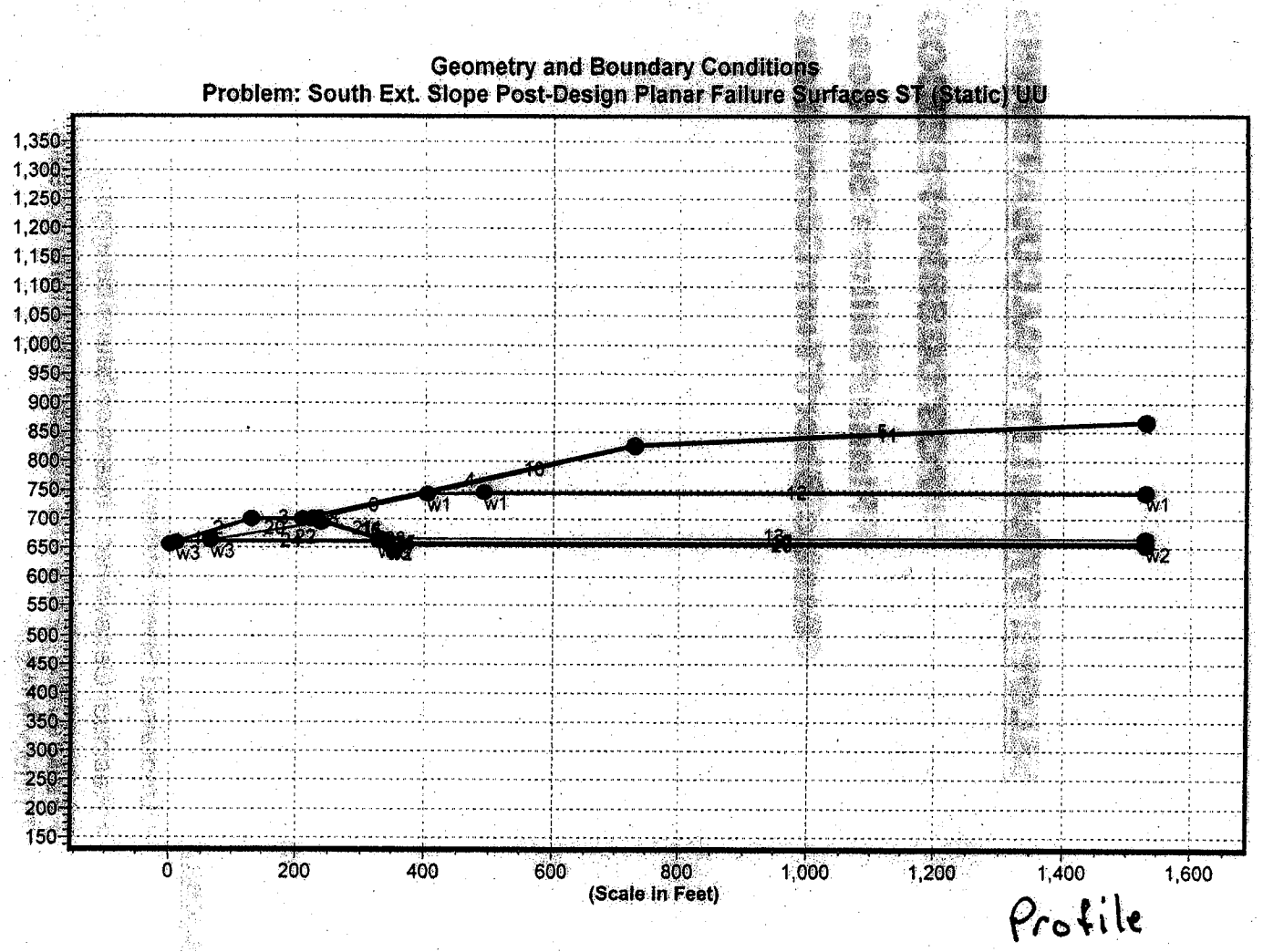
Residual Geosynthetic Interface Shear Strengths

Failure Along Floor and Sidewall Liner Interfaces and Through Waste

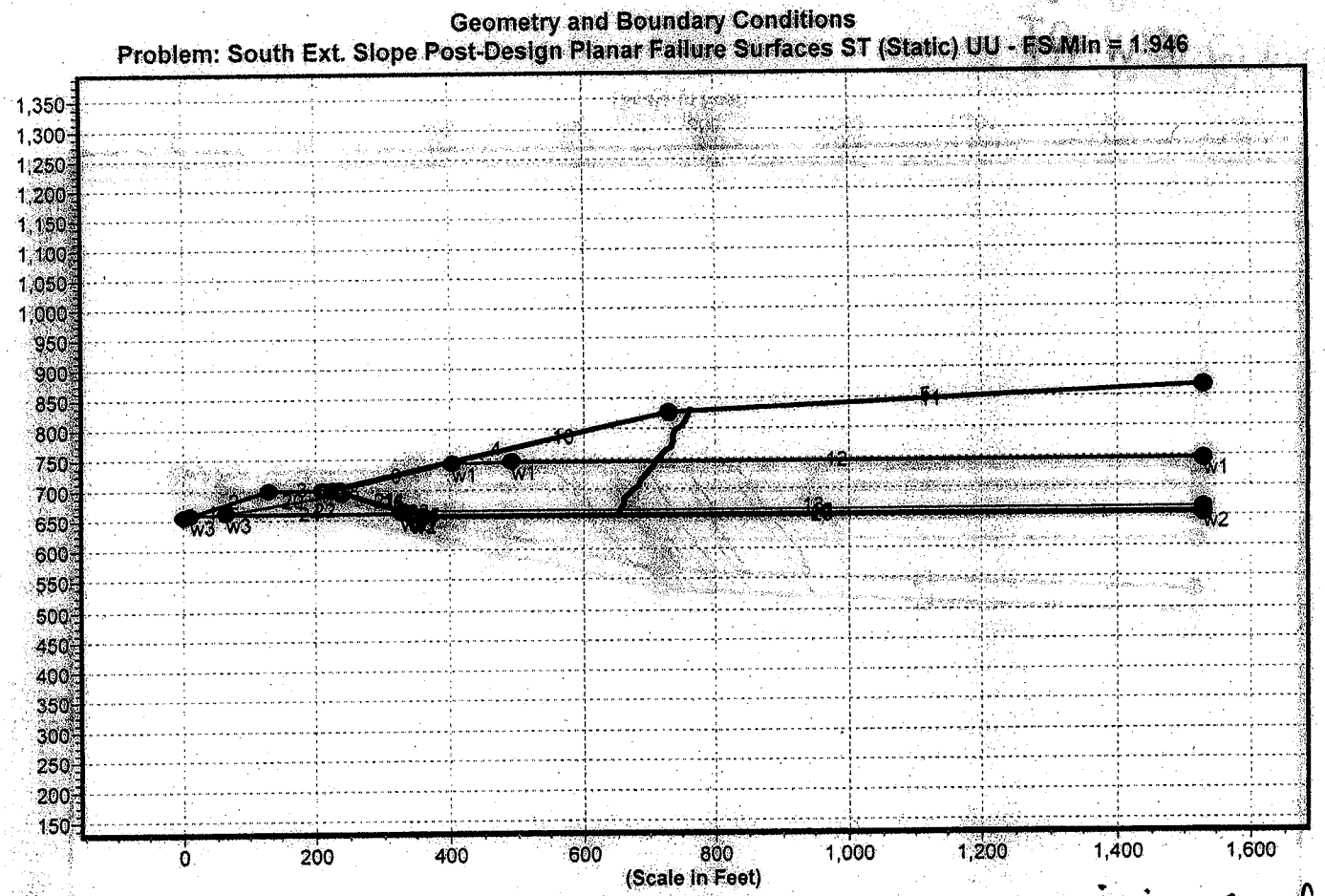
10' Degraded Waste

5' Perched Leachate at Mid-Height

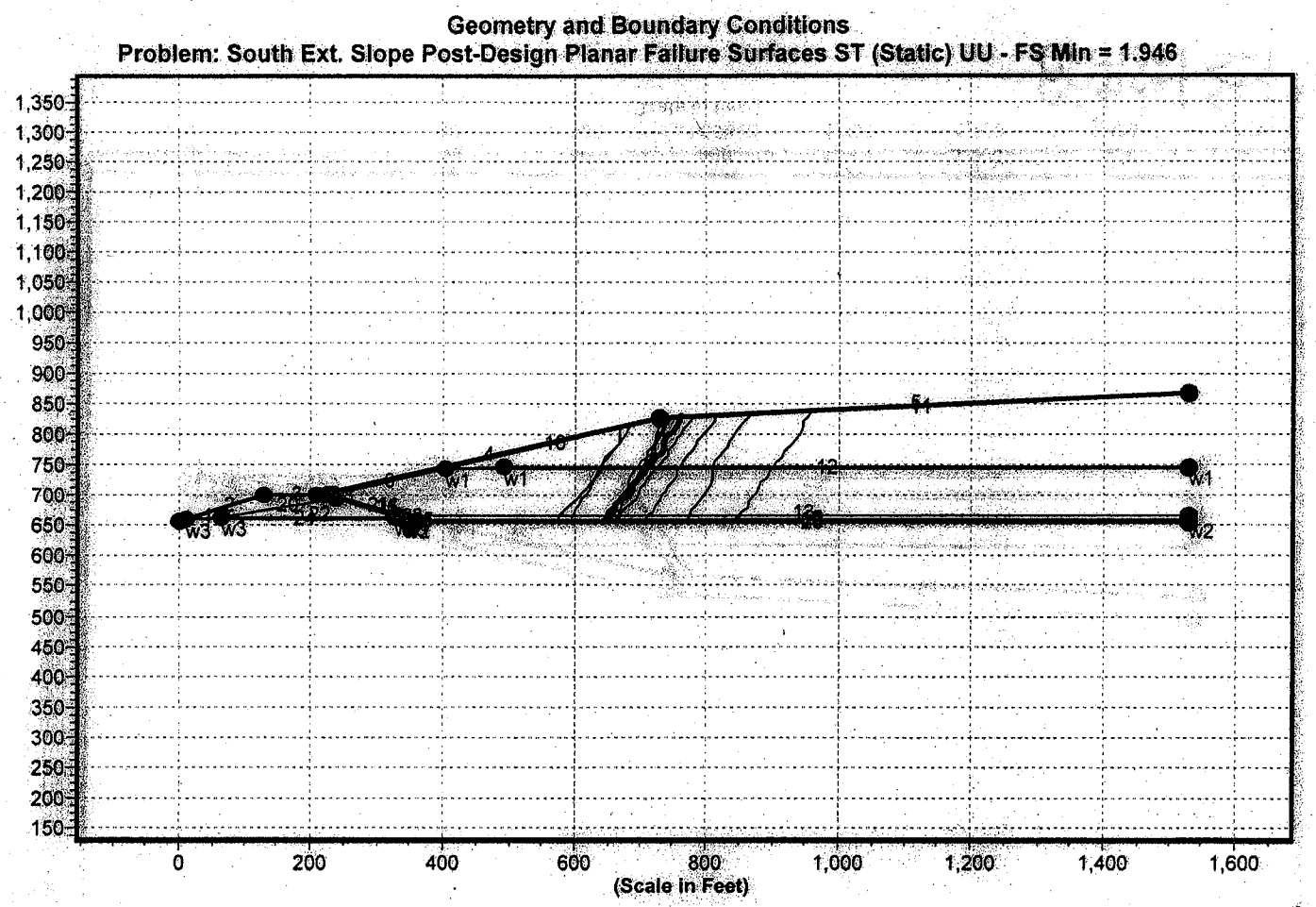
5' Leachate on Landfill Floor


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Planar Failure Surfaces ST (Static) UU
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1,000
1,200
1,400
1,600
(Scale in Feet)
w1
w2
w3

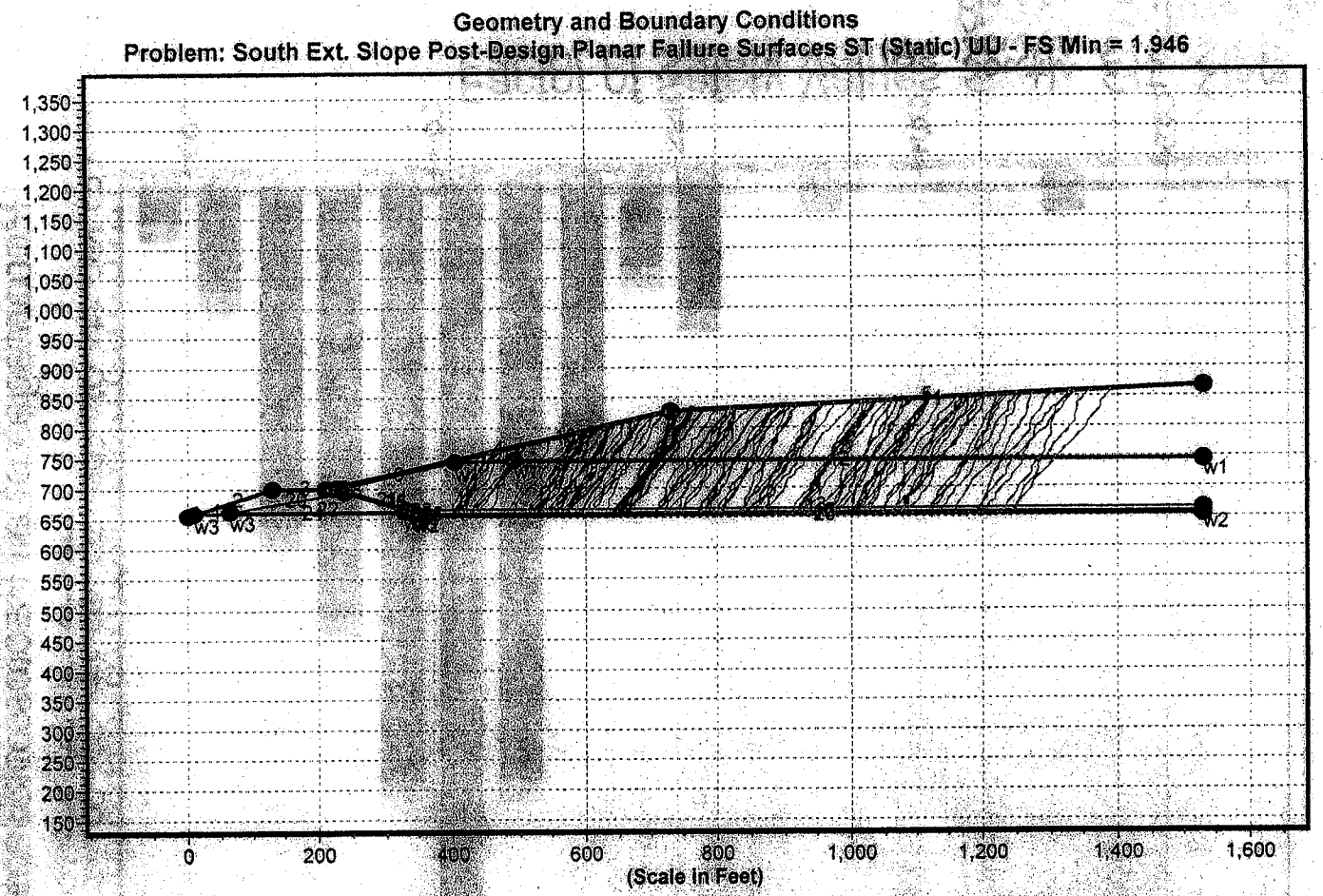
Profile



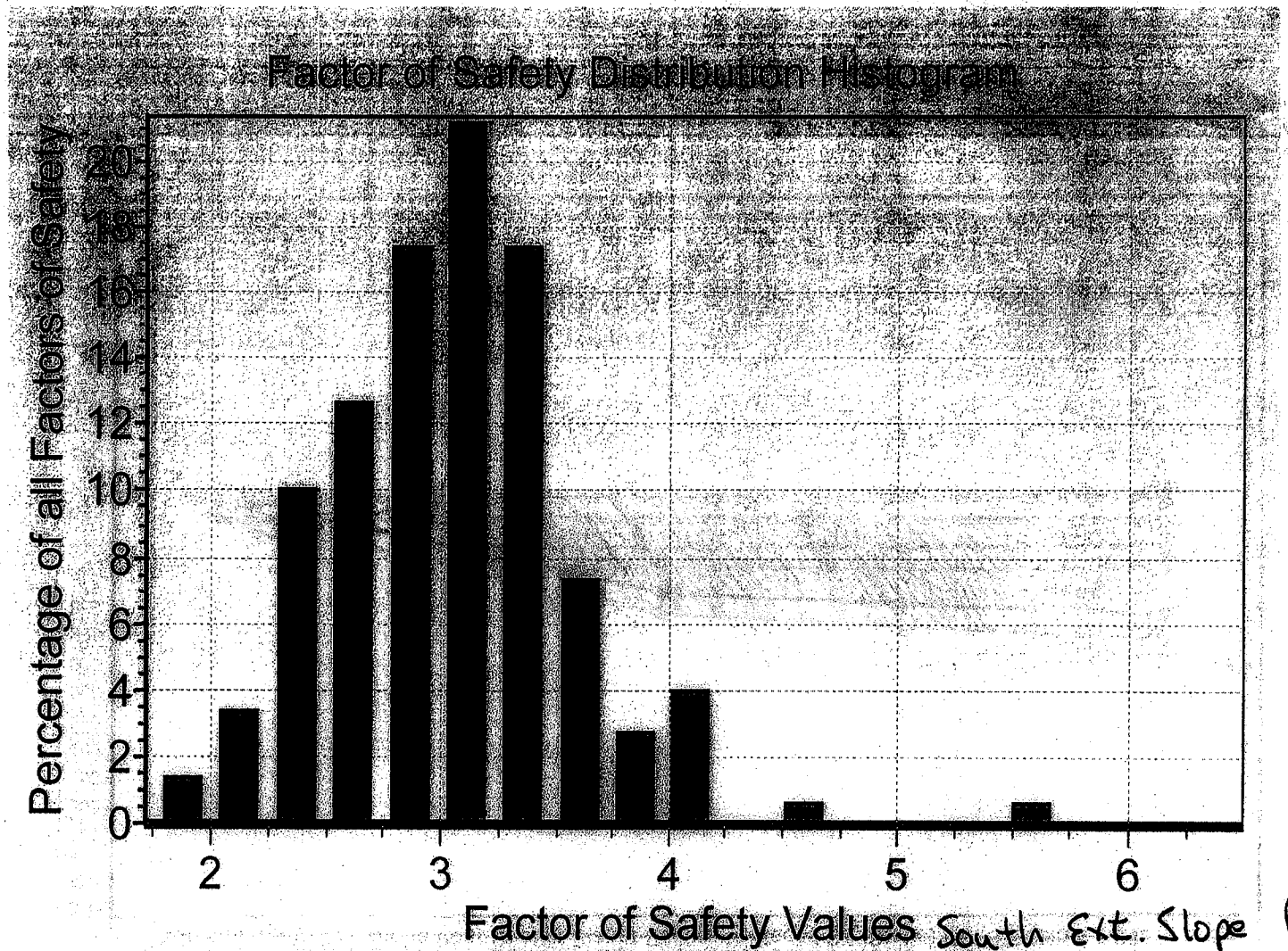
Critical Surfaces



10 Most Critical Surfaces



Generated Surfaces



South Ext. Slope Post-Design
Planar Failure Surfaces
Short Term (Static)
Unconsolidated/Undrained Soils

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Planar Fail
ure Surfaces ST (Static) UU

BOUNDARY COORDINATES

5 Top Boundaries
26 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	657.00	9.00	660.00	1
2	9.00	660.00	129.00	700.00	2
3	129.00	700.00	209.00	700.00	2
4	209.00	700.00	729.00	830.00	3
5	729.00	830.00	1529.00	870.00	3
6	209.00	700.00	220.00	700.00	2
7	220.00	700.00	229.49	700.00	4
8	229.49	700.00	232.25	700.66	5
9	232.25	700.66	403.62	743.50	6
10	403.62	743.50	729.00	825.00	7
11	729.00	825.00	1529.00	865.00	7
12	403.62	743.50	1529.00	743.50	6
13	330.23	668.00	1529.00	668.00	11
14	232.25	700.66	360.23	658.00	5
15	355.49	658.00	1529.00	658.00	8
16	229.49	700.00	358.49	657.00	4
17	358.49	657.00	1529.00	657.00	4
18	220.00	700.00	238.00	694.00	2
19	9.00	660.00	66.00	665.00	9
20	66.00	665.00	238.00	694.00	10
21	238.00	694.00	325.00	665.00	10
22	66.00	665.00	325.00	665.00	9
23	325.00	665.00	340.00	660.00	9
24	9.00	660.00	340.00	660.00	1
25	340.00	660.00	358.00	654.00	1
26	358.00	654.00	1529.00	654.00	1

1

ISOTROPIC SOIL PARAMETERS

11 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	6000.0	0.0	0.00	0.0	0
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	128.0	134.0	0.0	10.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	10.0	0.00	0.0	2
9	100.0	110.0	1400.0	0.0	0.00	0.0	3
10	135.0	140.0	3500.0	0.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	403.62	743.50
2	493.62	748.50
3	1529.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	343.49	662.00
2	1529.00	662.00

1

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)

result

1	9.00	660.00
2	66.00	665.00
3	325.00	665.00
4	340.00	660.00

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

3 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	232.49	699.00	235.49	698.00	1.00
2	358.00	657.00	365.00	657.00	1.00
3	380.00	657.00	1250.00	657.00	3.00

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.69	704.67
2	234.44	698.35
3	360.05	657.20
4	652.21	657.06
5	656.74	665.97
6	661.31	674.87
7	662.86	684.75
8	669.69	692.05
9	676.39	699.47
10	683.46	706.55
11	687.80	715.56
12	692.59	724.34
13	699.10	731.92
14	706.01	739.16
15	710.76	747.96

		result
16	717.68	755.17
17	724.51	762.48
18	731.58	769.55
19	734.45	779.13
20	735.61	789.06
21	740.49	797.79
22	747.56	804.86
23	753.39	812.99
24	758.02	821.85
25	760.68	831.49
26	760.74	831.59

*** 1.946 ***

Individual data on the 43 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.3	1428.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.2	150.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	2.2	1797.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.8	813.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	95.0	288285.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	15.2	83192.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	2.8	16803.6	0.0	85.5	0.0	0.0	0.0	0.0	0.0
9	9.4	59050.4	0.0	1518.4	0.0	0.0	0.0	0.0	0.0
10	2.4	16043.0	0.0	701.8	0.0	0.0	0.0	0.0	0.0
11	0.2	1176.2	0.0	52.8	0.0	0.0	0.0	0.0	0.0
12	43.4	307136.8	0.0	13015.0	0.0	0.0	0.0	0.0	0.0
13	90.0	749938.3	0.0	27185.0	0.0	0.0	0.0	0.0	0.0
14	158.6	********	0.0	48525.9	0.0	0.0	0.0	0.0	0.0
15	0.5	5797.8	0.0	295.3	0.0	0.0	0.0	0.0	0.0
16	2.0	24066.3	0.0	559.9	0.0	0.0	0.0	0.0	0.0
17	2.0	23131.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.0	11644.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	3.5	38300.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1.5	15927.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	6.8	66309.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	6.7	62226.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	7.1	62688.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	4.3	36307.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	4.8	37355.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	6.5	47453.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	6.9	47321.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	2.3	15253.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	2.4	14967.6	0.0	875.9	0.0	0.0	0.0	0.0	0.0
30	0.5	3159.7	0.0	12.8	0.0	0.0	0.0	0.0	0.0
31	6.4	37500.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	6.8	37258.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	4.5	22967.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	2.6	12662.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	2.9	12754.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1.2	4351.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	4.9	14839.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	7.1	17470.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

result

39	5.8	11226.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	4.6	6067.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1.3	1042.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1.4	445.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	218.70	702.42
2	225.47	698.94
3	235.46	698.49
4	360.26	657.07
5	639.85	657.49
6	646.36	665.09
7	650.92	673.99
8	657.80	681.25
9	664.52	688.65
10	669.00	697.59
11	675.34	705.33
12	679.86	714.24
13	681.16	724.16
14	683.29	733.93
15	690.31	741.05
16	696.33	749.04
17	702.09	757.21
18	708.99	764.45
19	711.69	774.08
20	718.74	781.16
21	723.06	790.19
22	726.55	799.55
23	733.43	806.82
24	737.09	816.12
25	743.71	823.62
26	748.62	830.98

*** 1.958 ***

1

Failure Surface Specified By 25 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	225.45	704.11
2	233.43	699.05
3	360.06	656.68
4	642.25	657.67
5	648.26	665.66
6	653.97	673.87
7	660.58	681.38
8	666.55	689.40
9	670.82	698.44
10	677.61	705.78
11	682.39	714.57

		result
12	687.09	723.39
13	694.13	730.49
14	698.55	739.46
15	705.49	746.66
16	710.63	755.24
17	716.56	763.29
18	721.84	771.78
19	723.70	781.61
20	725.67	791.41
21	731.63	799.44
22	736.96	807.90
23	740.17	817.38
24	745.66	825.73
25	750.10	831.06

*** 2.067 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	223.44	703.61
2	225.17	702.13
3	234.54	698.64
4	363.53	656.64
5	658.01	658.18
6	665.07	665.26
7	672.14	672.34
8	679.06	679.55
9	686.13	686.63
10	692.89	694.00
11	696.27	703.41
12	699.22	712.96
13	706.29	720.04
14	710.00	729.32
15	716.95	736.51
16	724.01	743.59
17	730.90	750.84
18	735.76	759.58
19	742.39	767.07
20	743.38	777.02
21	750.25	784.29
22	754.53	793.33
23	761.18	800.79
24	765.27	809.92
25	772.28	817.05
26	778.61	824.79
27	780.71	832.59

*** 2.173 ***

1

Failure Surface Specified By 26 Coordinate Points

result

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.64	704.66
2	233.64	698.74
3	359.53	657.01
4	769.35	657.45
5	772.77	666.84
6	777.44	675.69
7	783.87	683.35
8	790.74	690.61
9	795.03	699.65
10	800.31	708.14
11	805.69	716.57
12	808.11	726.27
13	808.58	736.26
14	809.39	746.23
15	812.11	755.85
16	817.40	764.34
17	824.02	771.83
18	830.34	779.59
19	836.11	787.75
20	840.98	796.48
21	845.21	805.54
22	849.81	814.42
23	856.82	821.56
24	863.82	828.70
25	870.21	836.39
26	870.45	837.07

*** 2.200 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	225.52	704.13
2	225.87	703.78
3	234.25	698.32
4	364.38	656.95
5	707.77	657.80
6	711.38	667.12
7	718.45	674.20
8	723.04	683.08
9	729.88	690.38
10	731.28	700.28
11	738.03	707.67
12	741.34	717.10
13	748.31	724.27
14	753.89	732.57
15	753.93	742.57
16	760.41	750.18
17	765.87	758.56
18	771.28	766.97
19	777.91	774.46

		result
20	784.95	781.55
21	787.54	791.21
22	794.61	798.29
23	800.75	806.18
24	806.71	814.20
25	811.22	823.13
26	812.98	832.97
27	814.24	834.26

*** 2.206 ***

1

Failure Surface Specified By 25 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	215.56	701.64
2	224.32	699.81
3	234.24	698.54
4	361.18	657.14
5	660.32	657.06
6	667.38	664.16
7	668.41	674.10
8	671.49	683.62
9	676.54	692.25
10	683.60	699.33
11	689.67	707.28
12	690.00	717.27
13	694.56	726.18
14	698.64	735.30
15	700.71	745.09
16	706.82	753.01
17	710.84	762.17
18	716.78	770.21
19	718.80	780.00
20	721.82	789.54
21	723.87	799.32
22	727.51	808.64
23	730.31	818.24
24	736.53	826.07
25	740.47	830.57

*** 2.236 ***

Failure Surface Specified By 25 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	224.68	703.92
2	233.08	698.97
3	362.03	657.20

		result
4	576.19	656.89
5	576.83	666.87
6	583.87	673.97
7	590.94	681.04
8	597.77	688.35
9	604.01	696.16
10	610.58	703.70
11	617.15	711.24
12	624.11	718.42
13	629.89	726.59
14	633.90	735.74
15	636.31	745.45
16	642.65	753.18
17	646.97	762.20
18	653.30	769.94
19	660.24	777.14
20	667.27	784.26
21	671.93	793.10
22	676.72	801.88
23	682.63	809.95
24	689.36	817.35
25	689.97	820.24

*** 2.261 ***

1

Failure Surface Specified By 23 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	226.90	704.47
2	233.69	698.18
3	363.43	657.04
4	593.88	657.77
5	598.03	666.86
6	601.22	676.34
7	607.44	684.17
8	610.50	693.69
9	616.05	702.01
10	622.86	709.34
11	626.36	718.71
12	629.31	728.26
13	636.12	735.58
14	641.71	743.87
15	643.56	753.70
16	649.70	761.59
17	656.71	768.72
18	661.18	777.66
19	668.25	784.73
20	669.45	794.66
21	669.78	804.66
22	673.25	814.04
23	674.66	816.41

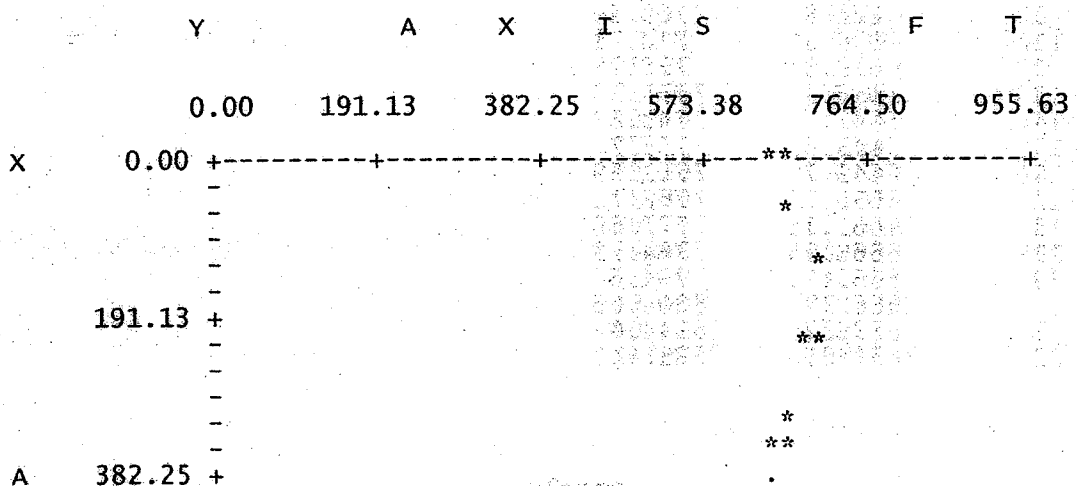
*** 2.275 ***

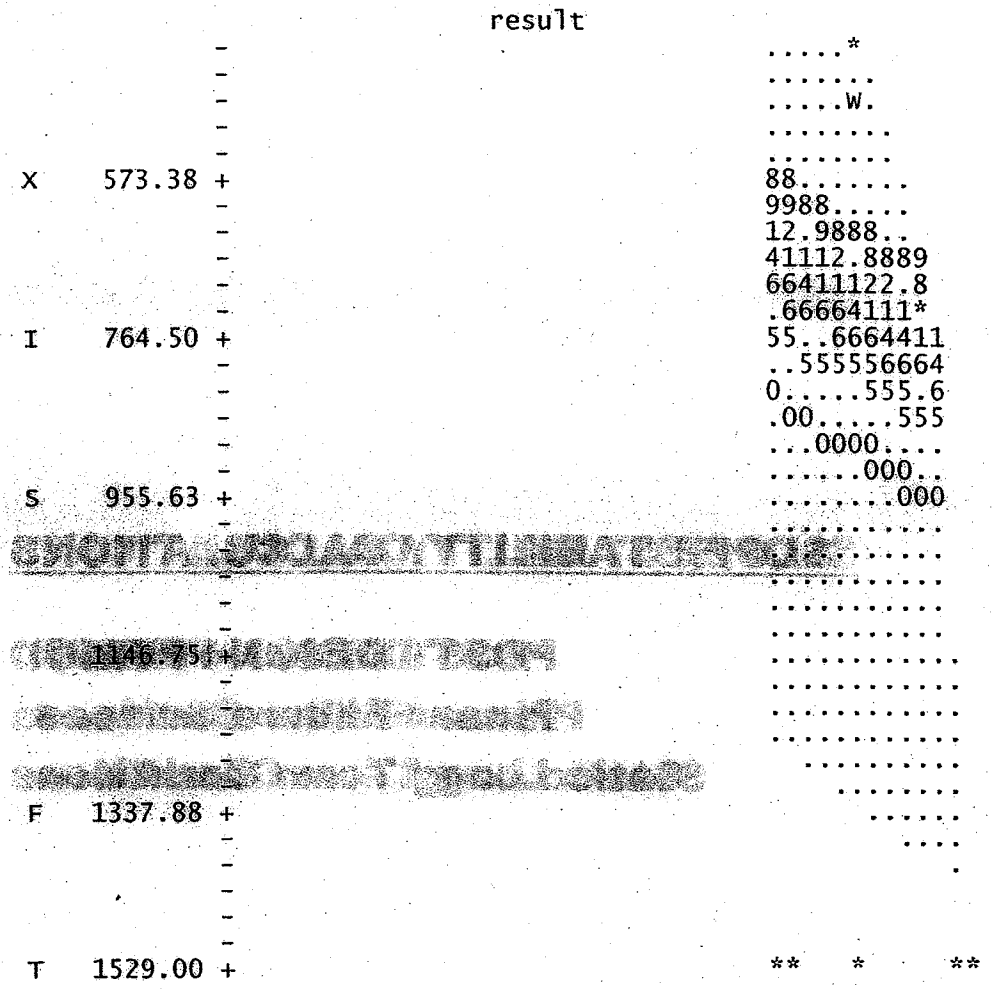
Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	225.42	704.10
2	226.30	703.26
3	234.78	697.96
4	362.74	657.45
5	841.59	657.52
6	848.66	664.59
7	855.35	672.02
8	862.29	679.22
9	864.83	688.89
10	871.09	696.69
11	877.96	703.96
12	880.58	713.61
13	884.07	722.98
14	891.14	730.05
15	895.32	739.14
16	901.86	746.70
17	906.52	755.54
18	913.52	762.68
19	917.91	771.67
20	924.90	778.82
21	931.96	785.90
22	937.51	794.22
23	942.48	802.90
24	946.47	812.07
25	947.22	822.04
26	953.96	829.43
27	960.11	837.31
28	963.83	841.74

*** 2.281 ***

1




result
X 573.38
I 764.50
S 955.63
1146.75
F 1337.88
T 1529.00

SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD
Planar Failure Surfaces
Static Long Term Conditions

Key Assumptions:

Drained Shear Strengths

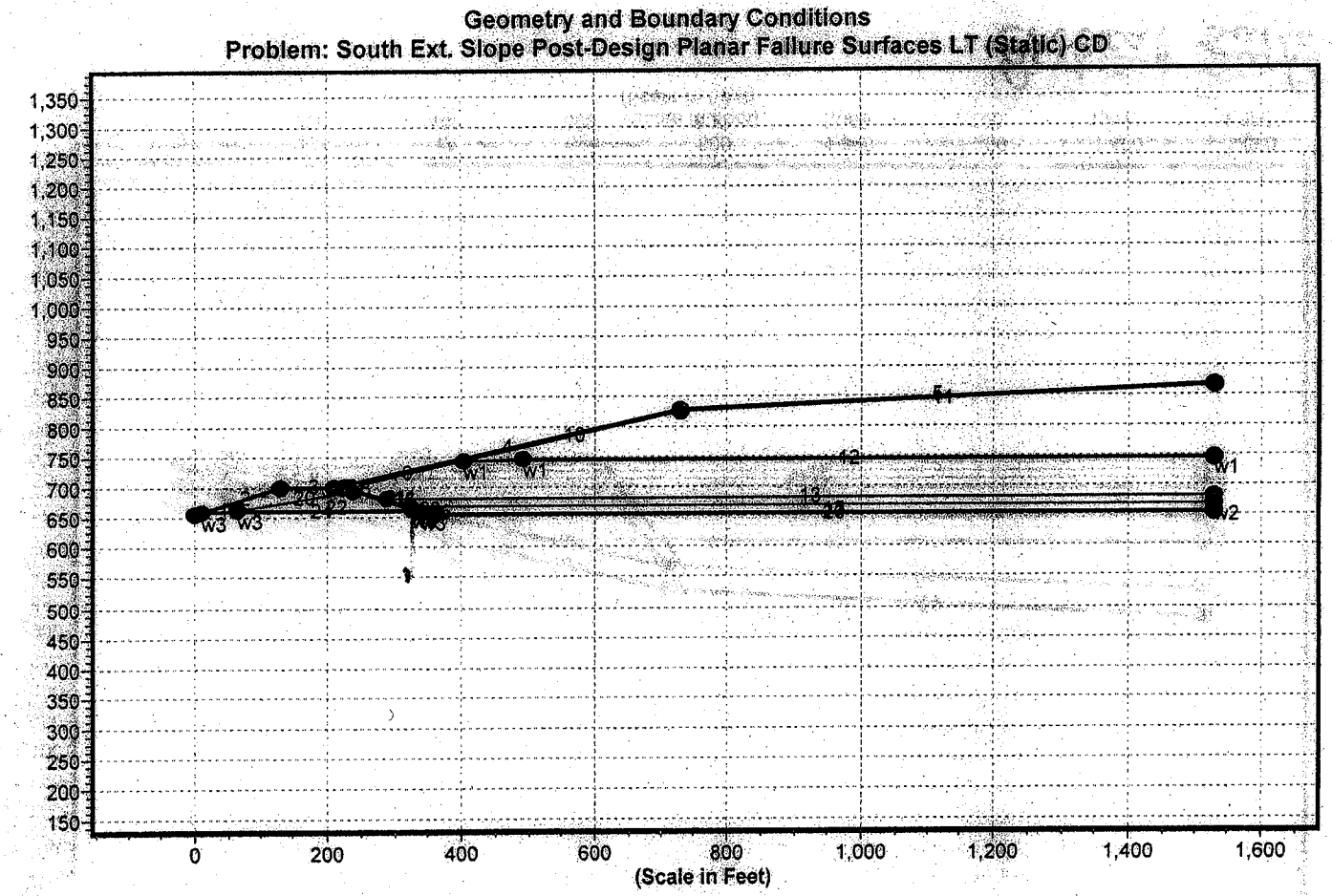
Residual Geosynthetic Interface Shear Strengths

Failure Along Floor and Sidewall Liner Interfaces and Through Waste

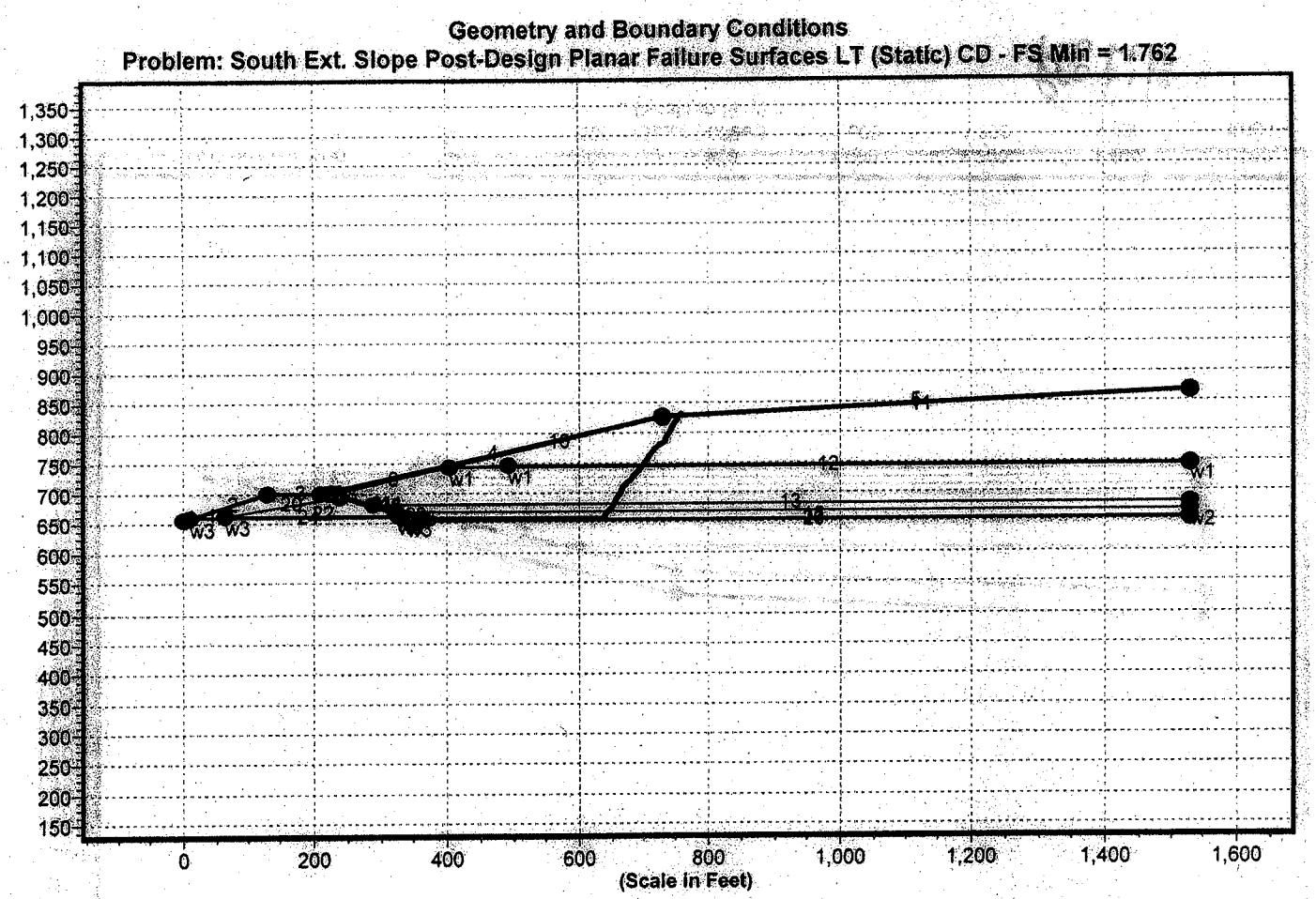
24' Degraded Waste

5' Perched Leachate at Mid-Height

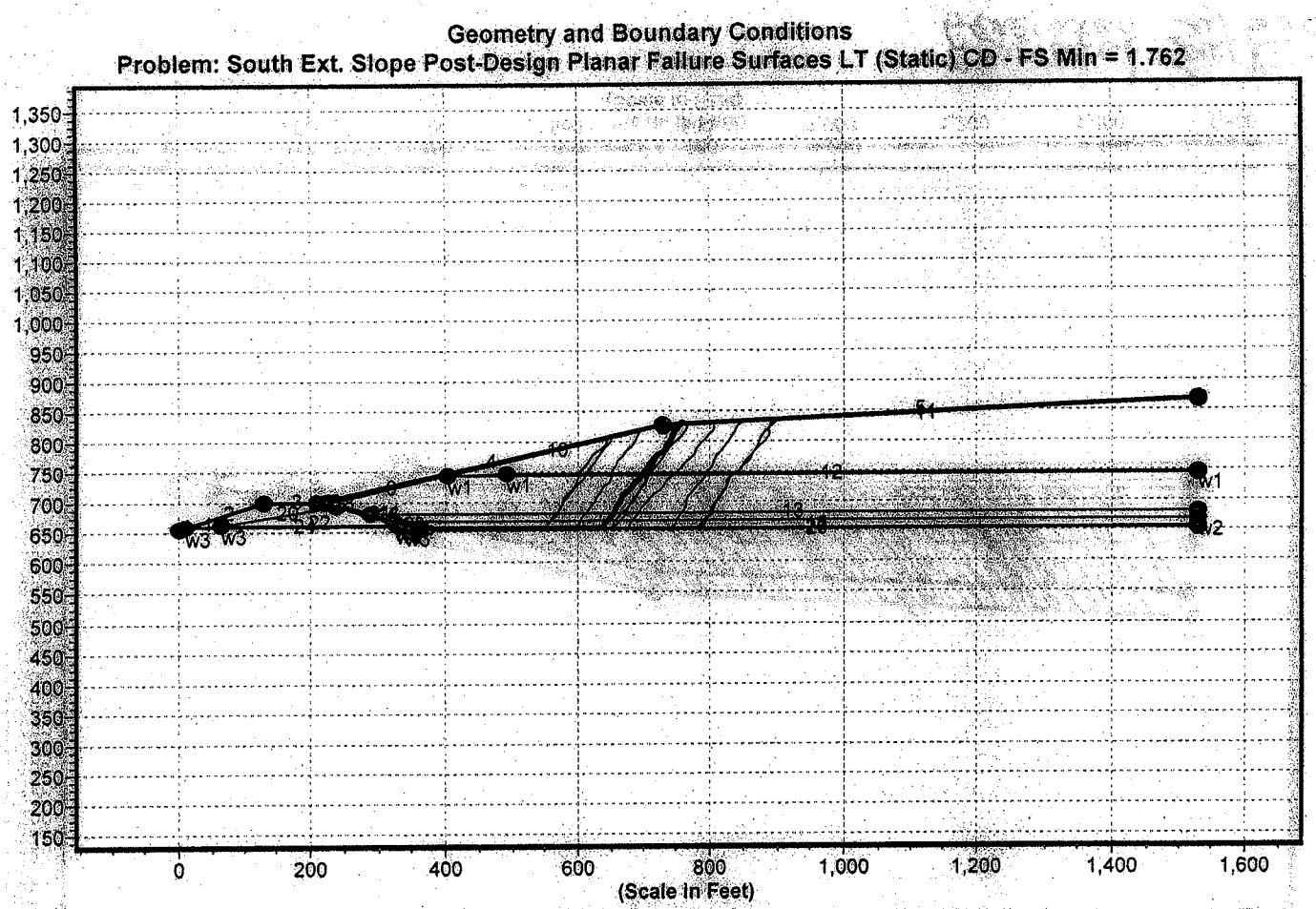
12' Leachate on Landfill Floor


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Planar Failure Surfaces LT (Static) CD
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1,000
1,200
1,400
1,600
(Scale in Feet)
w1
w2
w3

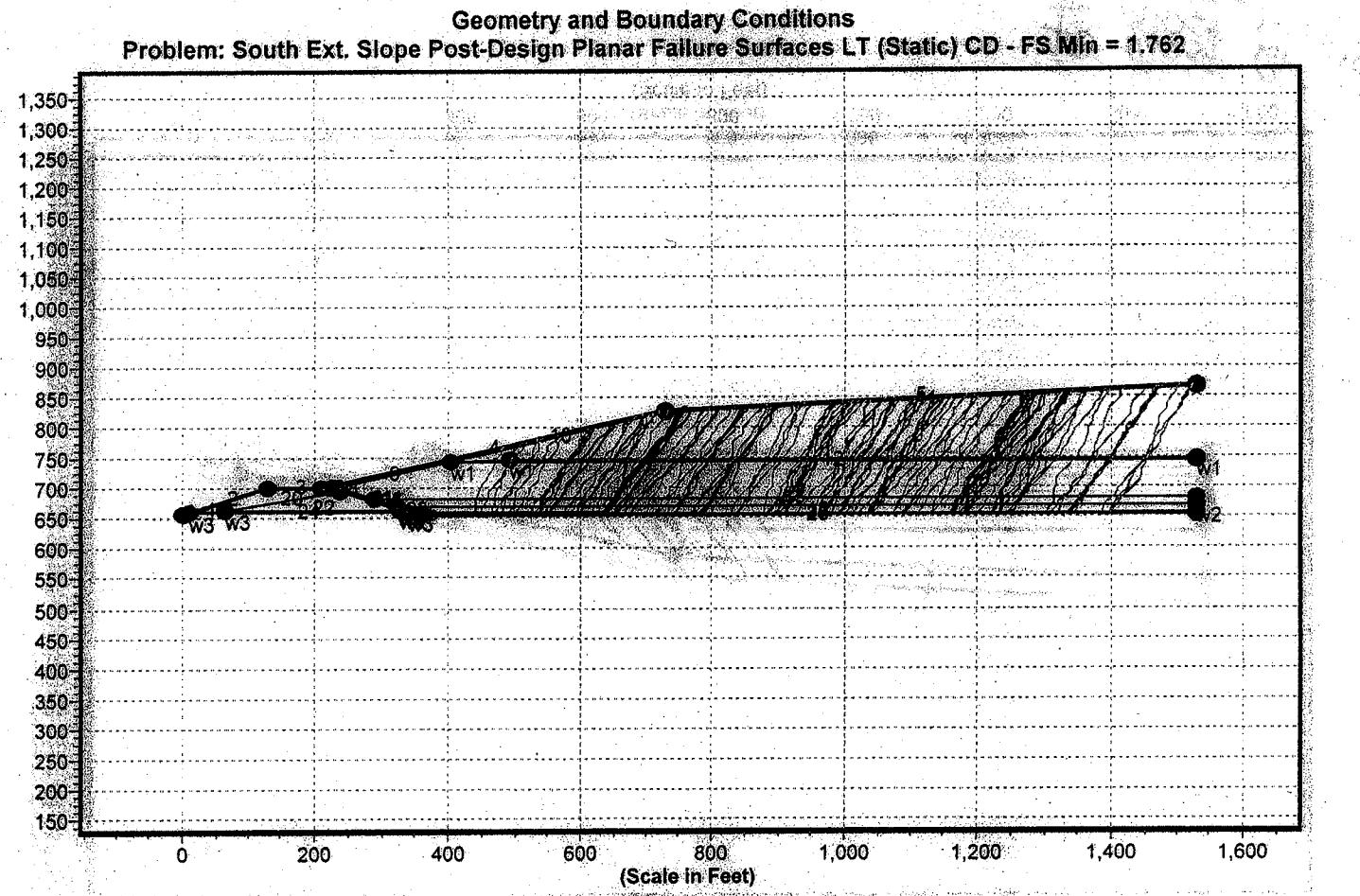
Profile



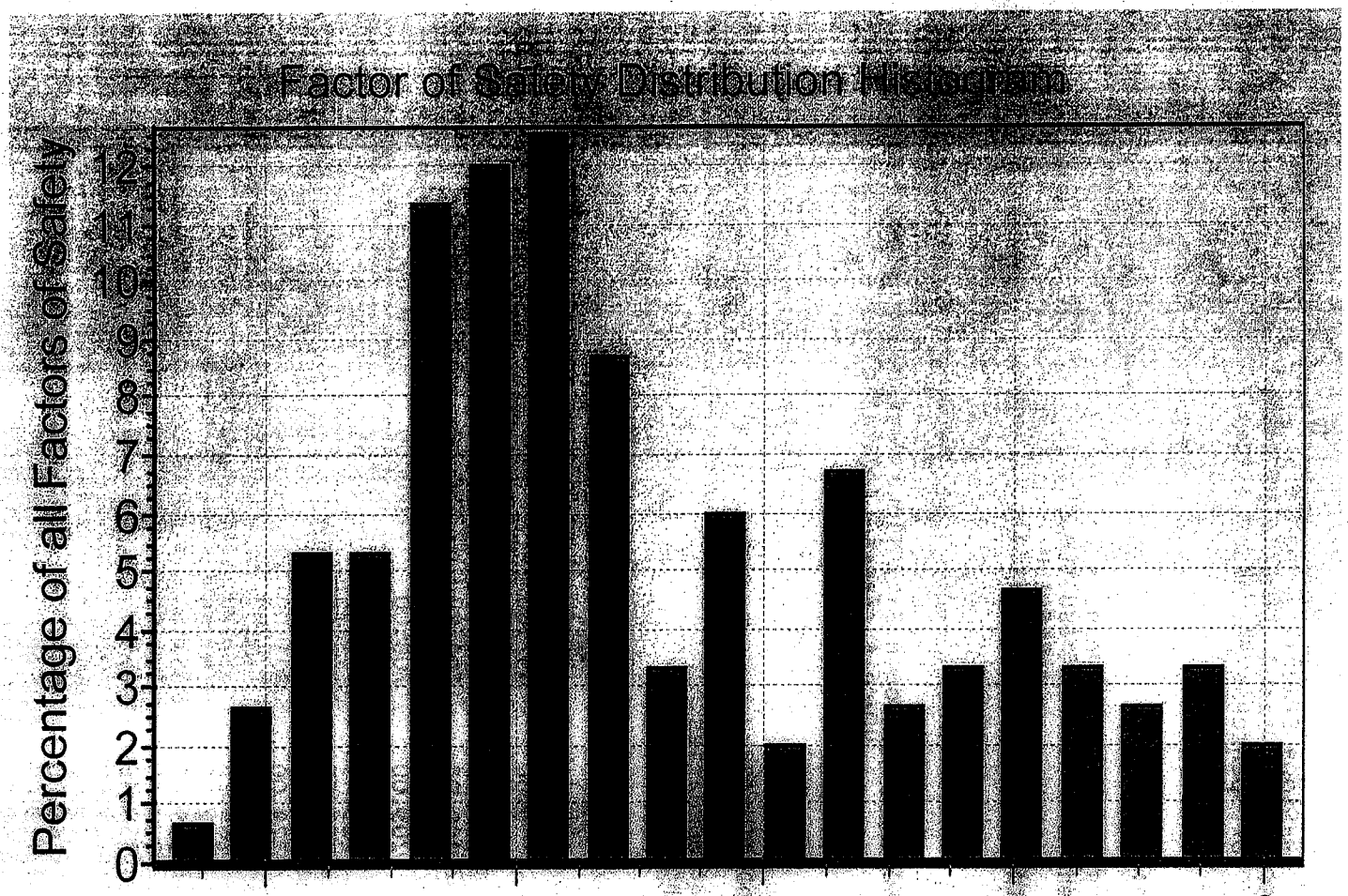
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



South ext. Slope Post-Design
Planar Failure Surfaces
Long Term (Static)
Consolidated/Drained Soils

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Planar Fail
ure Surfaces LT (Static) CD

BOUNDARY COORDINATES

5 Top Boundaries
26 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	657.00	9.00	660.00	1
2	9.00	660.00	129.00	700.00	2
3	129.00	700.00	209.00	700.00	2
4	209.00	700.00	729.00	830.00	3
5	729.00	830.00	1529.00	870.00	3
6	209.00	700.00	220.00	700.00	2
7	220.00	700.00	229.49	700.00	4
8	229.49	700.00	232.25	700.66	5
9	232.25	700.66	403.62	743.50	6
10	403.62	743.50	729.00	825.00	7
11	729.00	825.00	1529.00	865.00	7
12	403.62	743.50	1529.00	743.50	6
13	288.23	682.00	1529.00	682.00	11
14	232.25	700.66	360.23	658.00	5
15	355.49	658.00	1529.00	658.00	8
16	229.49	700.00	358.49	657.00	4
17	358.49	657.00	1529.00	657.00	4
18	220.00	700.00	238.00	694.00	2
19	9.00	660.00	66.00	665.00	9
20	66.00	665.00	238.00	694.00	10
21	238.00	694.00	325.00	665.00	10
22	66.00	665.00	325.00	665.00	9
23	325.00	665.00	340.00	660.00	9
24	9.00	660.00	340.00	660.00	1
25	340.00	660.00	358.00	654.00	1
26	358.00	654.00	1529.00	654.00	1

ISOTROPIC SOIL PARAMETERS

11 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	1100.0	18.0	0.00	0.0	0
2	135.0	140.0	700.0	21.0	0.00	0.0	0
3	128.0	134.0	1300.0	22.0	0.00	0.0	0
4	135.0	140.0	700.0	21.0	0.00	0.0	0
5	128.0	134.0	0.0	10.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	10.0	0.00	0.0	2
9	100.0	110.0	1500.0	19.0	0.00	0.0	3
10	135.0	140.0	600.0	26.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	403.62	743.50
2	493.62	748.50
3	1529.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	322.49	669.00
2	1529.00	669.00

1

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)

result

1	9.00	660.00
2	66.00	665.00
3	325.00	665.00
4	340.00	660.00

Janbus Empirical Coef is being used for the case of c=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

3 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	232.49	699.00	235.49	698.00	1.00
2	358.00	657.00	365.00	657.00	1.00
3	440.00	657.00	1400.00	657.00	3.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	218.87	702.47
2	224.25	698.91
3	234.24	698.65
4	358.23	657.33
5	638.51	657.55
6	643.36	666.29
7	648.88	674.63
8	655.40	682.21
9	659.19	691.47
10	664.08	700.19
11	668.53	709.15
12	674.79	716.94
13	681.60	724.27
14	688.18	731.80
15	693.94	739.97

		result
16	699.33	748.39
17	705.81	756.01
18	710.50	764.84
19	717.36	772.11
20	724.43	779.19
21	731.41	786.35
22	736.29	795.07
23	741.23	803.77
24	745.21	812.95
25	750.24	821.59
26	755.64	830.01
27	756.94	831.40

*** 1.762 ***

Individual data on the 44 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	3.7	810.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.7	884.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	5.2	3819.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	2.8	2393.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1.2	1127.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.8	698.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	54.0	113350.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	35.0	147666.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	4.0	21147.9	0.0	176.3	0.0	0.0	0.0	0.0	0.0
10	29.0	178724.5	0.0	11765.0	0.0	0.0	0.0	0.0	0.0
11	2.0	14025.3	0.0	1494.0	0.0	0.0	0.0	0.0	0.0
12	2.0	14108.0	0.0	1454.2	0.0	0.0	0.0	0.0	0.0
13	43.4	324406.2	0.0	31542.4	0.0	0.0	0.0	0.0	0.0
14	90.0	784695.9	0.0	65141.0	0.0	0.0	0.0	0.0	0.0
15	144.9	********	0.0	*******	0.0	0.0	0.0	0.0	0.0
16	0.3	3086.1	0.0	364.5	0.0	0.0	0.0	0.0	0.0
17	4.6	54291.1	0.0	4055.2	0.0	0.0	0.0	0.0	0.0
18	1.8	20249.9	0.0	275.0	0.0	0.0	0.0	0.0	0.0
19	3.7	40601.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	6.3	65270.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.2	1840.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	3.8	36616.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	4.9	44379.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	4.4	37703.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	6.3	49910.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	6.8	51152.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	6.6	46623.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	5.8	38149.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	2.3	14120.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	3.1	18728.6	0.0	925.5	0.0	0.0	0.0	0.0	0.0
31	0.1	536.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
32	6.4	35782.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	4.7	23848.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	6.9	31567.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	7.1	29589.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	4.6	17641.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	2.4	8777.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

					result				
38	4.9	15763.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	4.9	12800.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	4.0	7727.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	5.0	6498.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	3.0	2391.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	2.4	983.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1.3	110.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	218.56	702.39
2	223.05	699.55
3	233.02	698.78
4	364.06	657.26
5	651.68	657.53
6	655.84	666.62
7	661.14	675.10
8	668.08	682.31
9	675.15	689.38
10	681.84	696.81
11	688.78	704.01
12	691.32	713.68
13	697.58	721.48
14	704.45	728.74
15	707.07	738.40
16	710.56	747.77
17	717.63	754.84
18	721.80	763.92
19	728.35	771.48
20	733.01	780.33
21	740.01	787.47
22	744.40	796.46
23	751.39	803.61
24	758.45	810.69
25	764.00	819.01
26	768.97	827.69
27	770.89	832.09

*** 1.886 ***

1

Failure Surface Specified By 24 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	226.22	704.30
2	226.69	703.95
3	234.82	698.14
4	359.43	657.08
5	548.92	657.45
6	555.99	664.52
7	562.61	672.01
8	568.33	680.22

		result
9	573.90	688.52
10	579.46	696.83
11	580.69	706.76
12	586.98	714.53
13	594.01	721.64
14	598.76	730.44
15	602.05	739.88
16	604.55	749.57
17	609.65	758.17
18	616.72	765.24
19	621.00	774.28
20	628.00	781.42
21	635.07	788.49
22	642.09	795.62
23	646.44	804.62
24	651.81	810.70

*** 2.037 ***

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	226.29	704.32
2	232.99	698.35
3	362.87	656.99
4	780.29	657.65
5	787.34	664.74
6	794.41	671.81
7	801.48	678.89
8	805.35	688.11
9	808.57	697.57
10	812.63	706.71
11	819.10	714.34
12	823.87	723.13
13	827.33	732.51
14	832.12	741.29
15	839.17	748.38
16	846.05	755.64
17	851.01	764.32
18	856.60	772.61
19	863.49	779.86
20	870.06	787.40
21	873.54	796.78
22	877.67	805.88
23	881.38	815.17
24	888.45	822.24
25	893.25	831.01
26	894.96	838.30

*** 2.044 ***

result

Failure Surface Specified By 25 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	225.73	704.18
2	226.20	703.81
3	234.50	698.23
4	359.04	657.21
5	657.09	658.08
6	661.36	667.13
7	668.43	674.20
8	675.01	681.73
9	677.34	691.46
10	681.38	700.61
11	686.61	709.13
12	693.24	716.61
13	695.92	726.25
14	702.88	733.43
15	704.67	743.27
16	708.81	752.37
17	715.88	759.44
18	720.31	768.40
19	724.44	777.51
20	729.67	786.03
21	733.92	795.09
22	738.91	803.75
23	741.89	813.30
24	746.82	822.00
25	748.88	830.99

*** 2.048 ***

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.34	704.59
2	233.39	698.86
3	364.80	657.13
4	741.37	657.39
5	748.10	664.79
6	752.58	673.73
7	758.91	681.47
8	763.44	690.39
9	764.73	700.30
10	766.86	710.07
11	773.88	717.19
12	779.90	725.18
13	785.67	733.35
14	792.57	740.59
15	795.26	750.22
16	802.32	757.31
17	806.63	766.33
18	810.13	775.70
19	817.00	782.96

		result
20	820.66	792.27
21	827.28	799.76
22	832.83	808.08
23	837.23	817.06
24	842.81	825.36
25	849.39	832.89
26	850.73	836.09

*** 2.070 ***

1

Failure Surface Specified By 24 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.10	704.53
2	232.57	699.17
3	361.37	656.77
4	602.18	657.85
5	605.83	667.16
6	608.71	676.74
7	615.58	684.00
8	622.11	691.58
9	627.21	700.18
10	630.99	709.44
11	637.57	716.97
12	640.89	726.40
13	647.94	733.49
14	652.27	742.51
15	653.89	752.37
16	657.98	761.50
17	663.54	769.81
18	670.11	777.35
19	675.08	786.03
20	682.11	793.13
21	686.24	802.24
22	691.00	811.04
23	697.87	818.30
24	699.49	822.62

*** 2.156 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	228.34	704.83
2	235.22	698.08
3	362.20	657.47
4	785.60	657.33
5	791.72	665.24

		result
6	797.75	673.22
7	799.36	683.09
8	801.28	692.90
9	808.21	700.11
10	815.28	707.18
11	817.37	716.96
12	823.70	724.70
13	826.17	734.39
14	832.83	741.85
15	839.90	748.92
16	846.93	756.03
17	853.69	763.41
18	860.76	770.48
19	863.81	780.00
20	870.88	787.08
21	877.79	794.31
22	884.12	802.04
23	887.73	811.37
24	889.07	821.28
25	895.38	829.03
26	902.38	836.17
27	904.43	838.77

*** 2.163 ***

1

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	228.16	704.79
2	234.83	698.30
3	358.24	656.90
4	677.31	657.42
5	682.65	665.88
6	687.00	674.89
7	692.72	683.09
8	697.62	691.80
9	704.68	698.89
10	711.04	706.61
11	718.06	713.73
12	724.88	721.04
13	731.90	728.16
14	737.15	736.67
15	744.21	743.76
16	751.25	750.86
17	758.01	758.22
18	765.01	765.37
19	771.53	772.95
20	778.54	780.08
21	781.33	789.69
22	787.43	797.61
23	794.29	804.89
24	800.48	812.74
25	806.26	820.90
26	807.22	830.85
27	809.92	834.05

result

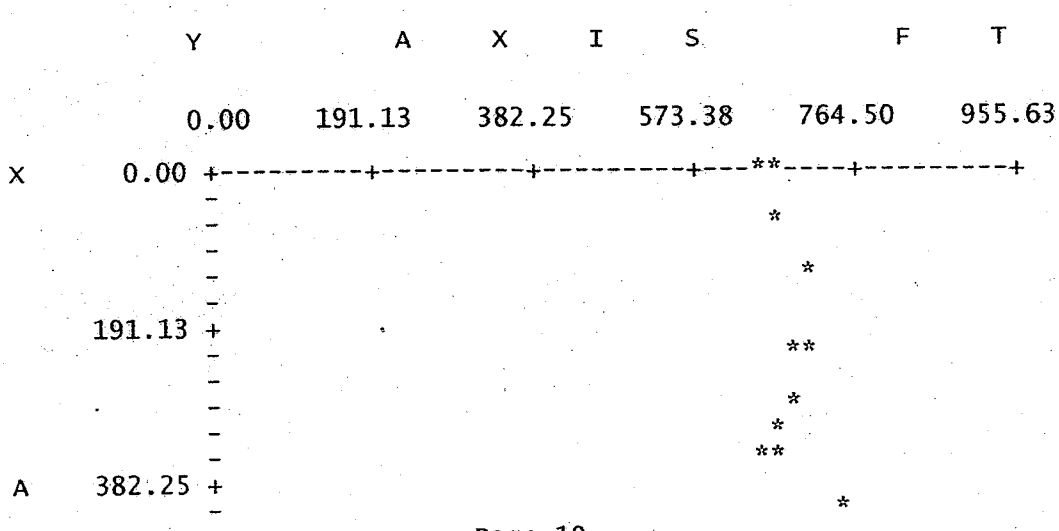
*** 2.202 ***

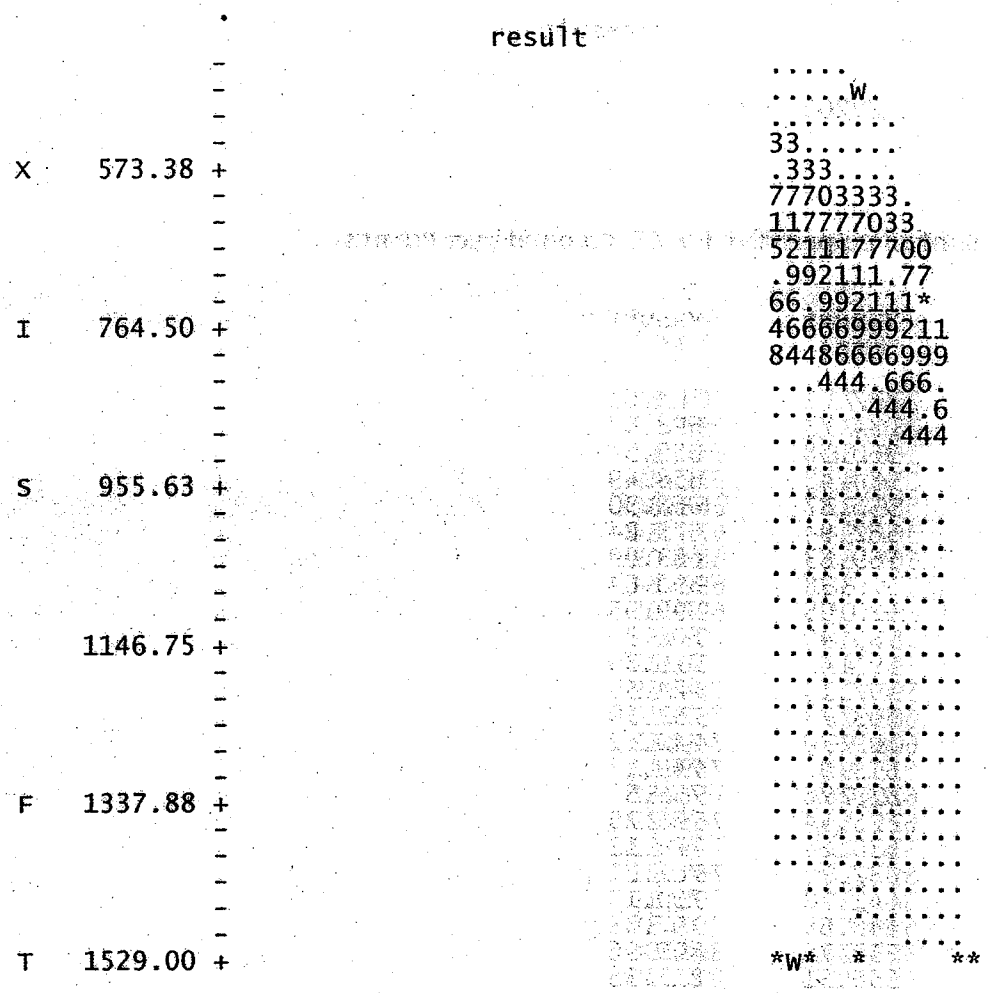
Failure Surface Specified By 23 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.71	704.68
2	234.73	698.67
3	360.58	656.91
4	554.43	658.49
5	556.37	668.30
6	562.94	675.84
7	569.83	683.09
8	576.38	690.64
9	580.05	699.95
10	585.40	708.39
11	591.41	716.39
12	597.13	724.59
13	603.73	732.10
14	609.70	740.12
15	613.97	749.17
16	620.76	756.51
17	625.54	765.29
18	630.24	774.12
19	637.29	781.21
20	641.70	790.19
21	648.65	797.38
22	653.78	805.96
23	658.51	812.38

*** 2.253 ***

1




result
X
573.38
I
764.50
S
955.63
1146.75
F
1337.88
T
1529.00

SLOPE STABILITY CALCULATIONS

POST DESIGN PERIOD

Planar Failure Surfaces
Seismic Conditions

Key Assumptions:

Undrained Shear Strengths

Peak Geosynthetic Interface Shear Strengths

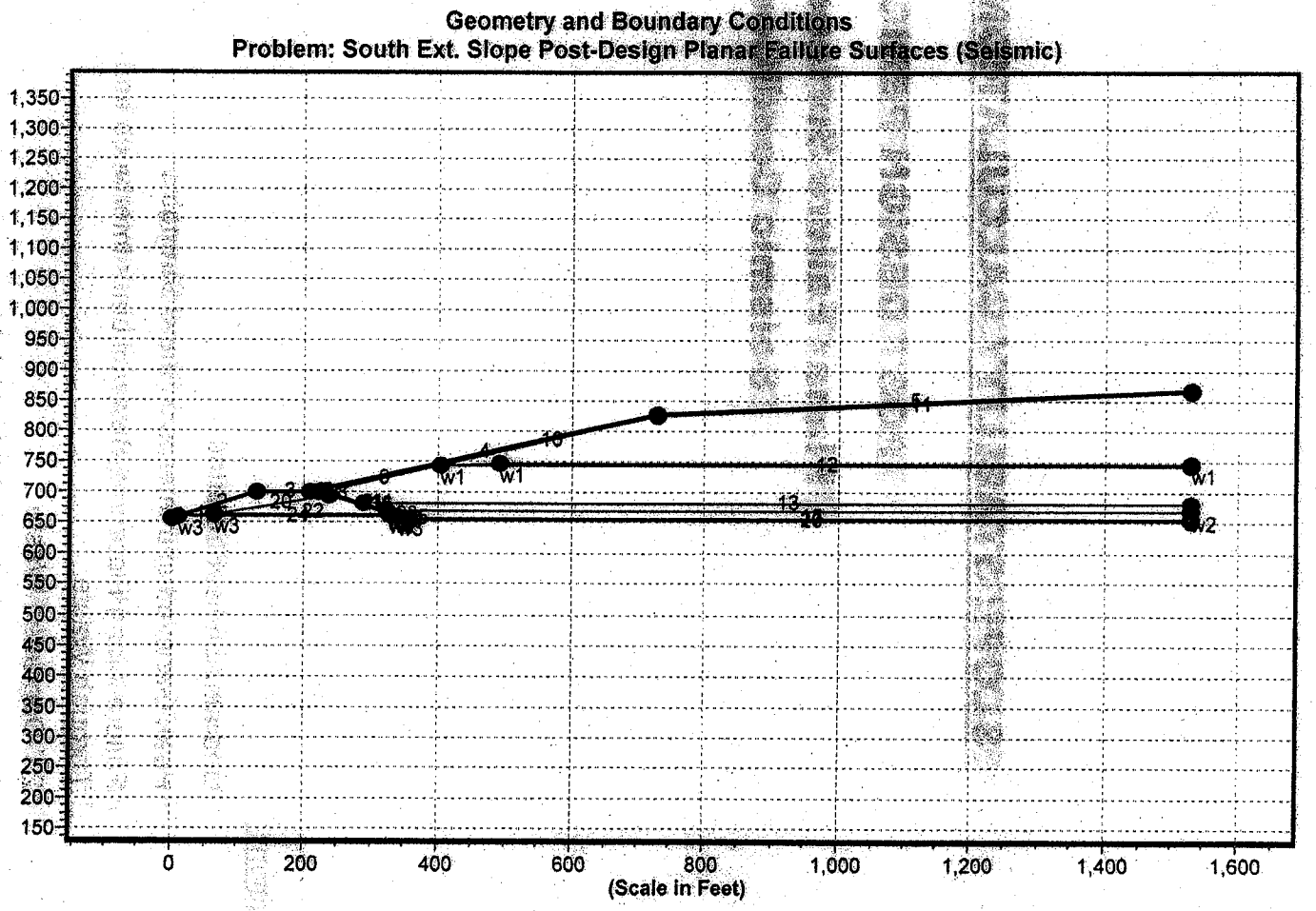
Failure Along Floor and Sidewall Liner Interfaces and Through Waste

24' Degraded Waste

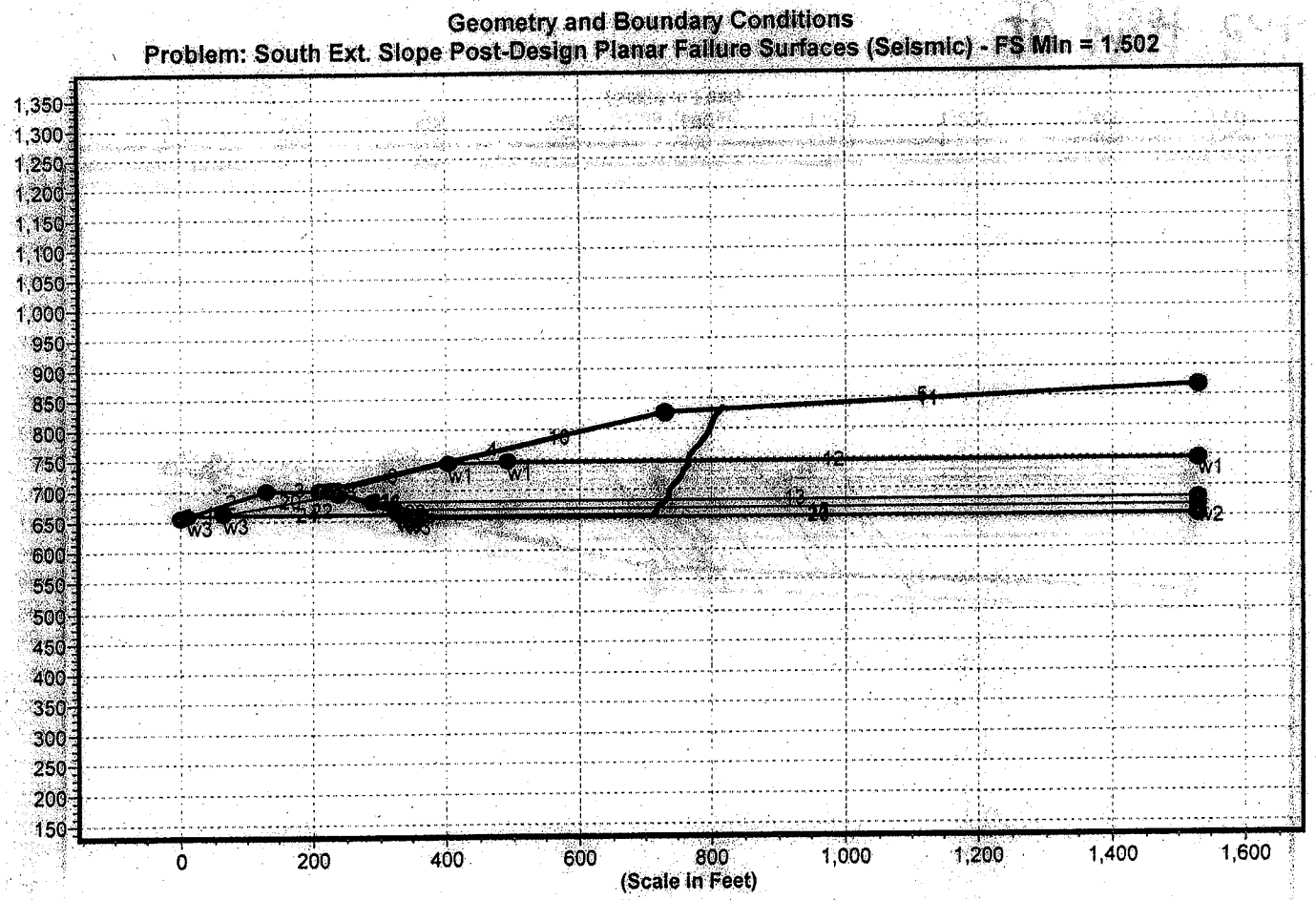
5' Perched Leachate at Mid-Height

12' Leachate on Landfill Floor

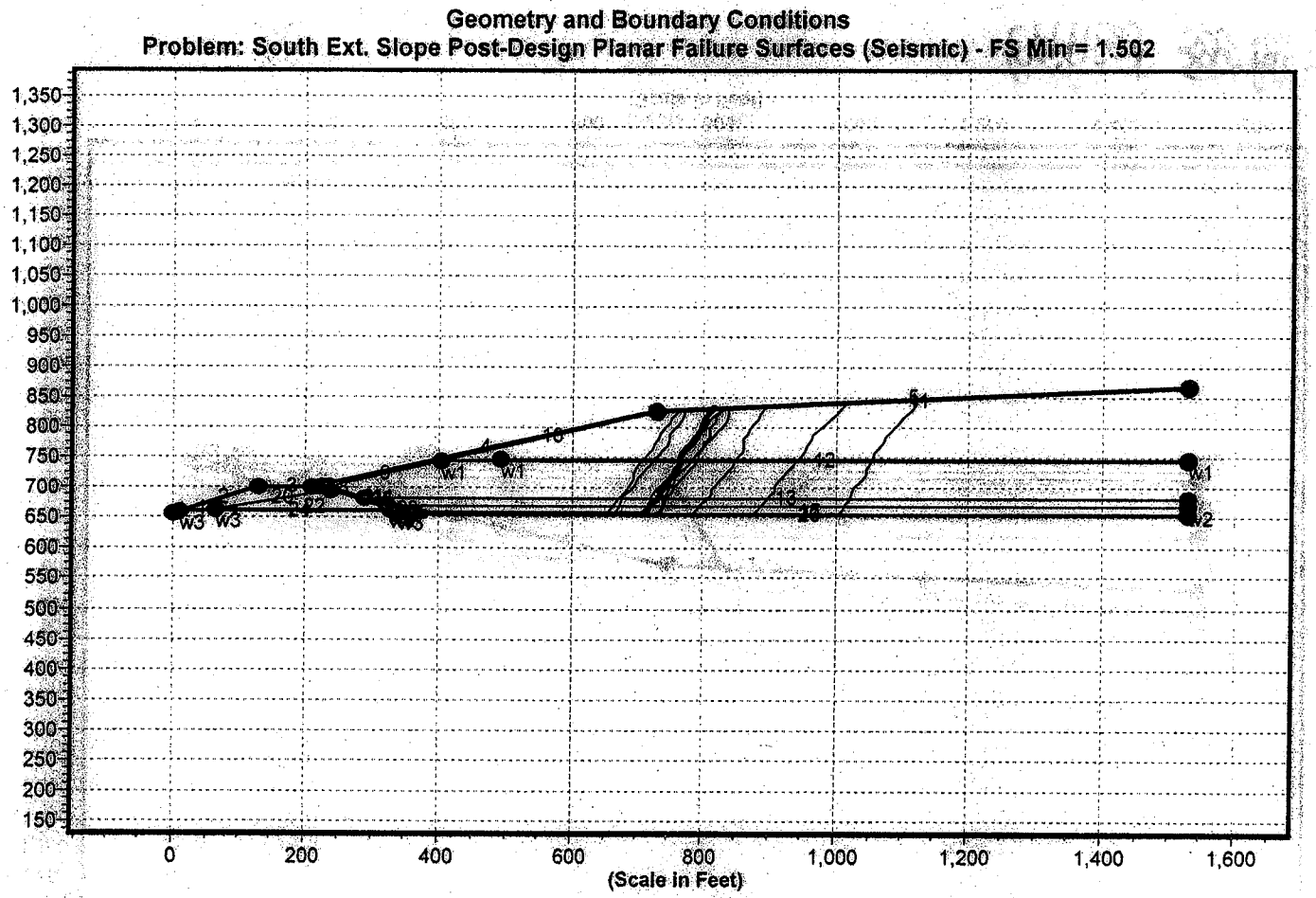
0.1g horizontal seismic acceleration


Geometry and Boundary Conditions
Problem: South Ext. Slope Post-Design Planar Failure Surfaces (Seismic)
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
0
200
400
600
800
1,000
1,200
1,400
1,600
(Scale in Feet)
w1
w2
w3

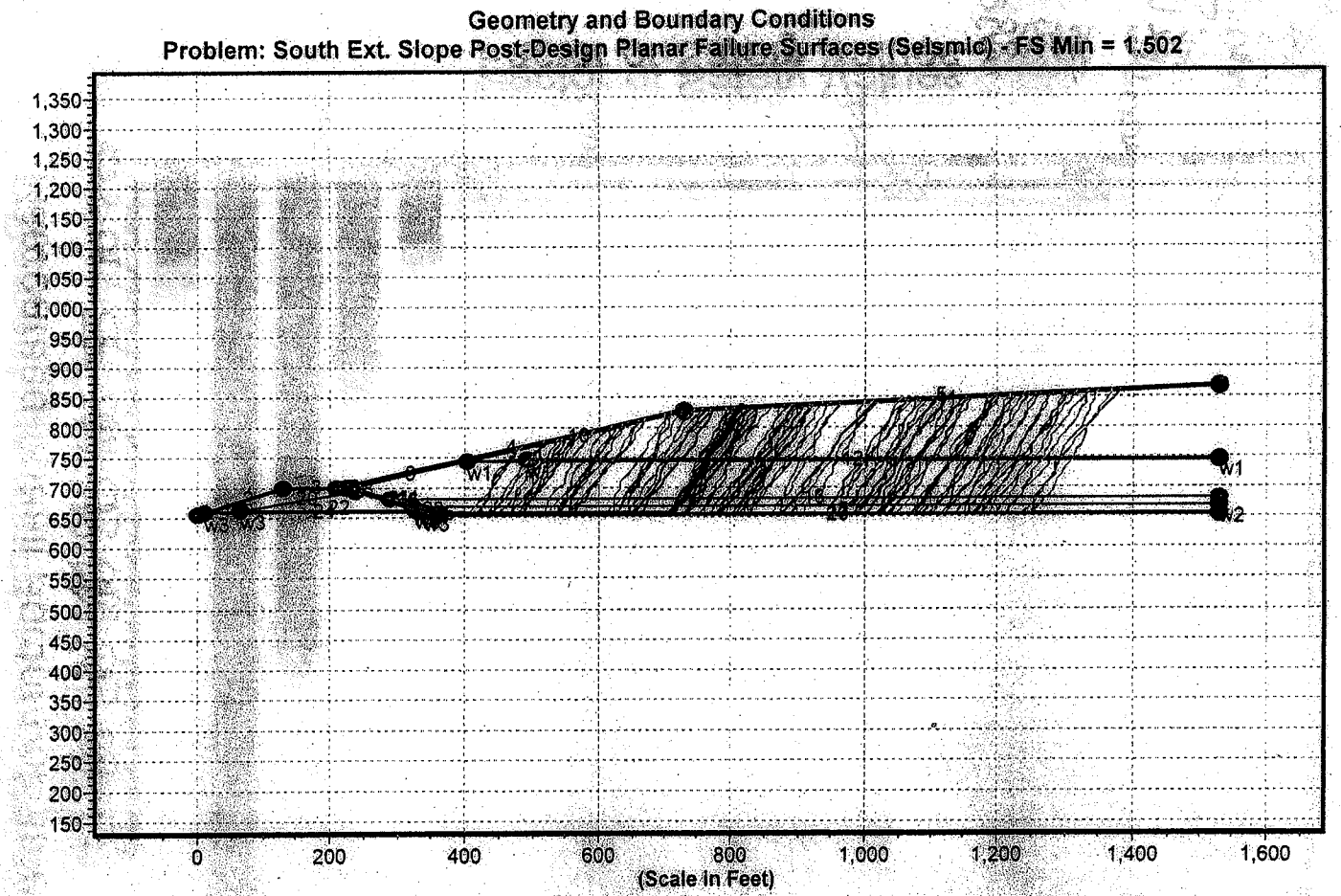
Profile



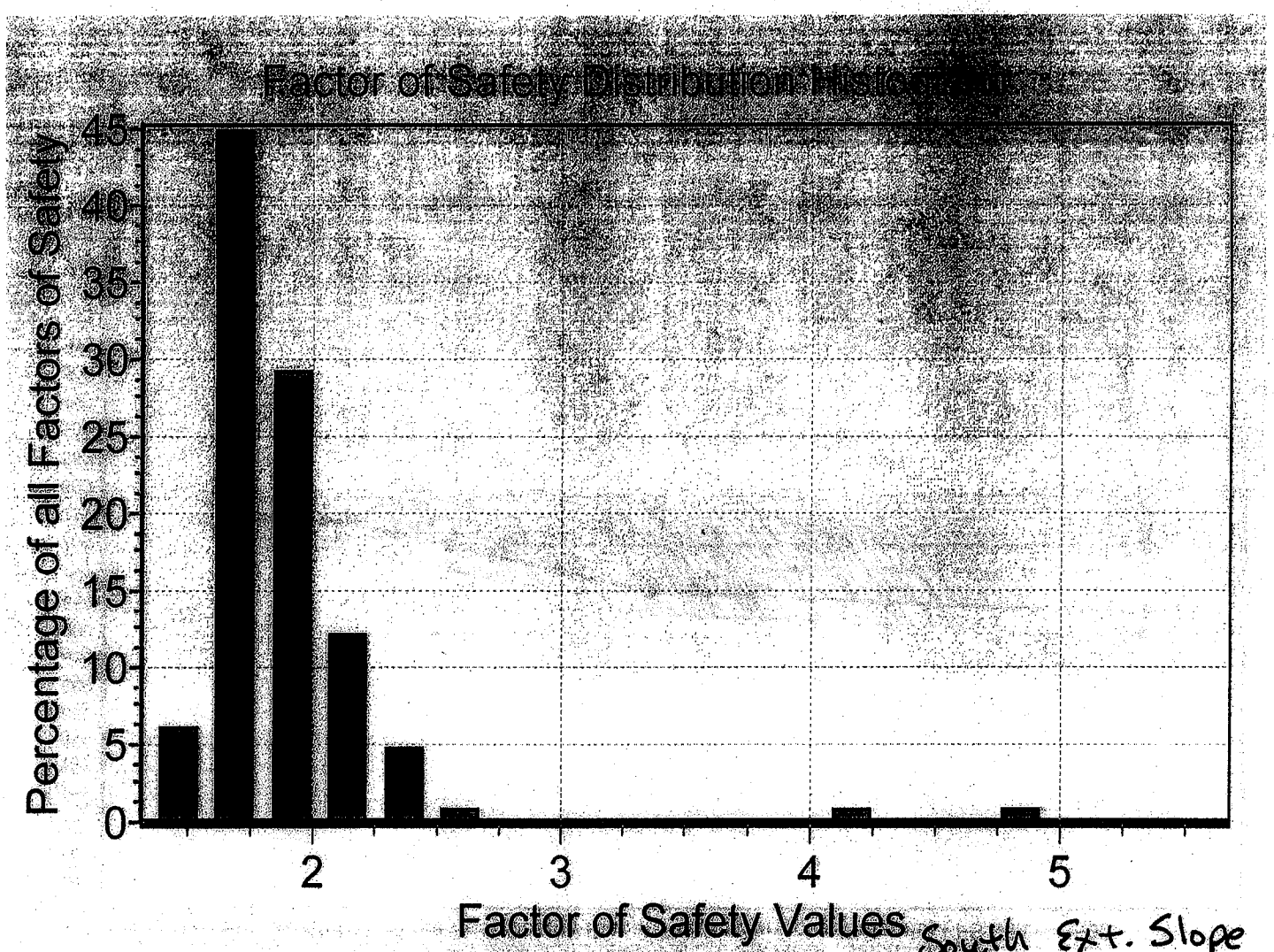
Critical Surface



10 Most Critical Surfaces



Generated Surfaces



South Ext. Slope Post-Design
Planar Failure Surfaces
(Seismic)

result
** PCSTABL6 **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

Run Date:
Time of Run:
Run By:
Input Data Filename: run.in
Output Filename: result.out
Unit: ENGLISH
Plotted Output Filename: result.plt

PROBLEM DESCRIPTION South Ext. Slope Post-Design Planar Failure Surfaces (Seismic)

BOUNDARY COORDINATES

5 Top Boundaries
26 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	0.00	657.00	9.00	660.00	1
2	9.00	660.00	129.00	700.00	2
3	129.00	700.00	209.00	700.00	2
4	209.00	700.00	729.00	830.00	3
5	729.00	830.00	1529.00	870.00	3
6	209.00	700.00	220.00	700.00	2
7	220.00	700.00	229.49	700.00	4
8	229.49	700.00	232.25	700.66	5
9	232.25	700.66	403.62	743.50	6
10	403.62	743.50	729.00	825.00	7
11	729.00	825.00	1529.00	865.00	7
12	403.62	743.50	1529.00	743.50	6
13	288.23	682.00	1529.00	682.00	11
14	232.25	700.66	360.23	658.00	5
15	355.49	658.00	1529.00	658.00	8
16	229.49	700.00	358.49	657.00	4
17	358.49	657.00	1529.00	657.00	4
18	220.00	700.00	238.00	694.00	2
19	9.00	660.00	66.00	665.00	9
20	66.00	665.00	238.00	694.00	10
21	238.00	694.00	325.00	665.00	10
22	66.00	665.00	325.00	665.00	9
23	325.00	665.00	340.00	660.00	9
24	9.00	660.00	340.00	660.00	1
25	340.00	660.00	358.00	654.00	1
26	358.00	654.00	1529.00	654.00	1

1

ISOTROPIC SOIL PARAMETERS

11 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	140.0	148.0	6000.0	0.0	0.00	0.0	0
2	135.0	140.0	3000.0	0.0	0.00	0.0	0
3	128.0	134.0	1350.0	0.0	0.00	0.0	0
4	135.0	140.0	3000.0	0.0	0.00	0.0	0
5	128.0	134.0	0.0	15.0	0.00	0.0	2
6	75.0	75.0	500.0	30.0	0.00	0.0	0
7	75.0	75.0	500.0	30.0	0.00	0.0	1
8	135.0	140.0	0.0	16.0	0.00	0.0	2
9	100.0	110.0	1400.0	0.0	0.00	0.0	3
10	135.0	140.0	3500.0	0.0	0.00	0.0	0
11	105.0	105.0	0.0	22.0	0.00	0.0	2

1

3 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 3 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	403.62	743.50
2	493.62	748.50
3	1529.00	748.50

Piezometric Surface No. 2 Specified by 2 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	322.49	669.00
2	1529.00	669.00

1

Piezometric Surface No. 3 Specified by 4 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)

result

1	9.00	660.00
2	66.00	665.00
3	325.00	665.00
4	340.00	660.00

A Horizontal Earthquake Loading Coefficient
Of0.100 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 (psf)

Janbus Empirical Coef is being used for the case of C=0

1

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

150 Trial Surfaces Have Been Generated.

3 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 10.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	232.49	699.00	235.49	698.00	1.00
2	358.00	657.00	365.00	657.00	1.00
3	400.00	657.00	1250.00	657.00	3.00

1

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	228.34	704.83
2	235.47	697.89
3	362.10	657.33
4	709.54	656.77
5	716.57	663.87

		result
6	721.13	672.77
7	727.86	680.17
8	734.75	687.42
9	736.96	697.17
10	741.74	705.96
11	748.65	713.19
12	753.94	721.67
13	757.63	730.97
14	763.30	739.20
15	765.39	748.98
16	767.66	758.72
17	774.34	766.16
18	780.66	773.91
19	786.55	782.00
20	792.24	790.22
21	797.19	798.91
22	801.25	808.05
23	802.85	817.92
24	808.88	825.90
25	815.94	832.98
26	816.40	834.37

*** 1.502 ***

Individual data on the 45 slices

Slice No.	Width (ft)	Weight (lbs)	Water Force Top (lbs)	Water Force Bot (lbs)	Force Norm (lbs)	Force Tan (lbs)	Earthquake Force Hor (lbs)	Earthquake Force Ver (lbs)	Surcharge Load (lbs)
1	4.2	1389.4	0.0	0.0	0.0	0.0	138.9	0.0	0.0
2	0.3	182.7	0.0	0.0	0.0	0.0	18.3	0.0	0.0
3	2.5	2074.0	0.0	0.0	0.0	0.0	207.4	0.0	0.0
4	0.2	179.7	0.0	0.0	0.0	0.0	18.0	0.0	0.0
5	8.8	10517.8	0.0	0.0	0.0	0.0	1051.8	0.0	0.0
6	44.0	101725.6	0.0	0.0	0.0	0.0	10172.6	0.0	0.0
7	37.4	157755.2	0.0	0.0	0.0	0.0	15775.5	0.0	0.0
8	1.6	8114.2	0.0	25.3	0.0	0.0	811.4	0.0	0.0
9	32.8	200829.9	0.0	12351.5	0.0	0.0	20083.0	0.0	0.0
10	0.2	1447.3	0.0	149.8	0.0	0.0	144.7	0.0	0.0
11	1.9	13184.6	0.0	1393.2	0.0	0.0	1318.5	0.0	0.0
12	41.5	311435.4	0.0	30311.0	0.0	0.0	31143.5	0.0	0.0
13	90.0	787309.9	0.0	66306.2	0.0	0.0	78731.0	0.0	0.0
14	73.6	757821.7	0.0	54827.5	0.0	0.0	75782.2	0.0	0.0
15	142.3	********	0.0	0.0	0.0	0.0	*******	0.0	0.0
16	0.2	3143.3	0.0	0.0	0.0	0.0	314.3	0.0	0.0
17	1.0	13473.8	0.0	1010.0	0.0	0.0	1347.4	0.0	0.0
18	5.8	77300.6	0.0	4159.1	0.0	0.0	7730.1	0.0	0.0
19	2.6	33584.4	0.0	921.4	0.0	0.0	3358.4	0.0	0.0
20	1.9	23899.6	0.0	0.0	0.0	0.0	2390.0	0.0	0.0
21	6.7	79769.9	0.0	0.0	0.0	0.0	7977.0	0.0	0.0
22	1.1	13118.7	0.0	0.0	0.0	0.0	1311.9	0.0	0.0
23	0.6	6769.5	0.0	0.0	0.0	0.0	676.9	0.0	0.0
24	5.2	57602.4	0.0	0.0	0.0	0.0	5760.2	0.0	0.0
25	2.2	23491.0	0.0	0.0	0.0	0.0	2349.1	0.0	0.0
26	4.8	47488.7	0.0	0.0	0.0	0.0	4748.9	0.0	0.0
27	6.9	64609.5	0.0	0.0	0.0	0.0	6460.9	0.0	0.0
28	5.3	46537.8	0.0	0.0	0.0	0.0	4653.8	0.0	0.0

					result				
9	3.7	30014.9	0.0	0.0	0.0	0.0	3001.5	0.0	0.0
30	5.7	42578.2	0.0	0.0	0.0	0.0	4257.8	0.0	0.0
31	0.9	6460.1	0.0	0.0	0.0	0.0	646.0	0.0	0.0
32	1.1	7148.8	0.0	797.5	0.0	0.0	714.9	0.0	0.0
33	0.1	669.2	0.0	0.0	0.0	0.0	66.9	0.0	0.0
34	2.3	13889.4	0.0	0.0	0.0	0.0	1388.9	0.0	0.0
35	6.7	36658.5	0.0	0.0	0.0	0.0	3665.8	0.0	0.0
36	6.3	31255.5	0.0	0.0	0.0	0.0	3125.5	0.0	0.0
37	5.9	25746.6	0.0	0.0	0.0	0.0	2574.7	0.0	0.0
38	5.7	21525.0	0.0	0.0	0.0	0.0	2152.5	0.0	0.0
39	5.0	15696.0	0.0	0.0	0.0	0.0	1569.6	0.0	0.0
40	4.1	10218.0	0.0	0.0	0.0	0.0	1021.8	0.0	0.0
41	1.6	2914.5	0.0	0.0	0.0	0.0	291.5	0.0	0.0
42	6.0	6986.5	0.0	0.0	0.0	0.0	698.6	0.0	0.0
43	3.3	2457.0	0.0	0.0	0.0	0.0	245.7	0.0	0.0
44	3.8	1554.8	0.0	0.0	0.0	0.0	155.5	0.0	0.0
45	0.5	40.5	0.0	0.0	0.0	0.0	4.0	0.0	0.0

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	222.92	703.48
2	223.80	702.66
3	233.15	699.10
4	359.96	657.39
5	727.70	655.93
6	734.66	663.11
7	737.82	672.60
8	739.50	682.46
9	744.45	691.15
10	749.55	699.75
11	753.68	708.85
12	758.62	717.55
13	765.68	724.63
14	771.55	732.73
15	778.46	739.96
16	783.10	748.82
17	789.28	756.68
18	795.06	764.84
19	802.12	771.91
20	809.19	778.99
21	816.22	786.10
22	823.25	793.22
23	829.44	801.07
24	833.89	810.02
25	836.69	819.62
26	838.15	829.52
27	842.15	835.66

*** 1.515 ***

1

Failure Surface Specified By 26 Coordinate Points

Point	X-Surf	Y-Surf

No.	(ft)	result (ft)
1	227.69	704.67
2	234.44	698.35
3	360.05	657.20
4	665.96	657.06
5	670.49	665.97
6	675.05	674.87
7	676.60	684.75
8	683.43	692.05
9	690.13	699.47
10	697.20	706.55
11	701.54	715.56
12	706.33	724.34
13	712.85	731.92
14	719.75	739.16
15	724.50	747.96
16	731.43	755.17
17	738.26	762.48
18	745.33	769.55
19	748.19	779.13
20	749.36	789.06
21	754.23	797.79
22	761.30	804.86
23	767.13	812.99
24	771.77	821.85
25	774.42	831.49
26	774.97	832.30

*** 1.523 ***

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	218.70	702.42
2	225.47	698.94
3	235.46	698.49
4	360.26	657.07
5	653.88	657.49
6	660.38	665.09
7	664.95	673.99
8	671.82	681.25
9	678.55	688.65
10	683.03	697.59
11	689.36	705.33
12	693.89	714.24
13	695.18	724.16
14	697.32	733.93
15	704.33	741.05
16	710.36	749.04
17	716.12	757.21
18	723.02	764.45
19	725.71	774.08
20	732.77	781.16
21	737.08	790.19
22	740.58	799.55

		result
23	747.46	806.82
24	751.11	816.12
25	757.73	823.62
26	763.13	831.71

*** 1.524 ***

1

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	222.62	703.40
2	224.42	701.96
3	233.91	698.79
4	359.22	657.32
5	703.61	655.81
6	709.89	663.60
7	716.58	671.03
8	718.16	680.90
9	722.78	689.78
10	729.56	697.12
11	736.21	704.59
12	743.27	711.67
13	749.43	719.55
14	756.49	726.63
15	763.15	734.09
16	767.83	742.93
17	769.24	752.83
18	772.77	762.18
19	779.77	769.32
20	786.41	776.80
21	793.14	784.20
22	794.44	794.12
23	799.54	802.71
24	805.15	811.00
25	805.50	820.99
26	811.71	828.83
27	814.57	834.28

*** 1.548 ***

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	227.21	704.55
2	233.70	698.60
3	358.20	657.45
4	734.36	656.57
5	739.94	664.87

		result
6	740.95	674.82
7	744.60	684.13
8	751.42	691.44
9	755.45	700.59
10	761.65	708.44
11	768.71	715.52
12	773.44	724.33
13	780.41	731.51
14	786.50	739.43
15	793.47	746.60
16	794.44	756.56
17	799.16	765.37
18	800.70	775.25
19	807.68	782.41
20	810.01	792.14
21	810.82	802.10
22	817.54	809.51
23	819.98	819.21
24	826.11	827.11
25	833.17	834.20
26	833.60	835.23

*** 1.572 ***

1

Failure Surface Specified By 29 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	221.61	703.15
2	223.58	701.19
3	233.33	698.95
4	358.95	657.38
5	1003.13	656.25
6	1009.64	663.83
7	1015.17	672.16
8	1020.66	680.53
9	1023.51	690.11
10	1026.50	699.65
11	1032.65	707.54
12	1039.64	714.68
13	1044.34	723.51
14	1046.78	733.21
15	1052.84	741.16
16	1054.73	750.98
17	1059.70	759.66
18	1066.08	767.37
19	1072.55	774.99
20	1073.01	784.98
21	1080.08	792.05
22	1085.90	800.18
23	1092.46	807.73
24	1098.91	815.37
25	1105.59	822.81
26	1112.64	829.90
27	1118.77	837.80
28	1122.08	847.24

result

29	1124.61	849.78

*** 1.573 ***

Failure Surface Specified By 28 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	226.63	704.41
2	233.89	698.45
3	362.70	656.83
4	877.31	656.05
5	884.25	663.25
6	888.77	672.17
7	895.75	679.33
8	901.00	687.84
9	906.88	695.93
10	909.92	705.45
11	914.94	714.10
12	922.00	721.18
13	928.14	729.07
14	934.87	736.47
15	939.33	745.43
16	946.30	752.59
17	951.64	761.04
18	955.99	770.05
19	961.71	778.25
20	966.61	786.97
21	973.67	794.05
22	980.03	801.77
23	987.05	808.89
24	993.88	816.20
25	1000.89	823.32
26	1006.14	831.83
27	1013.20	838.92
28	1018.72	844.49

*** 1.574 ***

1

Failure Surface Specified By 26 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	228.09	704.77
2	234.96	697.99
3	360.27	657.26
4	714.75	657.27
5	720.08	665.73
6	724.28	674.81
7	730.81	682.38

		result
8	737.08	690.17
9	742.66	698.47
10	747.18	707.39
11	751.90	716.20
12	757.77	724.31
13	764.33	731.85
14	765.59	741.77
15	767.55	751.58
16	773.92	759.29
17	780.71	766.63
18	787.19	774.25
19	793.31	782.15
20	796.71	791.56
21	803.61	798.80
22	806.33	808.42
23	813.40	815.49
24	820.39	822.64
25	827.46	829.71
26	829.50	835.03

*** 1.574 ***

Failure Surface Specified By 27 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	224.44	703.86
2	226.57	703.21
3	235.01	697.85
4	364.20	657.02
5	784.90	656.93
6	791.56	664.39
7	797.28	672.59
8	804.01	679.99
9	810.90	687.24
10	813.04	697.00
11	819.20	704.88
12	825.40	712.73
13	832.44	719.83
14	838.18	728.02
15	843.06	736.74
16	846.74	746.04
17	853.12	753.74
18	860.19	760.81
19	861.04	770.77
20	861.69	780.75
21	865.81	789.86
22	870.59	798.65
23	876.23	806.90
24	882.27	814.88
25	886.52	823.93
26	892.10	832.23
27	898.28	838.46

*** 1.580 ***

1

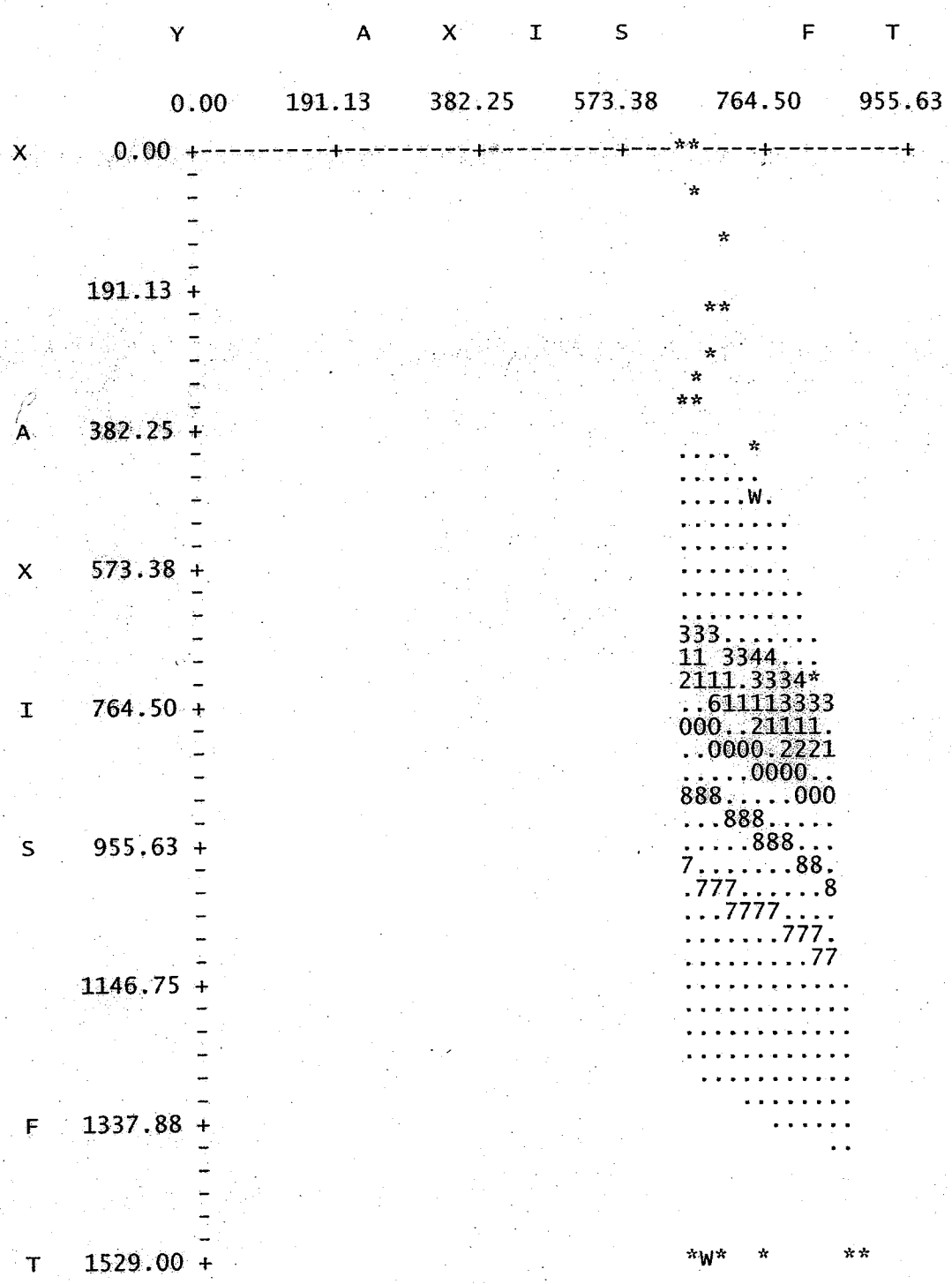

Y A X I S F T
0.00 191.13 382.25 573.38 764.50 955.63
X 0.00
191.13
A 382.25
X 573.38
I 764.50
S 955.63
1146.75
F 1337.88
T 1529.00

TABLE 9.3 Manning's Roughness Coefficients

Channel Material	n
Clean, uncoated cast iron	0.013–0.015
Clean, coated cast iron	0.012–0.014
Dirty, tuberculated cast iron	0.015–0.035
Riveted steel	0.015–0.017
Lock-bar and welded	0.012–0.013
Galvanized iron	0.015–0.017
Brass and glass	0.009–0.013
Wood stave	
Small diameter	0.011–0.012
Large diameter	0.012–0.013
Concrete	
With rough joints	0.016–0.017
Dry mix, rough forms	0.015–0.016
Wet mix, steel forms	0.012–0.014
Very smooth, finished	0.011–0.012
Vitrified sewer	0.013–0.015
Common-clay drainage tile	0.012–0.014
Asbestos	0.011
Planed timber	0.011
Canvas	0.012
Unplaned timber	0.014
Brick	0.016
Rubble masonry	0.017
Smooth earth	0.018
Firm gravel	0.023
Corrugated metal pipe	0.022
Natural channels, good condition	0.025
Natural channels with stones and weeds	0.035
Very poor natural channels	0.060
→ HDPE pipe	0.009
PVC pipe	0.010

Source: Lindeburg (1989), HDPE and PVC pipes added.

$$Q = \frac{1.486}{n} A R_h^{2/3} S^{1/2} \tag{9.18}$$

where Q is the flow, ft^3/s.

The leachate inflow (Q) to a LCRS pipe can be estimated using the water balance methods discussed in Section 9.3.1. Once the required flow through the pipe is known, equations (9.17) and (9.18) can readily be solved to determine the required pipe diameter. Figure 9.17 presents a chart showing the inside pipe diameter versus the flow rate at a given slope for full flow through a high-density polyethylene

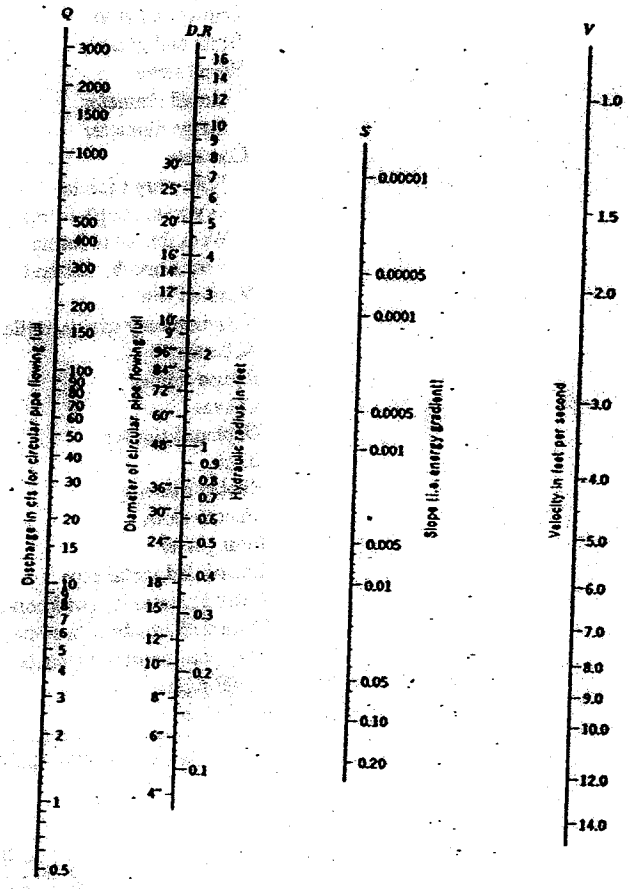


Figure 10-2 Nomograph (English units) for solution of the Manning equation ($n = 0.013$).

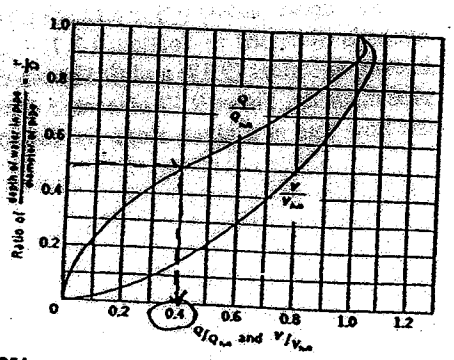


Figure 10-3 Hydraulic characteristics of circular pipes flowing partly full.

APPENDIX 812.305-F: SETTLEMENT CALCULATIONS

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Foundation Settlement Calculations

References: "Foundation Settlement Calculations" PDC Technical Memorandum, Nov. 2004, Feb. 2005

"Geotechnical Design Memo", November 2006

Revised Loads Due to Landfill (ΔP)

Vertical Pressure at Base of Final Cover

$$P_{FC} = (\gamma_{veg.cover} \times 3') + (\gamma_{protective} \times 1') + (\gamma_{cushion} \times 1')$$

$$= (120 \times 3) + (135 \times 1) + (120 \times 1)$$

$$= 617 \text{ psf}$$

Vertical Pressure Due To Leachate Drainage Layer

$$P_{LDL} = 135 \text{ pcf} \times 1' = 135 \text{ psf}$$

(Conservative, neglects reduction in effective unit weight due to leachate)

Waste Thickness at Point F (reference "Modeled Loading" on page 1, "Foundation Settlement Calculations", 11-05-01)

Point F is at the middle of the landfill, where the waste is at its thickest.

From Drawing P-4051, the geomembrane liner is at a maximum Elevation = 666.5' in the middle of the landfill. The bottom of waste is 3' above this elevation (See Section C - Drawing No. P-4052)

$\Rightarrow$ Min. Elev. of waste = 669.5'

From Drawing P-F64, the maximum waste elevation = 865'

⇒ Maximum Waste Thickness = 865 − 669.5
= 195.5'

Waste Thickness at Point E

Point E is at the crest of the 4:1 perimeter final waste slope (east or west of landfill crest). At this point:

Top of Waste Elev. = 825'
Bottom of Waste Elev. = 664
⇒ Waste Thickness = 161'

Waste Thickness at Point I

Point I is at the toe of the liner sidewall.

At this point:

Top of Waste Elev. = 795
Bottom of Waste Elev. = 663
Total Waste Thickness = 132'

Vertical Pressure at Points F, E, and I

As per the discussion provided with the Foundation Bearing Capacity calculations, the maximum bearing pressure will occur just as the final cover is placed. Consistent with the stability and bearing capacity calculations, it is assumed that the lower 10' of waste has fully degraded.

Partially degraded waste γ = 75 pcf
Fully degraded waste γ = 105 pcf
(inclusive of daily and intermediate cover)

Point	Thickness (FT) Partially Degraded Waste	Thickness (FT) Fully Deg. Waste	(P_w) Vertical Pressure (psf)
C	185.5	10	14,963
D	151	10	12,375
B	122	10	10,200

(See Modelled Waste Loading, p.4)

Points A', A''

$$\Delta P_A = I_{AHFC} \times (P_{HC} + P_{LDL} + P_{HF}) - I_{ALI} \times (P_{HI}) - I_{LCEI} \times (P_{HE} - P_{HI}) - I_{CHFE} \times (P_{HF} - P_{HE})$$

Point A'

$I_{AHFC} = 0.50$ ($B_1/z >> 3$)

I_{ALI}

$z = 24'$ $B_1 = 0$

$B_2 = 220 \Rightarrow \frac{B_2}{z} = 9.2$

$\Rightarrow I_{ALI} = 0.465$

I_{LCEI} $z = 24'$. $B_1 = 220' \Rightarrow \frac{B_1}{z} = 9.2$

$B_2 = 350 - 220' = 130 \Rightarrow \frac{B_2}{z} = 5.4$

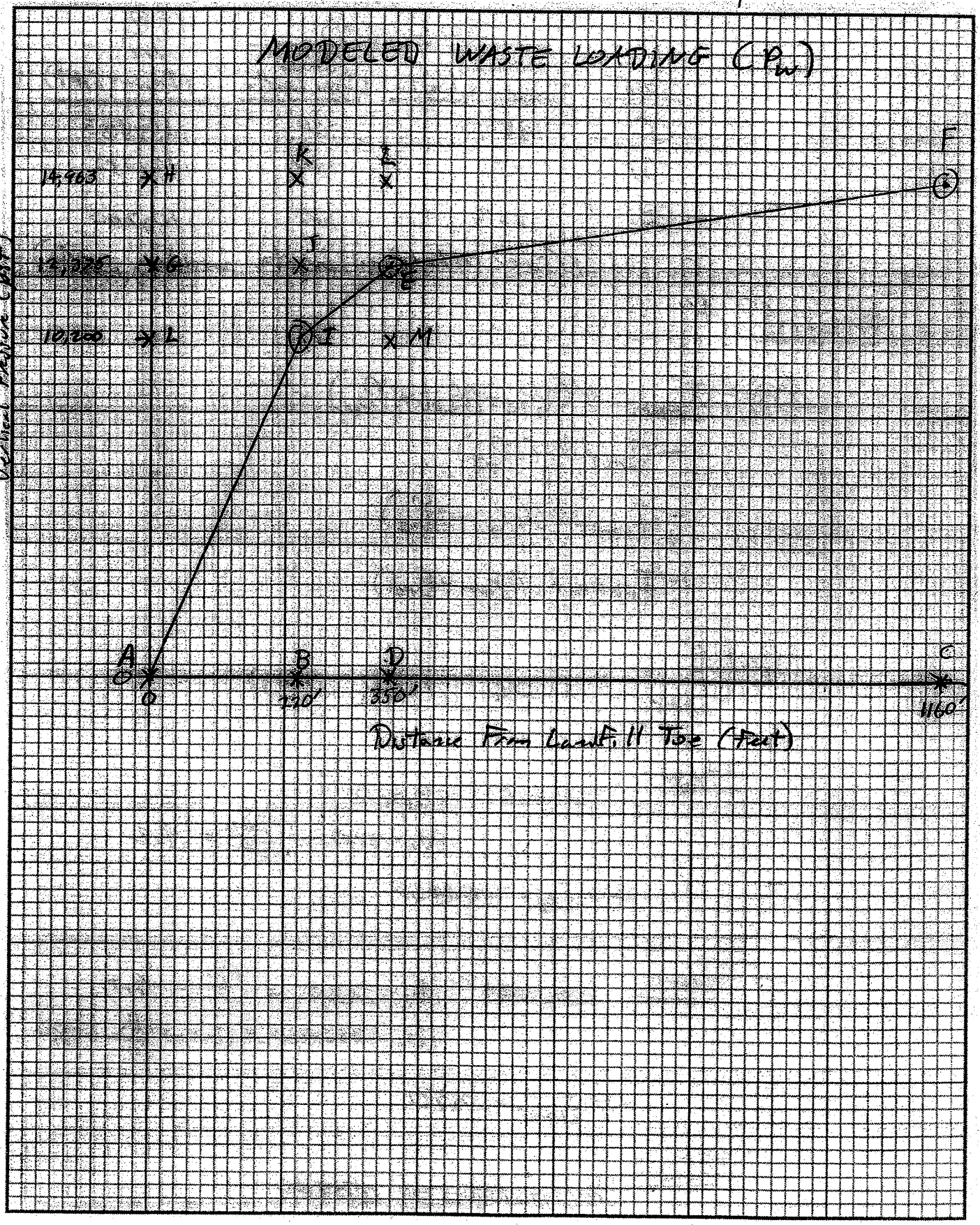
$\Rightarrow I_{LCEI} = 0.50$

I_{CHFE} By inspection $= 0.500$

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Project: Custer Landfill No. 3 Computed by: F. Armstrong Sheet 4 of 33

Project No.: 91-0119 Task No.: Checked By: J. Kelly Date: 11-16-06



$$\Delta P_{AE} = 0.50\,(647 + 135 + 14{,}963) \qquad (15{,}745)$$

$$- 0.465\,(10{,}200) - 0.50\,(12{,}375 - 10{,}200) \qquad (2175)$$

$$- 0.50\,(14{,}963 - 12{,}375) \qquad (2588)$$

$$= 7873 - 4743 - 1086 - 1294$$

$$= 749 \text{ psf}$$

Point A'' ($\zeta = 112.5°$)

$I_{AMPE} = 0.50 \quad (\frac{B_1}{z} >> 3)$

I_{ACE} $\quad B_1 = 0 \quad \frac{B_1}{z} = \frac{220}{112.5} = 2.0$

$\Rightarrow I_{ACE} = 0.350$

I_{LGEI} $\quad \frac{B_1}{z} = \frac{220}{112.5} = 2.0$

$\frac{B_2}{z} = \frac{730}{112.5} = 1.2$

$\Rightarrow I_{LGEI} = 0.49$

I_{CHPE} $\quad \frac{B_1}{z} = \frac{350}{112.5} = 3.1$

$\frac{B_2}{z} = \frac{810}{112.5} = 7.2$

$\Rightarrow I_{CHPE} = 0.499$

$\Delta P_{A''} = 7873 - 0.350(10{,}200) - 0.49\,(2175) - 0.5(2588)$

$= 1943$ psf

Points B' and B''

$\Delta P_B = I_{BKFC}(15,745) + I_{BAI}(10,200+647+135) - I_{IJE}(12,375-10,200) - I_{JKFE}(14,963-12,375)$

$10,982$

2175

2588

Point B'

$z = 24'$

I_{BKFC}

$B_1 = 1160 - 220 = 940$

$\frac{B_1}{z} = 39$

$\Rightarrow I_{BKFC} = 0.50$

I_{BAI}

$B_1 = 0$

$B_2 = 220' \Rightarrow \frac{B_2}{z} = 9.2$

$\Rightarrow I_{BAI} = 0.465$

I_{IJE}

$B_1 = 0$

$B_2 = 350 - 220 = 130'$

$\frac{B_2}{z} = 5.4$

$\Rightarrow I_{IJE} = 0.44$

I_{JKFC}

$B_1 = 130'$ $\frac{B_1}{z} = 5.4$

$B_2 = 810'$ $\frac{B_2}{z} = 34$

$\Rightarrow I_{JKFC} = 0.500$

$\Rightarrow \Delta P_B = 0.50\,(15,745) + 0.465\,(12,760) - 0.44\,(2175) - 0.50\,(6560)$

$= 10,748$ psf

Point B"

I_{BKFC} $\frac{B_1}{z} = \frac{940}{112.5} = 8.4$

$B_2 = 0$

$\Rightarrow I_{BKFC} = 0.50$

I_{BAI} $B_1 = 0$

$\frac{B_2}{z} = \frac{220}{112.5} = 2.0$

$\Rightarrow I_{BAI} = 0.350$

I_{IJC} $B_1 = 0$

$\frac{B_2}{z} = \frac{130}{112.5} = 1.2$

$\Rightarrow I_{IJC} = 0.46$

I_{JKFE}

$\frac{B_1}{c} = \frac{130}{112.5} = 1.2$

$\frac{B_2}{c} = \frac{810}{112.5} = 7.2$

$\Rightarrow I_{JKFE} = 0.49$

$\Rightarrow \Delta P_{B''} = 0.5(15,745) + 0.350(10,962)$

$- 0.26(2175) - 0.49(2588)$

$= 7863$ psf

Points C' and C''

$I = 1.0$ (middle of landfill)

$\Delta P_{C'} = \Delta P_{C''} = P_{FC} + P_{LDL} + P_{WT}$

$= 647 + 135 + 14,963$

$= 15,745$ psf

Points D' and D''

$\Delta P_D = I_{DAIM}$ (10,200 + 647 + 135 = 10,982)

$+ I_{MIE}$ (12,375 − 10,200 + 647 + 135 = 2957)

$+ I_{DLFG}$ (15,745)

$- I_{ELF}$ (14,963 − 12,375 = 2588)

Point D' $z = 24'$

I_{DAIM}

$B_1 = 350 - 220 = 130'$ $\frac{B_1}{z} = 5.4$

$B_2 = 220'$ $\frac{B_2}{z} = 9.2$

$\rightarrow I_{DAIM} = 0.50$

I_{AIE}

$B_1 = 0$

$B_2 = 130'$ $\rightarrow \frac{B_2}{z} = 5.4$

$\rightarrow I_{AIE} = 0.44$

I_{DLFC}

$B_1 = 1160 - 350 = 810'$ $\frac{B_1}{z} = \frac{810}{24} = 34$

$B_2 = 0$

$\rightarrow I_{DLFC} = 0.50$

I_{ELP}

$B_1 = 0$

$B_2 = 810$ $\frac{B_2}{z} = 33.8$

$\rightarrow I_{ELP} = 0.50$

$\rightarrow \Delta P_{D'} = 0.50(10,960) + 0.44(2957)$

$+ 0.50(15,745) - 0.50(2580)$

$= 13,371$ psf

Point D'' $z = 112.5'$

I_{DAM}

$\frac{B_1}{z} = \frac{130}{112.5} = 1.2$ $\frac{B_2}{z} = \frac{220}{112.5} = 2.0$

$\Rightarrow I_{DAM} = 0.48$

I_{DAC}

$B_1 = 0$ $\frac{B_2}{z} = \frac{130}{112.5} = 1.2$

$\Rightarrow I_{DAC} = 0.26$

I_{DLF}

$\frac{B_1}{z} = \frac{610}{112.5} = 7.2$ $\frac{B_2}{z} = 0$

$\Rightarrow I_{DLF} = 0.50$

I_{ELF}

$B_1 = 0$ $\frac{B_2}{z} = \frac{610}{112.5} = 7.2$

$\Rightarrow I_{ELF} = 0.455$

$\Delta P_{D''} = 0.48\,(10,960) + 0.26\,(2957) + 0.5\,(15,745) - 0.455\,(2568)$

$= 12,794$ psf

Consolidation Settlement

$$\Delta H = H \times \frac{C_c}{1+e_o} \log \frac{P_1 + \Delta P}{P_1}$$

e_o = Initial void ratio = 0.32
C_c = Recompression Index = 0.016
} Settlement Model

$$\Rightarrow \frac{C_c}{1+e_o} = \frac{0.016}{1.32} = 0.012$$

P_1 = Post-Excavation Overburden Pressure
(From 2-19-05 Settlement Calcs)

Points A', B', C', D': $H = 46'$

$$\Rightarrow 46' \frac{C_c}{1+e_o} = 0.576$$

Points A'', B'', C'', D'': $H = 129'$

$$\Rightarrow H'' \frac{C_c}{1+e_o} = 1.548$$

Point	P_1'	$\Delta P'$	$\Delta H'$	P_1''	$\Delta P''$	$\Delta H''$	ΔH
A	11,200	746	0.016'	23,200	1943	0.054	0.070'
B	5,000	19,728	0.287'	19,000	9063	0.282	0.569'
C	3,500	15,745	0.426'	16,300	15,745	0.455	0.881'
D	3,500	13,371	0.393'	16,300	13,794	0.390	0.783'

Elastic Settlement

From 2001 settlement Calculations:

$$\Delta H = \frac{q B (1-\nu^2) I}{E_u}$$

$\Rightarrow \Delta H$ is directly proportional to the applied load

The previous immediate settlement calculations are based on $\Delta z = 16,500$ psf. However, as demonstrated in the current calculations, the actual Δz will be less ($\Delta z_{max} = 15,745$ psf). However, to be conservative, use the same immediate settlement values as calculated before:

Point	ΔH (Feet)
A	0
B	0.124
C	0.247
D	0.247

Compacted Earth Liner / Clay Foundation Fill Compression

Reference 2-22-02 calculations

$\Delta H = H \times$ % Compression

H = Combined Thickness of Earth Liner and Compacted Clay Fill beneath Landfill

From review of Geologic Cross-Sections E on Drawing P-X54:

Middle of landfill: $H = 8'$

Top of landfill sidewall: $H = 3'$

⇒ Points A, B: $H = 3'$

Point D: $H = 4'$

Point C: $H = 8'$

% Compression is dependent on the overburden pressure - see chart provided with 2-22-05 settlement calculations.

Overburden pressure = $P_{FC} + P_{EQL} + P_W$ (from previous calculations, ↳ from p.4)

Point	Overburden Pressure + ASF (psf)	(tsf)	% Compression	H	ΔH
A	782	0.39	0.5	3'	0.015
B	10,982	5.49	3.4	3'	0.102
C	13,745	7.87	4.4	8'	0.352
D	13,157	6.58	3.8	4'	0.152

PDC TECHNICAL SERVICES, INC.

Project: Clinton Landfill No. 3 Computed by: G.L. Armstrong Sheet 14 of 33

Project No.: 91-0119 Task No.: Checked By: J. Kelly Date: 11-16-96

Settlement Summary

Point	Immediate Settlement Elastic	Liner	Total	Long-Term Consolidation	Total	Differential Settlement
A	0.00	0.015	0.015	0.070	0.085	0.710
B	0.124	0.102	0.226	0.569	0.795	0.307
D	0.247	0.152	0.399	0.783	1.182	0.298
C	0.247	0.352	0.599	0.881	1.46	

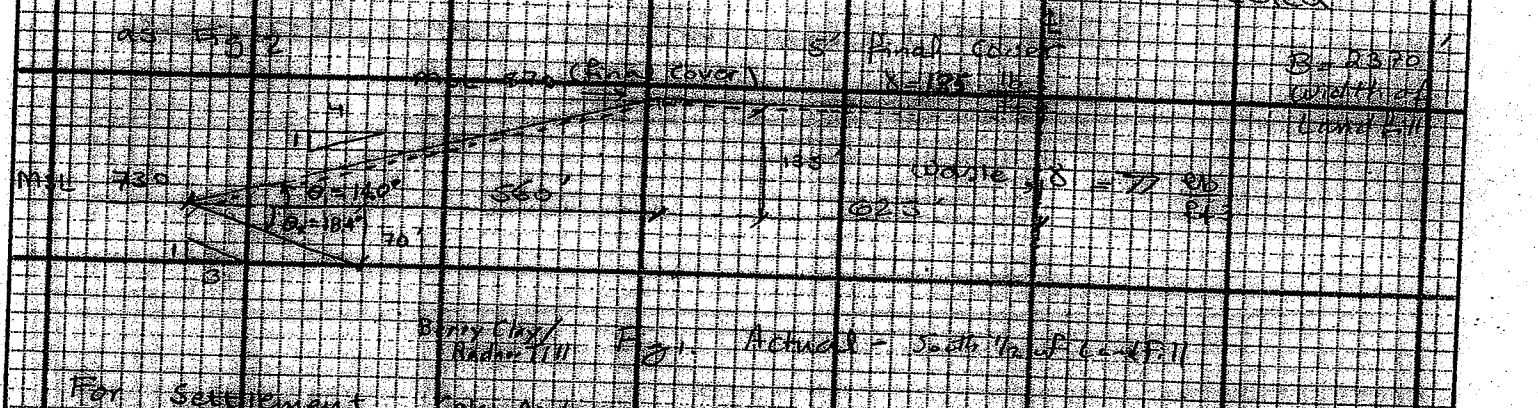
Excerpts From Previous Foundation Settlement Calculations and References

Foundation Settlement Calculations

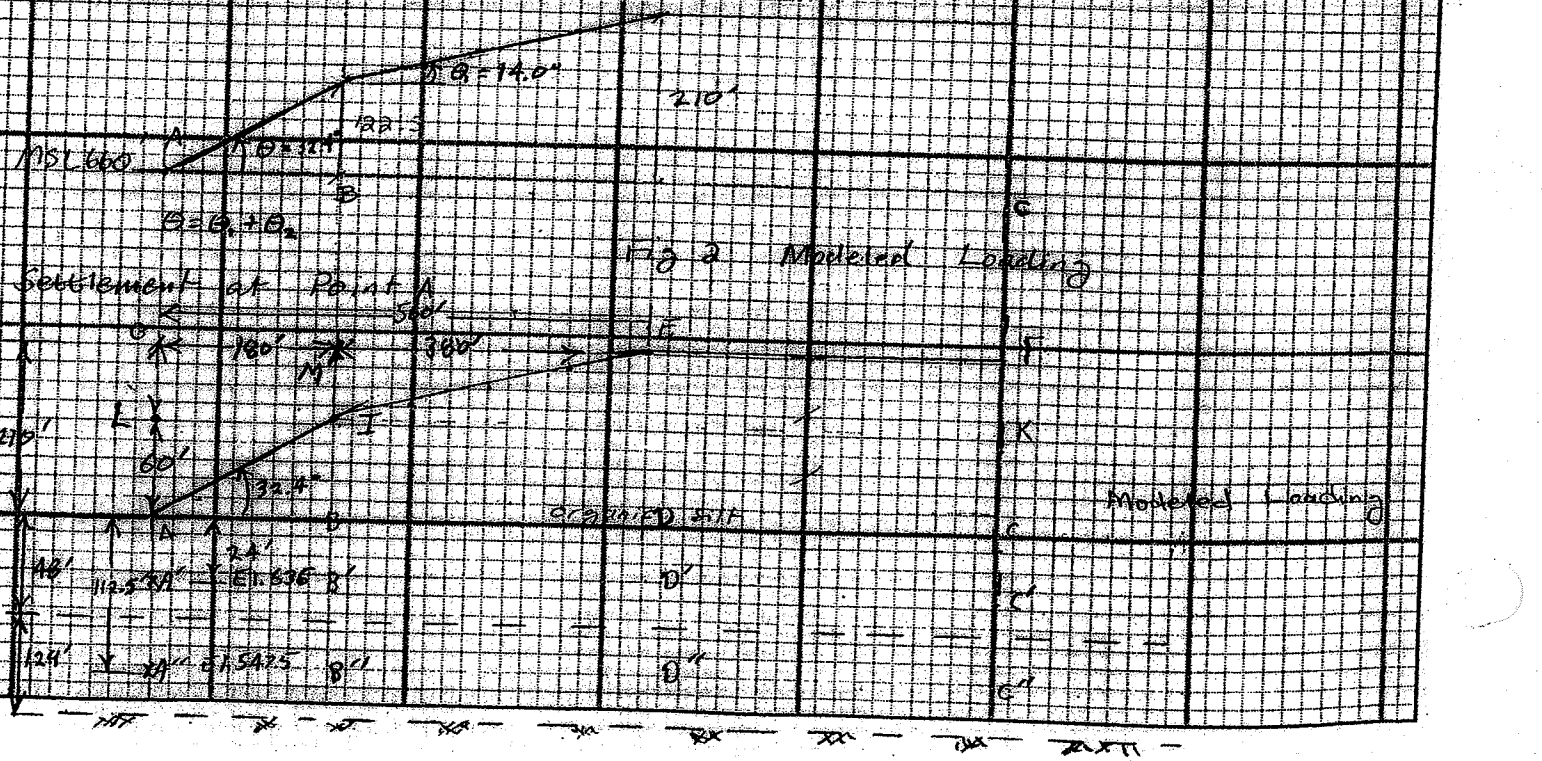
Consolidation Settlement

References: Principles of Foundation Engineering, Das

The actual following landfill (Fig 1) can be modeled as Fig 2.



For Settlements calculations, assume compressible clays to Elevation 483 based on log of boring drilled for C.I. #2. Subtitle D Sub Mod. This is consistent with Settlement calcs for subtitle D Sub Mod. Divide compressible layer into 2 layers, upper 78' thick sand layer 129' thick. Calculate the settlement at mid-height of the two layers.



Overburden Pressures

Existing Overburden Pressure (P_o)

Points A', B', C', D':

$P_o = [(\text{Elev. } 730 - 670) \times 120 \frac{\text{lb}}{\text{ft}^3}] + [(\text{Elev. } 670 - 660) \times (300 - 62.4)] + [(\text{Elev. } 660 - 636) \times 145]$

$= 7200 + 376 + 3480$

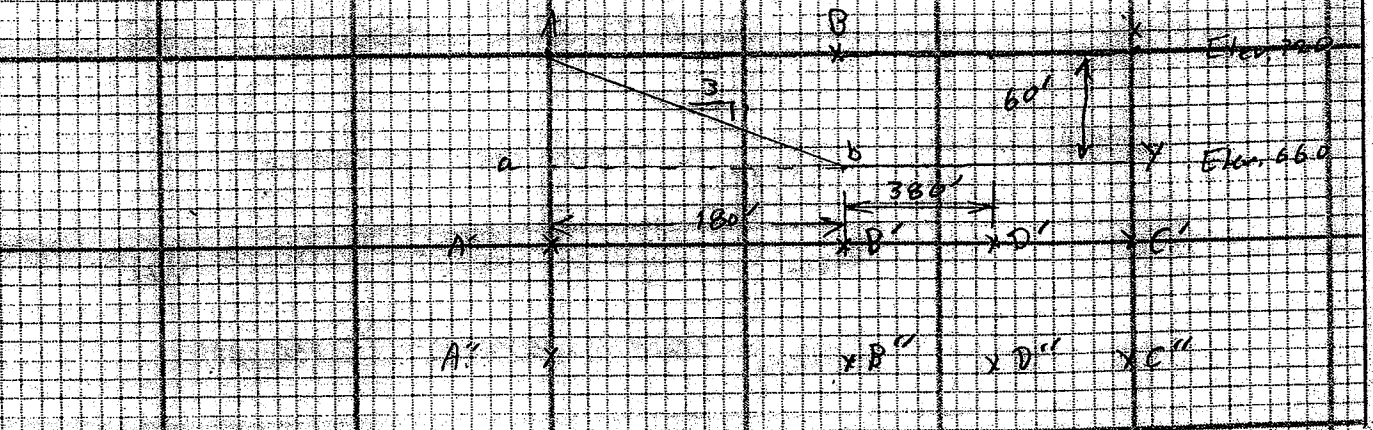
$= 11,536 \text{ psf}$ Say 11,500 psf

Points A'', B'', C'', D'':

$P_o = 11,500 + [(\text{Elev. } 636 - 542.5) \times 145]$

$= 24,333 \text{ psf}$ Say 24,500 psf

Post-Excavation Overburden (P_1)



Points A', A''

$P_1 = P_0 - P_{AXYa} + P_{Aba}$

Point A'

I_{AXYa}: Reference influence chart, Fig. 3.44 and Fig. 3.43 (attached)

$B_1 = B_2 = 0 \Rightarrow I_{AXYa} = 0.5$

$P_{AXYa} = I_{AXYa} \times [(50' \times 126\ lb/ft^3) + (10' \times (100-62.4))]$

$= 0.5\ (5776\ lb/ft^2)$

$= 3388$ psf

I_{Aba}: $B_1 = 0$, $B_2 = 160'$

$\frac{B_2}{z} = \frac{160}{24'} = 7.5$

$\Rightarrow$ From Fig. 3.44 $I_{Aba} = 0.455$

$\Rightarrow P_{Aba} = 0.455\ (6776) = 3083$

$\Rightarrow P_{1(A')} = 11,500 - 3388 + 3083$

$= 11,195$ psf Say 11,200 psf

Point A''

$P_{AXYa} = 3388$ psf as above

I_{Aba}: $\frac{B_2}{z} = \frac{160}{112.5} = 1.6 \Rightarrow I_{Aba} = 0.315$

$P_{Aba} = 0.315\ (6776) = 2134$ psf

$\Rightarrow P_{1(A'')} = 24,500 - 3388 + 2134$

$= 23,246$ Say 23,200 psf

Point B', B''

$P_1 = P_0 - P_{BXYa} - P_{BAb}$

Point B'

I_{BXYa}: $B_1 = 2700$ $B_2 = 0$

$\frac{B_1}{z} = \frac{2700}{24} = 88 \rightarrow I_{BXYa} = 0.5$

I_{BAb}: $B_1 = 0$ $B_2 = 180$

$\frac{B_2}{z} = \frac{180}{24} = 7.5$

$\rightarrow I_{BAb} = 0.455$

$P_{1(B')} = 11,500 - (0.5 \times 6776) - (0.455 \times 6776)$

$= 5029$ psf Say 5,000 psf

Point B''

$I_{BXYa} = 0.5$

$I_{BAb} = \frac{B_2}{z} = \frac{180}{112.5} = 1.6 \rightarrow I_{BAb} = 0.315$

$P_{1(B'')} = 24,500 - [(0.5 + 0.315) \times 6776]$

$= 16,976$ psf Say 19,000 psf

PDC TECHNICAL SERVICES, INC.

Project: Clinton Landfill No. 3 Calculated By: GLArentson Sheet 20 of 3

Project No.: 91-0118 Task No.: Checked By: Date: 2-14-05

Revised

Points C', C'', D', D''

Points C', C'', D', & D'' are at significant distance from the edge of the excavation.

Therefore:

$P_{H(C')} = P_{H(D')} = 24' \times 145 \frac{lb}{ft^3} = 3480$ say 3500 psf

$P_{V(C')} = P_{V(D')} = 112.5' \times 145 = 16,312$ say 16,300 psf

Load Due to Landfill (Δp)

Points A', A''

$\Delta p = (I_{AGEE} \times (\gamma_{waste} \times 205' + \gamma_{Fill} \times 5'))$

$- I_{AGEI} \times (\gamma_{waste} \times 5')$

$- I_{AGEI} \times [(\gamma_{waste} \times 150') + (\gamma_{Fill} \times 5')]$

$\gamma_{waste} =$ pcf (weighted average from Geotechnical Model)

$\gamma_{Fill} = 125$ pcf (Geotechnical Model)

Point A'

$I_{AGE} = 0.5$ ($B_1 = 2300'$)

$I_{AGI} = 0.455$ $\left\{ \begin{array}{l} z = 24' \\ B_1 = 0 \quad B_2 = 300 \Rightarrow \frac{B_2}{z} = 12.5 \end{array} \right.$

$I_{AGEI} = 0.495$ $z = 24 + 60 = 84'$

$B_1 = 180' \Rightarrow \frac{B_1}{z} = 2.1$ $B_2 = 300' \frac{B_2}{z} = 4.5$

PDC TECHNICAL SERVICES, INC.

Project: CLI Expansion Siting Calculated By: G.A. Armstrong Sheet 10 of 15

Project No.: 91-0116.02 Task No.: Checked By: Date: 1-18-02

Uplift Force Calculations

Area	Volume Between Potentiometric Surface & Top of Aquifer (Ft^3 x 100)		Uplift Force (lbs)
A	10,379 cys	$\times 27 \frac{ft^3}{cy} \times 62.4 \frac{lbs}{ft^3}$	68,031,000
B	24,810		159,736,000
C	23,777		153,078,000
D	20,887		134,477,000
E	18,992.5		122,279,000
F	18,448.5		118,775,000
G	18,522.5		119,252,000
H	18,408		118,516,000
I	19,074		122,807,000
J	19,129		123,161,000
K	19,302.5		124,278,000
L	27,148		174,809,000

PDC TECHNICAL SERVICES, INC.

Project: TLI Expansion Calculated By: C.C Armstrong Sheet 11 of 15

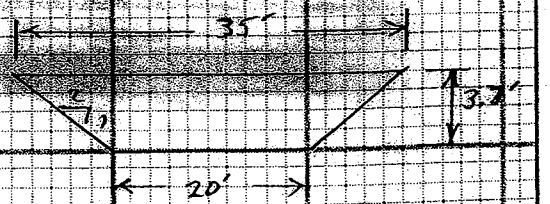
Project No.: 91-0118.02 Task No.: Checked By: Date:

Continuing Net Volume - Earth Layer In Place

Area		Volume = Top of Earth Layer Elevation - Top of Rock Elevation (FT)	Net Volume (FT³)
A	21,018 FT²	650,160	546,123
B	7,[illegible] FT²	1,[illegible]	[illegible]
C	68,706 FT²	1,450,870	1,448,633
D	58,784 FT²	1,427,685	1,425,588
E	60,088 FT²	1,439,667	1,437,650
F	61,944 FT²	1,465,236	1,463,199
G	63,[illegible] FT²	1,473,995	1,471,758
H	63,252 FT²	1,457,978	1,454,961
I	63,182 FT²	1,452,357	1,450,320
J	63,104 FT²	1,453,084	1,453,047
K	63,022 FT²	1,470,312	1,468,275
L	89,251 FT²	2,141,505	2,139,468

Net Volume = Volume - Lambie Collection Sump Volume

Lambie Collection Sump Volume =

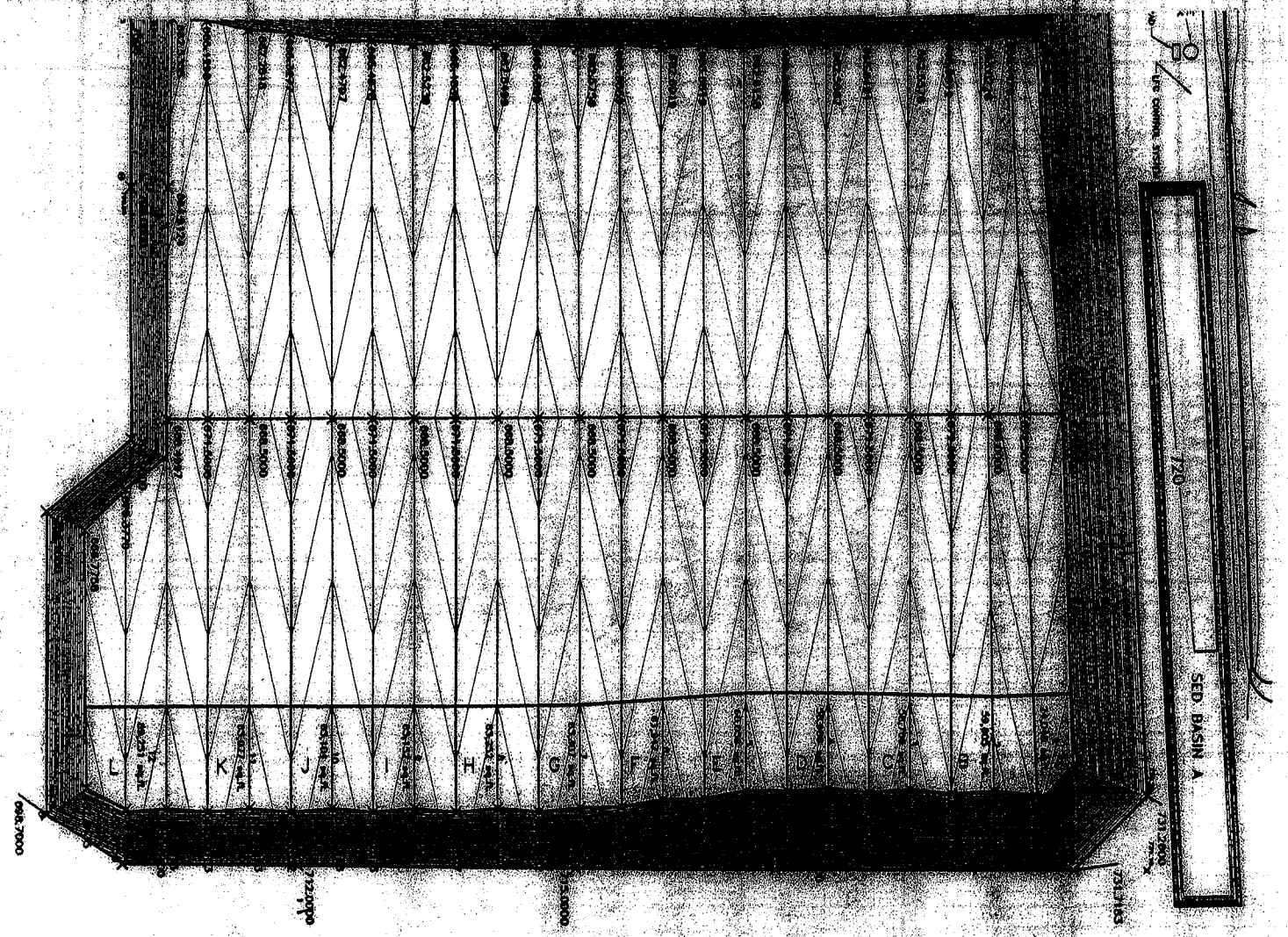


$$V = \frac{h}{3}\left[A_1 + A_2 + \sqrt{A_1 A_2}\right]$$

$$= \frac{3.7}{3}\left[20^2 + 35^2 + \sqrt{20 \times 35}\right]$$

$$= 2,037 \text{ FT}^3$$

CAD DWG NO:01110858 EMPLOYEE NO: 0536 DATE/TIME: 01/17/02 10:21:29 ACO-14.

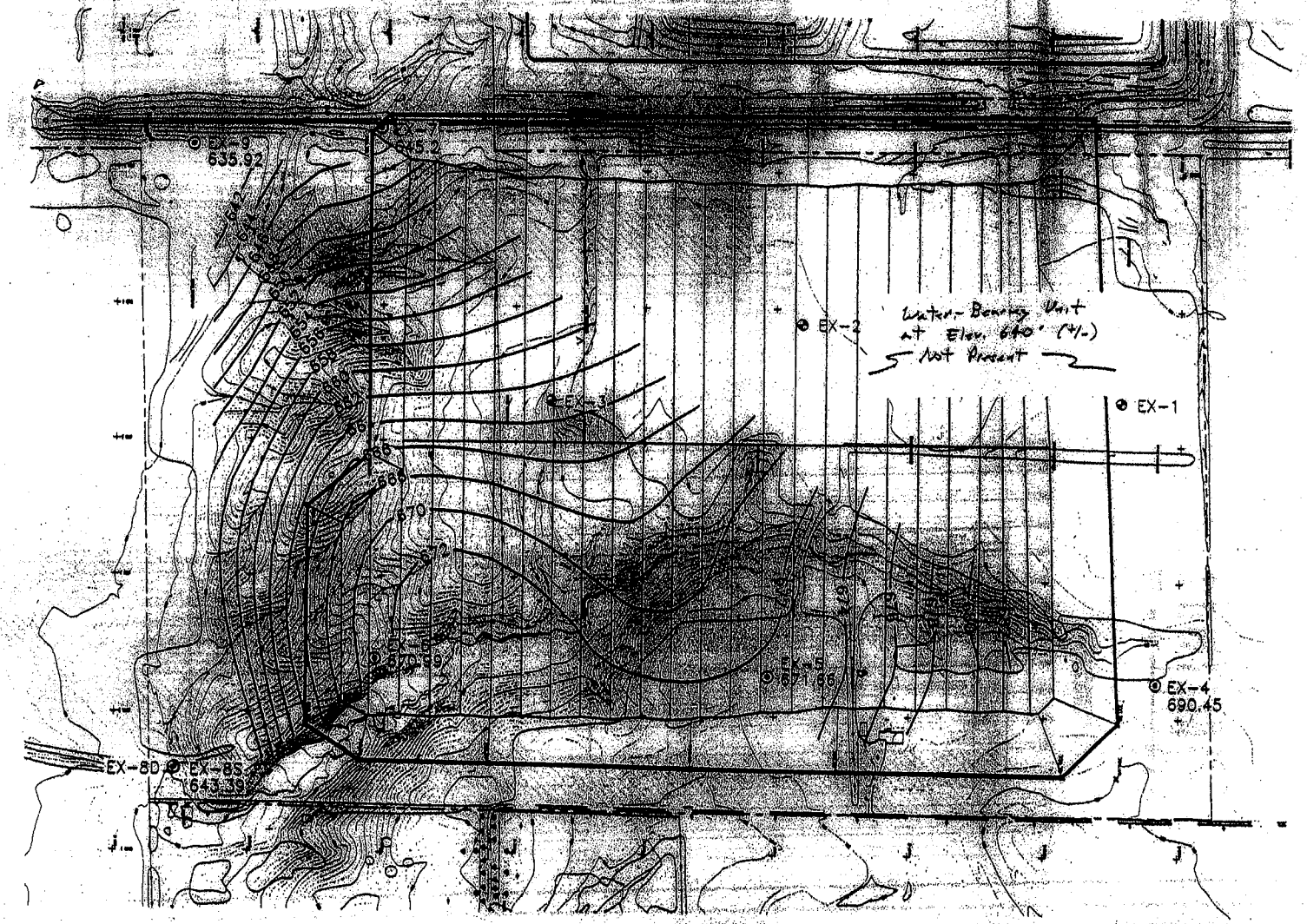


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PDC Technical Services, Inc.
pdc
Peoria, Illinois

FIGURE 1
AVERAGE THICKNESS B/N LF INVERT AND AQUIFER
CLINTON LANDFILL, INC.
CLINTON, IL
PROJECT NO.

CAD DWG NO:911185S5 EMPLOYEE NO: 8834 DATE/TIME: 11/21/01 11:04:51 ACD-14



LEGEND

- PIEZOMETER
- 670.99 POTENTIOMETRIC ELEVATION
- BORING
- —674— POTENTIOMETRIC CONTOUR LINE

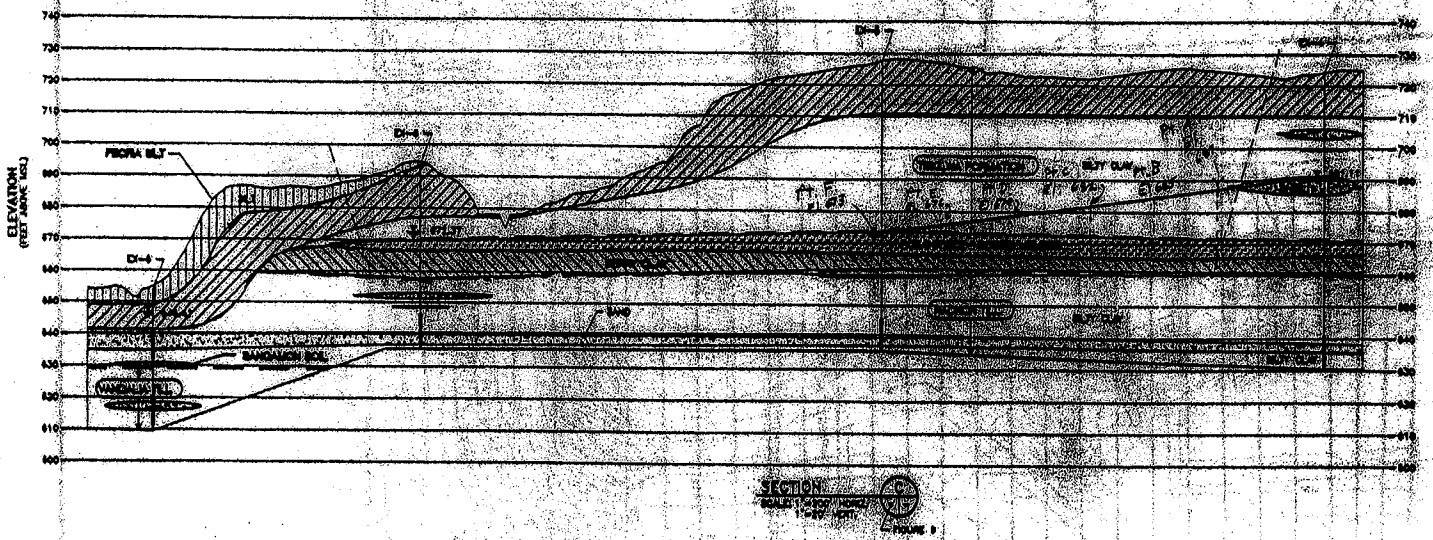
400' 200' 0 400' 800'

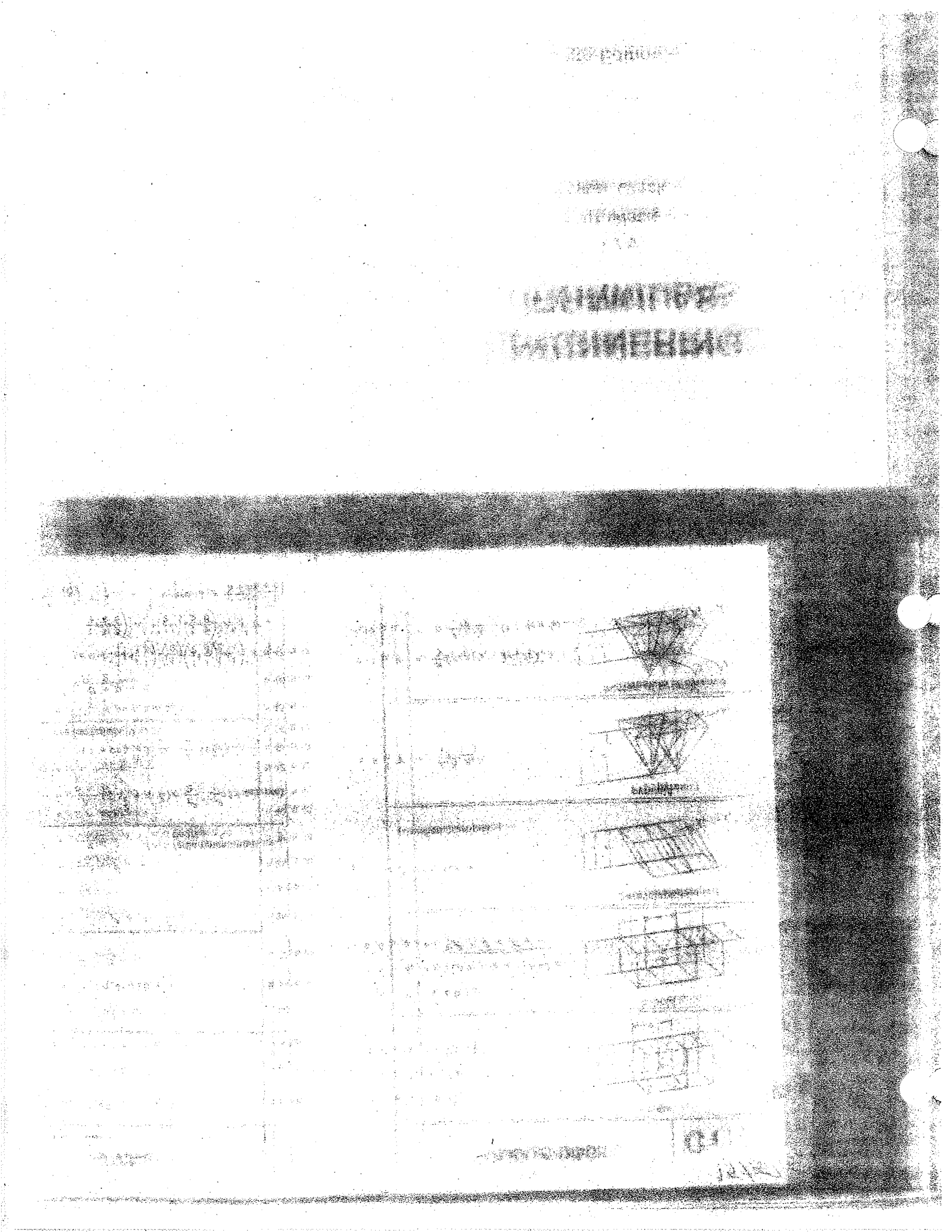
1"=400'

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Peoria, Illinois

POTENTIOMETRIC SURFACE VS. PROPOSED LANDFILL INVERT
CLINTON LANDFILL, INC.
CLINTON, ILLINOIS
PROJECT NO. 91-118


ELEVATION (FEET ABOVE MSL)
FIBRIA SILT
SILTY CLAY
SAND
BANDVILLE BOIL
VANDALIA TILL
SILTY CLAY
SAND
SILTY CLAY
SILTY CLAY
SILTY CLAY



15/15

AREAS

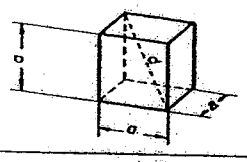
$A = \frac{\pi}{4} d^2 = \pi r^2$	b 30	
$\approx 0{\cdot}785\, d^2$	b 31	
$U = 2\pi r = \pi d$	b 32	
$A = \frac{\pi}{4}(D^2 - d^2)$	b 33	
$= \pi (d + b) b$	b 34	
$r = \frac{D - d}{2}$	b 35	
$A = \frac{\pi}{360^\circ} r^2 \alpha = \frac{\hat{\alpha}}{2} r^2$	b 36	
$= \frac{b r}{2}$	b 37	
$b = \frac{\pi}{180^\circ} r \alpha$	b 38	
$= \frac{\pi}{180^\circ} \alpha$ ($\hat{\alpha}$ in radian measure, α in degree)	b 39	
$= 2 r \sin\frac{\hat{\alpha}}{2}$	b 40	
$= \frac{h}{6a}(3h^2 + 4s^2) = \frac{r^2}{2}(\hat{\alpha} - \sin\alpha)$	b 41	
$= \frac{h}{2} + \frac{s^2}{8h}$	b 42	
$= r\left(1 - \cos\frac{\alpha}{2}\right) = \frac{s}{2}\tan\frac{\alpha}{4}$	b 43	
see formula b 39	b 44	
$= \frac{\pi}{4} D d = \pi a b$	b 45	
$\approx \pi \frac{D + d}{2}$	b 46	
$= \pi(a+b)\left[1 + \left(\frac{1}{2}\right)^2 \lambda^2 + \left(\frac{1}{2}\cdot\frac{1}{4}\right)^2 \lambda^4 + \left(\frac{1}{2}\cdot\frac{1}{4}\cdot\frac{3}{6}\right)^2 \lambda^6 + \left(\frac{1}{2}\cdot\frac{1}{4}\cdot\frac{3}{6}\cdot\frac{5}{8}\right)^2 \lambda^8 + \left(\frac{1}{2}\cdot\frac{1}{4}\cdot\frac{3}{6}\cdot\frac{5}{8}\cdot\frac{7}{10}\right) \lambda^{10} + \ldots\right]$, where $\lambda = \frac{a-b}{a+b}$	b 47	

SOLID BODIES

C 1

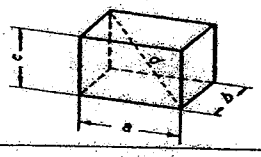
cube

c 1	$V = a^3$
c 2	$A_o = 6 a^2$
c 3	$d = \sqrt{3}\, a$



cubold

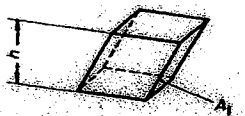
c 4	$V = a b c$
c 5	$A_o = 2(a b + a c + b c)$
c 6	$d = \sqrt{a^2 + b^2 + c^2}$



parallelepiped

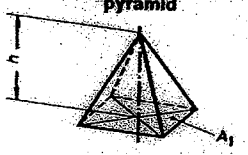
c 7	$V = A_1 h$

(Cavalieri principle)



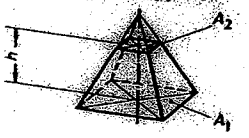
pyramid

c 8	$V = \frac{A_1 h}{3}$



frustum of pyramid

c 9	$V = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$
c 10	$= h \frac{A_1 + A_2}{2}$ (for $A_1 = A_2$)



ENGINEERING FORMULAS

by

Kurt Gieck

Reiner Gieck

Sixth Edition

APPENDIX 812.306-B: SIDEWALL LINER GEOSYNTHETIC MATERIAL STRESS CALCULATIONS

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PDC TECHNICAL SERVICES, INC.

Project: Clinton LF Expansion Calculated By: SMS Sheet 1 of 42

Project No.: 91-118.02 Task No.: Checked By: EJA Date: 01/14/02

Sidewall Liner Geosynthetic Material Stress Calculations

References: ① Waste Containment Systems (Sharma & Lewis, 1994)

② Designing with Geosynthetics, Koerner

③ "Exposed Geomembrane Covers: Part 1- Geomembrane Stress," (Richardson, 2000)

④ Final Covers for Solid Waste Landfills and Abandoned Dumps (Koerner and Daniel)

Geotextile Stresses – Prior to Placing Protective Soil Layer

① Force (Fw) per foot width due to self weight (W)



$F_w = W \sin\beta - f$

$W = \frac{H}{\sin\beta} \times t \times \gamma_{geotextile}$

t = Geotextile Thickness

γ = Geotextile unit weight

$t\gamma = 8 \frac{oz}{yd^2}$ (specified material property)

$= 0.0556 \frac{lbs}{ft^2}$

Max Slope height = 75.12'

$W = \frac{75.12}{\sin 18.4} \times 0.0556 \frac{lbs}{ft^3} = 13.2 \frac{lbs}{ft}$ width

δ = Geotextile and Geonet interface friction

Prior to waste placement [lab testing] → $\delta = 25°$, $c = 0$ psf

$f = W \cos\beta \tan\delta + c$ (Sharma & Lewis, eq. 8.11)

$= 13.2 \cos 18.4 \tan 25 = 5.8 \frac{lbs}{ft}$

$F_w = W \sin\beta - f = 13.2 \sin 18.4 - 5.8 = -1.6 \frac{lbs}{ft}$ → 4.2 ∴ No tension in geotextile

(2) Wind force (F wind) per foot width because of wind loading: wind velocities in attached article are for long-term exposure. However full length of sidewall liner will be exposed to wind loads for relatively short duration (2 mos. typically). Furthermore, any damage will occur prior to being covered with waste and should be readily apparent. Therefore, reduce design wind speed to 40 mph and inspect exposed sidewall liner for damage when windspeed exceeds 40 mph.

40 mph = 59 $\frac{ft}{sec}$

$S_e = 0.00124\ V^2 = 0.00124 V^2 = 4.32\ \frac{lb}{ft^2}$

$S_e \lambda = 4.32 \times 0.7$ (from attached article) $= 3.02\ \frac{lb}{ft^2}$

$\lambda = 0.7$

Assume geotextile is ballasted with sandbags @ 100' weight = $11.11 \times 0.005 = 0.056\ \frac{lb}{ft^2}$

$w = S_e w = 3.02 - 0.056 = 2.97\ \frac{lb}{ft^2}$

$L = 100'$

E = for geotextile (assume $65{,}000\ \frac{lb}{in^2} = 9.36 \times 10^6\ \frac{lb}{ft^2}$

$P = \left[\frac{2.97^2 \times 100^2 \times 9.36 \times 10^6 \times 0.00075}{24}\right]^{1/3} = 636.6\ \frac{lb}{ft}$

(geotextile thickness = 90 mil) $\rightarrow$ $A = \frac{90}{12} \times \frac{1}{1000} \times 1 = 0.00075\ ft^2$

(3) Thermal (This effect can be ignored based on phone conversation with Scott Bennett, Technical Support)

(4) Total design force

Short term peak = $636.6\ \frac{lb}{ft}$

long term peak = $0\ \frac{lb}{ft}$

(5) Factor of Safety against Failure

Allowable wide width Length Tensile Stress 75 lb/in

[Manufacturer's information]

Short term peak $F.S = \frac{75 \times 12}{636.6} = 1.4$ OK ✓

Long term peak $F.S = \frac{75 \times 12}{0} = \infty$ OK ✓

Geonet Stresses - Prior to Placing Protective Soil Layer

(1) Self weight

Fw Force per Foot width due to self weight

$w = \frac{H}{\sin\beta} \times t \times \gamma_{geonet}$ 0.162 lb/ft² (manufacturer info)

$w = \frac{75.12}{\sin 18.4} \times 0.162 = 38.55$ lb/ft

$F_w = w \sin\beta - [w \cos\beta \tan\delta + c]$ $L = w\cos\beta\tan\delta + c$

δ = Geonet - Geomembrane interface friction angle = 8°] Interface friction Test data

c = Apparent geonet-geomembrane cohesion = 65 psf

$F_w = 38.55(\sin 18.4 - \cos 18.4 \times \tan 8) - 65 = -58^0$ ⇒ No tension in geonet due to self weight

(2) Wind force and thermal effect can be neglected because lower end of the geonet will be free (not fixed).

(3) Factor of Safety against Failure

$F.S = \frac{75 \times 12}{0} = \infty$

Allowable Tensile Stress for geonet (according to manufacturer info = 45 lb/in

Geomembrane Stresses - Prior to Placing Protective Soil Layer

① Force per foot width due to self-weight

$F_W = w \sin\beta - f$

$w = \frac{H}{\sin\beta} \times \gamma_s \times \delta - \frac{75.12}{\sin 18.4} \times 0.005 \times (0.94 \times 62.4)$ ← manufacturer info for 60 mil HDPE

$w = 69.8 \frac{lb}{ft}$ width

$F_W = w \sin\beta - w \cos\beta \times \tan\delta - C$

δ = Geomembrane and Soil interface Friction angle

From lab data = 12° $C = 185$ psf

$F_W = 69.8(\sin 18.4 - \cos 18.4 \times \tan 12) - 185 = -117.0 \frac{lb}{ft}$ ⇒ No tension in geomembrane

② Thermal forces (Ft) per foot width due to Temperature change $\Delta T = 40°F$

[Geomembrane installation Specifications will require sufficient slack be placed for 40°(F) temperature differential. However to be conservative, design for another additional 40° temperature differential

assuming $E = 61{,}000 \frac{lb}{in^2}$ (from Koerner)

Coefficient of thermal expansion = $6.7 \times 10^{-5} \frac{in}{in°}$ ← manufacturer info Tab. Note #3

$\varepsilon_L = \frac{\Delta L}{L} = \mu \Delta T$

$= 40 \times 6.7 \times 10^{-5} = 0.268\%$ $\left(\frac{in}{in}\right)$

$\sigma = E\varepsilon = 61{,}000 \frac{lb}{in^2} \times 0.00268 = 163.48 \frac{lb}{in^2}$

$F_t = \sigma \times A = 163.48 \times \frac{144 in^2}{ft^2} \times \frac{0.06}{12} = 117.71 \frac{lb}{ft}$

PDC TECHNICAL SERVICES, INC.

Project: Clinton LF Expansion area Calculated By: SMS Sheet 5 of 42

Project No.: 91-118.02 Task No.: Checked By: ZA Date: 01/14/02

(3) Wind force (F Wind)

$w = \frac{3.02}{S_e} - \frac{0.29}{\text{Wt. (geomembrane)}} = 2.73 \frac{lb}{ft}$

Assume geomembrane is ballasted (with sand bags) every 100'

$P = \left[\frac{w^2 \Delta\ell^2 \times E \times A}{24}\right]^{1/3}$

$P = \left[\frac{2.73^2 \times 100^2 \times 28{,}110 \times 0.005}{24}\right]^{1/3}$

$P = 5.14 \frac{lb}{ft}$

Wt. $= \frac{0.005 \times 0.94 \times 62.4 \times 0.2}{\left(0.06'' \times \frac{1\,ft}{12''}\right)}$

$E = 61{,}000 \frac{lb}{in^2} \times \frac{6}{} = 28{,}110 \frac{lb}{ft^2}$

(4) Total design force = $0 \frac{lb}{ft} + 717.71 \frac{lb}{ft} + 5.14 \frac{lb}{ft} = 631.71 \frac{lb}{ft}$

(5) Tensile stress at yield = $126 \frac{lb}{in} = 1512 \frac{lb}{ft}$ (Manufacturer's spec)

(6) Factor of safety $= \frac{1512}{631.71} = 2.4$ OK ✓

Calculated by: SMS

Checked by: GA

SIDEWALL PROTECTIVE SOIL STABILITY / GEOSYNTHETIC MATERIAL STRESSES FOLLOWING PLACEMENT OF PROTECTIVE SOIL COVER AND PRIOR TO WASTE PLACEMENT

Protective Cover Soil vs. Geotextile

Clinton Landfill Expansion Siting

References: 1. ***Final Covers for Solid Waste Landfills and Abandoned Dumps***
Koerner and Daniel, 1997

2. Interface friction specifications and test data

Earth Material Parameters

Total unit weight of soil:	gamma(t) =	110 pcf	
Saturated unit weight of soil:	gamma(sat) =	120 pcf	
Unit weight of water:	gamma(w) =	62.4 pcf	
Soil friction angle:	phi =	0 degrees	0.00 radians
Soil cohesion:	c =	190 psf	
Psuedo-static seismic coefficient:	C(s) =	(varies by analysis case)	
Minimum interface: friction angle:	delta =	24 degrees	0.42 radians
adhesion:	c(a) =	0 psf	
Allowable geosynthetic tension:	T =	(varies by analysis case)	

Slope Design Parameters

Soil cover thickness:	h =	3.0 feet
Seepage water thickness:	h(w) =	0.0 feet
Slope height:	H =	75.1 feet
Slope gradient:	Slope =	3.0 horizontal
		1.0 vertical
	beta =	18.4 degrees
Slope length:	L =	237.5 feet

Equations

Interwedge Force Acting on Active Wedge:

$$E(a) = \frac{1}{\cos(beta)} \times [(U(n) + N(A)) \times \sin(beta) + C(s) \times W(A) - ((N(A) \times \tan(delta) + C(a) + T) \times \cos(beta)) / FS)] - U(h)]$$

(Eq. 5.51)
(modified to account for seepage parallel to slope and geosynthetic tension)

Interwedge Force Acting on Passive Wedge:

$$E(p) = \frac{C + (W(p) - U(v)) \times \tan(phi) - (FS \times (U(h) + C(s) \times W(p)))}{FS \times \cos(beta) - (\sin(beta) \times \tan(phi))}$$

(Eq. 5.53)
(modified to account for seepage parallel to slope)

For given slope, soil strength, seismic coeff., geosynthetic tension and interface friction parameters, the Factor of Safety against instability can be solved by equating the interwedge force acting on the active wedge (E(a)) with that acting on the passive wedge (E(p)).

Therefore, set: E(a) - E(p) = 0

$$W(A) = gamma(t) \times [\frac{H \times (h - h(w))}{\sin(beta)} - \frac{(h - h(w))^2 \times \sin(beta)}{2 \times \cos(beta)}] + gamma(sat) \times [\frac{H \times h(w)}{\sin(beta)} - \frac{h(w)^2 \times \sin(beta)}{2 \times \cos(beta)}]$$

(Eq. 5.3)
(modified to account for saturation)

Calculated by: SMS

Checked by: GA

$$U(v) = U(h) \times \cot(\beta) \qquad \text{(Eq. 5.44)}$$

$$U(h) = \frac{\gamma(w) \times (h(w))^2}{2} \qquad \text{(Eq. 5.49)}$$

$$N(A) = W(A) \times \cos(\beta) + U(h) \times \sin(\beta) - U(n) \qquad \text{(Eq. 5.41)}$$

$$U(n) = \frac{\gamma(w) \times h(w) \times \cos(\beta) \times (2 \times H \times \cos(\beta) - h(w))}{\sin(2 \times \beta)} \qquad \text{(Eq. 5.48)}$$

$$W(p) = \frac{\gamma(t) \times (h^2 - h(w)^2) + \gamma(sat) \times h(w)^2}{\sin(2 \times \beta)} \qquad \text{(Eq. 5.50)}$$

$$C(a) = c(a) \times (L - (h / \sin(\beta))) \qquad \text{(Eq. 5.5)}$$

$$C = \frac{c \times h}{\sin(\beta)} \qquad \text{(Eq. 5.10)}$$

Intermediate Equation Solutions

W(A) =	78,206	W(p) =	1,650.0
N(A) =	74,192	U(h) =	0.00
U(v) =	0.0	C(a) =	0.0
U(n) =	0	C =	1,802.5

SLOPE STABILITY - STATIC, LONG-TERM

Assumptions:

C(s) = 0.00

T = 0 lbs / foot ← No tensile stresses in geosynthetics.

Solution:

E(a) = 1,345.1

E(p) = 1,345.1

E(a) - E(p) = 0.0

FACTOR OF SAFETY = 1.41 > 1.3 OK

SLOPE STABILITY - SEISMIC

Assumptions:

C(s) = 0.072

T = 0 lbs / foot ← No tensile stresses in geosynthetics

Solution:

E(a) = 1,549.5

E(p) = 1,549.5

E(a) - E(p) = 0.0

FACTOR OF SAFETY = 1.13 > 1.0 OK.

Calculated by: SMS

Checked by: CLA

SIDEWALL PROTECTIVE SOIL STABILITY / GEOSYNTHETIC MATERIAL STRESSES FOLLOWING PLACEMENT OF PROTECTIVE SOIL COVER AND PRIOR TO WASTE PLACEMENT

Geomembrane vs. Geonet

Clinton Landfill Expansion Siting

References: 1. ***Final Covers for Solid Waste Landfills and Abandoned Dumps***
Koerner and Daniel, 1997

2. Interface friction specifications and test data

Earth Material Parameters

Total unit weight of soil:	gamma(t) =	110 pcf	
Saturated unit weight of soil:	gamma(sat) =	120 pcf	
Unit weight of water:	gamma(w) =	62.4 pcf	
Soil friction angle:	phi =	0 degrees	0.00 radians
Soil cohesion:	c =	190 psf	
Psuedo-static seismic coefficient:	C(s) =	(varies by analysis case)	
Minimum interface: friction angle:	delta =	8 degrees	0.14 radians
adhesion:	c(a) =	65 psf	
Allowable geosynthetic tension:	T =	(varies by analysis case)	

Slope Design Parameters

Soil cover thickness:	h =	3.0 feet
Seepage water thickness:	h(w) =	0.0 feet
Slope height:	H =	75.1 feet
Slope gradient:	Slope =	3.0 horizontal
		1.0 vertical
	beta =	18.4 degrees
Slope length:	L =	237.5 feet

Equations

Interwedge Force Acting on Active Wedge:

$$E(a) = \frac{1}{\cos(beta)} \times [(U(n) + N(A)) \times \sin(beta) + C(s) \times W(A) - ((N(A) \times \tan(delta) + C(a) + T) \times \cos(beta)) / FS)] - U(h)]$$

(Eq. 5.51)
(modified to account for seepage parallel to slope and geosynthetic tension)

Interwedge Force Acting on Passive Wedge:

$$E(p) = \frac{C + (W(p) - U(v)) \times \tan(phi) - (FS \times (U(h) + C(s) \times W(p)))}{FS \times \cos(beta) - (\sin(beta) \times \tan(phi))}$$

(Eq. 5.53)
(modified to account for seepage parallel to slope)

For given slope, soil strength, seismic coeff., geosynthetic tension and interface friction parameters, the Factor of Safety against instability can be solved by equating the interwedge force acting on the active wedge (E(a)) with that acting on the passive wedge (E(p)).

Therefore, set: E(a) - E(p) = 0

$$W(A) = gamma(t) \times \left[\frac{H \times (h - h(w))}{\sin(beta)} - \frac{(h - h(w))^2 \times \sin(beta)}{2 \times \cos(beta)}\right] + gamma(sat) \times \left[\frac{H \times h(w)}{\sin(beta)} - \frac{h(w)^2 \times \sin(beta)}{2 \times \cos(beta)}\right]$$

(Eq. 5.3)
(modified to account for saturation)

Calculated by: SMS

Checked by: GLA

$$U(v) = U(h) \times \cot(\beta) \qquad \text{(Eq. 5.44)}$$

$$U(h) = \frac{\gamma_w \times (h_w)^2}{2} \qquad \text{(Eq. 5.49)}$$

$$N(A) = W(A) \times \cos(\beta) + U(h) \times \sin(\beta) - U(n) \qquad \text{(Eq. 5.41)}$$

$$U(n) = \frac{\gamma_w \times h_w \times \cos(\beta) \times (2 \times H \times \cos(\beta) - h_w)}{\sin(2 \times \beta)} \qquad \text{(Eq. 5.48)}$$

$$W(p) = \frac{\gamma_t \times (h^2 - h_w^2) + \gamma_{sat} \times h_w^2}{\sin(2 \times \beta)} \qquad \text{(Eq. 5.50)}$$

$$C(a) = c(a) \times (L - (h / \sin(\beta))) \qquad \text{(Eq. 5.5)}$$

$$C = \frac{c \times h}{\sin(\beta)} \qquad \text{(Eq. 5.10)}$$

Intermediate Equation Solutions

W(A) =	78,206	W(p) =	1,650.0
N(A) =	74,192	U(h) =	0.00
U(v) =	0.0	C(a) =	14,820.0
U(n) =	0	C =	1,802.5

SLOPE STABILITY - STATIC, LONG-TERM

Assumptions:

C(s) = 0.00

T = 0 lbs / foot → No tensile stresses in geosynthetic

Solution:

E(a) = 944.4

E(p) = 944.4

E(a) - E(p) = 0.0

FACTOR OF SAFETY = 2.01 > 1.3 OK

SLOPE STABILITY - SEISMIC

Assumptions:

C(s) = 0.07

T = 0 lbs / foot → No tensile stresses in geosynthetic

Solution:

E(a) = 1,050.7

E(p) = 1,050.7

E(a) - E(p) = 0.0

FACTOR OF SAFETY = 1.62

Geosynthetic Stresses Following Waste Placement

Calculate the strain in the sidewall liner geosynthetics due to differential settlement of Landfill foundation.

(Reference page 7 of settlement calculations.

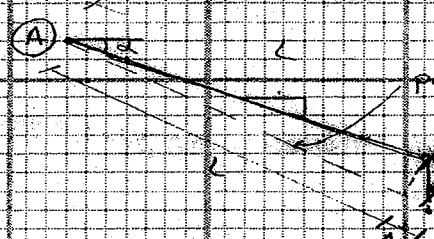
Strain Between Landfill Edge and Landfill Floor Edge (Points A and B)

(This is the critical case)

Total Settlement: point A = 0.0846

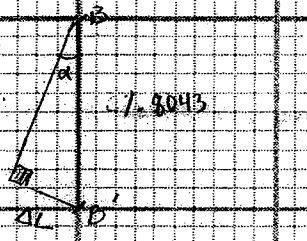
" B = 1.1353

Differential Settlement = 1.1353 − 0.0846 = 1.0507



For Simplicity assume:

$\Delta L = 1.0507 \times \sin 18.4 = 0.3317$



L varies, but is minimum at SW corner where LF edge is at Elev. 699' and LF invert is at Elev. 660'

At this point $L_{min} = \frac{699 - 660}{\sin \alpha} = 124$

$\text{Max strain} = \frac{\Delta L}{L_{min}} = \frac{0.3317}{124} = 0.1675\%$

PDC TECHNICAL SERVICES, INC.

Project: Clinton Landfill Expansion Calculated By: SMS Sheet 11 of 42

Project No.: 91-118.02 Task No.: 20001 Checked By: GCA Date: 11/09/01

Geomembrane Strain

Industry standard 60 mil geomembrane elongation at yield = 12% (GRI GM-13)

Therefore, factor of safety of reaching yield strain

$$= \frac{12\%}{0.27\%} = 44.4 \text{ ; Acceptable}$$

Geomembrane Stress

$\sigma = E \times \epsilon$

E = Modulus of Elasticity = 61,000 $\frac{lb}{in^2}$ for HDPE

$\epsilon = 2.7 \times 10^{-3}$

$\sigma = 2.7 \times 10^{-3} \times 61{,}000 = 164.7 \frac{lb}{in^2}$

Tensile force = 164.7×0.06 (thickness) $= 9.8 \frac{lb}{in}$

Factor of safety of overstressing geomembrane

$$= \frac{\text{Tensile strength}}{\text{Tensile force (yield)}}$$

Tensile Strength = 126 $\frac{lbs}{in}$ } Typical Material Specifications

Tensile Strength (break) = 228 $\frac{lbs}{in}$

Factor of safety against yield = $\frac{126}{9.8} = 12.9$ OK ✓

Factor of safety against break = $\frac{228}{9.8} = 23.3$ OK ✓

Geotextile Strain

Grab elongation = 50% (Manufacturer's material spec.)

→ Factor of safety against reaching maximum strain = $\frac{50\%}{0.27\%}$

$= 185.2$ ∴ OK

Geotextile Stress

$\sigma = E \times \epsilon$

E = Modulus of Elasticity = 65,000 $\frac{lb}{in^2}$ for Geotextile

$\epsilon = 2.7 \times 10^{-3}$

$\sigma = 2.7 \times 10^{-3} \times 65{,}000 = 175.5 \frac{lb}{in^2}$ ← thickness =

Tensile force $= 175.5 \times 0.09 = 15.8 \frac{lb}{in}$

F.S. against overstressing geotextile $= \frac{\text{Tensile Strength (yield)}}{\text{Tensile force}} = \frac{75 \text{ lb/in}}{15.8 \text{ lb/in}} = 4.8$ OK ✓

$= \frac{\text{Tensile strength (break)}}{\text{Tensile force}} = \frac{95 \text{ lb/in}}{15.8 \text{ lb/in}} = 6.01$ OK ✓

Tensile Strength (yield) = 75 lb/in } Typical Material
" " (break) = 95 " } Specifications

Geonet Strain / Strain

Geonet will not be fixed at bottom ∴ no strain will be induced in the geonet due to settlement.

INTERFACE FRICTION TEST SUMMARY
Clinton Landfill Expansion
Testing conducted by Precision Analytical Laboratories, March, April, May, and September 2001

Description	Normal Stress (psf)	Shear Stress (psf) Peak	Shear Stress (psf) Residual	Design Phi	Design C (psf)
Final Cover Components					
Final cover soil vs. Smooth HDPE	250	218	206	28	65
	350	278	262		
	450	339	316		
Liner Floor Components					
LCS Sand vs. Smooth HDPE	5000	2427	1940	16	0
	7500	3164	2134		
	10000	4300	2860		
Sidewall Liner - Prior to Waste Placement					
Protective cover soil vs. Geotextile	250	198	168	24	0
	350	210	175		
	450	328	310		
Geotextile vs. Geonet	250	181	149	25	0
	350	216	171		
	450	286	226		
Geomembrane vs. Geonet	100	96	81	8	65
	275	136	125		
	450	160	135		
Sidewall Liner - Following Waste Placement					
Geotextile vs. Geonet	2500	719	610	14	0
	5000	1351	1183		
	8000	2600	1975		
Geonet vs. Smooth HDPE	2500	622	622	11	110
	5000	1102	1070		
	8000	1702	1683		
Clay liner soil vs. Smooth HDPE	2500	1072	748	12	185
	5000	1765	1288		
	8000	2651	1950		

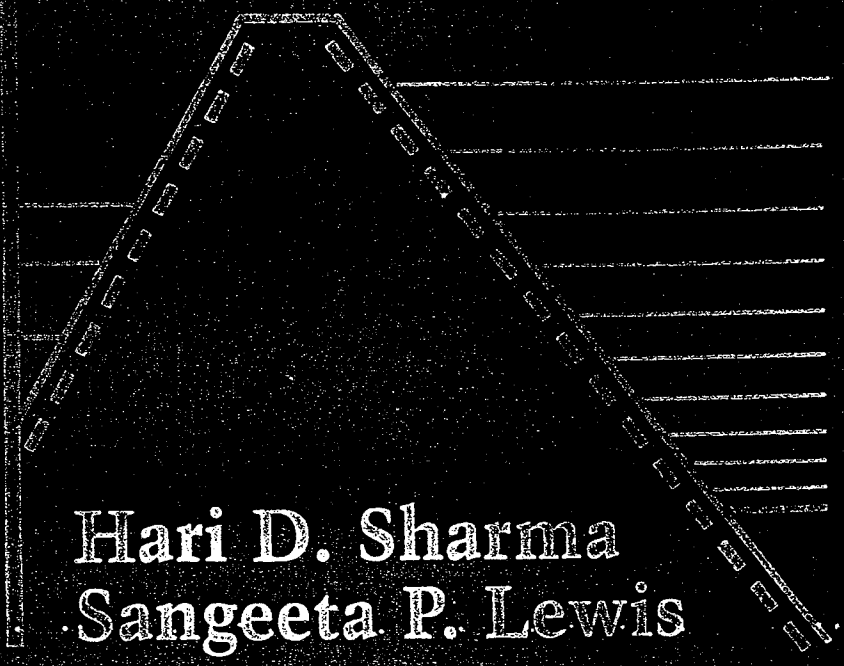
INTERFACE FRICTION TEST SUMMARY
Clinton Landfill Expansion
Testing conducted by Precision Analytical Laboratories, March, April, May, and September 2001

Description	Normal Stress (psf)	Shear Stress (psf)		Design	
		Peak	Residual	Phi	C (psf)
Clay liner soil vs. Geotextile	2500	1598	1528	24	380
	5000	2612	2582		
	8000	4112	3990		

15/42

Waste Containment Systems, Waste Stabilization, and Landfills

Design and Evaluation



Hari D. Sharma
Sangeeta P. Lewis

may then be compensated for in the base liner grades so that gravity drainage of the LCRS may be maintained.

8.3.2.2 Geomembrane Puncture. The compression loads imposed by refuse on the containment lining system can cause granular drainage material in the LCRS to push into and potentially puncture an underlying geomembrane liner. As discussed in Chapter 3 this can be mitigated to some extent by placing a geotextile cushion over the geomembrane. However, the benefit of the increased puncture resistance must be weighed against the potential stability concerns caused by the low interface strength between geomembranes and geotextiles. Whether or not a geotextile cushion is used, a well-rounded granular drainage material should be specified. This will reduce the potential puncture concerns.

There is no widely used standard equation for evaluating the required puncture resistance of a geomembrane. This is due to the relatively complex puncture mechanisms illustrated in Figure 3.22 and due to the variability in dimensions and angularity of materials that may puncture a geomembrane at any given site. There is also no current method available to relate the majority of laboratory puncture-resistance tests to field conditions due to the relatively small laboratory sample sizes, the atypical standard probe dimensions, and the fact that the tests are run independent of soil (Montalvo and Sickler, 1993). The laboratory puncture-resistance tests do, however, provide a relative measure of the puncture resistance for different geomembranes.

The one laboratory test that may provide the designer with a method for evaluating geomembrane puncture is the multiaxial burst test discussed in Chapter 3. In this test the actual field conditions may be simulated to assess the geomembrane's puncture resistance. The performance of the geomembrane in the multiaxial burst test may then be related to the geomembrane's index puncture resistance value to allow appropriate material specification. The multiaxial burst test procedure is not yet standardized, however, and further research is required prior to using the test as a standard (Motan et al., 1993).

8.3.2.3 Geomembrane Self-Weight. The thickness and associated tensile strength of a geomembrane must be large enough to support its self-weight on a side slope without yielding. This is generally not a problem on most slopes, but should be checked for very steep slopes. To check this, the free-body diagram shown on Figure 8.12 may be used assuming a unit strip of geomembrane. Equation (8.9) may be used to calculate the applied tensile stress.

$$\sigma_{TA} = \frac{W \sin \beta - F}{1 \times t} \tag{8.9}$$

where

$$W = SG \cdot \gamma_w \, t \frac{1 \times H}{\sin \beta} \tag{8.10}$$

and

$$F = W \cos \beta \tan \delta \tag{8.11}$$

and where σ_{TA} = applied tensile stress
W = geomembrane weight
β = slope
F = interface frictional strength between geomembrane and underlying material
SG = specific gravity of geomembrane
γ_w = unit weight of water
t = geomembrane thickness
H = slope height
δ = interface friction angle between geomembrane and underlying material
A = cross-sectional area of unit strip of geomembrane $= 1 \times t$

The yield stress of the geomembrane obtained from wide-width tensile tests is then divided by the applied tensile stress to obtain the factor of safety. A factor of safety greater than 1 is acceptable; typical factors of safety range from 10 to 100 (Koerner and Richardson, 1987).

8.3.2.4 Downdrag. A good example of how minimizing stresses on the geomembrane and treating the liner as a system prevents geomembrane failure is the issue of downdrag stresses imposed on a side-slope geomembrane due to waste settlement. These stresses are difficult to quantify due to the variable settlement rate of refuse and its inherent heterogeneity; however, there does not appear to be a problem at slopes flatter than 3:1 (Von Pein and Prasad, 1990). Rather than an analytical solution to the problem, a physical solution may be utilized to prevent the transfer of downdrag stresses to the geomembrane. This is achieved by reducing

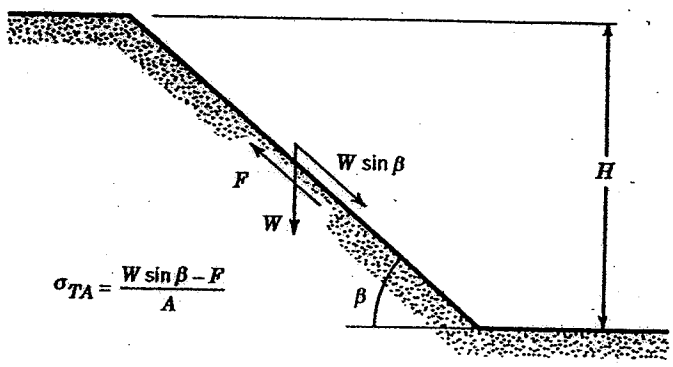


Figure 8.12 Free-body diagram for geomembrane self-weight calculations.

18/42

Third Edition

Designing with Geosynthetics

Robert M. Koerner, Ph.D., P.E.
H. L. Bowman Professor of Civil Engineering
and Director, Geosynthetic Research Institute
Drexel University



Prentice Hall
Englewood Cliffs, New Jersey 07632

Table 5.5 Tensile behavior properties of 60-mil HDPE, 40-mil VLDPE, 30-mil PVC, and 36-mil CSPE-R

		Index Tension Tests (Figure 5.2)				*Wide-Width Tension Tests (Figure 5.3)*				*Axi-Symmetric Tension Tests (Figure 5.5)*			
Test Property	*Units*	*HDPE*	*VLDPE*	*PVC*	*CSPE-R*	*HDPE*	*VLDPE*	*PVC*	*CSPE-R*	*HDPE*	*VLDPE*	*PVC*	*CSPE-R*
Maximum stress	(lb./in.²)	2700	≈1200	3000	7900	2300	≈1100	2000	4500	3400	1500	2100	4500
	(MPa)	19	8	21	55	16	8	14	31	23	10	15	31
Corresponding strain	(%)	17	500+	480	19	15	400+	210	23	12	75	100	13
Modulus	(lb./in.²)	48,000	11,000	4500	48,000	61,000	10,000	2900	43,000	105,000–	24,000–	15,000–	50,000–
	(MPa)	330	76	31	330	450	69	20	300	720–	170–	100–	350–
Ultimate stress	(lb./in.²)	≈2000	≈1200	3000	830	≈1600	≈1100	2000	410	3400	1500	2100	4500
	(MPa)	14	8	21	6	11	8	14	3	23	10	15	31
Corresponding strain	(%)	500+	500+	480	110	400+	400+	210	79	25	75	100	13

Note: + = did not fail;
– = values felt to be high.

Serrot Technical Note – #3

Coefficient of Expansion

Compensation for Thermal Expansion of HDPE Geomembranes

The Linear Coefficient of thermal expansion of Serrot's HDPE geomembrane is approximately 6.7×10^{-5} in/in°F. For a 100 foot length of HDPE liner, thermal expansion or contraction is approximately 0.8 inches per 10°F change in temperature. Accordingly, in order to eliminate "trampolining" or excess tension in an HDPE liner, 0.8 inches of slack should be built into an installation for every 10°F expected maximum reduction in temperature for every 100 feet of liner.

The best way to determine if enough slack has been incorporated into the liner is to evaluate the condition of the liner early in the morning before the sun has a chance to warm the liner. Calculate the amount of slack it is necessary to add with the following equation:

$$S_n = [(T-T_1)/10)0.8]\,[L/100]-S_e$$

or

$$S_n = [(T-T_1)6.7 \times 10^{-5}](L)(12)-S_e$$

Where:
- S_n = The amount of additional required slack in inches
- T = The current temperature of the liner in °F
- T_1 = The lowest temperature the liner is expected to experience
- L = The length of the liner in feet (length or width of installation)
- S_e = The amount of slack already in the liner in inches

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Toll Free: 800-237-1777 www.serrot.com

Serrot Technical Note – #11

Geonet Tensile Testing

Currently, there is no standard test method for determining geonet tensile strength. Most project specifications reference either of two geotextile tensile test methods; ASTM D 1682 or ASTM D 5035. Both of these test methods are virtually identical. However, Serrot International Inc. tests its Poly-Net® geonet per ASTM D 5035 with certain modifications. These modifications affect specimen size, testing speed and gage length.

	ASTM D 1682[1]	ASTM D 5035	ASTM D 5035 (as modified by Serrot)
Specimen Size	1" or 2" width	1" or 2" width	4" width
Test Speed	12 in/min	12 in/min	8 in/min
Gage Length	3 inches	3 inches	4 inches

1 –ASTM discontinued this test in 1992.

Serrot's modification arose from the need to decrease the variability in test results inherent in the existing geotextile test when applied to geonet. The number of strand intersections or "nodes" included in the test specimen influence tensile strength. A laboratory technician preparing geonet tensile specimens should ensure the same number of nodes for each specimen. Unfortunately, it is relatively easy to include variable number of nodes in a series of one or two inch test specimens.

Serrot's technical group evaluated a variety of specimen sizes, test speeds and gage lengths. It was determined that using the four-inch wide specimen, four-inch gage length and eight inch per minute test speed resulted in more reproducible test results than any other combination.

The wider test specimen tended to include the same number of nodes no matter how the cutting die was placed on the material. In addition, if there was a one-node difference between specimens, the influence on tensile strength was less for a 4-inch wide specimen versus a 2-inch wide specimen.

The slower test speed produced more consistent results. The greater distance between the grips at the start of the test had little influence on test results but is consistent with geonet/geotextile composite test methods using the same size test specimen and speed.

Serrot developed this modification in 1989 and re-evaluated the test method in 1992 and again in 2000. Below is a comparison of values from the latest evaluation, generated from a single roll of Poly-Net® PN3000 chosen at random.

	ASTM D 5035 (as modified by Serrot)	ASTM D 5035
Average:	79 lbs./inch-width	73 lbs./inch-width
Standard Deviation:	3.5 lbs./inch-width	5.3 lbs./inch-width
Coefficient of Variation:	4.4%	7.3%

Although the average tensile strength values are quite close, there is a significant difference in the coefficient of variation due to the greater scatter in data (i.e. larger standard deviation) for the D 5035 method. Clearly, the Serrot modified test method results in more reproducible data. Reproducible data reduces the likelihood of a third party laboratory rejecting conforming material due to statistical scatter.

(Serrot International, Inc. reserves the right to update the information contained herein or modify the product in accordance with technological advances.)

The information contained herein has been compiled by Serrot International, Inc. and is, to the best of our knowledge, true and accurate. This information is offered without warranty. Final determination of suitability for use contemplated is the sole responsibility of the user. This information is subject to change without notice. TN 011 4/17/01

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Specifications

English

POLY-NET® Geonet

POLY-NET is a profiled geonet manufactured by extruding two sets of polyethylene strands to form a diamond shape drainage material. The resulting net provides superior planar water flow, is inert to biological attack, naturally encountered chemicals, alkalis and acids and is resistant to UV light exposure.

Property	Test Method	Frequency	PN2000[1]	PN3000CN[1]	PN3000[1]	PN5000[1]
Density (g/cm³)	D1505	Batch	0.94	0.94	0.94	0.94
Carbon Black Content (%)	D4218	4 per batch	2.0	2.0	2.0	2.0
Thickness (mils)	D5199	40,000 SF	160	200	200	250
Mass per Unit Area (lbs/ft²)	D5261	40,000 SF	0.100	0.140	0.162	0.200
Tensile Strength (lb/in) (Machine Direction)	D5035 Modified	40,000 SF	30	32	45	50
Transmissivity[2] (m^2/sec)	D4716	Shift	1×10^{-3}	1×10^{-3}	1×10^{-3}	1.5×10^{-3}
• Hydraulic Gradient			1.0	1.0	1.0	1.0
• Confining Stress (psf)			2,000	4,000	15,000	15,000

[1]These values represent minimum average test values for a typical roll. Individual test specimen values are not addressed in this specification.
[2]Measured in the machine direction between two steel plates one hour after application of the confining pressure.

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GEOTEX™ 861 Nonwoven Geotextile

GEOTEX 861 is a polypropylene, staple fiber, needlepunched nonwoven geotextile manufactured at one of Synthetic Industries' facilities that has achieved ISO-9002 certification for its systematic approach to quality. The fibers are needled to form a stable network that retains dimensional stability relative to each other. The geotextile is resistant to ultraviolet degradation and to biological and chemical environments normally found in soils. GEOTEX 861 conforms to the property values listed below[1] which have been derived from quality control testing performed by one of Synthetic Industries' GAI-LAP accredited laboratories:

PROPERTY	TEST METHOD	MINIMUM AVERAGE ROLL VALUES[2] *English*	*Metric*
Mechanical			
Grab Tensile Strength	ASTM D4632	220 lbs	975 N
Grab Elongation	ASTM D4632	50%	50%
Puncture Strength	ASTM D4833	135 lbs	600 N
Mullen Burst	ASTM D3786	420 psi	2895 kPa
Trapezoidal Tear	ASTM D4533	95 lbs	420 N
Hydraulic			
Apparent Opening Size (AOS)	ASTM D4751	80 US Std Sieve	0.180 mm
Permittivity	ASTM D4491	1.50 sec^{-1}	1.50 sec^{-1}
Permeability	ASTM D4491	0.38 cm/sec	0.38 cm/sec
Water Flow Rate	ASTM D4491	110 gpm/ft^2	4480 l/min/m^2
Physical			
Mass Per Unit Area	ASTM D5261	8.0 oz/sy	270 gr/m^2
Endurance			
UV Resistance (% retained after 500 hours)	ASTM D4355	70%	70%

90 mil

NOTES:

Thickness 90 mil

1 **The property values listed above are effective 4/28/97 and are subject to change without notice.**
2 **Values shown are in weaker principal direction. Minimum average roll values are calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken during quality assurance testing will exceed the value reported.**

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This is to certify that Product GEOTEX 861 , a nonwoven polypropylene geotextile produced by Synthetic Industries, will meet the following certifiable minimum average values when tested in accordance with the proper ASTM test methods. A minimum average roll value is calculated as the mean minus two standard deviations, yielding a 97.5 percent confidence level. This geotextile has been continuously inspected for the presence of needles and none were detected.

Physical Property	Test Method		MARV	SI Unit
Wide Width Tensile (min):	ASTM D-4595	lb-in / kN-m	75	(13.14)
Wide Width Tensile XMD:	ASTM D-4595	lb-in / kN-m	95	(16.644)

Sincerely

Patti Weaver

Patti Weaver
Technical Manager
Geosynthetic Products Division

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HD600: Liner – Floor and Sidewalls

HD 400: Final Cover

Specifications

Series HDX00 – English

High Density Polyethylene (HDPE) – Smooth

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Property	Test Method	Frequency[1]	HD400	HD600	HD800	HD1000
Thickness (nominal) (mils)			40	60	80	100
Thickness (min. ave.) (mils)	D5199	per roll	40	60	80	100
• Lowest individual of 10 values			36	54	72	90
Tensile Properties (min. ave.)	D638 Type IV	50,000 SF				
• Yield Strength (lb/in)	(2 ipm)		84	126	168	210
• Break Strength (lb/in)			152	228	304	380
• Yield Elongation (%)	(1.3" gauge)		12	12	12	12
• Break Elongation (%)	(2.0" gauge)		700	700	700	700
Tear Resistance (min. ave.) (lb)	D1004	50,000 SF	28	42	56	70
Puncture Resistance (min. ave.) (lb)	D4833	50,000 SF	72	108	144	180
	FTMS 101/ Method 2065[2]	Certified	52	78	104	130
Carbon Black Content (range) (%)	D1603/D4218	50,000 SF	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Carbon Black Dispersion	D5596	50,000 SF	Note	Note	Note	Note
Density (min. ave.) (g/cc)	D1505/D792	Resin Batch	0.940	0.940	0.940	0.940
Stress Crack Resistance (hr)	D5397 (App.)	Resin Batch	200	200	200	200
Dimensional Stability (max. ave.) (%)	D1204	Resin Batch	±2	±2	±2	±2

[1]Testing frequencies are rounded to the nearest full roll.
[2]FTMS 101 has been replaced with D4833. Value shown for comparison purposes only.
Carbon black dispersion for 10 different views: all 10 in Categories 1 or 2.

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Designer's Forum

By Gregory N. Richardson, Ph.D. P.E.
principal of GN Richardson and Assoc.

Exposed geomembrane covers: Part 1 - geomembrane stresses

During the late 1980s and early 1990s, many mixed-waste disposal areas owned by the U.S. Department of Energy were given an interim closure using exposed geomembrane covers (EGCs). These interim covers were necessary because Congress had failed to promulgate regulations that clearly defined the performance criteria, mainly acceptable radiation emission release levels, for the final covers. Photo 1 shows one such closure at the DOE reservation at Oak Ridge, Tenn. Still, the use of similar interim exposed geomembrane covers in MSW landfills was not envisioned under the 1993 RCRA Subtitle D regulations that govern municipal landfills. §258.60 simply indicates that final closure must occur within one year of the final placement of waste in an area.

EGCs might have remained exclusively in the DOE arena if three factors had not emerged in the past five years in MSW landfills:

1) The lateral expansion mode of operation of most MSW landfills creates interim slopes that may be exposed for many years prior to receiving additional wastes,

2) NPSE air quality regulations increasingly force control of landfill gas (LFG) emissions from operational landfills, and

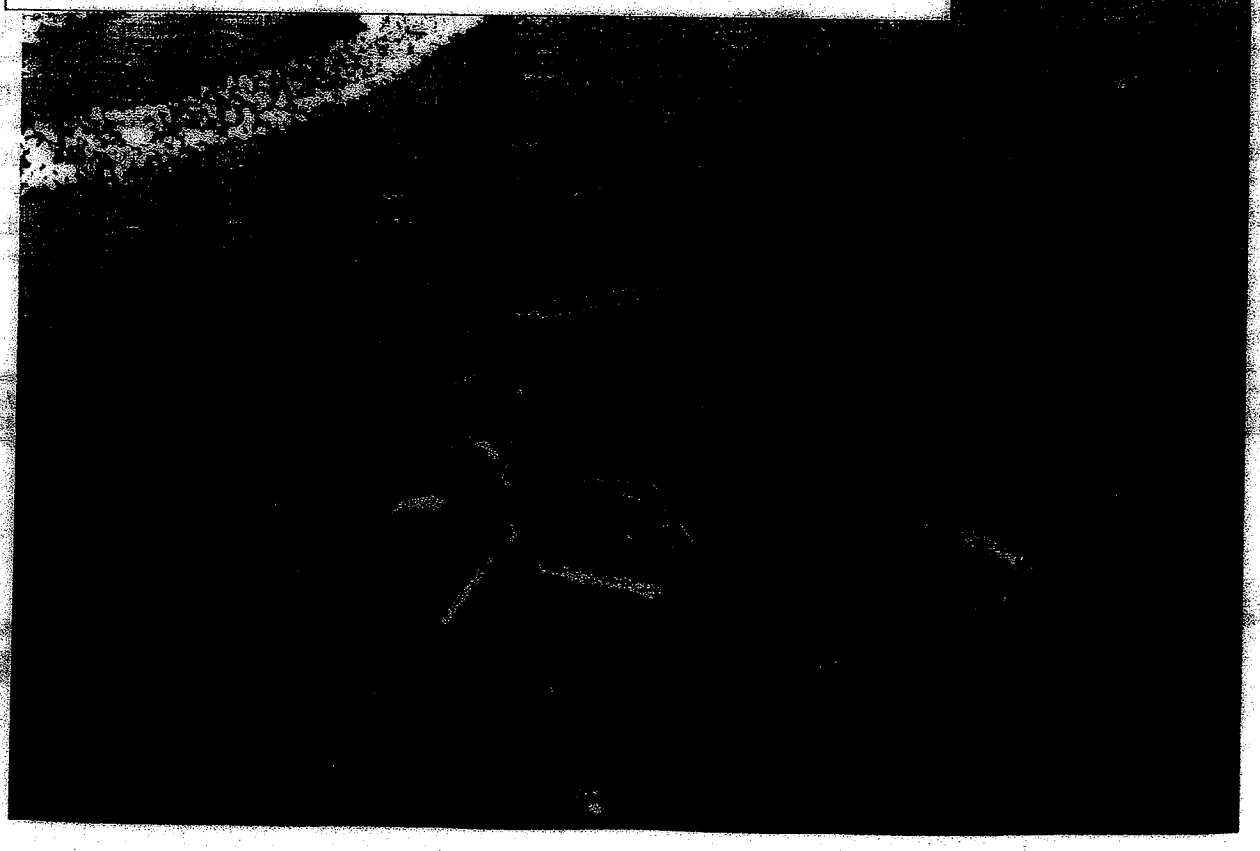
3) The move to "leachate recirculation" or bioreactor landfills results in accelerated settlements of the waste.

These factors make EGCs an attractive solution to MSW landfill closure problems that are now becoming apparent. One of the first Subtitle D facilities to use an EGC was the 1996 closure of 40 acres at the Delaware Solid Waste Authority (DSWA) using an EGC (Germain, et al. 1996, Gleason, et al. 1998). The author is aware of other EGCs in the design stage in Virginia and Florida. This article will review key design considerations for EGCs.

Long-term vs. interim role for EGC

As shown in Photo 1, an EGC may be an integral part of the long-term final cover for the landfill. In this application, considerations for stability of the final cover may require the use of a high-interface friction geomembrane and a surface-water drainage layout based on long-term needs. Here the EGC is simply phase 1 of a two-phase construction of the final cover. Interestingly, this phased approach to final closure also provides significant cost savings to the owner. Delay of placement of

Photo 1. An interim closure using exposed geomembrane covers at the Department of Energy reservation in Oak Ridge, Tenn.



the drainage layer and vegetative layer postpones the cost of these sub-systems. Estimating the cost of these delayed sub-systems at $55,000/acre, a delay of only 10 years represents a cost savings of approximately 50 percent, or approximately $28,000/acre. Germain estimates that DSWA saved approximately $35,000/acre by using an EGC interim closure.

An EGC may also be simply a long-term interim cover over a slope that will receive future waste. In this application, the geomembrane is not a component of the final cover, and greater flexibility exists in its selection. Interface friction may not be a concern, except for ballast features described later in this article.

Design for wind uplift

Discussions in the provided references cover such environmental concerns for the EGC as hail damage and thermal stresses. This topic will be covered in greater detail in Part 3 of this series. However, the primary selection criteria for the geomembrane will be its ability to resist the significant wind loads it will be exposed to during its service life. Guidelines for evaluating the wind-uplift force have been provided by both Wayne and Koerner (1988) and Giroud et al. (1995). Both of these papers rely on the earlier work performed by Dedrick (1975).

The wind uplift pressure, S_e, for a given wind velocity can be conservatively expressed as follows:

$$S_e \text{ (Pa)} = 0.6465\ V^2 \text{ (m/s)}$$
$$S_e \text{ (psf)} = 0.00124\ V^2 \text{ (ft/s)}$$

This force decreases with increasing site elevation. A general guideline for design wind velocities is provided in **Figure 1**. Designs based on lesser wind velocities would have to provide for field inspection of the EGC if the design velocity is exceeded in service.

The more important modifications to the wind forces relate to the impact of the slopes of the landfill. **Figure 2** shows that the above wind-uplift forces can be reduced by an average factor of 0.7 for an EGC placed on side slopes.

Figure 1. Maximum design wind velocities.

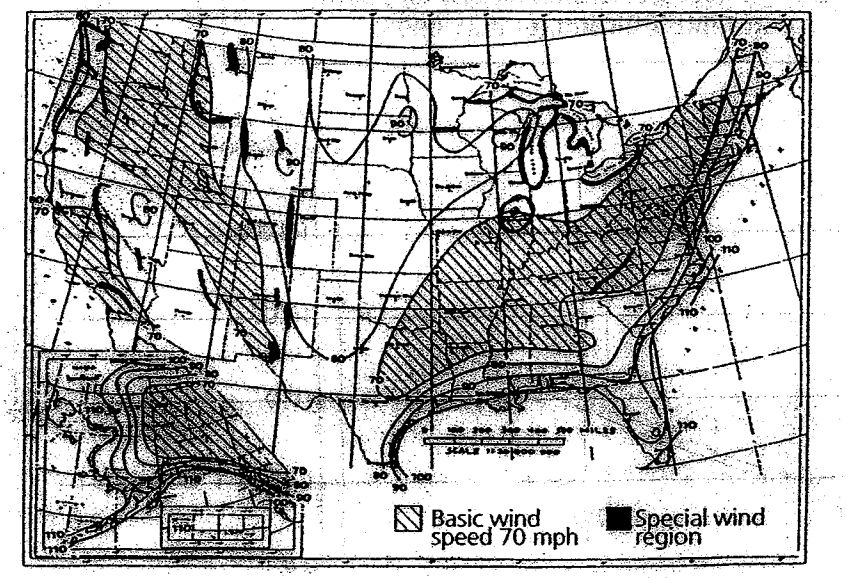


Figure 2. Slope modification factor, λ.

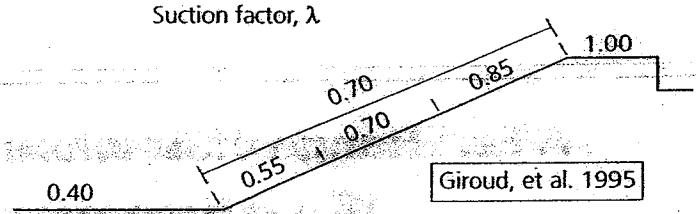


Figure 3. Giroud EGC Membrane Model.

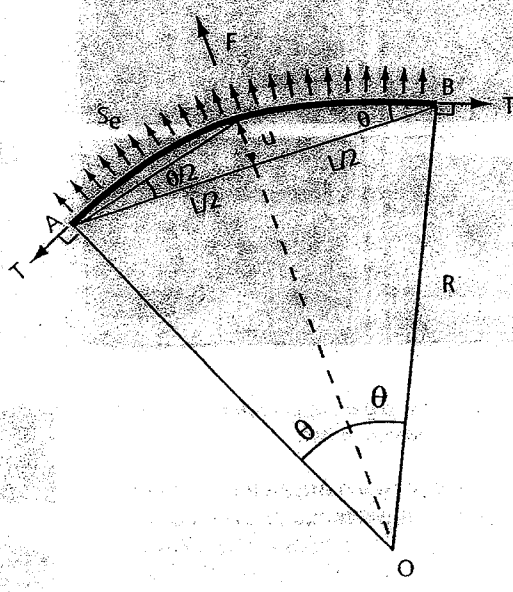
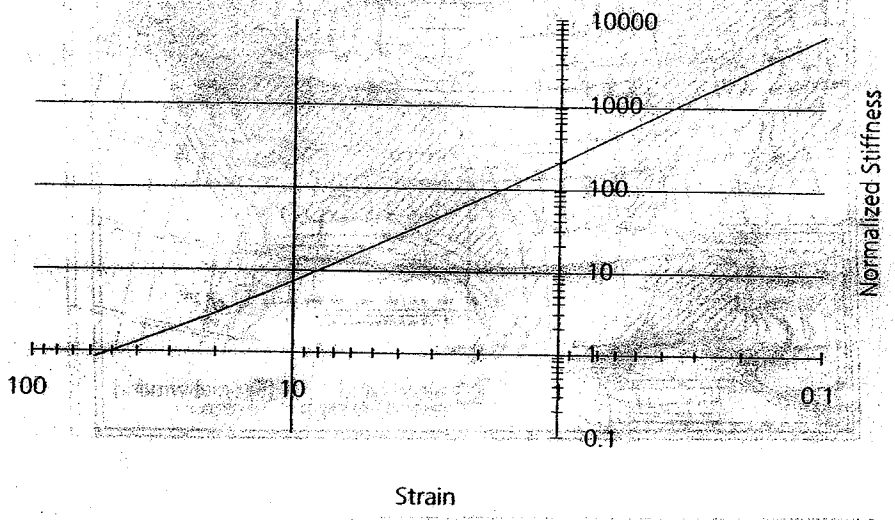


Figure 4. Normalized Tension Stiffness vs. Strain (Ref. Table 4 Giroud, et al. 1995).



Geomembrane tension due to wind uplift

As I have reminded readers in the past, J.P. Giroud has been a man possessed to define the impact on geomembranes of all forces known to man, and wind uplift is no exception. Giroud et al. (1995) presents two solutions for tension in a geomembrane due to wind uplift: one for the simpler condition of a linear modulus for the geomembrane, and a second solution for a non-liner modulus. Both solutions are correct for large displacements/strains of the geomembrane and are based on the mode shown in Figure 3.

The simpler linear modulus solution will serve most designers who wisely choose to limit the design strains in the EGC geomembrane. For this case, Giroud solves for the strain in the geomembrane as

$$\frac{S_e L}{2J\varepsilon} = \sin\left[\frac{S_e L}{2J}\left(1+\frac{1}{\varepsilon}\right)\right]$$

where J is the tensile stiffness of the geomembrane, S_e is the uplift pressure, and L is the length between restraints. Lacking an explicit solution for this equation, Giroud

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developed a simple numerical solution. The normalized tensile stiffness of the geomembrane (S_eL/J) is calculated and the strain is then obtained from Figure 4. The tension in the geomembrane, T, is given by εJ.

An interesting variation on the above solution is the classical beam solution for a "flexible" beam, e.g. cable, supporting a uniform load. This model is shown in Figure 5. The horizontal force at the points of anchorage are given by

$$P=\left[\frac{w^2l^2EA}{24}\right]^{1/3}$$

where w is the applied load (previously S_e), l is the unsupported length, E is the elastic modulus of the geomembrane, and A is the area per unit width. The vertical reaction at each end of the beam, V, is equal to $wl/2$ and the total reaction at each end is $(P^2+V^2)^{0.5}$.

Figure 6 presents a comparison of tensions in a 60-mil HDPE geomembrane, calculated using both Giroud's membrane model and the classic beam model. The solutions are very close and offer an excellent means of check for the designer.

Both solutions determine the maximum vertical displacement of the geomembrane between the restraints. The beam theory solution calculates the maximum vertical displacement, Δ, as

$$\Delta=l\left[\frac{3wl}{64EA}\right]^{1/3}$$

Giroud solves for the displacement using the simple geometry shown in Figure 3 and obtained

$$u=\frac{L}{2}\tan(\Theta/2)$$

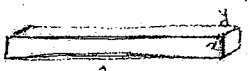
where u and Δ are equivalent. Note that both L and l denote the total distance between restraints. For strains from less than 5 to 8 percent, the above equations yield very similar predictions for vertical displacement.

It is recommended that these solutions be used only over the 'elastic' portion of the geomembrane tensile-stiffness curve. This curve should be established using ASTM D-4595. For HDPE, the above solutions are adequate to approximately 5 percent strain. For strains beyond these levels, Giroud's more rigorous solution should be used.

Geomembrane restraint

The two constant modulus solutions also provide reaction forces at the ends of the geomembrane that must be resisted by some device. For Giroud 's solution, the angle the geomembrane makes at the point of restraint is given by

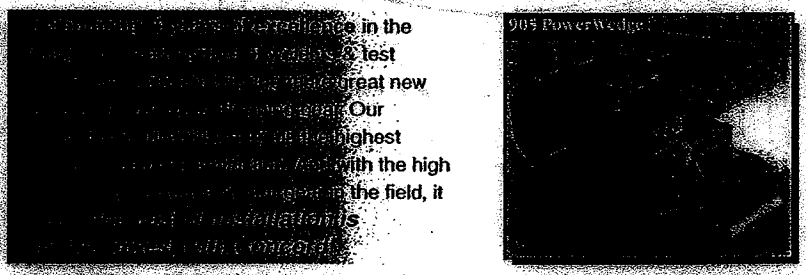
$$\Theta=\sin^{-1}\left(\frac{S_eL}{2T}\right)$$



This allows determination of the vertical and horizontal components of the geomembrane tension T. The beam solution produces these components directly.

With typical wind-uplift forces on the order of 6-15 psf (0.3—0.72 kPa), the vertical reaction can become very large. For a 60-mil HDPE geomembrane, the unsupported length will be limited by the strength of the geomembrane. Limiting the tension in a 60-mil HDPE geomembrane to 115

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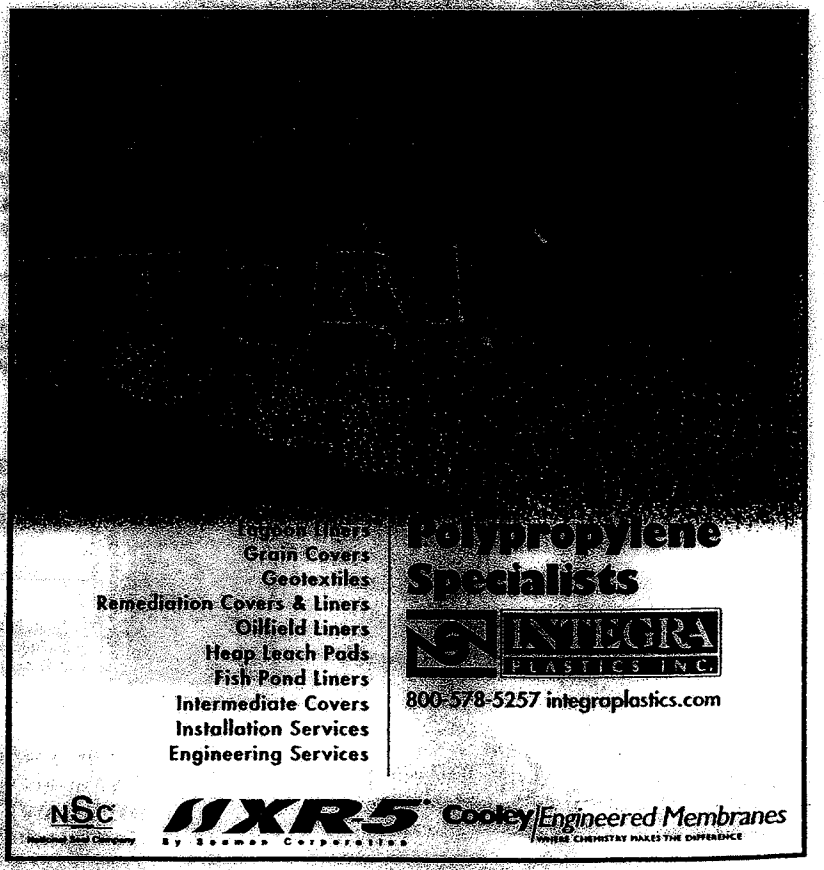


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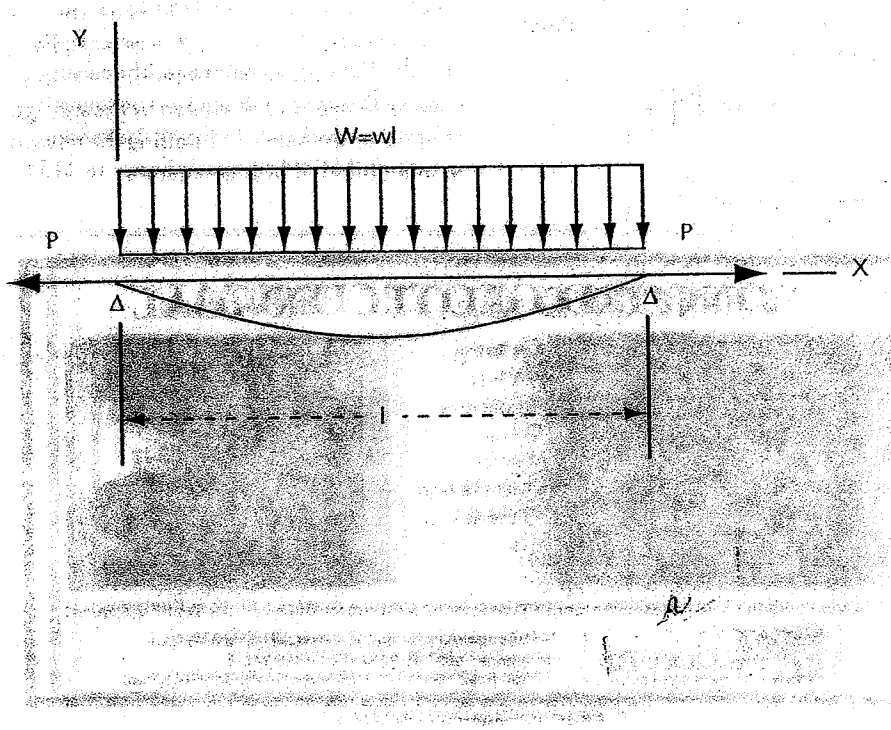
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Figure 5. Flexible Beam Model.

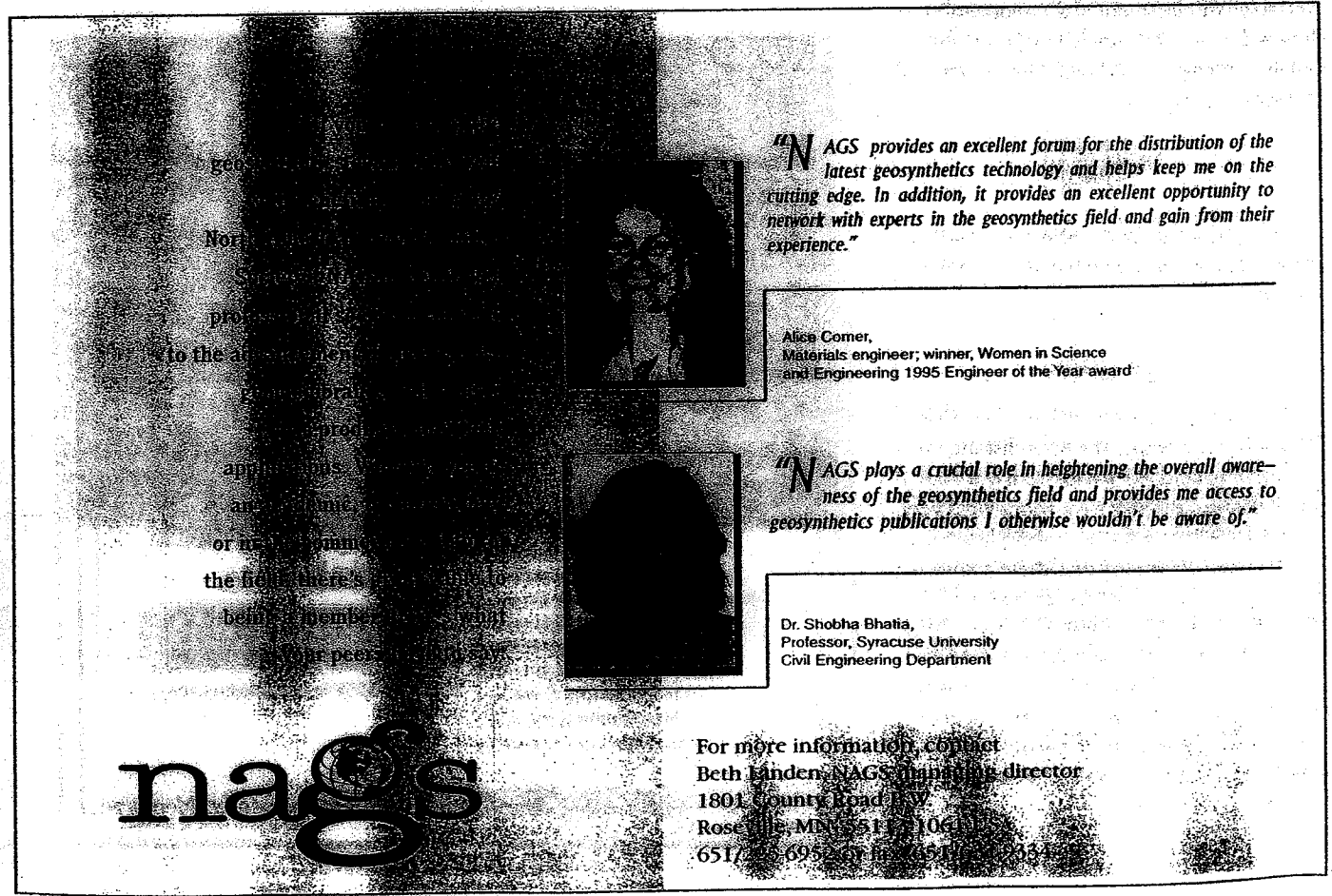


lb/inch (20 kN/m), the maximum unsupported length would range from approximately 38 to 15 feet. At high wind velocities, the need for a reinforced geomembrane becomes obvious. Vertical reaction forces for the HDPE geomembrane are approximately 1400 lbs/ft and require more than an occasional sandbag.

EGC restraints are typically existing design features of the final cover that can be used due to their weight. Features such as roads, swales, down chutes, gas collection lines, and surface water berms make excellent candidates for EGC restraints. The DSWA cover relies on side-slope swales and toe and top-of-slope berms to hold the ESC down. Part 2 of this article will explore alternative means of anchoring the EGC.

Summary

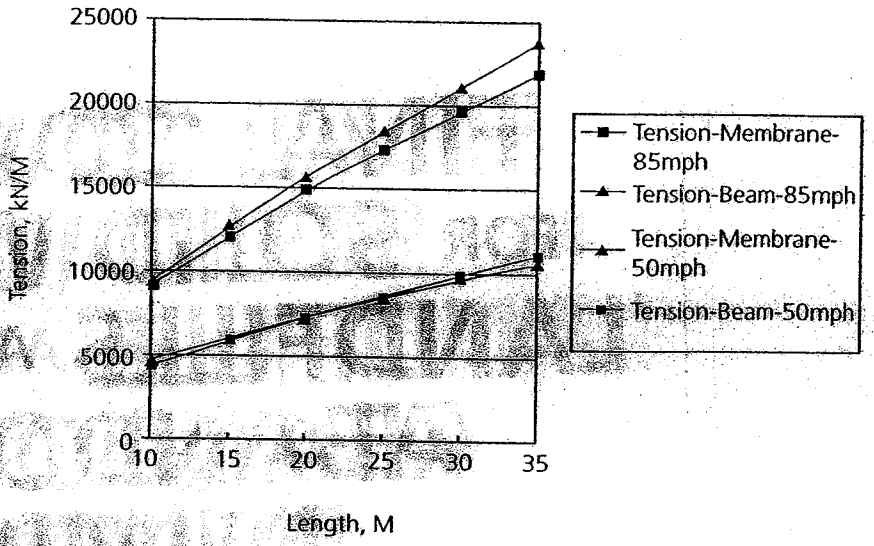
The use of EGC will increase dramatically if wet-cell MSW landfills become the rule and not the exception. It is always encouraging to see the strong role played by geosynthetics in the evolution of landfill technol-



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ogy. The author would like to acknowledge review comments provided by Matt Adams, J.P. Giroud, and Ann Germain. GFR

Figure 6. Beam vs. Membrane Model.



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and/or to use geosynthetic reinforcement. This latter option is called "veneer reinforcement" in the literature and comes about by the inclusion of a geogrid or high strength geotextile within the cover soil. Both of these situations will be illustrated.

Unfortunately, cover soil failures have occurred, and perhaps the majority of the failures have been associated with seepage forces. Indeed, drainage above a geomembrane (or other barrier material) in the cover soil cross section must be accommodated to avoid the possibility of seepage forces. A section will be devoted to this class of slope stability problems.

Lastly, the possibility of seismic forces exists in earthquake-prone locations. If an earthquake occurs in the vicinity of an engineered landfill, abandoned dump, or remediation site, the seismic wave travels through the solid waste mass, reaching the upper surface of the cover. It then decouples from the cover soil materials, producing a horizontal force which must be appropriately analyzed. A section will be devoted to the seismic aspects of cover soil slope analysis as well.

5.3 COVER SOIL SLOPE STABILITY PROBLEMS

This section presents the analytic formulations, design curves, and example problems for a number of common slope stability situations. The standard problem of a uniformly thick cover soil is developed without, then with, equipment loading. When the resulting FS value is too low, the designer can select a number of options. For example, lowering of the slope angle, reduction of the slope length with intermediate berms, or the use of higher shear strength materials are possible design options. The analysis procedure is the same regardless of these decisions. Quite different strategies are the use of tapered cover soil thickness and/or the use of high strength geosynthetic inclusions. These two strategies will be developed later in this section, being fundamentally different design alternatives.

5.3.1 Slopes with Uniformly Thick Cover Soils

Figure 5.3 illustrates a uniformly thick cover soil on a geomembrane at a slope angle "β" which is of finite length. It includes a passive wedge at the base and a tension crack at the top. The analysis that follows is after Koerner and Hwu (1991), but comparable analyses are available from Giroud and Beech (1989) and McKelvey and Deutsch (1991). The symbols used in Figure 5.3 are defined below.

W_A = total weight of the active wedge
W_P = total weight of the passive wedge
N_A = effective force normal to the failure plane of the active wedge
N_P = effective force normal to the failure plane of the passive wedge

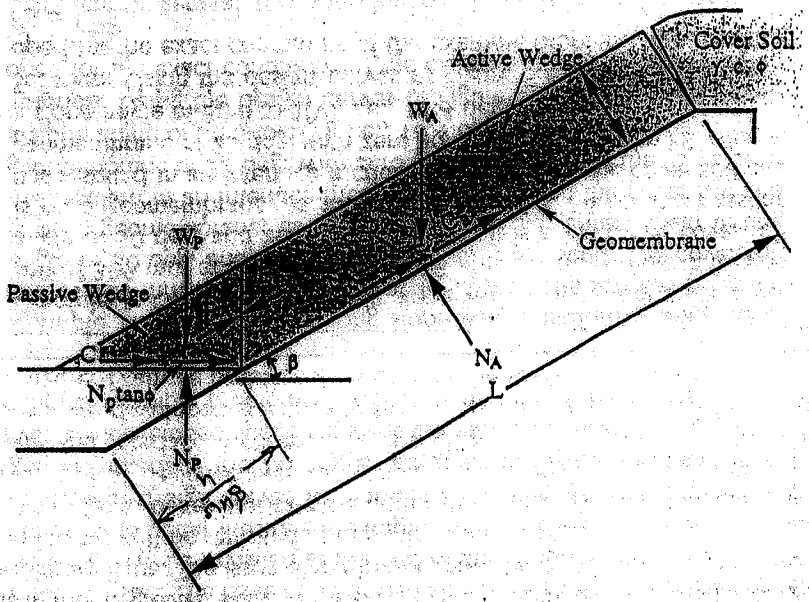


FIG. 5.3. Limit Equilibrium Forces Involved in Finite Length Slope Analysis for Uniformly Thick Cover Soil

h = thickness of the cover soil
L = length of slope measured along the geomembrane
β = soil slope angle beneath the geomembrane
ϕ = friction angle of the cover soil
δ = interface friction angle between cover soil and geomembrane
C_a = adhesive force between cover soil of the active wedge and the geomembrane
c_a = adhesion between cover soil of the active wedge and the geomembrane
C = cohesive force along the failure plane of the passive wedge
c = cohesion of the cover soil
E_A = interwedge force acting on the active wedge from the passive wedge
E_P = interwedge force acting on the passive wedge from the active wedge
FS = factor of safety against cover soil sliding on the geomembrane

The expression for determining the factor of safety can be derived as

Considering the active wedge,

$$W_A = \gamma h^2 \left(\frac{L}{h} - \frac{1}{\sin \beta} - \frac{\tan \beta}{2} \right) \quad (5.3)$$

$$N_A = W_A \cos \beta \quad (5.4)$$

$$C_a = c_a \left(L - \frac{h}{\sin \beta} \right) \quad (5.5)$$

By balancing the forces in the vertical direction, the following formulation results:

$$E_A \sin \beta = W_A - N_A \cos \beta - \frac{N_A \tan \delta + C_a}{FS} \sin \beta \quad (5.6)$$

Hence, the interwedge force acting on the active wedge is:

$$E_A = \frac{(FS)(W_A - N_A \cos \beta) - (N_A \tan \delta + C_a)\sin \beta}{\sin \beta (FS)} \quad (5.7)$$

The passive wedge can be considered in a similar manner:

$$W_P = \frac{\gamma h^2}{\sin 2\beta} \quad (5.8)$$

$$N_p = W_P + E_P \sin \beta \quad (5.9)$$

$$C = \frac{(c)(h)}{\sin \beta} \quad (5.10)$$

By balancing the forces in the horizontal direction, the following formulation results:

$$E_P \cos \beta = \frac{C + N_P \tan \phi}{FS} \quad (5.11)$$

Hence, the interwedge force acting on the passive wedge is:

$$E_P = \frac{C + W_P \tan \phi}{\cos \beta (FS) - \sin \beta \tan \phi} \quad (5.12)$$

By setting $E_A = E_P$, the following equation can be arranged in the form of $ax^2 + bx + c = 0$, which in our case use FS values, thus:

$$a(FS)^2 + b(FS) + c = 0 \quad (5.13)$$

where

$$a = (W_A - N_A \cos \beta)\cos \beta$$

$$b = -[(W_A - N_A \cos \beta)\sin \beta \tan \phi + (N_A \tan \delta + C_a)\sin \beta \cos \beta + \sin \beta (C + W_P \tan \phi)]$$

$$c = (N_A \tan \delta + C_a)\sin^2 \beta \tan \phi \quad (5.14)$$

The resulting FS value is then obtained from the following equation:

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \quad (5.15)$$

When the calculated FS value falls below 1.0, a stability failure, with the cover soil sliding on the geomembrane, is to be anticipated. Thus, a value of greater than 1.0 must be sought as being the minimum factor of safety. How much greater than 1.0 the FS value should be is a design and/or regulatory issue. The issue of minimum allowable FS values, under different conditions, will be revisited at the end of this chapter.

In order to better illustrate the implications of Equations 5.13, 5.14, and 5.15, typical design curves for various FS values, as a function of slope angle and interface friction angle, are given in Figure 5.4. Note that the curves are developed specifically for the variables stated in the legend of the figure. Example problem #1 illustrates the use of the curves.

Example 1: Given: a 30 m long slope with a uniformly thick cover soil of 300 mm at a unit weight of 18 kN/m³. The soil has a friction angle of 30 deg. and zero cohesion, i.e., it is a sand. The cover soil is on a geomembrane, as shown in Figure 5.3. Direct shear testing has resulted in an interface friction angle between the cover soil and geomembrane of 22 deg. with zero adhesion. What is the FS value at a slope angle of 3(H)-to-1(V), i.e., 18.4 deg?

Solution: Using the design curves of Figure 5.4 (which were developed for the exact conditions of the example problem), the resulting FS = 1.25.

Comment: In general, this is too low of a value for a final cover slope factor of safety, and a redesign is necessary. While there are many possible options for changing the geometry of the situation, the example will be revisited later in this section using tapered cover soil thickness and veneer reinforcement. Furthermore, this general problem will be used later, for comparison purposes to other cover soil slope stability situations.

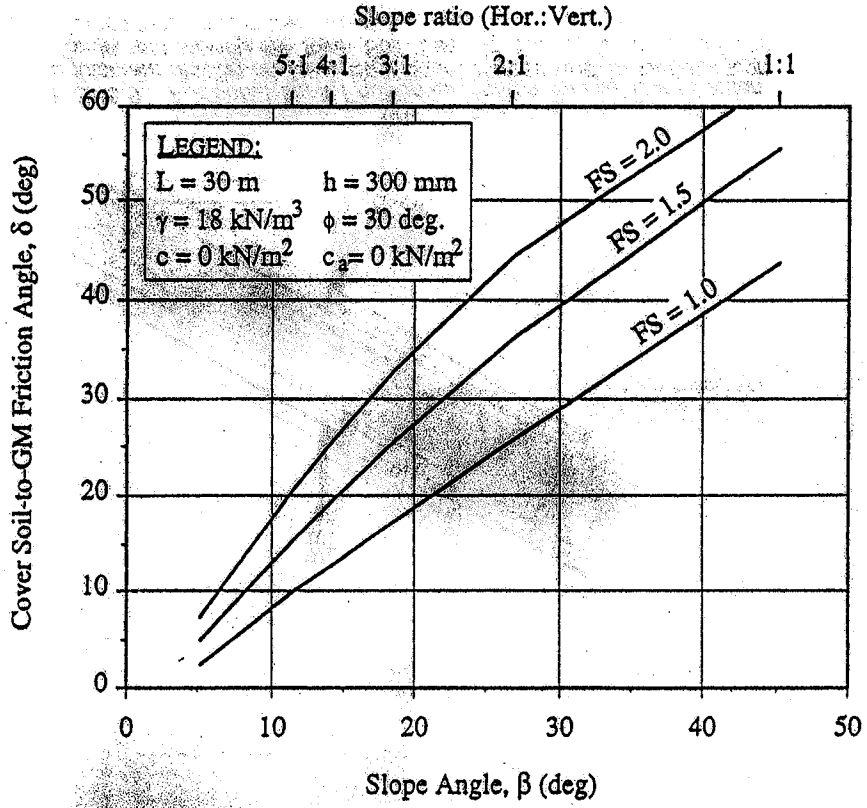


FIG. 5.4. Design Curves for Stability of Uniform Thickness Cover Soils on Linear Failure Planes for Various Global Factors of Safety

5.3.2 Incorporation of Equipment Loads

The placement of cover soil on a slope with a relatively low shear strength inclusion (like a geomembrane) should *always* be from the toe upward to the crest. Figure 5.5a shows the recommended method. In so doing, the gravitational forces of the cover soil and live load of the construction equipment are compacting previously placed soil and working with an ever-present passive wedge and stable lower portion beneath the active wedge. While it is prudent to specify low ground pressure equipment to place the soil, the reduction of the FS value from no equipment load while working up the slope will be seen to be nominal.

For soil placement down the slope, however, a stability analysis must add an additional dynamic stress into the solution. This stress decreases the

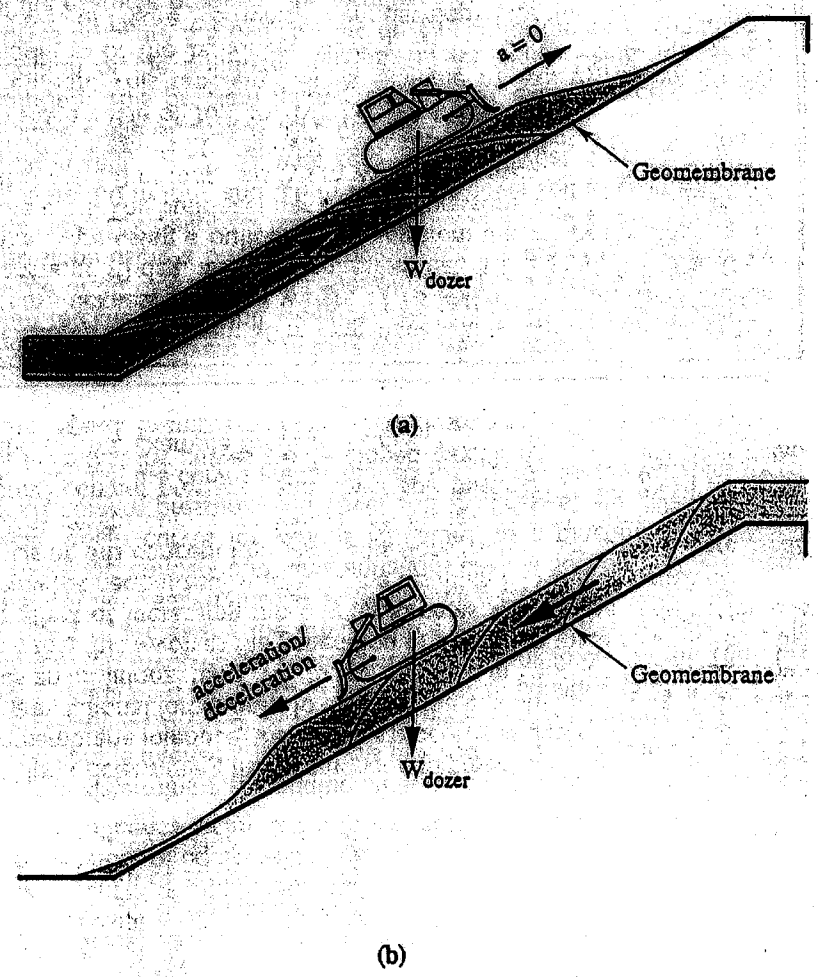


FIG. 5.5. Construction Equipment Placing Cover Soil on Slopes Containing Geosynthetics

FS value, and in some cases to a great extent. Figure 5.5b shows this procedure. Unless absolutely necessary, it is not recommended to place the cover soil in this manner. If it is necessary, the design must consider the dynamic force of the construction placement equipment.

For the first case of a bulldozer pushing cover soil up from the toe of the slope to the crest, the calculation uses the free body diagram of Figure 5.6a. The analysis uses a specific piece of construction equipment (like a

35/42

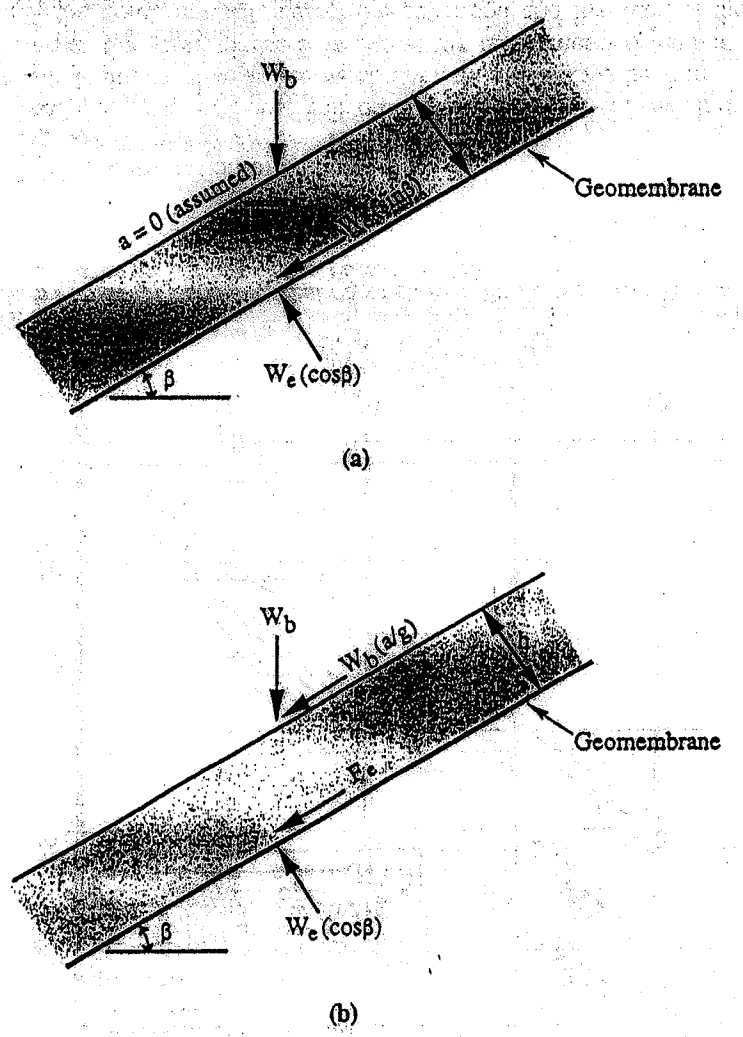


FIG. 5.6. Additional Limit Equilibrium Forces due to Construction Equipment Moving on Cover Soil (See Fig. 5.3 for Gravitational Soil Forces that Remain the Same)

bulldozer, characterized by its weight or ground-contact pressure), and dissipates this force or stress through the cover soil thickness to the surface of the geomembrane. A Boussinesq analysis is used (see Poulos and Davis 1974). This results in an equipment force per unit width as follows:

where

W_e = equivalent equipment force per unit width at the geomembrane interface
q = $W_b/(2wb)$
W_b = actual weight of equipment (e.g., a bulldozer)
w = length of equipment track
b = width of equipment track
I = influence factor at the geomembrane interface (see Figure 5.7)

Upon determining the additional equipment force at the cover soil-to-geomembrane interface, the analysis proceeds as described in Section 5.3.1 for gravitational forces only. In essence, the equipment moving up the slope adds an additional term, W_e, to the W_n-force in Equation (5.3). Note, however, that this involves the generation of a resisting force as well. Thus, the net effect of increasing the driving force as well as the resisting force is somewhat neutralized, insofar as the resulting FS value is concerned.

Using this concept (the same equations used in Section 5.3.1 are used), typical design curves for various FS values, as a function of equivalent ground content pressures and cover soil thicknesses, are given in Figure 5.8. Note that the curves are developed specifically for the variables stated in the legend. Example problem #2(a) illustrates the use of the curves.

Example 2(a): Given: 30 m long slope with uniform cover soil of 300 mm thickness at a unit weight of 18 kN/m³. The soil has a friction angle of 30 deg. and zero cohesion, i.e., it is a sand. It is placed on the slope using a bulldozer moving from the toe of the slope up to the crest. The bulldozer has a ground pressure of 30 kN/m² and tracks that are 3.0 m long and 0.6 m wide. The cover soil to geomembrane friction angle is 22 deg. with zero adhesion. What is the FS value at a slope angle of 3(H)-to-1(V), i.e., 18.4 deg?
Solution: This problem follows example #1 exactly, except for the addition of the bulldozer moving up the slope. Using the design curves of Figure 5.8 (which were developed for the exact conditions of the example problem), the resulting FS = 1.24.
Comment: While the resulting FS value is low, the result is best assessed by comparing it to example #1, i.e., the same problem except without the bulldozer. It is seen that the FS value has only decreased from 1.25 to 1.24. Thus, in general, a low ground contact pressure bulldozer placing cover soil up the slope does not significantly decrease the factor of safety.

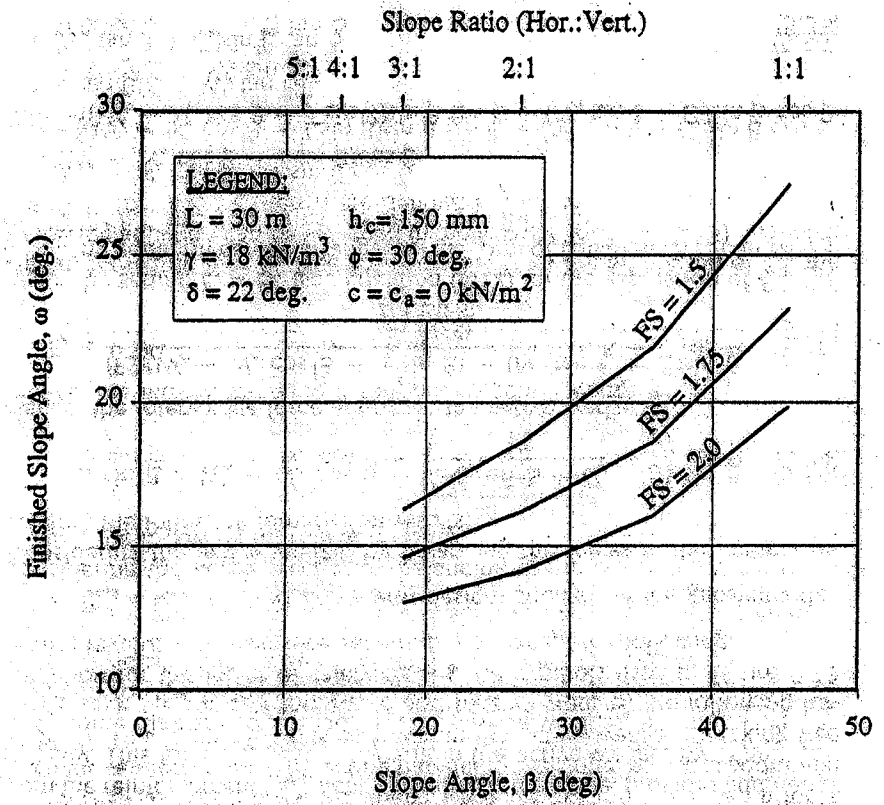


FIG. 5.12. Design Curves for FS Values for Different Upper and Lower Cover Soil Slope Angles

soil slope angle than that of the slope angle of the geomembrane and the soil beneath, i.e., the value of "ω" being less than "β." Note that the curves are developed specifically for the variables stated in the legend. Example problem #3 illustrates the use of the curves.

Example 3: Given: a 30 m long slope with a tapered thickness cover soil of 150 mm at the crest extending at an angle "ω" of 16 deg. to the toe. The unit weight of the cover soil is 18 kN/m³. The soil has a friction angle of 30 deg. and zero cohesion, i.e., it is a sand. The interface friction angle with the underlying geomembrane is 22 deg. with zero adhesion. What is the FS value at an underlying soil slope

Solution: Using the design curves of Figure 5.12 (which were developed for the exact conditions of the example problem), the resulting FS = 1.57.

Comment: The result of this problem (with tapered thickness cover soil) is FS = 1.57, versus example #1 (with a uniform thickness cover soil) which gave FS = 1.25. Thus the increase in FS value is 24%. Note, however, that at ω = 16 deg., the thickness of the cover soil at the toe of the slope is approximately 1.4 m. Thus, the increase in cover soil *volume* used over example #1 is approximately 165%. The trade-offs between these two issues should be considered when using the strategy of tapering cover soil thickness to increase the FS value of a particular cover soil slope.

5.3.4 Veneer Reinforcement of Cover Soil Slopes

A different way of increasing a given slope's factor of safety is to reinforce it with a geosynthetic material. Such reinforcement can be either *intentional* or *non-intentional*. By intentional, we mean to include a geogrid or high strength geotextile within the cover soil to purposely reinforce the system against instability (see Figure 5.13). Depending on the type and

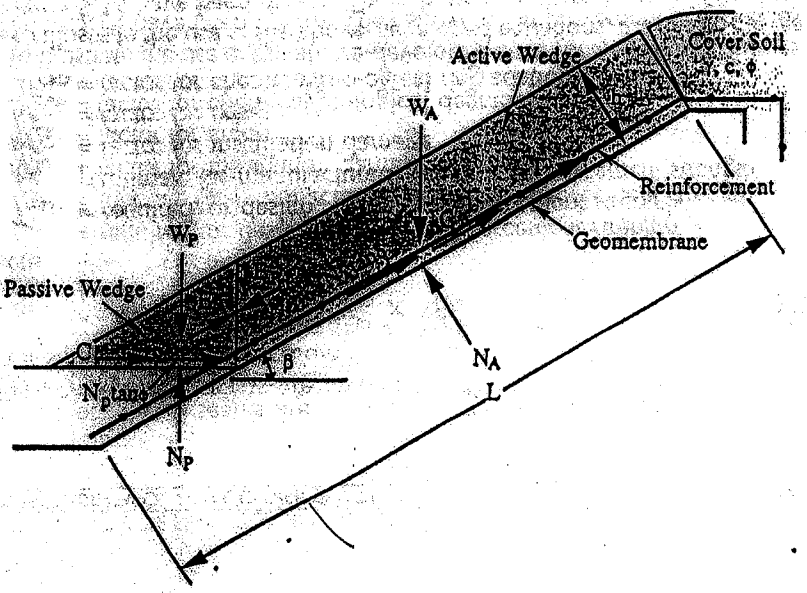


FIG. 5.13. Limit Equilibrium Forces Involved in Finite Length Slope Analysis

amount of reinforcement, the majority, or even all, of the gravitational stresses can be supported, resulting in a major increase in the FS value. By non-intentional, we refer to multi-component liner systems where a low shear strength interface is located beneath an overlying geosynthetic(s). In this case, the overlying geosynthetic(s) is inadvertently acting as veneer reinforcement to the system. In some cases, the designer may not realize that such geosynthetics are being stressed in an identical manner as a geogrid or high strength geotextile, but they are. Intentional, or non-intentional, the stability analysis is identical.

As seen in Figure 5.13, the analysis follows Section 5.3.1, but a force from the reinforcement "T," acting parallel to the slope, provides additional stability. This force "T," acts only within the active wedge. By taking free body force diagrams of the active and passive wedges, the following formulation for the factor of safety results. All symbols used in Figure 5.13 were previously defined (see Section 5.3.1) except the following:

$T = T_{reqd}$ = the required (long-term design) strength of the geosynthetic

Considering the active wedge, by balancing the forces in the vertical direction, the following formulation results:

$$E_A \sin\beta = W_A - N_A \cos\beta - \left(\frac{N_A \tan\delta + C_a}{FS} + T\right)\sin\beta \qquad (5.34)$$

Hence, the interwedge force acting on the active wedge is:

$$E_A = \frac{(FS)(W_A - N_A\cos\beta - T\sin\beta) - (N_A\tan\delta + C_a)\sin\beta}{\sin\beta(FS)} \qquad (5.35)$$

Again, by setting $E_A = E_P$, [see Equation (5.12) for the expression of E_P], the following equation can be arranged in the form of Equation (5.13), in which the "a," "b," and "c" terms are defined as follows:

$$a = (W_A - N_A\cos\beta - T\sin\beta)\cos\beta$$

$$b = -[(W_A - N_A\cos\beta - T\sin\beta)\sin\beta\tan\phi + (N_A\tan\delta + C_a)\sin\beta\cos\beta + \sin\beta(C + W_P\tan\phi)]$$

$$c = (N_A\tan\delta + C_a)\sin^2\beta\tan\phi \qquad (5.36)$$

Again, the resulting FS value can be obtained using Equation (5.15).

The value of required, or design, tensile strength is necessary for the long-term stability of the cover soil. In order to obtain an ultimate, or as-manufactured, tensile strength of the geogrid or high strength geotextile, the value of T_{reqd} must be *increased* for site-specific conditions via various factors (all ≥ 1.0) which values as installation damage, creep, and long-term [illegible] considered [see Equation (5.37) after Koerner

1994]. Note that if seams are involved in the reinforcement, a reduction factor should be added accordingly.

$$T_{ult} = T_{reqd}(RF_{ID} \times RF_{CR} \times RF_{CBD}) \qquad (5.37)$$

where

T_{reqd} = required, or design, value of reinforcement strength
T_{ult} = ultimate (as-manufactured) value of reinforcement strength
RF_{ID} = factor for installation damage
RF_{CR} = factor for creep
RF_{CBD} = factor for chemical/biological degradation

To illustrate the use of the above-developed equations, the design curves of Figure 5.14 have been drawn. They show the improvement of FS values

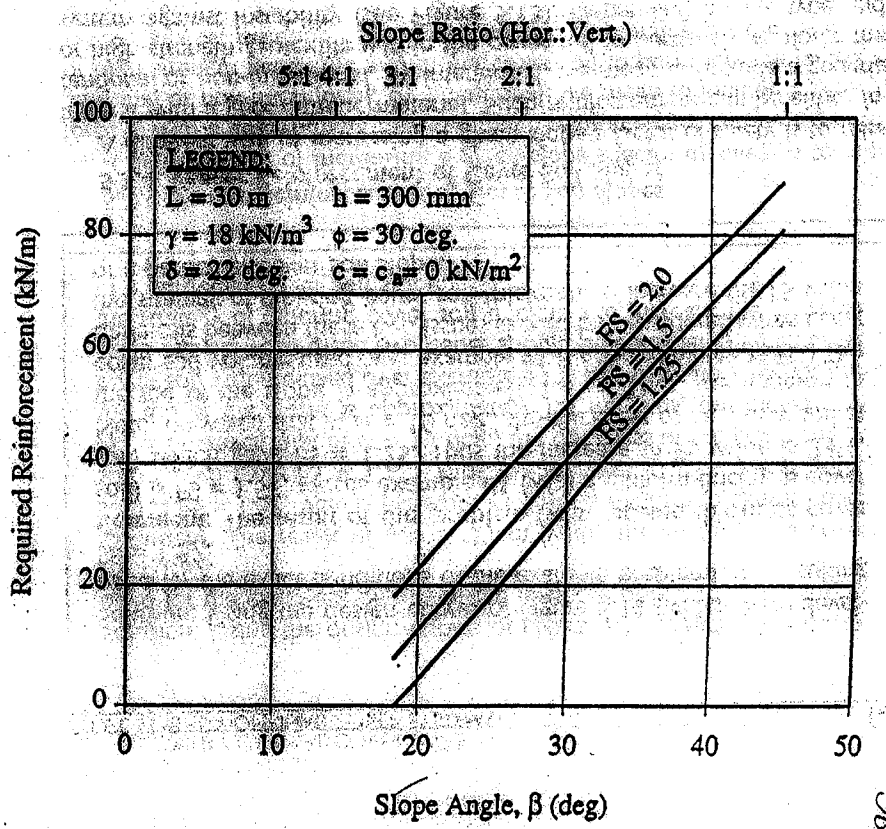


FIG. 5.14. Design Curves for FS Values for Different Slope A[illegible]nd Veneer Reinforcement Strengths

38/42

with increasing strength of the reinforcement. Note that the curves are developed specifically for the variables stated in the legend. Example problem #4 illustrates the use of the design curves.

Example 4: Given: a 30 m long slope with a uniform thickness cover soil of 300 mm and a unit weight of 18 kN/m³. The soil has a friction angle of 30 deg. and zero cohesion, i.e., it is a sand. The proposed reinforcement is a geogrid with a design wide-width tensile strength of 10 kN/m. Thus, the reduction factors in equation (5.37) have already been included. The geogrid apertures are large enough that the cover soil will strike through and provide an interface friction angle with the underlying geomembrane of 22 deg. and zero adhesion. What is the FS value at a side slope angle of 3(H)-to-1(V), i.e., 18.4 deg.?

Solution: Using the design curves of Figure 5.14 (which were developed for the exact conditions of the example problem), the resulting FS = 1.57.

Comments: Note that the use of T_{reqd} = 10 kN/m in the analysis will require a T_{ult} value of the geogrid per equation (5.37). For example, if the cumulative reduction factor in equation (5.37) was 4.0, the ultimate (as-manufactured) strength of the geogrid would have to be 40 kN/m. Also, note that this same type of analysis could also be used for high strength geotextile reinforcement. The only difference is that strike-through of the cover soil will not occur. Hence, the geotextile must carry the difference in interface friction values between the cover soil above and the geomembrane below. The analysis follows along the same general lines as presented here.

It should be emphasized that the preceding analysis is focused on *intentionally* improving the FS value by the inclusion of geosynthetic reinforcement. This is provided by geogrids or high strength geotextiles being placed above the upper surface of the low strength interface material. It is often placed directly above a geomembrane or within the cover soil itself.

Interestingly, some amount of veneer reinforcement is often *non-intentionally* provided by a protection geotextile placed beneath the cover soil and above a geomembrane-lined slope. The geotextile will often be highly stressed by the cover soil, and if its interface friction strength against the underlying geomembrane is relatively low, it will tend to slide on the underlying geomembrane. When contained in an anchor trench, however, the protection geotextile actually acts as a de facto reinforcement material. [illegible] tensile strength is usually low, it does relatively little

to improve the slope's factor of safety. Furthermore, when it fails or pulls out of its anchor trench, the sliding of the geotextile (and overlying cover soil) on the underlying (and stationary) geomembrane is very abrupt. Clearly, if veneer reinforcement is to be provided, it must be done intentionally with the proper type of geosynthetic, and designed accordingly.

5.4 CONSIDERATION OF SEEPAGE FORCES

The previous section presented the general problem of slope stability analysis for final cover soils placed on slope angles of varying degrees. The tacit assumption throughout was that a drainage layer was placed above the barrier layer with adequate capacity to remove, i.e., transmit, permeating water parallel to the slope and safely away from the cross section. The amount of water to be removed is obviously a site-specific situation. Note that in arid areas, drainage may not be required.

Unfortunately, adequate drainage of final covers has sometimes not been available, and seepage-induced slope stability problems have occurred. The following situations have resulted in seepage-induced slides:

- Inadequate drainage capacity at the toe of the slope, where seepage quantities accumulate and are at their maximum.
- Fines from quarried stone accumulating at the toe of the slope thereby decreasing the as-constructed permeability over time.
- Fine, cohesionless, cover soil particles migrating through the filter (if one is even present) and the drainage layer, and then accumulating at the toe of the slope, thereby decreasing the as-constructed permeability over time.
- Freezing of the drainage layer at the toe of the slope, while the top of the slope thaws, thereby mobilizing seepage forces against the ice wedge at the toe.

These types of seepage-induced failures appear to require a variation in slope stability design methodology, which is the focus of this subsection. Detailed discussion is given in Soong and Koerner (1996).

Consider a cover soil of uniform thickness placed directly above a geomembrane at a slope angle of "β" as shown Figure 5.15. Unlike previous examples, however, a saturated soil zone exists within the cover soil for part or all of the thickness. The saturated boundary is shown as two different phreatic surface orientations. This is because seepage can be built up in the cover soil in two different ways: a horizontal buildup from the toe and a parallel-to-slope buildup. These two hypotheses are defined and quantified as a horizontal submergence ratio (HSR) and a parallel submergence ratio (PSR). The dimensional definitions of both ratios are given in Figure 5.15.

39/42

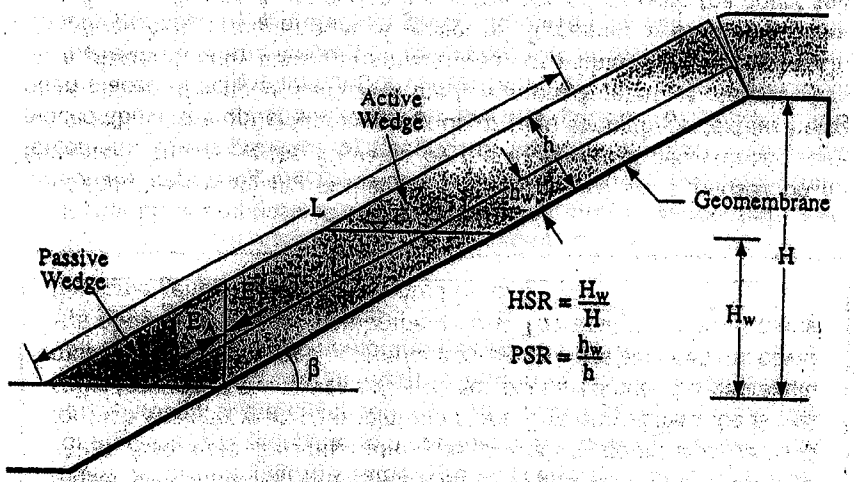


FIG. 5.15. Cross Section of Cover Soil on a Geomembrane Illustrating Different Submergence Assumptions and Related Definitions

When analyzing the stability of slopes using the limit equilibrium method, free body diagrams of the passive and active wedges are taken with the appropriate forces (now including pore water pressures) being applied. Note that the two interwedge forces, namely, E_a and E_p, are also shown in Figure 5.15. The formulation for the resulting factor of safety, for horizontal seepage buildup and then for parallel to slope seepage buildup, follows.

The Case of Horizontal Seepage Buildup. Figure 5.16 shows the free body diagram of both the active and the passive wedges, assuming horizontal seepage buildup.

All symbols used in Figure 5.16 were previously defined except the following:

γ_{sat} = saturated unit weight of the cover soil
γ_{dry} = dry unit weight of the cover soil
γ_w = unit weight of water
H = vertical height of the slope measured from the toe
H_w = vertical height of the free water surface measured from the toe
U_h = resultant of the horizontal pore pressures acting on both wedges
U_n = resultant of the pore pressures acting perpendicular to the slope

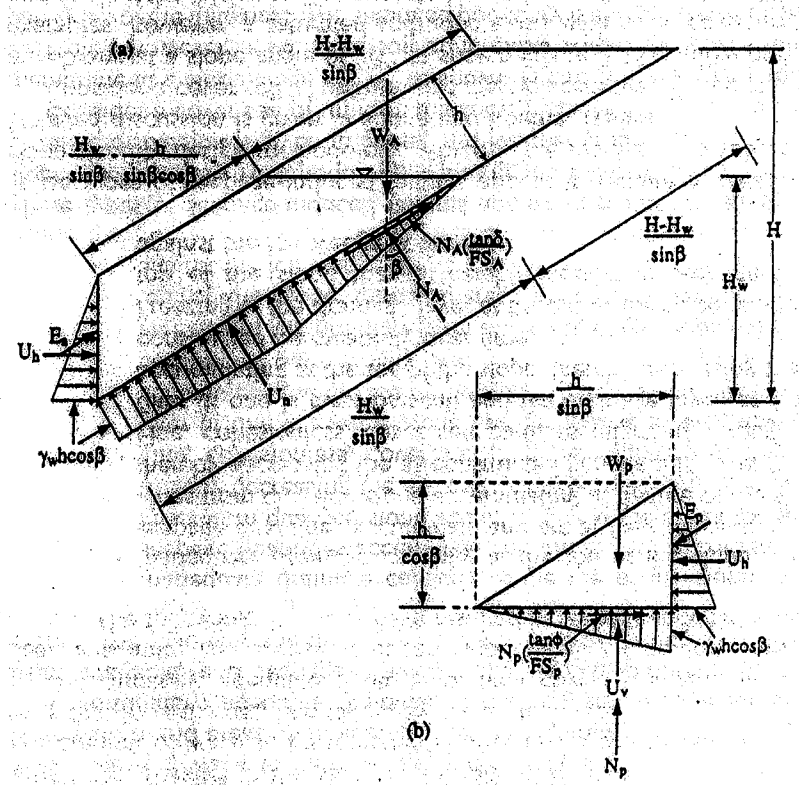


FIG. 5.16. Free Body Diagrams of Cover Soil with Horizontal Seepage Buildup

U_v = resultant of the vertical pore pressures acting on the passive wedge

The expression for finding the factor-of-safety can be derived as follows:

Considering the active wedge,

$$W_A = \left(\frac{\gamma_{sat}(h)(2H_w\cos\beta - h)}{\sin 2\beta}\right) + \left(\frac{\gamma_{dry}(h)(H - H_w)}{\sin\beta}\right) \quad (5.38)$$

$$U_n = \frac{\gamma_w(h)(\cos\beta)(2H_w\cos\beta - h)}{\sin 2\beta} \quad (5.39)$$

$$U_h = \frac{\gamma_w h^2}{2} \quad (5.40)$$

$$N_A = W_A(\cos\beta) + U_h(\sin\beta) - U_n \quad (5.41)$$

The interwedge force acting on the active wedge can then be expressed as:

$$E_A = W_A \sin\beta - U_h \cos\beta - \frac{N_A \tan\delta + C_a}{FS} \qquad (5.42)$$

The passive wedge can be considered in a similar manner and the following expressions result:

$$W_P = \frac{\gamma_{sat} h^2}{\sin 2\beta} \qquad (5.43)$$

$$U_V = U_h \cot\beta \qquad (5.44)$$

The interwedge force acting on the passive wedge can then be expressed as:

$$E_P = \frac{U_h(FS) - (W_P - U_V)\tan\phi - C}{\sin\beta \tan\phi - \cos\beta(FS)} \qquad (5.45)$$

Again, by setting $E_A = E_P$, the following equation can be arranged in the form of $ax^2 + bx + c = 0$ which in this case is

$$a(FS)^2 + b(FS) + c = 0 \qquad (5.13)$$

where

$$a = W_A \sin\beta \cos\beta - U_h \cos^2\beta + U_h$$
$$b = -W_A \sin^2\beta \tan\phi + U_h \sin\beta \cos\beta \tan\phi - N_A \cos\beta \tan\delta - (W_P - U_V)\tan\phi$$
$$c = N_A \sin\beta \tan\delta \tan\phi \qquad (5.46)$$

Again, the resulting FS value is obtained using Equation (5.15).

The Case of Parallel-to-Slope Seepage Buildup. Figure 5.17 shows the free body diagrams of both the active and passive wedges with seepage buildup in the direction parallel to the slope. Identical symbols as defined in the previous case are used here with an additional definition of h_w equal to the height of free water surface measured in the direction perpendicular to the slope.

Note that the general expression of factor of safety shown in Equation (5.15) is still valid. However, the *a*, *b*, and *c* terms shown in Equation (5.46) have different definitions in this case owing to the new definitions of the following terms:

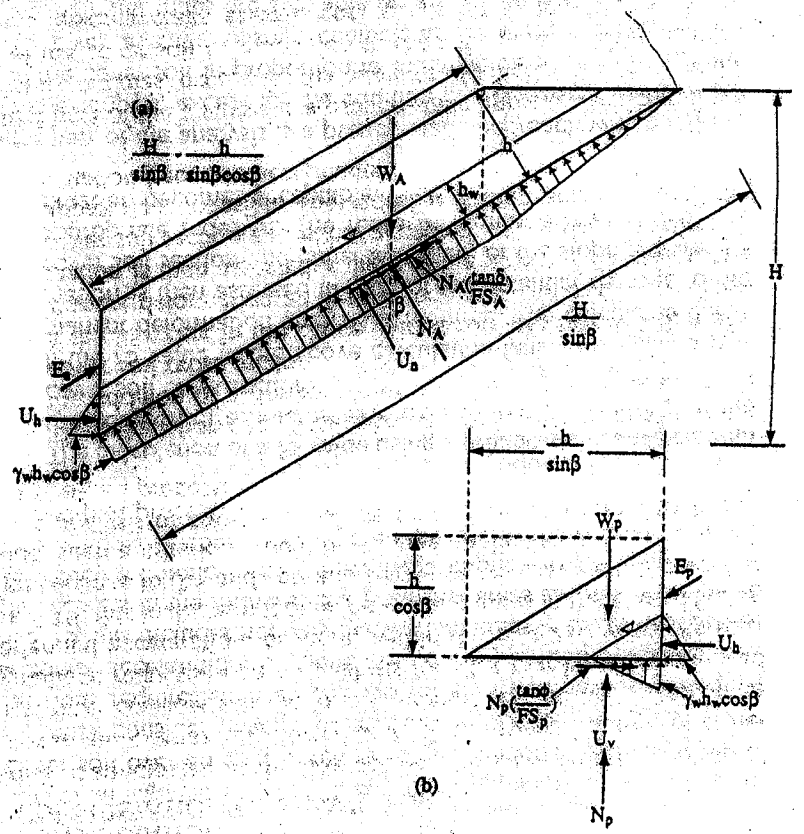


FIG. 5.17. Free Body Diagrams of Cover Soil with Parallel-to-Slope Seepage Buildup

$$W_A = \frac{\gamma_{dry}(h - h_w)(2H\cos\beta - (h + h_w)) + \gamma_{sat}(h_w)(2H\cos\beta - h_w)}{\sin 2\beta} \qquad (5.47$$

$$U_a = \frac{\gamma_w h_w \cos\beta(2H\cos\beta - h_w)}{\sin 2\beta} \qquad (5.48$$

$$U_h = \frac{\gamma_w (h_w)^2}{2} \qquad (5.49$$

$$W_P = \frac{\gamma_{dry}(h^2 - h_w^2) + \gamma_{sat}(h_w^2)}{\sin 2\beta} \qquad (5.50$$

In order to illustrate the effect of the above developed equations, th design curves of Figure 5.18 have been drawn. They show the decrease i FS value with increasing submergence ratio for all values of interface fric

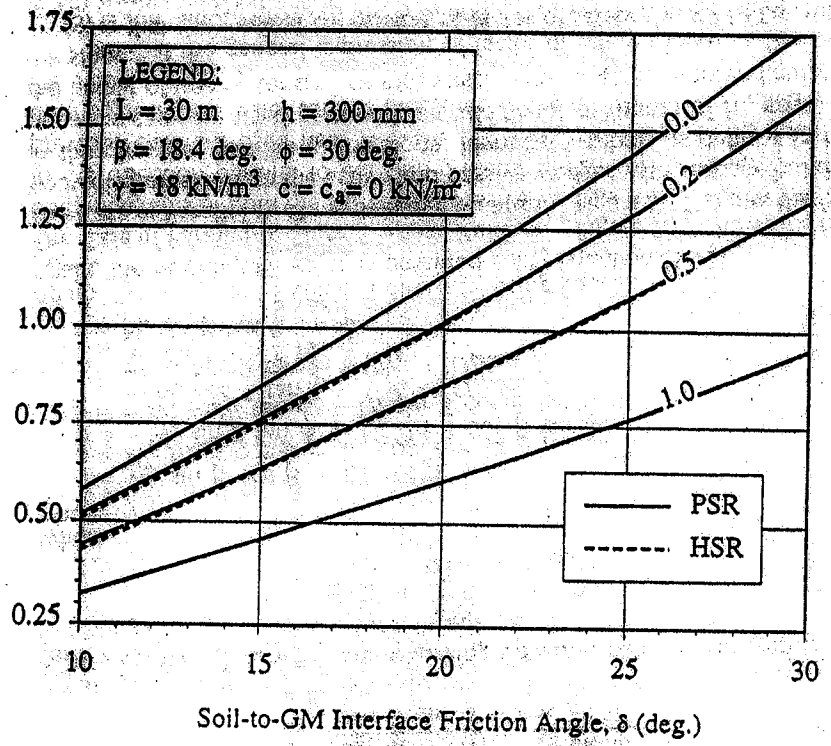


FIG. 5.18. Design Curves for Stability of Cover Soils for Different Submergence Ratios

tion. Furthermore, the differences in response curves for the parallel and horizontal submergence ratio assumptions are seen to be very small. Note that the curves are developed specifically for the variables stated in the legend. Example problem #5 illustrates the use of the design curves.

Example 5: Given: a 30 m long slope with a uniform thickness cover soil of 300 mm at a dry unit weight of 18 kN/m³. The soil has a friction angle of 30 deg. and zero cohesion, i.e., it is a sand. The soil becomes saturated through 50% of its thickness, i.e., it is a parallel seepage problem with PSR = 0.5, and its saturated unit weight increases to 21 kN/m³. Direct shear testing has resulted in an interface friction angle of 22 deg. and zero adhesion. What is the factor of safety at a slope angle of 3(H)-to-1(V), i.e., 18.4 deg.?

Solution: Using the design curves of Figure 5.18 (which were developed for the exact conditions of the example problem), the resulting FS = 0.93.

Comment: The seriousness of seepage forces in a slope of this type is immediately obvious. Had the saturation been 100% of the thickness, the FS value would have been even lower. Furthermore, the result from a horizontal assumption of saturated cover soil with the same saturation ratio will give almost identically low FS values. Clearly, the lesson to take from this example problem is that adequate *long-term* drainage above the barrier layer in cover soil slopes must be provided to avoid saturation from occurring.

5.5 CONSIDERATION OF SEISMIC FORCES

In areas of anticipated earthquake activity, the slope stability analysis of a final cover soil over an engineered landfill, abandoned dump, or remediated site must consider seismic forces. Subtitle "D" of the United States EPA regulations requires such an analysis for sites that have experienced 0.1*g* horizontal acceleration, or more, within the past 250 years. As seen in Figure 5.19, this includes not only the western areas in the United States, but major sections in the midwest and northeast areas as well. If practiced worldwide, such a criterion would have huge implications.

Seismic analysis of cover soils of the type under consideration in this book is a two-part process:

- The calculation of a FS value using a pseudo-static analysis with the addition of a horizontal force acting at the centroid of the cover soil cross section.
- If the FS value in the above calculation falls below 1.0, a permanent deformation analysis is required. The calculated deformation is then assessed in light of the potential damage to the cover soil section and either accepted, or the slope requires an appropriate redesign. The redesign is then analyzed until the situation becomes acceptable.

The **first part** of the analysis is a pseudo-static approach which follows the previous examples, except for the addition of a horizontal force at the centroid of the cover soil in proportion to the anticipated seismic activity. Figure 5.19 gives average seismic coefficients for various zones in the United States. Similar maps are available on a worldwide basis. Note that C_s is nondimensional and is a ratio of the bedrock acceleration to gravitational acceleration. This value of C_s is modified using available computer codes such as "SHAKE" (see Schnabel et al. 1972), for propagation to the

APPENDIX 812.306-C: ANCHOR TRENCH DESIGN CALCULATIONS

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* Sidewall Liner Anchor Trench Design

Reference: Sherman & Lewis, 1974

Assuming rectangular Anchor

Part 1

Part 2

(1) Anchor Trench Tensile Capacity = $T_o + F_{soil} + F_{AT} + F_A + F_B + F_{Bs}$

Fig. 18-21 page 408 (Sherman & Lewis)

F_{AT} = overburden soil will move with FML to cause of failure =

$T_o + \gamma_{Soil} \frac{D}{2} x L x \tan\delta + C_{have} x D_{AT} x \left[\tan\delta + \frac{1}{\tan\delta}\right] +$

$+ \gamma_{Soil} x V_{AT} x (D_T + d) x \left[\tan\delta + \tan\delta'\right] + C x \left[L + D_{AT} + W_{AT}\right]$

$+ C' x \left[D_{AT} + W_{AT}\right]$

γ_{Soil} = bulk density of backfill material = 125 $\frac{lb}{ft^3}$

δ = interface friction angle between soil & geomembrane = 12°

δ' = " " " " " soil & geotextile = 24°

C = Apparent cohesion between soil & geomembrane = 185 psf

C' = " " " " soil & geotextile = 0

$C_{have} = K_o \left[\left(\gamma_{Soil} x \frac{D_{AT}}{2}\right) + \gamma_{Soil} x d\right]$

From interface friction test report

$K_o = 1 - \sin\phi$

Assume $\phi = 30°$

$\Rightarrow K_o = 1 - \sin 30° = 0.5$

$\gamma_{soil} = 125 \frac{lb}{ft^3}$

For $D_{AT} = 3'$, $L = 4'$

$C_{have} = 0.5\left[\left(125 \times \frac{3}{2}\right) + 185(1.5)\right] = 187.5 \frac{lbs}{ft}$

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Project: Clinton LF Expansion Calculated By: SMS Sheet 2 of 7

Project No.: 91-118.02 Task No.: Checked By: GLA Date: 01/15/02

$T = 125 \times 4 \times \frac{1.5}{2} \times \tan 12 + 1537.5 \times 3 \times (\tan 12 + \tan 24) +$

$125 \times 2k \times (3+15) \times (\tan 12 + \tan 24) + 185 (4k + 3 + 2k)$

$= 745.31 + 3310 + 7450 + 15,750 = 28548$ ...

(3) Factor of Safety Against Pull Out = $\frac{\text{Anchor Tensile Capacity}}{\text{Total Design Force}}$

Total Design Force = Force in geotextile + Force in anchor + Force in geomembrane

Force in Sideslope Liner Geosynthetics Acting Along Slope (Friction, Adhesion, Interlock, Passive Forces Acting Perpendicular to Slope)

$\Rightarrow$ Total Design Force = $637 + 1811 + 832 = 1280 \frac{lb}{ft}$

Factor of Safety against pullout = $\frac{28,512}{1280} = 22.3$ ... OK

(2) Anchorage Capacity of Fabric

Design Anchor Trench Capacity $\geq$ Tensile Strength Geosynthetics

$\geq$ Tensile Strength Geosynthetics = Tensile Strength (geotextile) + Tensile Strength (geomembrane)

$= 75 \frac{lb}{yd} + 15 \frac{lb}{yd} + 126 \frac{lb}{yd}$ (Multiply by 15 yds)

$= 216 \frac{lb}{yd} = 2295 \frac{lb}{ft}$ $\Rightarrow$ T ... OK

34

Waste Containment Systems, Waste Stabilization, and Landfills

Design and Evaluation



Hari D. Sharma
Sangeeta P. Lewis

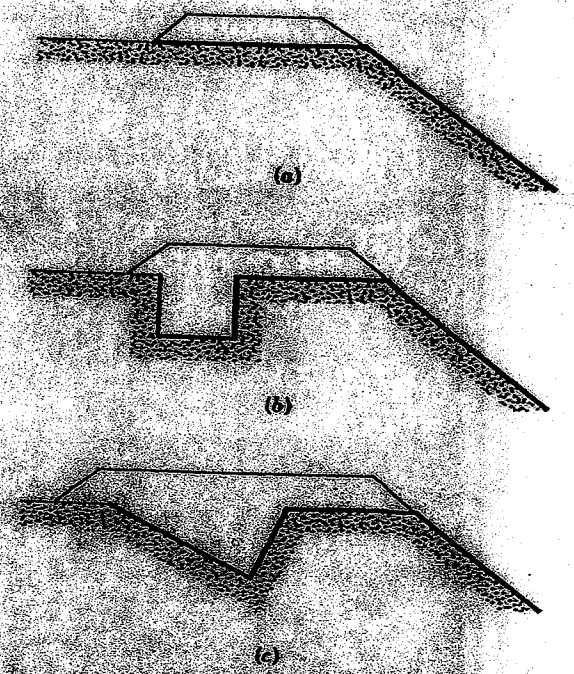


Figure 8.19 Typical anchor trench configurations: *(a)* flat anchor, and *(b)* rectangular anchor, and *(c)* V-shaped anchor.

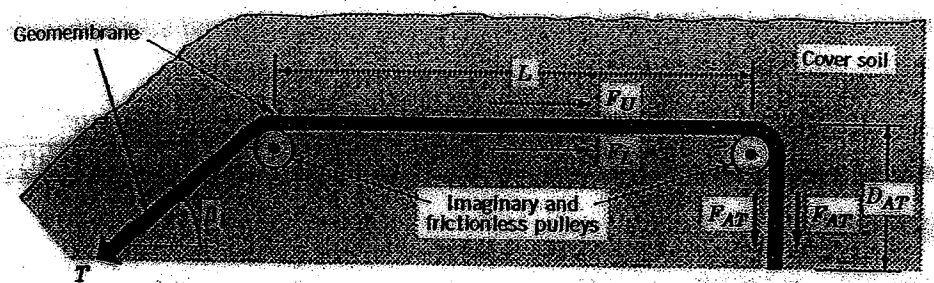
geosynthetic is likely to move with the geosynthetic. The soil depth, type of soil or other material underlying the geosynthetics, and geosynthetic anchorage length are therefore the key factors in developing the required anchor trench holding capacity.

The easiest anchor trench configuration to analyze is the flat anchor. The free-body diagram for the flat anchor and the development of equation (8.14) for anchorage length is shown in Figure 8.20.

$$L = \frac{T\cos\beta - T\sin\beta\tan\delta_L}{\gamma d\tan\delta_L} \tag{8.14}$$

There is no ideal solution for rectangular or V trenches. Koerner (1990) recommends that the problem be solved using imaginary, frictionless pulleys, as shown in Figure 8.21.

The anchor trench should be designed to resist pullout loads (T) caused by the self-weight of the geosynthetics. For geomembranes that may be exposed to severe temperature and wind loading conditions, stresses caused by these forces should also be evaluated. Ideally, the anchor trench should be designed to allow the geosynthetics to pull out slightly rather than cause tearing of the geosynthetics. The reasoning for this is that even if complete pullout occurred, it would usually be easier to replace pulled-out materials than to repair torn geosynthetics. The maxi-



$$T = F_U + F_L + 2F_{AT}$$

Where: T = tensile stress in geomembrane

F_U = friction force above geomembrane (assumed to be negligible since cover soil likely moves with geomembrane)

$F_L = q \tan \delta(L)$ $+ cL$

q = surcharge pressure = γd

d = depth of cover soil

γ = unit weight of cover soil

δ = interface friction angle

L = runout length

$F_{AT} = (\sigma_h \text{ ave}) \tan \delta(d_{AT})$ $+2c\, D_{AT}$

σ_h = average horizontal stress in anchor trench

$= k_o \sigma_V$

$\sigma_V = \gamma$ Have

Have = average depth of anchor trench (requires an estimate)

$k_o = 1 - \sin \phi$

ϕ = angle of shearing resistance of backfill soil

D_{AT} = depth of anchor trench (unknown)

Figure 8.21 Design of a rectangular and V anchor trenches. (From Koerner, 1990.)

mum holding capacity of the anchor trench should therefore be slightly less than the ultimate tensile strength of the geosynthetic to be anchored, irrespective of the applied loads. If the applied loads are greater than the tensile strength of the geosynthetics, measures should be taken to reduce the applied loads or higher-strength geosynthetics should be used.

If soil materials are placed above side-slope geosynthetics, the load caused by soil, seepage forces, and construction equipment should be assessed. Often, a high-strength reinforcing geotextile or geogrid is required to hold the soil on the slopes. Druschel and Underwood (1993) used a force equilibrium method to assess the required anchorage force for these high-strength materials. The free-body and force vector diagram for this method are illustrated in Figures 8.22 and 8.23, respectively. As shown, the items[4] to be evaluated include the toe buttress resistance, soil

INTERFACE FRICTION TEST SUMMARY
Clinton Landfill Expansion
Testing conducted by Precision Analytical Laboratories, March, April, May, and September 2001

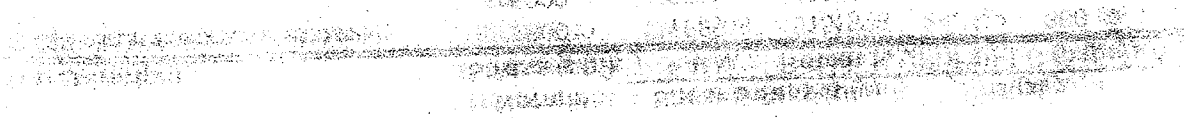
Description	Normal Stress (psf)	Shear Stress (psf) Peak	Shear Stress (psf) Residual	Design Phi	Design C (psf)
Final Cover Components					
Final cover soil vs. Smooth HDPE	250	218	206	28	65
	350	278	262		
	450	339	316		
Liner Floor Components					
LCS Sand vs. Smooth HDPE	5000	2427	1940	16	0
	7500	3164	2134		
	10000	4300	2860		
Sidewall Liner - Prior to Waste Placement					
Protective cover soil vs. Geotextile	250	198	168	24	0
	350	210	175		
	450	328	310		
Geotextile vs. Geonet	250	181	149	25	0
	350	216	171		
	450	286	226		
Geomembrane vs. Geonet	100	96	81	8	65
	275	136	125		
	450	160	135		
Sidewall Liner - Following Waste Placement					
Geotextile vs. Geonet	2500	719	610	14	0
	5000	1351	1183		
	8000	2600	1975		
Geonet vs. Smooth HDPE	2500	622	622	11	110
	5000	1102	1070		
	8000	1702	1683		
Clay liner soil vs. Smooth HDPE	2500	1072	748	12	185
	5000	1765	1288		
	8000	2651	1950		

INTERFACE FRICTION TEST SUMMARY

Clinton Landfill Expansion

Testing conducted by Precision Analytical Laboratories, March, April, May, and September 2001

Description	Normal Stress (psf)	Shear Stress (psf)		Design	
		Peak	Residual	Phi	C (psf)
Clay liner soil vs. Geotextile	2500	1598	1528	24	380
	5000	2612	2582		
	8000	4112	3990		



APPENDIX 812.305-H: LIQUEFACTION POTENTIAL CALCULATIONS

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Revised 6-8-06

Project: Clinton Landfill Expansion Calculated By: GLA Sheet 1 of 11

Project No.: 91-0118.02 Task No.: 20001 Checked By: SMS Date: 11-27-01

Liquefaction Potential

The potential for liquefaction is greatest in shallow clean sands that exhibit low standard penetration test N-values. Based on a review of boring logs and geologic cross-sections, saturated sands are first encountered at a depth of about 22' (refer to logs for borings B-22 6385, 6390, EX-1, EX-3, and EX-4). Review of N-value data, the N-values for sand are typically above 30. The minimum N-value was 15.

Assume the following conservative geotechnical conditions for evaluating the potential for liquefaction:

Saturated Sand at depth 20-30'

$\gamma_T = 130$ pcf

$N = 15$

Reference: Liquefaction of Soils During Earthquakes - National Research Council Committee on Earthquake Engineering (1985) [after Seed and Idriss]

$$\frac{\tau_{av}}{\sigma_o'} = 0.65\, \alpha_{max}\, \frac{\sigma_o}{\sigma_o'}\, \frac{r_d}{g}$$

$\sigma_o' = 20' \times 130 + 5' \times (130 - 62.4) = 2938$ psf (at mid-depths)

$\sigma_o = 25' \times 130 = 3250$ psf

$\alpha_{max} = 0.10g$ (from foundation bearing capacity calcs, maximum ~~bedrock acceleration = 0.06g, seismic coeff. = 0.10~~)

$r_d = 0.93$ (interpolated, $r_d = 1.0$ @ ground surface, $= 0.90$ at depth = 35')

$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \left(\frac{0.10g}{g}\right)(3250)\left(\frac{0.93}{2938}\right) = 0.07$$

Elastic Settlement Reference: NAVFAC DM 7.1

Immediate Settlement at Points C and D

at center

$$\Delta = \frac{q \times B(1-\nu^2) \times I_c}{E_u} \times 4$$ (4 due to symmetry)

$q = 16{,}500$ psf $\quad I_{(c)} = 0.015$ (see page 7)

$B = 1200$

P_o from geotechnical data $= 35{,}000$ psf

OCR $= \frac{P_c}{\text{overburden pressure}} = \frac{35{,}000}{12{,}832} = 2.7$ and PI<30

Overburden pressure at mid-depth of Peat, Clay, Rock = $\frac{129{,}448}{2} \times 145$ pcf $= 12{,}832$ psf

Task 2: $\frac{E_u}{c} = 600 \rightarrow E_u = 600 \times 6000 = 3.6 \times 10^6$ psf

$$\Delta = \frac{16{,}500 \times 1200(1-0.5^2) \times 0.015}{3.6 \times 10^6} \times 4 = 0.247'$$

Point B Method 1: Immediate settlement at edge

$$= 2 \times \frac{16{,}500 \times 1200 \times (1-0.5^2) \times 0.015}{3.6 \times 10^6} = 0.124$$

Method 2: Proportion from elastic settlement at Point C based on ratio of consolidation settlement:

Elastic Settlement $= \frac{0.362}{0.906} \times 0.124 = 0.050$

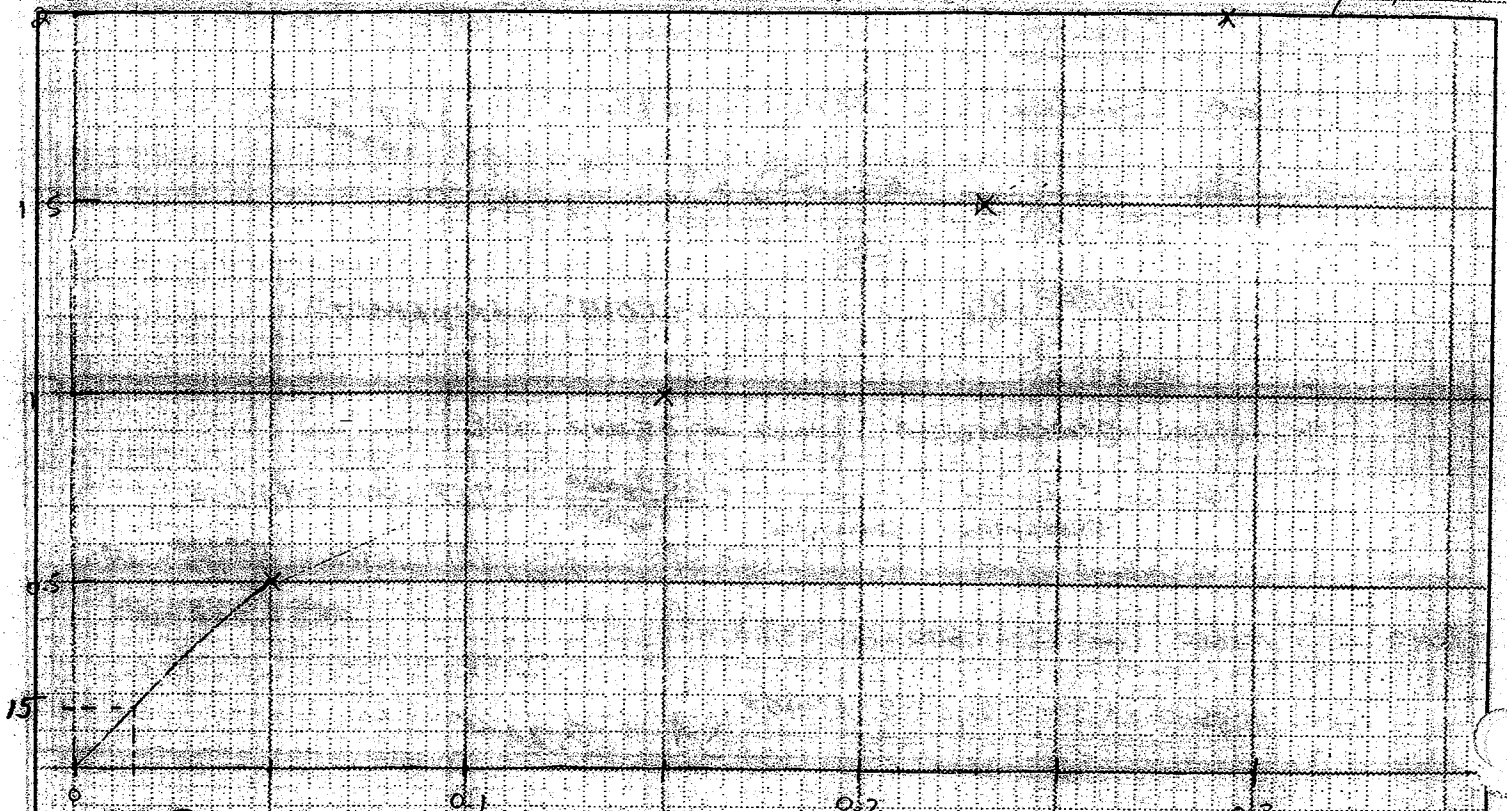
Say elastic settlement at point $E = 0.124'$

Point A Elastic Settlement = Negligible

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Project: Clinton Landfill Calculated By: SMS Sheet 22 of 30

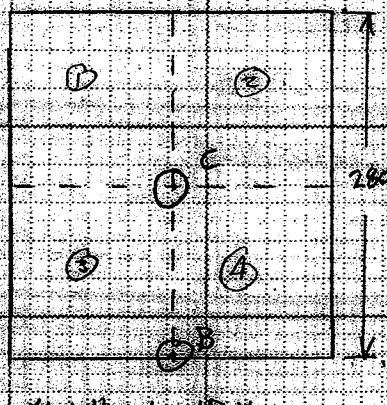
Project No.: 91-0118.02 Task No.: 2001 Checked By: CLA Date: 10/08/01



I_c (For $\frac{L}{B} = 1$)

(For Corner of Flexible Rectangular Area)

Based on Table 1, NAVFAC DM 7.1 p213



Influence Factor at corners of Areas ①, ②, ③, ④

$B = \frac{2400}{2} = 1200'$

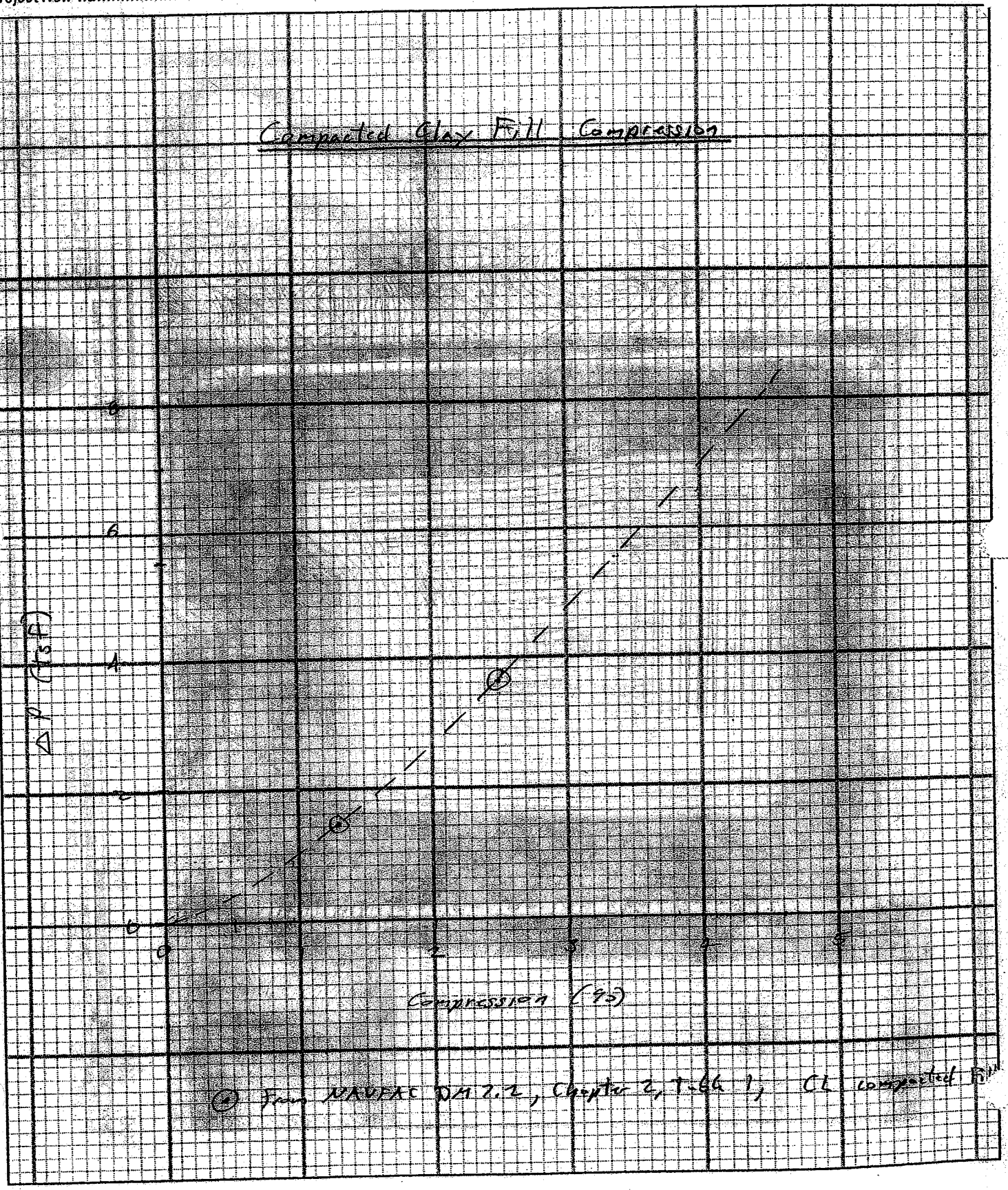
Assume compressible soil extends to the Mahoney Aquifer (at approx. Elev. 485')

$\Rightarrow H$ = Elev 660 − Elev. 485 = 175'

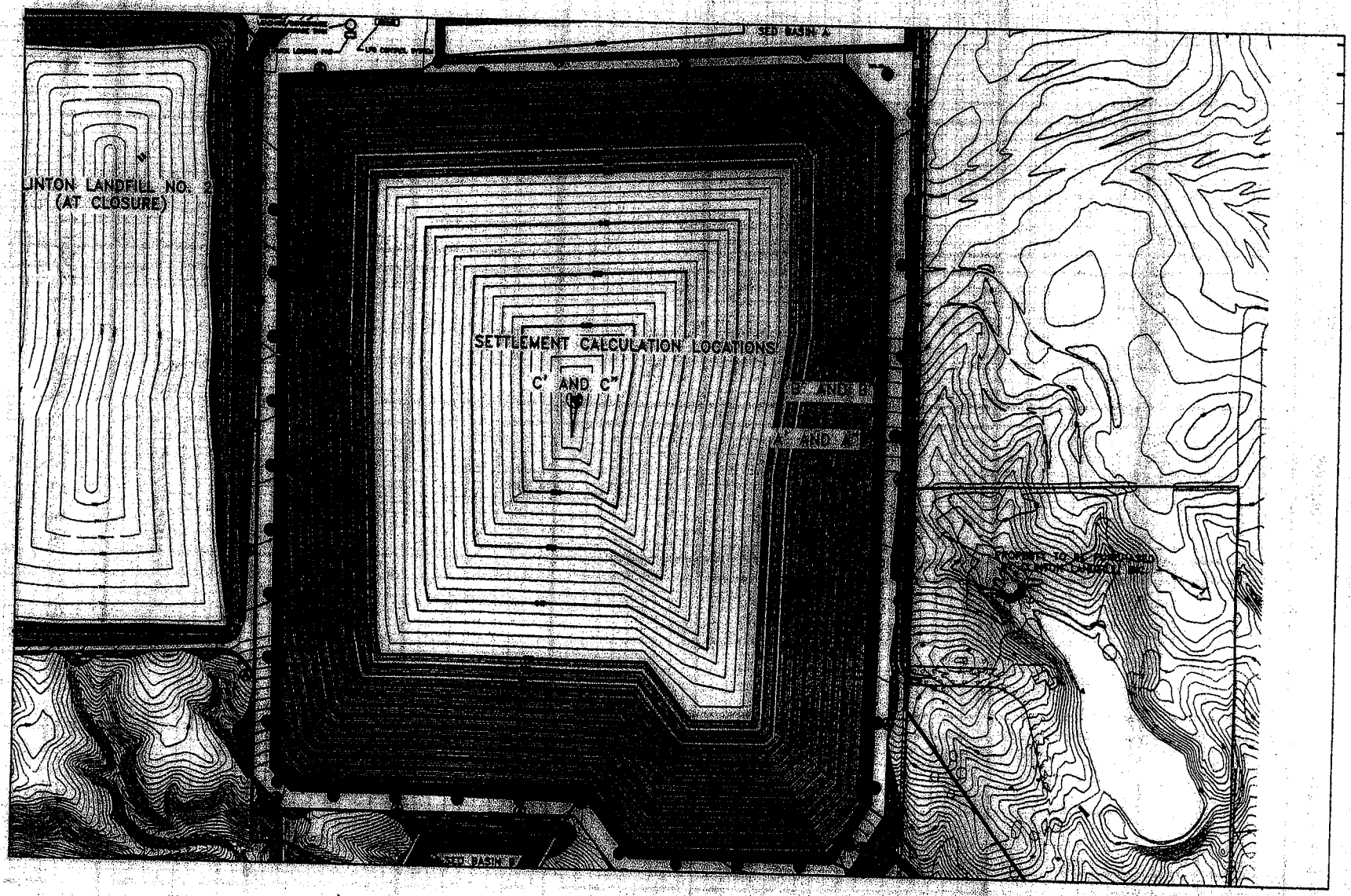
$\frac{H}{B} = \frac{175}{1200} = 0.15$

From chart, For $\frac{H}{B} = 0.15$ $I_c = 0.015$

Compacted Clay Fill Compression



① From NAVFAC DM 7.2, Chapter 2, T-64 1, CL compacted fill



600' 300' 0 600' 1200'

1"=600'

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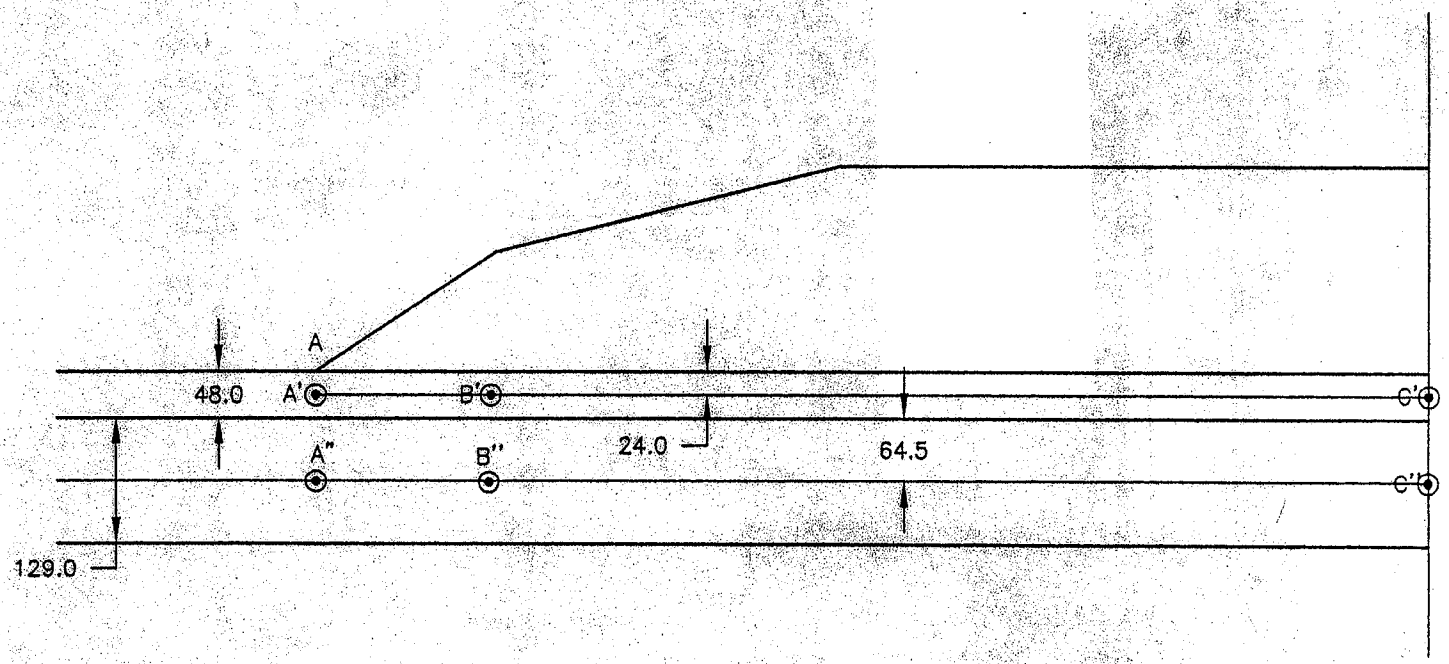
SETTLEMENT CALCULATION LOCATIONS
PLAN VIEW

CLINTON LANDFILL NO.3

CLINTON, ILLINOIS

PROJECT NO. 91-118

24/33



200 100 0 200 400

1"=200

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SETTLEMENT CALCULATION LOCATIONS

CLINTON LANDFILL NO.3

CLINTON, ILLINOIS

PROJECT NO. 91-118

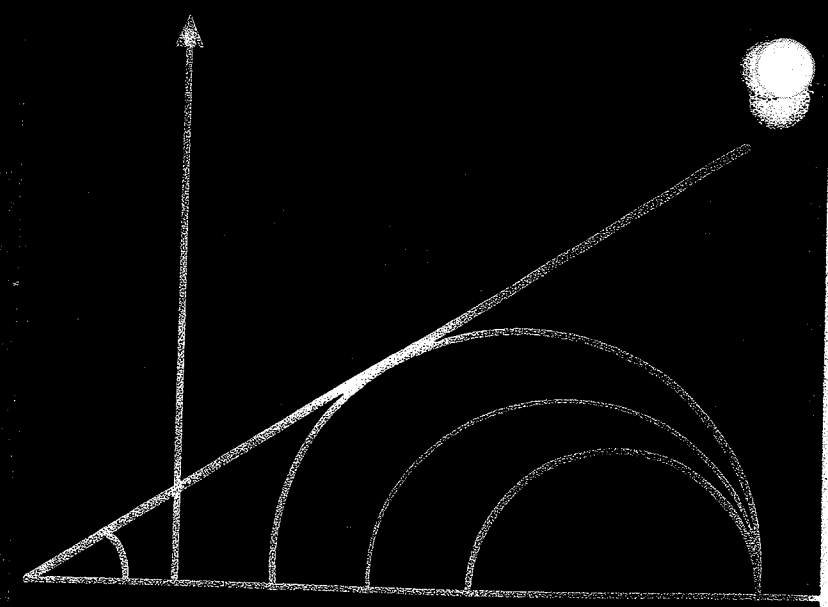
26/33

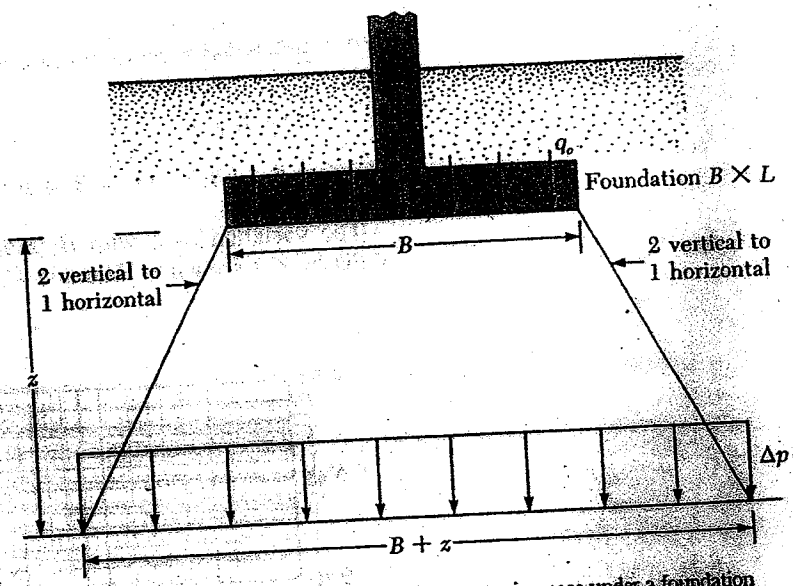
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Principles of Foundation Engineering

Third Edition





▼ **FIGURE 3.42** 2:1 method of finding stress increase under a foundation

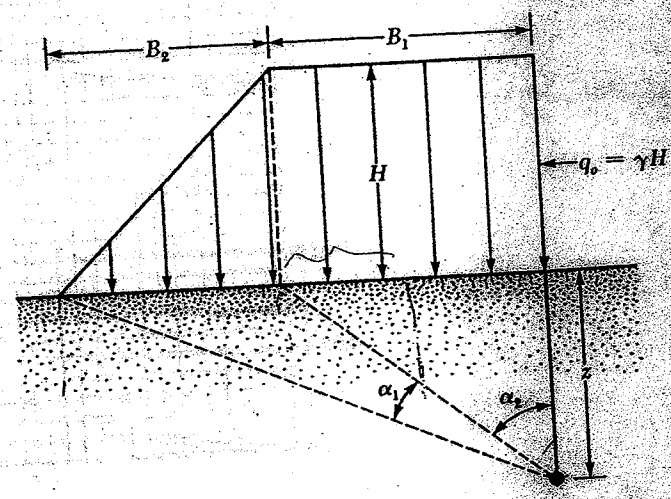
where $q = \gamma H$

γ = unit weight of the embankment soil

H = height of the embankment

$$\alpha_1 \text{ (radians)} = \tan^{-1}\left(\frac{B_1 + B_2}{z}\right) - \tan^{-1}\left(\frac{B_1}{z}\right) \tag{3.}$$

$$\alpha_2 = \tan^{-1}\left(\frac{B_1}{z}\right) \tag{3.}$$



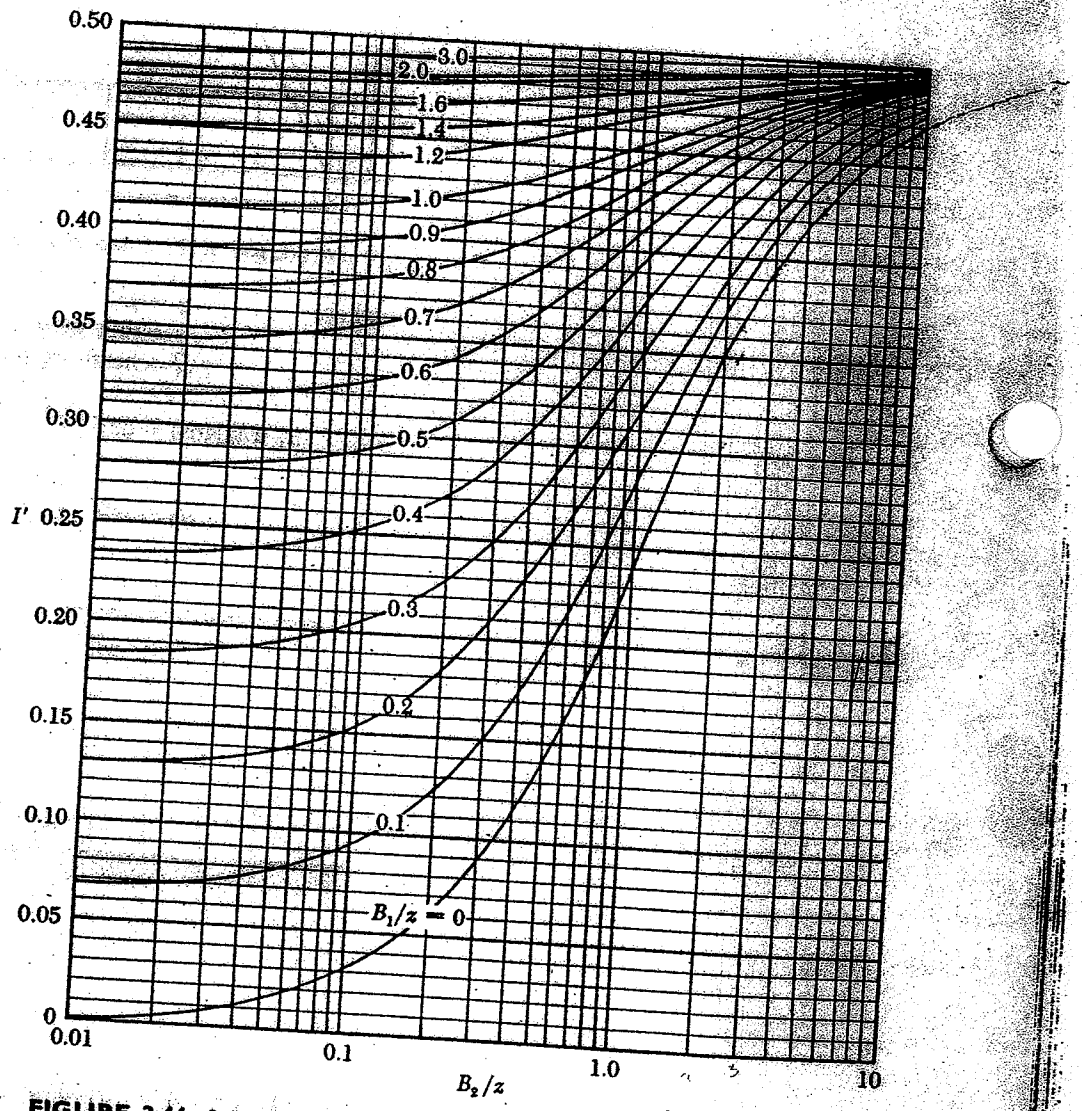
▼ **FIGURE 3.43** Embankment loading

For a detailed derivation of the equation, see Das (1983). A simplified form of Eq. (1.109) is

$$\Delta p = q_o I' \tag{3.112}$$

where I' = a function of B_1/z and B_2/z.

The variation of I' with B_1/z and B_2/z is shown in Figure 3.44. Application of this diagram is shown in Example 3.12 on page 204.



▼ **FIGURE 3.44** Influence value of I' for embankment loading (after Osterberg, 1957)

29/33

G. Armstrong

NAVFAC DM-7.1
MAY 1982

APPROVED FOR PUBLIC RELEASE

SOIL MECHANICS

DESIGN MANUAL 7.1

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL STREET
ALEXANDRIA, VA. 22332

c. Evaluation of Existing Conditions. Determine consolidation conditi at start of construction by the following steps:

(1) Review the data available on site history and geology to estimate probable preconsolidation or underconsolidation.

(2) Compare profile of preconsolidation stress determined from laboratory consolidation tests (Chapter 3) with the profile of effective overburden pressures.

(3) Estimate preconsolidation from c/P_c ratio, where c is the cohesion ($q_u/2$) and P_c is the preconsolidation stress, using laboratory data from unconfined compression test and Atterberg limits (see Chapter 3).

$$P_c = \frac{q_u/2}{0.11 + 0.0037\ PI}$$, in which q_u is the unconfined compressive strength, and PI is the soil plasticity index.

(4) If underconsolidation is indicated, install piezometers to measure the magnitude of hydrostatic excess pore water pressures.

d. Computation of Added Stresses. Use the elastic solutions (Chapter 4) to determine the vertical stress increment from applied loads. On vertical lines beneath selected points in the loaded area, plot profiles of estimate preconsolidation and effective overburden stress plus the increment of appli stress. See Figure 3 for typical profiles. Lowering of groundwater during construction or regional drawdown increases effective stress at the boundaries of the compressible stratum and initiates consolidation. Stress applied by drawdown equals the reduction in buoyancy of overburden corresponding to decrease in boundary water pressure. In developed locations, settlement of surrounding areas from drawdown must be carefully evaluated before undertaking dewatering or well pumping.

Section 3. INSTANTANEOUS (Elastic) SETTLEMENT

1. IMMEDIATE SETTLEMENT OF FINE-GRAINED SOILS. Generally, the instantaneous settlement results from elastic compression of clayey soil. For foundations on unsaturated clay or highly overconsolidated clay, the elastic settlement constitutes a significant portion of the total settlement.

b. Approximate Values. See Figure 3 for a relationship between preconsolidation pressure and liquidity index. For samples with natural moisture at the liquid limit (liquidity index of 1), preconsolidation ranges between about 0.1 and 0.8 tsf depending on soil sensitivity. For natural moisture at the plastic limit (liquidity index equal to zero), preconsolidation ranges from about 12 to 25 tsf.

FROM DM 7.1 PAGE 210

Immediate settlement δ_v is estimated as:

$$\delta_v = q\, B\, \left(\frac{1-\nu^2}{E_u}\right) I$$

q is applied uniform pressure; B is width of loaded area; I is combined shape and rigidity factor; ν is Poisson's ratio - ranges between 0.3 and 0.5, the higher value being for saturated soil with no volume change during loading; and E_u is undrained modulus obtained from laboratory or field (pressure-meter) tests. Table 1 (Reference 1, Stresses and Deflections in Foundations and Pavements, by Department of Civil Engineering, University of California, Berkeley) provides values of I. Empirical relationship derived from field measurement may be used to determine E_u when actual test values are not available; see Table 2 (adapted from Reference 2, An Engineering Manual For Settlement Studies, by Duncan and Buchignani). Empirical correlations for estimation of OCR (Over Consolidation Ratio) are presented in Chapter 3.

TABLE 2

Relationship Between Undrained Modulus and Overconsolidation Ratio

OCR*	Eu/c		
	PI<30	30<PI<50	PI>50
<3	600	300	125
3 - 5	400	200	75
>5	150	75	50

* OCR = Overconsolidation ratio

c = Undrained shear strength

PI = Plastic index

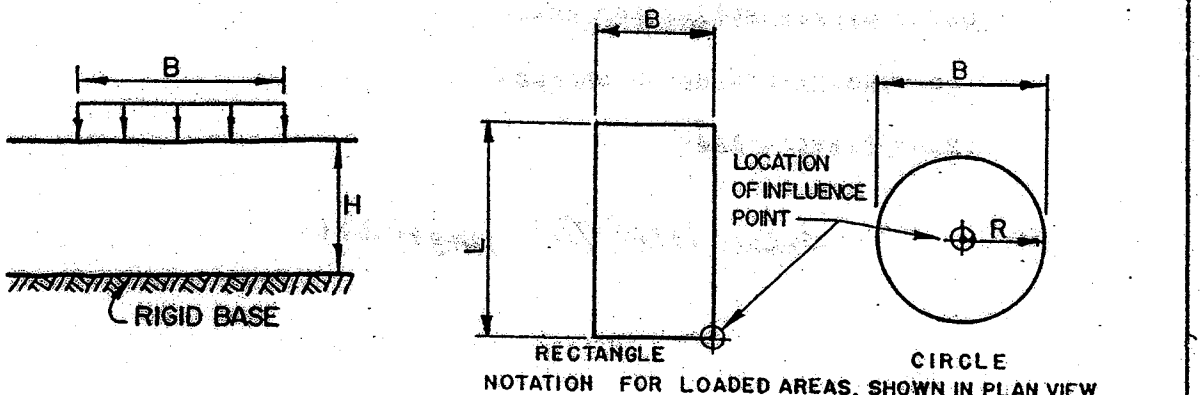
From DM 7.1 page 211

TABLE 1 (continued)
Shape and Rigidity Factors I for Calculating Settlements
of Points on Loaded Areas at the Surface of an Elastic Half-Space

Shape and Rigidity Factor I for Loaded Areas
on an Elastic Half-Space of Limited Depth Over a Rigid Base

(See Attached Graph)

H/B	Center of Rigid Circular Area Diameter = B	Corner of Flexible Rectangular Area				
		L/B = 1	L/B = 2	L/B = 5	L/B = 10	(strip) L/B = ∞
		for ν = 0.50				
0	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.14	0.05	0.04	0.04	0.04	0.04
1.0	0.35	0.15	0.12	0.10	0.10	0.10
1.5	0.48	0.23	0.22	0.18	0.18	0.18
2.0	0.54	0.29	0.29	0.27	0.26	0.26
3.0	0.62	0.36	0.40	0.39	0.38	0.37
5.0	0.69	0.44	0.52	0.55	0.54	0.52
10.0	0.74	0.48	0.64	0.76	0.77	0.73
		for ν = 0.33				
0	0.00	0.00	0.00	0.00	0.00	0.00
0.5	0.20	0.09	0.08	0.08	0.08	0.08
1.0	0.40	0.19	0.18	0.16	0.16	0.16
1.5	0.51	0.27	0.28	0.25	0.25	0.25
2.0	0.57	0.32	0.34	0.34	0.34	0.34
3.0	0.64	0.38	0.44	0.46	0.45	0.45
5.0	0.70	0.46	0.56	0.60	0.61	0.61
10.0	0.74	0.49	0.66	0.80	0.82	0.81



NOTATION FOR LOADED AREAS, SHOWN IN PLAN VIEW

(3) Gradual Load Application. If construction time is appreciable compared to time required for primary consolidation, use the time factors of Figure 13 (Reference 10, Consolidation Under Time Dependent Loading, by Olson) to determine consolidation rate during and following construction.

(4) Coefficient of Consolidation From Field Measurements. Where piezometers are installed to measure pore water pressure under the applied loads, c_v is computed as shown in Figure 14.

c. Time Rate of Multi-Layer Consolidation. If a compressible stratum contains layers of different overall properties, use the procedure of Figure 15 to determine overall settlement time rate.

3. SECONDARY COMPRESSION.

a. Laboratory e-log p Curve. A laboratory e-log p curve includes an amount of secondary compression that depends on duration of test loads. Secondary compression continues exponentially with time without definite termination. Thus, total or ultimate settlement includes secondary compression to a specific time following completion of primary consolidation.

b. Settlement Computation. Compute settlement from secondary compression following primary consolidation as follows:

$$H_{sec} = C_\alpha (H_t) \log \frac{t_{sec}}{t_p}$$

H_{sec} = settlement from secondary compression

C_α = coefficient of secondary compression expressed by the strain per log cycle of time (See Chapter 3)

H_t = thickness of the compressible stratum

t_{sec} = useful life of structure or time for which settlement is significant

t_p = time of completion of primary consolidation

See example in Figure 9 for calculating the secondary settlement. The parameter C can be determined from laboratory consolidation tests (Chapter 3); for preliminary estimates, the correlations in Figure 16 (after Reference 2) may be used. This relationship is applicable to a wide range of soils such as inorganic plastic clays, organic silts, peats, etc.

c. Combining Secondary and Primary Consolidation. If secondary compression is important, compute the settlement from primary consolidation separately, using an e-log p curve that includes only compression from primary consolidation. For each load increment in the consolidation test, compression is plotted versus time (log scale) (see Chapter 3). The compression at the end of the primary portion (rather than standard 24 hours) may be used to establish e-log p curve.

APPENDIX 812.305-G: HYDROSTATIC UPLIFT CALCULATIONS

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CLI Expansion Calculated By: GC Armstrong Sheet 1 of 15

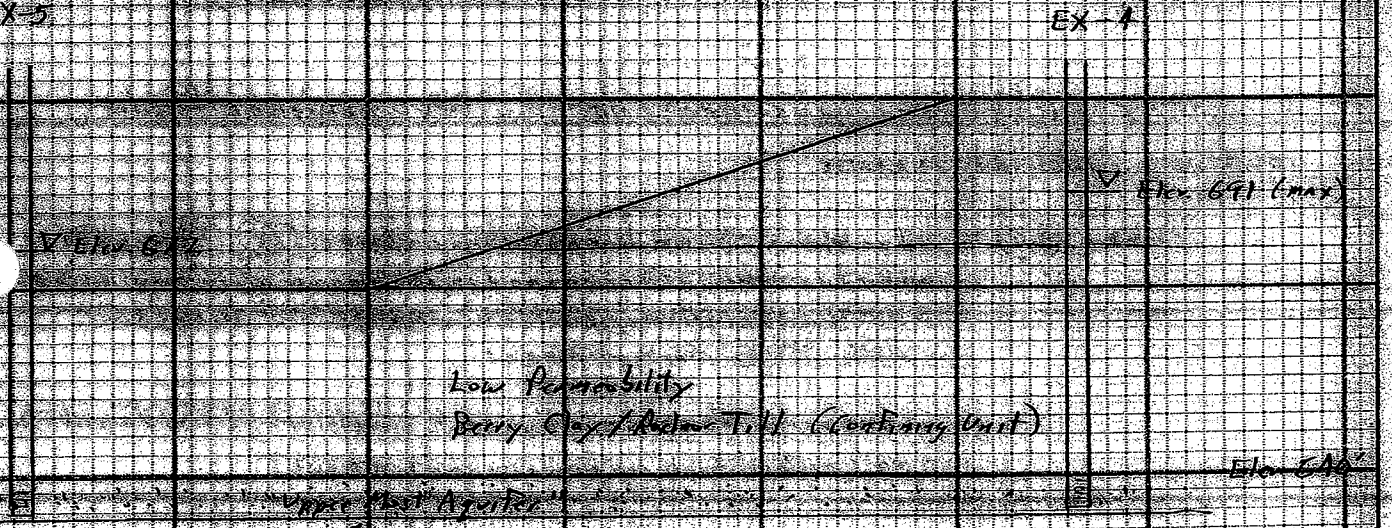
Project No.: 91-0118.02 Task No.: Checked By: SMS Date: 12-10-01

Hydrostatic Uplift

Reference: Potentiometric Surface vs. Proposed Landfill Invert
Geologic Cross-Sections

Check for potential landfill excavation floor instability due to hydrostatic uplift on the foundation soil.

Northwestern Edge of Landfill



Highest potentiometric head is at EX-4, north of the landfill, where the maximum potentiometric head measurement = Elev. 691. The potentiometric head decreases southward (see attached potentiometric surface drawing).

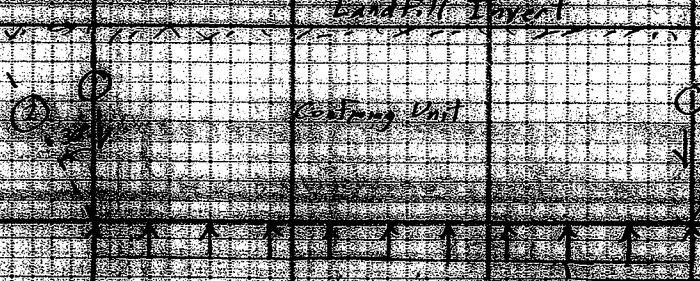
Check for stability at critical location (northern edge of landfill)

Apply the following factors of safety against hydrostatic uplift:

① Completed Earth Liner — F.S. ≥ 1.25
(This condition will exist for a few months as the overlying geomembrane and leachate collection/drainage system are installed and operating approval is granted)

② Earth Liner Subgrade: F.S. ≥ 1.1
(This condition will be of very limited area and will exist for a short period of time (days) as the Earth Liner is installed).

Potential Failure Modes



Uplift failure can occur under one of two potential failure modes as illustrated above.

Mode ①: In order to fail along failure plane ①, the uplift must exceed the shearing resistance of the soil along the failure plane plus the weight of the soil within the failure planes.

Considering the relatively high strength of the foundation soil, this failure plane is not critical.

Mode ②: Uplift is resisted by the weight of the soil within the failure planes which are angled at about 30° due to soil arching. Shearing resistance of the soil is neglected.

Consideration of soil arching decreases in importance as the area under consideration increases.

Analysis Approach

1. Check the overall factor of safety for the eastern (lower-most) one-quarter of each leachate drainage cell. These are the critical areas since the thickness of the containing unit is the least at these bottoms.

Neglect soil arching; check factors of safety with and without the earth liner.

2. Check local factors of safety at the base of each leachate collection sump, considering soil arching.

Uplift Resistance - Overall Stability

The areas to be evaluated for overall factor of safety are shown on the attached Figure 1. Figure 1 shows the area (Ft.^{2}) of each area under consideration, as well as the elevation at the top of earth liner at its low point (note that the elevation of the top of earth liner at the leachate collection sumps may be as much as 3' below that for the adjacent liner).

The volume of the containing unit between the top of earth liner and the top of the Upper-Most Aquifer (based on soil boring data) was calculated by establishing a digital terrain model (DTM) of each surface. AutoDesk Land Development Desktop was then used to calculate the volume between each surface, from which the uplift resistance can be calculated.

Uplift Resistance - Local Stability

Local failure was checked assuming a 20' x 20' leachate collection sump founded 3'8" below the earth liner low point. The volume of the confining unit was calculated using the volume equation for a frustum of a pyramid:

$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$ (See attached reference)

where: h = Confining unit thickness
for completed earth liner case = low point elevation from final minus 3'2" minus the elevation of the top of the aquifer

A_1 = Assumed area of the top of the leachate collection sump (1444 ft²)

$A_2 = \left[B - 2h\tan 30^\circ\right]^2$

B = Top width of leachate collection sump (35' assumed)

30° = ∠ w.r.t. vertical of failure plane (See p. 2 of these calculations)

Design Uplift Pressures

Design uplift pressures are based on potentiometric elevation measurements at the site, see attached Potentiometric Surface vs. Proposed Landfill Invert, and Geologic Cross-Sections C-C' & D-D'. Within the eastern 1/4 segment of each leachate collection cell, AutoDesk Land Development Desktop was used to calculate the volume between the potentiometric surface and top of aquifer. This volume multiplied by the unit weight of water (62.4 lbs/ft³) is the uplift pressure acting on the base of the till overlying the aquifer.

Equations

Overall Factor of Safety

Uplift Force = Volume between potentiometric surface and top of aquifer (From Land Development Desktop) $\times \gamma_w$

$\gamma_w = 62.4\ lb/ft^3$

Confining Unit Volume: Earth Liner In Place

V_1 = Volume From Land Development Desktop − Volume of leachate collection sump (See attachment 4)

Confining Unit Weight: Earth Liner In Place

W_1 = (Confining Unit Volume × Berry Clay/Radnor Till Unit weight) − (Leachate Collection Cell Area × Earth Liner Thickness × [Berry Clay/Radnor Till Unit Weight − Earth Liner Unit Weight])

Earth Liner Thickness = 3'

Confining Unit Volume: Earth Liner Subgrade

V_2 = V_1 − (Earth Liner Thickness × Leachate Collection Cell Area)

PDC TECHNICAL SERVICES, INC.

Project: CLI Expansion Calculated By: G.L. Armstrong Sheet 6 of 11

Project No.: 91-0118.02 Task No.: Checked By: SMS Date: 12-12-01

Confining Unit Weight: Earth Liner Subgrade

$W_2 = V_2 \times$ Bentonite Clay/Rubber Unit Weight

Factor of Safety

$$\frac{\text{Confining Unit Weight}}{\text{Uplift Force}}$$

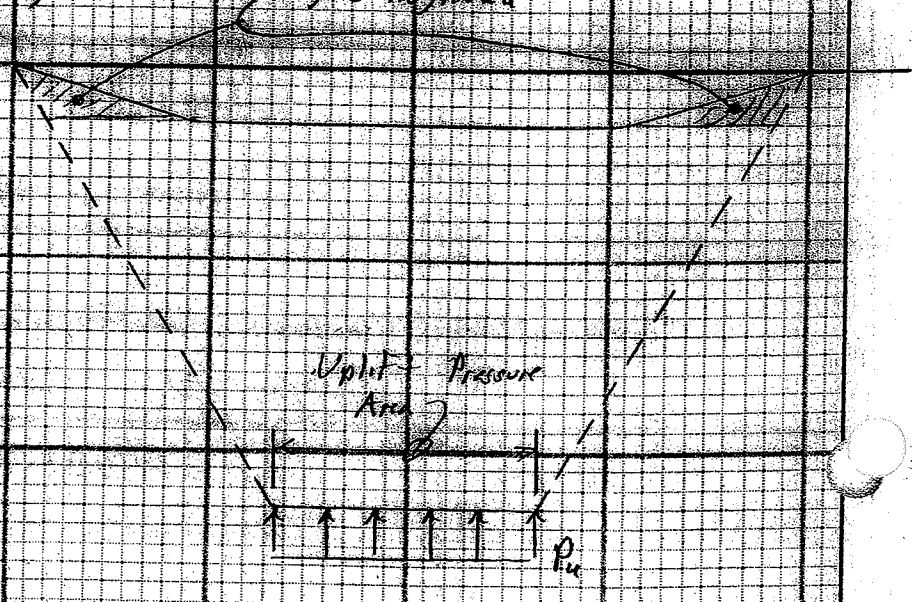
Localized Failure Factors of Safety

Confining Unit Thickness

T = Liner Elevation at Low Point − Depth of Sump (3.7') − Elev. 640

Uplift Pressure Area

See calculation of $A_{2,2}$ page 7.



Uplift Force = (Potentiometric Elev − Elev. 640) × Uplift Pressure Area × γ_w

Confining Unit Volume: Earth Liner In Place (V_3)

See volume equations, page 4

Confining Unit Weight: Earth Liner In Place

W_3 = [V_3 × Berry Clay/Redwood Till Unit Weight] − (Top Area of Sump × Earth Liner Thickness × (Berry Clay/Redwood Till Unit Weight − Earth Liner Unit Weight))

Confining Unit Volume: Earth Liner Subgrade

$V_4 = V_3 - (\text{Earth Liner Thickness} \times \text{Top Area of Sump})$

Confining Unit Weight: Earth Liner Subgrade

$W_4 = V_4 \times$ Berry Clay/Redwood Till Unit Weight

Factor of Safety:

$$\frac{\text{Confining Unit Weight}}{\text{Uplift Force}}$$

Calculations are provided on the following spreadsheets

HYDROSTATIC UPLIFT
Clinton Landfill Expansion

OVERALL FACTORS OF SAFETY

Leachate Collection Cell	Area (sq. ft.)	Uplift Force (lbs)	Earth Liner in Place			Earth Liner Subgrade		
			Confining Unit		Factor of Safety	Confining Unit		Factor of Safety
			Volume (cu. ft.)	Weight (lbs)		Volume (cu. ft.)	Weight (lbs)	
A	24,048	68,031,000	648,123	93,256,395	1.37	575,979	82,916,955	1.23
B	59,605	159,736,000	1,533,885	220,625,175	1.38	1,355,070	195,490,150	1.23
C	58,766	140,722,000	1,448,833	208,317,805	1.48	1,272,535	184,517,575	1.31
D	58,986	130,887,000	1,425,588	204,940,680	1.57	1,248,630	181,051,350	1.38
E	60,058	122,978,000	1,437,630	206,654,610	1.68	1,257,456	182,331,120	1.48
F	61,947	119,955,000	1,463,199	210,305,445	1.75	1,277,358	185,216,910	1.54
G	63,307	121,175,000	1,471,758	211,505,700	1.75	1,281,837	185,866,365	1.53
H	63,252	120,443,000	1,457,961	209,506,785	1.74	1,268,205	183,889,725	1.53
I	63,152	122,947,000	1,450,320	208,401,840	1.70	1,260,864	182,825,280	1.49
J	63,104	123,646,000	1,453,047	208,798,695	1.69	1,263,735	183,241,575	1.48
K	63,077	124,342,000	1,468,275	211,007,565	1.70	1,279,044	185,461,380	1.49
L	89,251	175,469,000	2,139,468	307,545,330	1.75	1,871,715	271,398,675	1.55

Earth Liner Compacted Unit Weight = 135 pcf
Berry Clay / Radnor Till Unit Weight = 145 pcf

8/15

HYDROSTATIC UPLIFT
Clinton Landfill Expansion

LOCALIZED FAILURE FACTORS OF SAFETY

Leachate Collection Cell Sump	Sump Base Elevation (ft)	Top of Sump Area (sq. ft.)	Confining Unit Thick. (ft)	Uplift Pressure Area (sq. ft.)	Potentiometric Elev. (ft MSL)	Uplift Force (lbs)	Earth Liner in Place			Earth Liner Subgrade		
							Confining Unit Volume (cu. ft.)	Confining Unit Weight (lbs)	Factor of Safety	Confining Unit Volume (cu. ft.)	Confining Unit Weight (lbs)	Factor of Safety
A	661.0	1,225	21.0	115.6	687	339,003	12,018	1,705,869	5.03	8,343	1,209,764	3.57
B	659.3	1,225	19.3	161.7	685	453,921	11,764	1,671,977	3.68	8,109	1,175,752	2.59
C	658.8	1,225	18.8	176.7	682	463,010	11,699	1,659,617	3.58	8,024	1,163,492	2.51
D	658.9	1,225	18.9	173.6	679	422,500	11,717	1,662,156	3.93	8,042	1,166,031	2.76
E	658.9	1,225	18.9	173.6	676	390,000	11,717	1,662,156	4.26	8,042	1,166,031	2.99
F	658.7	1,225	18.7	179.8	673	370,142	11,681	1,657,035	4.48	8,006	1,160,908	3.14
G	658.6	1,225	18.6	182.9	673	376,545	11,663	1,654,404	4.39	7,988	1,158,279	3.08
H	658.2	1,225	18.2	195.6	673	402,707	11,587	1,643,431	4.08	7,912	1,147,306	2.85
I	658.2	1,225	18.2	195.6	673	402,707	11,587	1,643,431	4.08	7,912	1,147,306	2.85
J	658.2	1,225	18.2	195.6	673	402,707	11,587	1,643,431	4.08	7,912	1,147,306	2.85
K	658.2	1,225	18.2	195.6	673	402,707	11,587	1,643,431	4.08	7,912	1,147,306	2.85
L	658.2	1,225	18.2	195.6	673	402,707	11,587	1,643,431	4.08	7,912	1,147,306	2.85

Earth Liner Compacted Unit Weight =	135	pcf
Berry Clay / Radnor Till Unit Weight =	145	pcf
Leachate Collection Sump Bottom Width =	20	feet
Leachate Collection Sump Top Width =	35	feet

9/15

Calculate corrected N-value

$$N_c = N_{Field} \times C_N$$

$C_N = 0.8$ (From Figure 4-5)

$\rightarrow N_c = 15 \times 0.8 = 12$

Plot $\frac{\tau_{av}}{\sigma_v'}$ vs N_c (See attached Fig. 4-6)

$\longrightarrow$ The site is well below the lower bound for site where liquefaction occurred $\therefore$ liquefaction potential is negligible

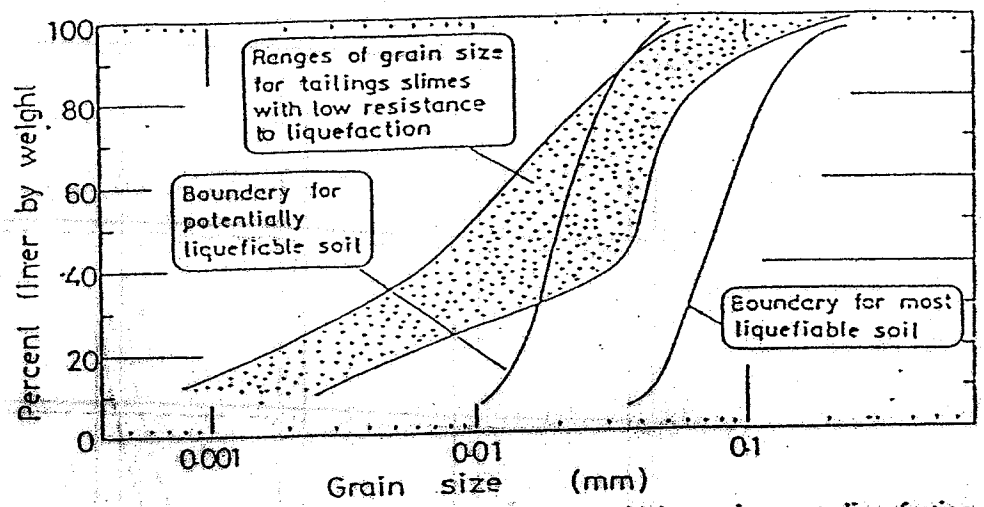


FIGURE 4-2 Ranges of grain sizes for tailings slimes with low resistance to liquefaction. Source: Ishihara (1985).

deposit, the presence of strata with lower permeabilities, and other factors. This matter has been examined in a preliminary way by Seed et al. (1976), who show that grain size can have a major effect upon dissipation of pore pressures for coarse sands with $D_{20} > 0.6$ mm. They conclude that it is unlikely that soils with $D_{20} > 0.7$ mm would ever develop a condition of initial liquefaction, provided there are no overlying or intervening layers of low permeability to inhibit drainage.

Empirical Correlations Using In-Situ Evaluation of Resistance

Since the Niigata earthquake, considerable field experience with liquefaction during actual earthquakes has been obtained and interpreted. This mass of data forms a basis for establishing empirical correlations relating the occurrence or nonoccurrence of liquefaction to the intensity of ground shaking and the principal characteristics of cohesionless soils.

Correlations Based on Standard Penetration Resistance

Figure 4-3 shows information applying to sites with clean sands and earthquakes with a magnitude of about 7.5. Each point corresponds usually to one boring record during some particular earthquake. The intensity of ground motion at the site is represented by the vertical ordinate τ_{av}/σ'_o, where τ_{av} is the average peak shear stress and σ'_o is the initial vertical effective stress. τ_{av}/σ'_o is computed from the peak

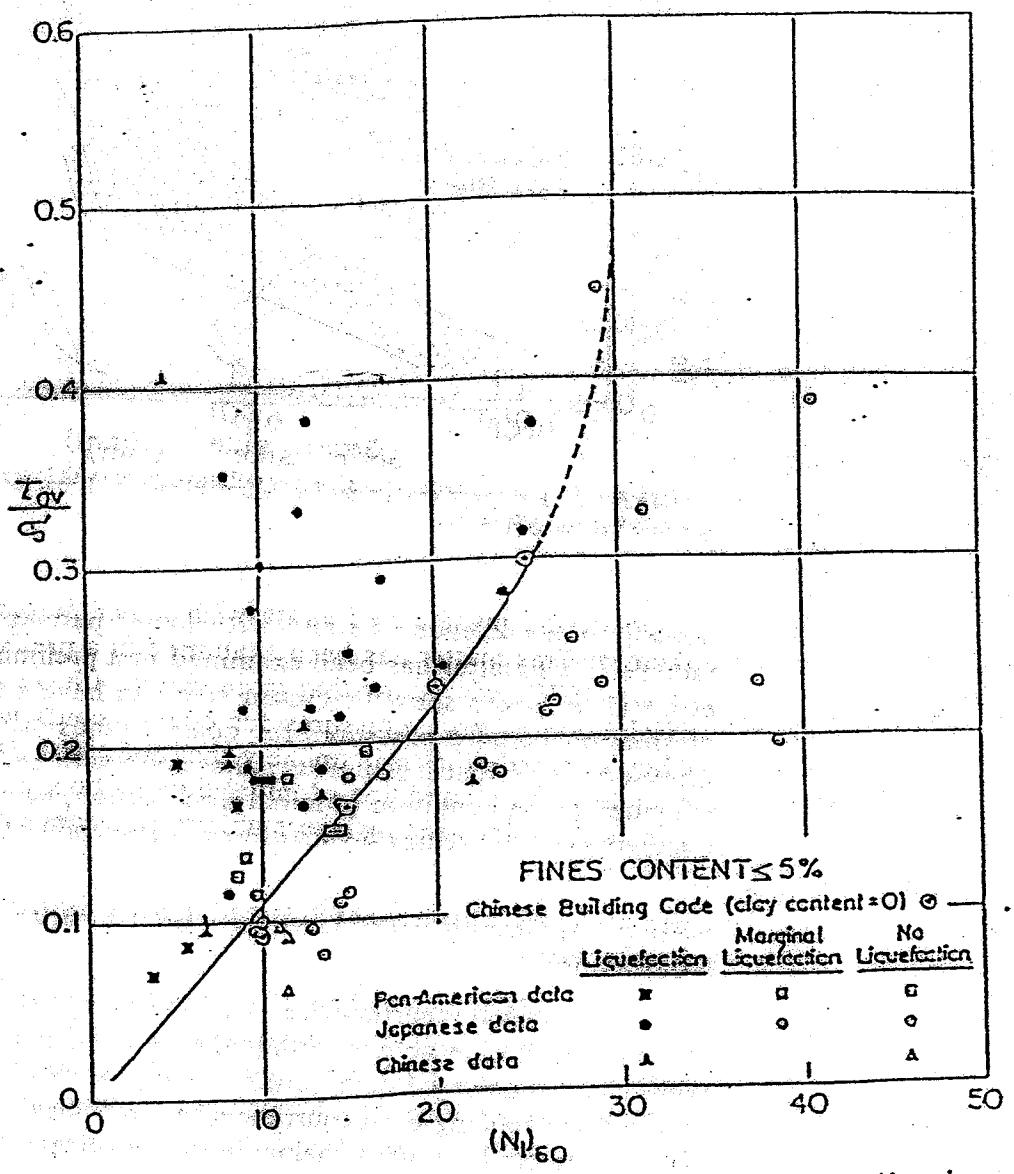


FIGURE 4-3 Relationship between stress ratios causing liquefaction and $(N_1)_{60}$ values for clean sands for magnitude 7.5 earthquakes. Source: Seed et al. (1984).

surface acceleration by a simple equation that accounts approximately for the relative importance of the many different acceleration peaks in a typical ground motion record (Seed and Idriss, 1971):

$$\tau_{av}/\sigma'_o = 0.65\, a_{max}\, \sigma_o\, r_d/\sigma'_o\, g \qquad \text{(Eq. 4-1)}$$

where a_{max} is the maximum acceleration at ground surface, σ_o equals the total overburden stress at depth under consideration, σ'_o is the effective overburden stress at this same depth, and r_d equals a stress

reduction factor that decreases from a value of 1 at the ground surface to a value of 0.9 at a depth of 35 ft.

The resistance of the soil is represented by the horizontal abscissa $(N_1)_{60}$, which is the blow count in the standard penetration test (SPT), corrected (as discussed later) for the depth of overburden and for certain details in the performance of the test. Both τ_a/σ'_o and $(N_1)_{60}$ are evaluated at the depth in the particular deposit most critical from the standpoint of liquefaction.

The curve drawn in Figure 4-3 is intended to divide zones corresponding to liquefaction and nonliquefaction. A new site would be evaluated by plotting a point corresponding to the blow count for the site and to the design earthquake ground motion. If the point plots on or above the curve, the site would be judged susceptible to liquefaction. If the point plots below the curve with an adequate margin of safety, the site is judged to be safe.

There is no general agreement on the appropriate margin of safety, primarily because the degree of conservatism thought desirable at this point depends upon the extent of the conservatism already introduced in assigning the design earthquake. If the design earthquake ground motion is regarded as reasonable, a safety factor of 1.33 or 1.35 on τ_a/σ'_o is suggested as adequate. However, when the design ground motion is excessively conservative, engineers are content with a safety factor only slightly in excess of unity.

The important effect of the duration of the ground shaking can be taken into account by a correction related to the magnitude of the earthquake. Statistical studies (Seed et al., 1975c) show that the number of cycles representative of different magnitude earthquakes is typically as in Table 4-2. Using a representative shape for the relationship between cyclic stress ratio and the number of cycles required to cause liquefaction, a factor with which to correct the ordinates of

TABLE 4-2 Representative Number of Cycles and Corresponding Correction Factors

Earthquake Magnitude (M)	Number of Representative Cycles at 0.65 τ_{max}	Factor to Correct Abscissa of Curve in Figure 4-3
8.5	26	0.89
7.5	15	1.0
6.75	10	1.13
6.0	5-6	1.32
5.25	2-3	1.5

SOURCE: After Seed and Idriss (1982).

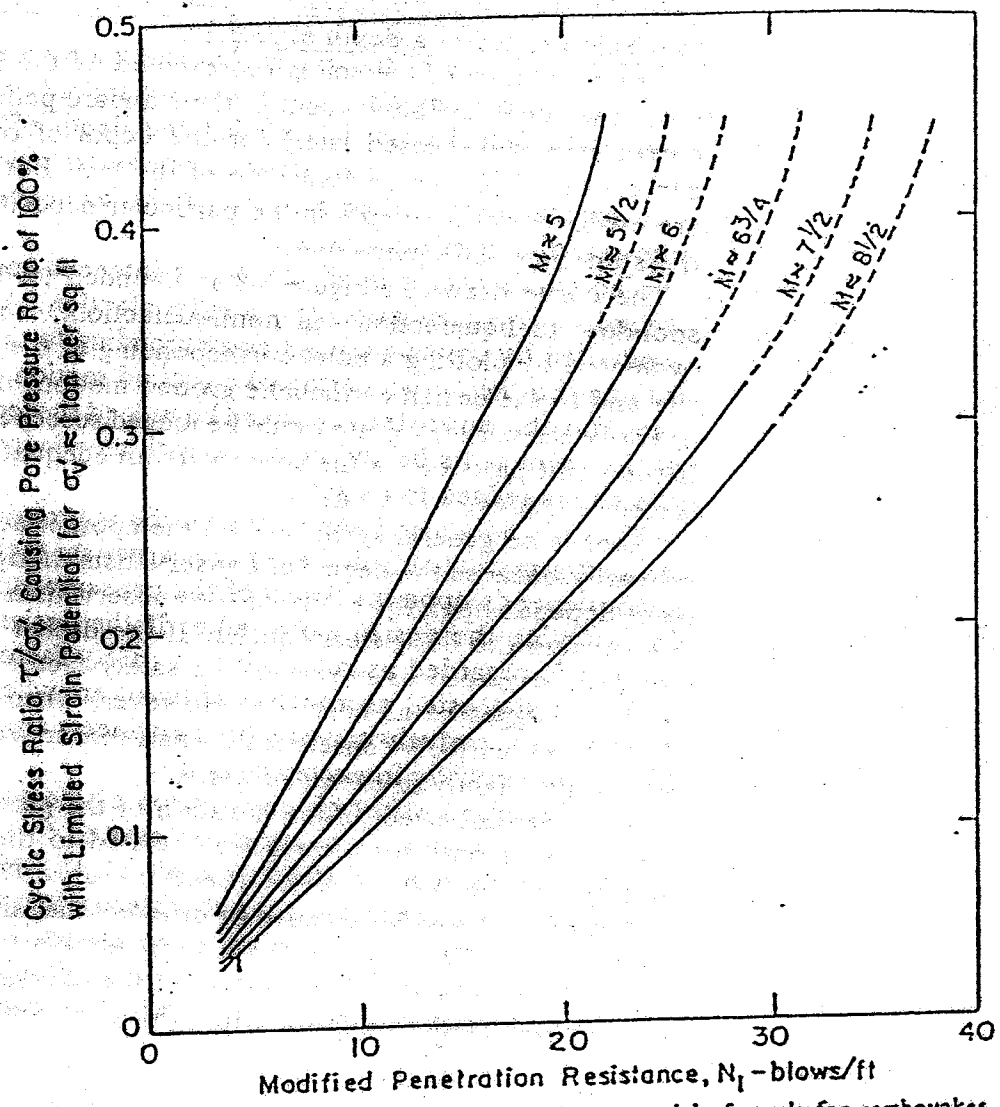


FIGURE 4-4 Chart for evaluation of liquefaction potential of sands for earthquakes of different magnitudes. Source: Seed and Idriss (1982).

Figure 4-3 can be deduced. These correction factors are also listed in the table. Using these factors leads to a family of curves such as those in Figure 4-4.*

The form of the plot in Figure 4-3 is well-grounded in theory. Laboratory tests and theoretical analyses have shown the general appropriateness of the ratio τ_a/σ'_o as a measure of resistance to liquefaction. Use of this ratio means that the depth of the water table

*Note that the curves for $M = 7\frac{1}{2}$ are somewhat different in Figures 4-3, 4-7, and 4-4, since the curves were based on different data sets. Figure 4-4 is included for illustrative purposes only; use of Figure 4-3 plus Table 4-2 represents the most up-to-date practice.

7/11

is automatically taken into account. The penetration resist
various factors (e.g., relative density and horizontal effe
known from laboratory tests to affect susceptibility to
This figure is the latest in a gradually evolving lineage of
(Seed and Idriss, 1971; Seed and Peacock, 1971; Whi
Castro, 1975; Seed et al., 1975a; Seed, 1976; Seed, 1979a
1983; Tokimatsu and Yoshimi, 1983; Seed et al., 198
improved as more data have become available and as the in
of the data have been refined. Many eminent engineers
plots such as Figure 4-3 as the best method available
liquefaction susceptibility. This practice avoids the diffic
and questions concerning undisturbed testing and samplir
the most direct use of actual experience during earthqua

Nonetheless, there are additional factors that must be

Corrections to Blow Count

It has been apparent that the standard penetration test
standardized. There are important differences between th
used in different countries, and there can be significant
the practice followed within a country. It is important
and correct for these differences when preparing data s
Figure 4-3, and such understanding is vital when applyin
to evaluation of a new site. There are several aspects o
to consider: for example, the manner in which energy i
the drill rod, the length of the drill rod, the effect c
sampling tube, the effective stress present at the depth w
count is being evaluated, and the drilling fluid (DeMello,
mann and Palacios, 1979; Kovacs and Salomone, 1982;
1984).

The manner of delivering energy to the drill roc
important. Table 4-3 summarizes results from studies i
of theoretical energy actually reaching the rod when
hammer types and hammer release mechanisms. Mos
difficulties can be eliminated by standardizing the test
recommended by Kovacs et al. (1983, 1984) and Seed
by correcting results to this standardized procedure.
using the standard conditions shown in Table 4-4 and cc
to an energy ratio of 60 percent and an effective overt
of 1 ton/ft^2.

Figure 4-5 is a chart used to correct the observed blo
value, (N_1), which would be measured at an effect
stress of 1 ton/ft^2. Thus the combined correction is:

$$(N_1)_{60} = C_N ER_m N_m/60$$

TABLE 4-3 Summary of Energy Ratios for SPT Procedures

Country	Hammer Type	Hammer Release	Estimated Rod Energy (Percent)	Correction Factor for 60 Percent Rod Energy
Japan[a]	Donut	Free-fall	78	78/60 = 1.30
	Donut	Rope and pulley with special throw release	67	67/60 = 1.12
United States	Safety	Rope and pulley	60	60/60 = 1.00
	Donut[b]	Rope and pulley	45	45/60 = 0.75
Argentina	Donut	Rope and pulley	45	45/60 = 0.75
China	Donut	Free-fall[c]	60	60/60 = 1.00
	Donut	Rope and pulley	50	50/60 = 0.83

[a]Japanese SPT results have additional corrections for borehole diameter and frequency effects.
[b]Prevalent method in the United States today.
[c]Pilcon-type hammers develop an energy ratio of about 60 percent.
SOURCE: Seed et al. (1984).

TABLE 4-4 Recommended SPT Procedure for Use in Liquefaction Correlations

Factor	Recommended Procedure
Borehole	Four-to five-in.-diameter rotary borehole with bentonite drilling mud for borehole stability
Drill bit	Upward deflection of drilling mud (tricone of baffled drag bit)
Sampler	O.D. = 2.00 in. I.D. = 1.38 in., constant (i.e., no room for liners in barrel)
Drill rods	AW for depths less than 50 ft; N, BW, or NW for greater depths
Energy delivered to sampler (rod energy)	2,520 in.-lb (60 percent of theoretical maximum)
Blowcount rate	Thirty to forty blows per minute
Penetration resistance count	Measures over range of 6 to 18 in. of penetration into the ground

SOURCE: Seed et al. (1984).

where N_m is the measured blow count and ER_m the corresponding energy ratio in percent. Both corrections were made to all observed blow counts in Figure 4-3. Other corrections were also applied in some instances.

With respect to the overburden correction factor C_N, it has been pointed out by Liao and Whitman (1985) that discrepancies exist with

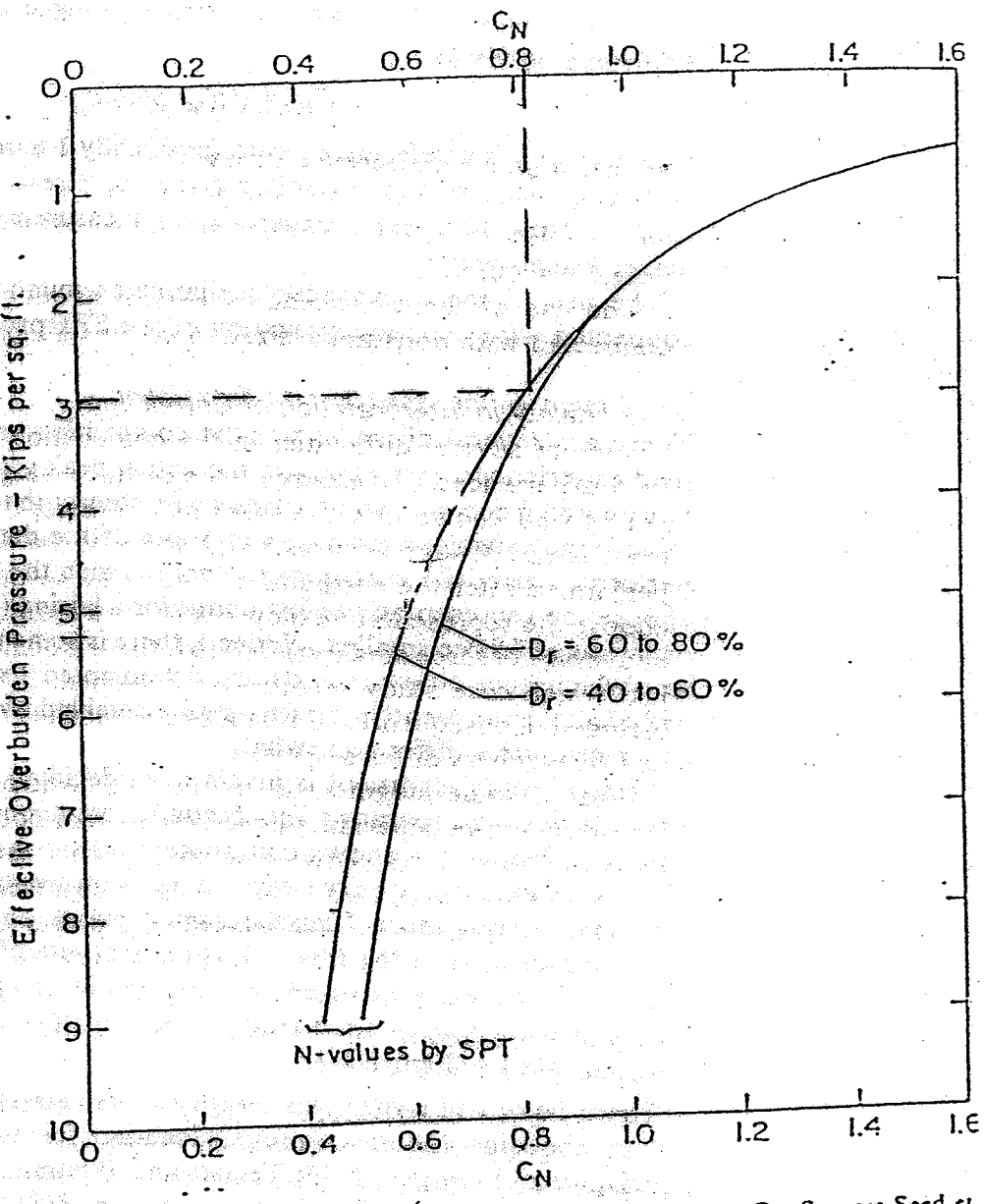


FIGURE 4-5 Charts for values of overburden correcting factor C_N. Source: Seed et al. (1984) based on data and analyses from Marcuson and Bieganousky (1977).

correction factors used in the past compared to what is the current state of practice, as represented by Figure 4-5. To some degree, this is a standardization problem in terms of SPT interpretation. As a simple useful approximation to the curves in Figure 4-5, Liao and Whitman suggest the following formula:

$$C_N = (1/\sigma'_o)^{1/2} \qquad \text{(Eq. 4-3)}$$

where σ'_o is in tons/ft² or kg/cm². They also suggest a more generalized formula of the form:

$$C_N = \{(\sigma'_o)_{ref}/\sigma'_o\}^k \qquad \text{(Eq. 4-4)}$$

where $(\sigma'_o)_{ref}$ is a reference stress (nominally 1 ton/ft²) and k would be a value that depends on soil grain size, stress history, and other factors. However, more experimental measurements are needed to define k accurately.

The use of these procedures eliminates much of the uncertainty connected with nonstandardization of the SPT procedure.

Uncertainty in Interpretation of Correlation

There are several difficulties in the compilation and interpretation of field experiences. For example, the actual peak ground acceleration is not as well known in some cases as in others; the depth of the water table is not always accurate; and some of the data are from borings performed after the earthquake. There is also the question of how to choose the representative blow count for a boring (e.g., smallest value or average of three smallest). Indeed, there is some problem of deciding just which case study records are documented "well enough" to be included. Consequently, the data sets assembled by different engineers and researchers differ somewhat.

Finally, some judgment is involved in deciding where to draw the boundary curve separating liquefaction from nonliquefaction. Examination of Figure 4-3 shows that some points corresponding to liquefaction lie below the curve while some representing nonliquefaction lie above. Even more "misclassified" points appear in a data set compiled recently at the Massachusetts Institute of Technology (Liao, 1985) after an exhaustive and careful review of published catalogs, although the import of the results is not significantly different from that indicated in Figure 4-3.

There have been various attempts to use statistical techniques to aid in choosing the most proper location for the boundary curve (Christian and Swiger, 1975; Yegian and Whitman, 1978; Yegian and Vitelli, 1981a). One effort is under way at MIT (Liao, 1985) using sophisticated techniques developed in connection with other types of engineering and scientific problems. The particular class of methods selected for this purpose is called dichotomous regression (Cox, 1970; McFadden, 1974) and provides an estimate for the probability of liquefaction given a value for τ_{av}/σ'_o and $(N_1)_{60}$. A result from this analysis is given in Figure 4-6.

Effect of Fines

Thus far the discussion has focused on clean sands free of gravel and

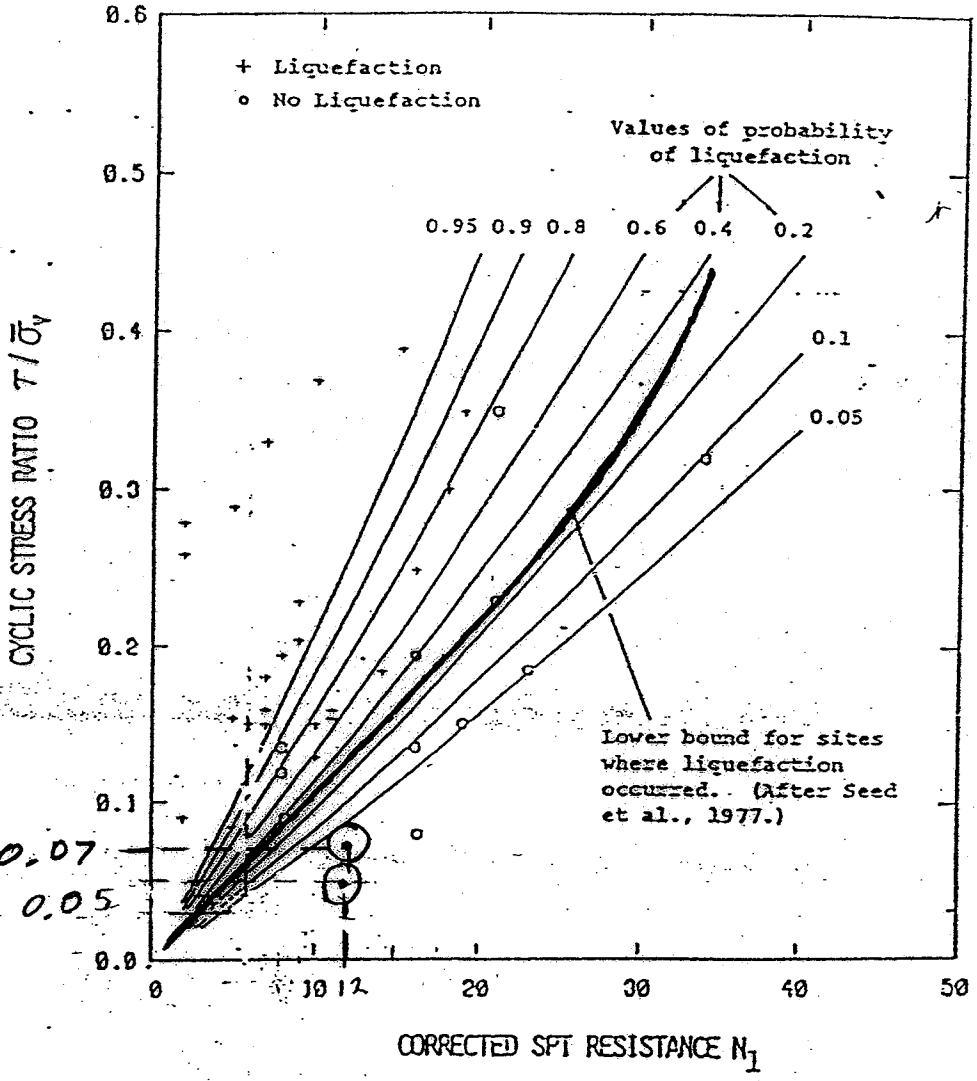


FIGURE 4-6 Preliminary results from a dichotomous regression technique showing contours of equal probability of liquefaction. Note that these results are preliminary partly because they are based on a relatively early data set from Seed and Idriss (1971). Source: Veneziano and Liao (1984).

with fines composing less than 5 percent of the soil. Deviations from these conditions require special treatment.

Figure 4-7 presents results from field observations of liquefaction or nonliquefaction involving silty sands with a content of fines greater than 5 percent. The number alongside each data point is the actual fines content. The curve labelled "≤5 percent fines" is the same curve as on Figure 4-3. Clearly there are a number of instances of nonliquefaction that lie above this curve. The curves for 15 percent and 35