

Permit Application

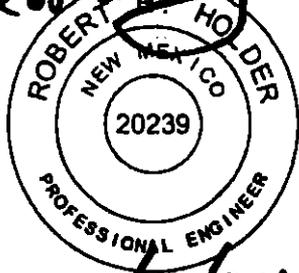
Lea County, New Mexico

C.K. Disposal E & P Landfill and
Processing Facility

Permit No. TBD

Attachment M

Engineering Design Calculations

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PARKHILLSMITH&COOPER

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1.0 LANDFILL VOLUMETRIC CALCULATIONS

Landfill volumetric calculations were computed based on Attachment B – Engineered Design Plans. Landfill volumetric calculations include waste capacity analysis and the soil material balance. The C.K. Disposal facility has a gross airspace of approximately 24,585,056-cubic yards (yd³). Assuming a contingency of 15% for variation in waste density and other operational uses, resulting in approximately 20,897,298-cubic yards of waste capacity remaining. A cut/fill analysis was computed for the site which shows a 7,717,488-cubic yard volume of cut. Table 1.1 shows the soil needed onsite for operations (see attached calculations):

Table 1.1 – Soil Necessary for Operations

Soil Type	Cubic Yards
Protective Soil	472,707
Final Cover	928,451
Perimeter Berm	5,124
Daily and Intermediate Cover	4,179,460
TOTAL	5,585,742
Volume of Cut	7,717,4881
Soil Remaining	27.6%

Therefore, the site will have ample soil for use as protective cover, final cover, daily cover, intermediate cover, and waste perimeter berm.

2.0 PIPE STRENGTH CALCULATIONS

Pipe Strength Calculations confirm that solid or perforated pipe made from Schedule 80 polyvinyl chloride (PVC) or high-density polyethylene (HDPE) standard dimension ratio (SDR 11) solid piping will withstand structural loading and other stresses at the C.K. Disposal facility. The basic design approach consists of calculating the leachate collection pipe deflection (which cannot exceed the allowable value), with a minimum factor of safety against failure of 1.0.

Table 2.1 - 6-Inch Diameter Leachate Collection Pipes

Attributes	Schedule 80 PVC	HDPE
Dimension Ratio	16	11.0
Method of Joining	Gasketed	Welded
Outside Diameter (in)	6.625	6.625
Minimum Wall Thickness (in)	0.432	0.602
Nominal Weight/ft (lb/ft)	5.313	4.970
Modulus of Elasticity (psi)	400,000 ⁽¹⁾	35,000 ⁽²⁾

(1) Reference 2

(2) Reference 4

2.1 Pipe Strength Calculations for 6-inch Schedule 80 PVC Perforated Pipe

To confirm 6-inch Schedule 80 PVC Perforated Collection Piping can withstand maximum stresses from overlying soil loading, pipes were analyzed for protection against ring deflection, wall buckling, and equipment loading. The following PVC pipe dimensions were used (from Reference 2):

- Pipe Nominal Diameter: 6-inch
- Pipe Outside Diameter (OD): 6.625-inch
- Pipe Wall Thickness (t): 0.432-inch
- Pipe Inner Diameter (ID): 5.76-inch
- Perforation Hole (/FT): 12 perforation holes
- Perforated Hole Diameter (IN): 0.5-in

2.2 Loads Acting on the PVC Leachate Collection Pipe

To calculate total vertical load on pipes (P_T), pressure from each overlying layer was calculated and summed. Each layer includes:

- 3-foot thick final cover
- 1-foot thick intermediate cover
- Fifteen, 10-foot thick layers of waste for 150 feet of total waste thickness
- 2-feet of protective soil layer
- A 1-foot thick leachate collection layer

Based on the known thickness of each layer and assigned unit weights, the pressure exerted by each layer was calculated. The results for P_T are presented in Table 2.2.

Table 2.2 – Pipe Loading Calculation

Layer	Thickness (ft)	Unit Weight (pcf)	Actual Load (psf)
Firm Cover Soil	3	110	330
Intermediate Cover Soils	1	110	110
Waste	150	74	11,100
Protective Soil Layer	2	110	220
Drainage Rock above Pipe	1	130	130
Total Actual Load (P_T)			11,890 psf
			(82.6 psi)

2.3 PVC Correction of Load on Pipe with Perforations

Perforating pipes reduce the effective pipe length available to carry loads and resist deflection. The effect of perforations can be taken into account by using an increased load per nominal unit length of pipe. The increased vertical stress to be used equals:

Static Vertical Load per Unit Length of Pipe (W_c):

$$W_c = (P_T)(D_O)/(1-((n)(d)/12)) \text{ (Reference 1)}$$

Where:

P_T = Total Actual Load (psi)

D_O = Outside Diameter of the Pipe (in)

n = Number of Perforated Holes per Foot of Pipe

d = Diameter of Perforated Hole on the Pipe (in)

$$W_c = [(82.6 \text{ psi})(6.625)]/[1-((12)(0.5 \text{ in})/12)]$$

$$W_c = 1,094.45 \text{ lbs/in} = 13,133.4 \text{ lbs/ft}$$

2.4 PVC Deflection

The standard formula used for solid waste industry applications in calculating flexible pipe deflection under earth loading is developed by Sprangler. This equation, also known as the Modified Iowa formula, is presented together with suggested values for the various constants in Reference 1, and is as follows:

$$\Delta X = \frac{(D_L)(K)(W_c)(r^3)}{(E)(I)+0.061(E')(r^3)} \text{ (Reference 1)}$$

Where:

ΔX = horizontal and vertical deflection of the pipe (in)

D_L = conservative value of 1.5, compensating for the lag or time dependent behavior of the soil/pipe systems (dimensionless). (Reference 1)

W_c = vertical load acting on the pipe per unit of pipe length (1,094.45 lbs/in).

r = mean radius of the pipe ($OD - t$) = $((6.625 \text{ in} - 0.432 \text{ in})/2) = 3.1 \text{ in}$

E = modulus of elasticity of the pipe materials (400,000 psi) (Reference 2)

E' = modulus of passive soil resistance in crushed rock (3,000 psi) (Reference 2)

K = bedding constant, reflecting the support the pipe receives from the bottom of the trench (assumes bedding angle = 180° ; therefore $K = 0.083$) (Reference 2)

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I = moment of inertia of pipe wall per unit of length (in⁴/in); for any round pipe

$$I = t^3/12 \text{ where } t \text{ is the average thickness (in)} = ((0.432)^3/12) = 0.0067 \text{ in}^4/\text{in}$$

$$\Delta X = \frac{(1.5)(0.083)(1094.45)(3.1^3)}{(400,000)(0.0067)+0.061(3,000)(3.1^3)}$$

$$\Delta X = \frac{(4,059.3 \text{ lbs/in}^2)}{(8,131.75 \text{ lbs/in})}$$

$$\Delta X = 0.5 \text{ in}$$

The percent (%) Ring Deflection (RD) is defined by the following equation:

$$\%RD = [\Delta X/(D_i+t)] \times 100$$

Where:

D_i = Internal Pipe Diameter

t = Pipe Wall Thickness

$$\%RD = [0.5/(5.76+0.432)] \times 100$$

$$\%RD = 8.1\%$$

Recognizable reversal of curvature is found in buried PVC pipe at a deflection of 30% (Reference 2); this deflection is a conservative performance limit. The deflection of 8.1% has a factor of safety of 30%/8.1%=3.7.

2.5 PVC Wall Buckling

Wall buckling may govern design of flexible pipes under conditions of loose soil burial, if external load exceeds the pipe material compressive strength. For a circular ring subjected to a uniform external pressure, the critical buckling pressure (P_{cr}) is defined as:

$$P_{cr} = 2 \times \left\{ \left[\frac{E'}{(1-\nu^2)} \right] \left[\frac{E(I)}{r^3} \right] \right\}^{0.5} \text{ (Reference 1)}$$

Where:

P_{cr} = critical buckling pressure, psi

E' = modulus of soil reaction = 3,000 psi

E = modulus of elasticity of pipe = 400,000 psi

ν = Poisson's Ratio = 0.38 for PVC pipe (Reference 2)

I = moment of inertia of the pipe wall per unit length = $t^3/12 = 0.0067 \text{ in}^4/\text{in}$

t = pipe wall thickness = 0.432 in

r = mean radius of pipe = 3.1 in

$$P_{cr} = 2 \times \left\{ \left[\frac{(3,000 \text{ psi})}{(1-(0.38^2))} \right] \left[\frac{(400,000)(0.0067)}{29.79} \right] \right\}^{0.5}$$

$$P_{cr} = 2 \times \left\{ [3,506.3][89.96] \right\}^{0.5}$$

$$P_{cr} = 1,123.3 \text{ psi}$$

The factor of safety is then determined:

$$FS = P_{cr} / \text{Actual Total Load}$$

$$FS = 1,123.3 \text{ psi} / 82.6 \text{ psi}$$

$$FS = 13.6$$

2.6 PVC Equipment Loading

Worst-case conditions would include equipment operating over the leachate collection pipe after 2-feet of protective soil layer has been placed. A loaded CAT 627 Scraper was used conservatively as the piece of equipment operating on top of the leachate collection pipe. The CAT 627 Scraper has the following specifications:

- Tractor Weight = 48,061 lbs
- Scraper Weight = 33,399 lbs
- Soil Load (20 cy) = 48,000 lbs
- Total Weight = 129,460 lbs
- Maximum Weight per Tire = 32,365 lbs (assuming equal distribution)
- D = Tire Width = Approximately 18 inches = 1.5 foot
- M = Tire Contact Length = Approximately 4 inches = 0.33 foot
- Tire Contact Area = (18 inches)(4 inches) = 72 inches² = 0.50 foot²

Superimposed loads distributed over an area during equipment operations are determined from the following equation:

$$W_{SD} = (C_s)(p)(F)(B_c)$$

Where:

W_{SD} = load on pipe (lbs/ft)

p = intensity of distributed load (lbs/ft²)

F = impact factor = 1.2, Table 4C.4 (Reference 3)

B_c = outside diameter of pipe (ft) = 6.625 inches = 0.55 foot

C_s = load coefficient = 0.053

C_s is from Table 4C.3 (Reference 3)

The table uses D/2H and M/2H to find the corresponding C_s value.

- $D/2H = 1.5 \text{ ft} / 2(3 \text{ ft}) = 0.25$
- $M/2H = 0.33 \text{ ft} / 2(3 \text{ ft}) = 0.055$

Therefore:

$$W_{SD} = (0.053)[(32,365 \text{ lbs})/(1.5 \text{ ft})(0.33 \text{ ft})](1.2)(0.55)$$

$$W_{SD} = 2,287 \text{ lbs/ft} = 190 \text{ lbs/in}$$

The superimposed load due to equipment loading is less than static loading conditions (W_c) calculated as 1,094.45 lbs/in; therefore the static loading conditions govern.

2.7 Perforated PVC Pipe Loading Summary

The critical design criteria of ring deflection and wall buckling for PVC pipe were evaluated and results are summarize in Table 2.3.

Table 2.3 – PVC Pipe Results

Design Criteria	Critical Value	Actual Value	Factor of Safety
Ring Deflection	30%	8.1%	3.7
Wall Buckling	1,123.26 psi	82.6 psi	13.6

As shown, for each limiting design criterion, the factor of safety is greater than design criteria, thus the performance standard for the selected pipe is adequate.

2.8 6-inch SDR 11.0 HDPE Pipe

To determine the capability of 6-inch HDPE SDR 11.0 perforated collection pipes to withstand maximum stresses from the overlying soil profile, the pipes were analyzed for adequate protection against ring deflection and wall buckling using Reference 4.

Wall buckling occurs if the total external soil pressure exceeds the pipe-soil system’s critical buckling pressure, and excessive ring deflection occurs if the vertical strain in the surrounding soil envelope is greater than the allowable ring deflection of the pipe. Standard dimension ratio (SDR) is the ratio of the outside pipe diameter to the pipe wall thickness $SDR = OD/t$. The dimensions are:

- Pipe Nominal Diameter: 6 inches
- Pipe Outside Diameter (OD): 6.625 inches
- Pipe Wall Thickness (t): 0.602 inch
- Pipe Inner Diameter (ID): 5.35 inches
- SDR: 11.0
- Perforation Hole (/FT): 12 perforation holes
- Perforated Hole Diameter (IN): 0.5 inch

The total actual load is the pressure from each overlying layer of soil and waste:

- 3-foot thick final cover
- 1-foot thick intermediate cover
- Fifteen, 10-foot thick layers of waste for 150 feet of total waste
- 2-feet of protective soil layer
- 1-foot thick leachate collection layer

Based on the known thickness of each layer and assigned unit weights, the pressure that will be exerted by each layer was calculated. The total actual load is the same load applied to the PVC pipe (82.6 psi).

2.9 Correction of Load on Pipe with Perforations (HDPE SDR 11.0)

Perforating pipes reduce the effective length of pipe available to carry loads and resist deflection. The effect of perforations can be taken into account by using an increased load per nominal unit length of the pipe. The increased vertical load per unit length of pipe is calculated as follows:

Static vertical load per unit length of pipe (W_c):

$$W_c = (P_T)(D_O)/(1-((n)(d)/12)) \text{ (Reference 1)}$$

Where:

P_T = total actual load (psi)

D_O = outside diameter of the pipe (in)

n = number of perforated holes per foot of pipe = 12

d = diameter of perforated hole on the pipe (in) = 0.5 in

$$W_c = [(82.6 \text{ psi})(6.625)]/[1-((12)(0.5 \text{ in})/12)]$$

$$W_c = 1,094.45 \text{ lbs/in} = 13,133.4 \text{ lbs/ft}$$

The design value in psi is found by dividing the design load in lbs/in by the diameter of pipe.

$$P_D = 1,094.45/6 = 182.4 \text{ psi}$$

2.10 HDPE Deflection

The ring deflection of the pipe can be calculated from the following Modified Iowa formula:

$$\Delta X = \frac{(D_L)(K)(W_c)(r^3)}{(E)(I)+0.061(E')(r^3)} \quad \text{(Reference 1)}$$

Where:

ΔX = ring deflection (in)

D_L = conservative value of 1.5, compensating for the lag or time dependent behavior of the soil/pipe systems (dimensionless). (Reference 1)

K = bedding factor = 0.083 (Reference 2)

W_c = vertical load per unit of pipe length, lb/in (1,094.45 lbs/in).

r = mean radius of the pipe ($OD - t$) = $((6.625 \text{ in} - 0.602 \text{ in})/2) = 3.0 \text{ in}$

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E = modulus of elasticity = 35,000 psi (Reference 4)

I = moment of inertia = $t^3/12$ (in⁴/in) = $((0.602)^3/12)$ = 0.0182

E' = soil modulus = 3,000 psi (Reference 2)

$$\Delta X = \frac{(1.5)(0.083)(1,094.45)(3^3)}{(35,000)(0.0182)+(0.061)(3,000)(3^3)}$$

$$\Delta X = \frac{(3,678.99)}{(637.0)+(4,941)}$$

$$\Delta X = 0.66 \text{ in}$$

The ring deflection is then used to determine the ring bending strain using the equation:

$$\epsilon = f_D (\Delta x/D_M + 2C/D_M)$$

Where:

ϵ = wall strain

f_D = deformation shape factor = 6.0 (Reference 5)

Δx = deflection from previous calculation = 0.66in

D_M = mean diameter, in

C = distance from outer fiber to wall centroid, in

C = 0.5(1.06t), where t = wall thickness

C = 0.5 x 1.06 x 0.602 = 0.319 in

$$\epsilon = 6.0 \left(\frac{0.66}{6} \right) \left(\frac{2(0.319)}{6} \right) = 0.07 = 7.0\%$$

The wall strain of 7.0% is less than 8% (Reference 5), which has an acceptable factor of safety of 8%/7.0% = 1.14.

2.11 HDPE Wall Buckling

Wall buckling may govern design of flexible pipes under conditions of loose soil burial, if the external load exceeds the compressive strength of the pipe material. To determine a factor of safety for wall buckling, the pipe critical-collapse differential pressure P_c must be calculated using the following formula (Reference 4):

$$P_c = 2.32(E)/SDR^3 \text{ where } E \text{ is the modulus of elasticity, approximately } 35,000 \text{ psi}$$

$$P_c = (2.32)(35,000)/11.0^3 = 61.0 \text{ psi}$$

The critical-collapse pressure can then be used to determine the critical buckling pressure from the following relation (Reference 4):

$$P_{cb} = 0.0.8 \sqrt{(E')(P_c)}$$

Where:

P_{cb} = critical buckling pressure

E' = long term degree of compaction of bedding = 3,000 psi

$$P_{cb} = 0.8 \sqrt{(3,000)(61.00)} = 342.23 \text{ psi}$$

The factor of safety is then determined:

$$FS = P_{cb} / P_D = 342.23/182.4 = 1.88$$

2.12 HDPE Wall Crushing

To determine a factor of safety for wall crushing, the following equations were used (Reference 4):

$$S_A = ((SDR-1)/2) \times P_D$$

Where:

S_A = actual compressive stress, psi

P_D = total external pressure on top of the pipe, psi

$$P_D = W_c/D = 1,094.45/6 = 182.4 \text{ psi}$$

For a SDR of 11.0 the actual compressive stress is:

$$S_A = ((11.0-1)/2) \times 182.4 = 912 \text{ psi}$$

The factor of safety can then be found using the compressive yield strength of HDPE pipe of 1,500 psi (Reference 4):

$$FS = 1,500 \text{ psi}/910 \text{ psi} = 1.64$$

2.13 HDPE Equipment Loading

Equipment loading on the HDPE pipe is based on the same assumptions as the PVC pipe calculation; therefore, the static vertical load will govern.

2.14 HDPE Pipe Loading Results

Calculations for ring deflection, wall crushing, and wall buckling due to dead and live loading stresses for the existing and proposed 6-inch laterals were completed and Table 2.4 summarizes the results.

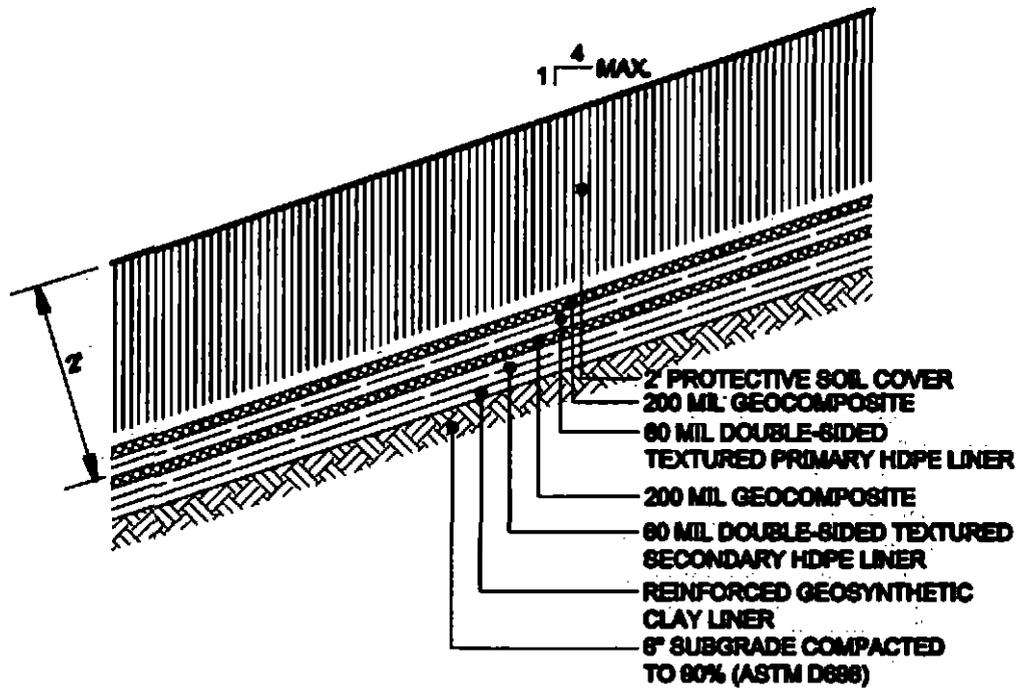
Table 2.4 – SDR 11.0 HDPE Pipe Results Dncs Environmental Solutions

Design Criteria	Critical Value	Actual Value	Factor of Safety
Dead Load Only			
Ring Deflection	8.0%	7%	1.1
Wall Buckling	342.23 psi	182.4 psi	1.88
Wall Crushing	1,500 psi	912 psi	1.64

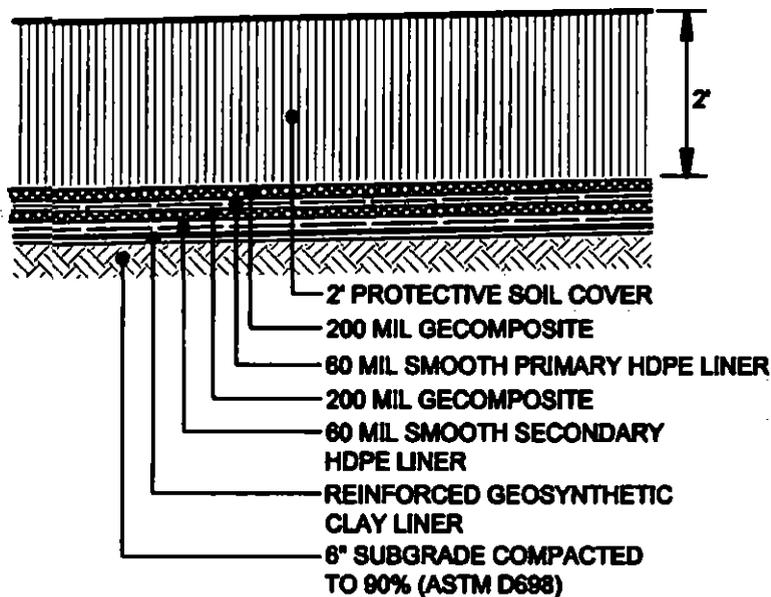
As shown, for each limiting design criterion, the factor of safety is greater than design criteria, thus the performance standard for the HDPE pipes is adequate.

3.0 LINER DESIGN

The liner design for the landfill sideslopes, consists of the following components below the waste:



The liner design for the landfill floor from top to bottom, consists of the following components below the waste:



3.1 Calculation of Tensile Stresses in Geosynthetics and Sideslope Liner Stability

External shear forces will develop on the 4H:1V sideslopes assuming the placement of an initial 2-foot lift of protective soil and 10-foot lift of waste; assuming the lifts are unsupported and no adhesion. Unbalanced forces, due to assumed unsupported placement of the 2-foot protective soil layer and 10-foot waste layer, must be supported by liner components above the interface with the least amount of frictional resistance.

Interface friction angles (Φ) and adhesion (as determined by direct shear testing) for geosynthetics will vary depending on the normal load applied to the geosynthetics. Interface friction angles and adhesion for C.K. Disposal was found based on direct shear testing on similar "silty sand" soil.

**Table 3.1 – Geosynthetic Interface Friction Angles and Adhesions,
Sideslope Liner System**

Geosynthetic to Geosynthetic Interface	Mohr-Coulomb Failure Envelope	
	Φ	Adhesion
Protective Soil Layer (SM) to Geocomposite	32°	0
Geocomposite to Double-Sided Textured HDPE FML ⁽¹⁾	26.3°	0
Double-Sided Textured HDPE FML to Nonwoven Geotextile of GCL	27.3°	0
Nonwoven Geotextile of GCL to Subgrade Soil (undrained)	28.2°	87

⁽¹⁾Average of direct shear testing values on geocomposite to double-sided texture HDPE FML

Table 3.2 – Geosynthetic Interface Friction Angles and Adhesions,
 Floor Liner System

Geosynthetic to Geosynthetic Interface	Mohr-Coulomb Failure Envelope	
	Φ	Adhesion
Protective Soil Layer (SM) to Geocomposite	32°	0
Geocomposite to Smooth HDPE ⁽¹⁾	8° - 12° Average = 10°	0
Geonet to Smooth HDPE FML ⁽¹⁾	5° - 19° Average = 12°	0
Nonwoven Geotextile of GCL to Subgrade Soil (undrained)	28.2°	87

⁽¹⁾Reference 9

3.2 Tensile Stress in Liner System

Tensile stresses in the liner system were calculated based on the assumption that waste will be placed in 10-foot thick lifts, are unsupported, and have no adhesion. The liner system must support the weight of the 10-foot thick waste lift.

Side Slope Liner Stability

The following calculations were performed with guidance from Reference 6. Using this guide, tensile stresses and shear stresses carried by the upper geomembrane were calculated. Waste will be placed in 10-foot lifts.

$$W_w = \frac{1}{2}\gamma_w H(H/\tan\beta) + \frac{1}{2}\gamma_s H(H/\tan\beta)$$

Where:

W_w = weight of lift per unit width

H = lift height

β = slope angle

γ_w = unit weight of waste

$$W_w = \frac{1}{2}(74)(8)(8/\tan 14.04) + \frac{1}{2}(110)(2)(2/\tan 14.04) = 10,349 \text{ lbs/ft}$$

$$T_w = K_o \sigma_v \tan \Phi_w H$$

$$K_o = 1 - \sin(\Phi_w)$$

$$\sigma_v = 1/2 \gamma_w H$$

Where:

T_w = frictional resistance force per unit width

σ_h = horizontal stress of waste lift

Φ_w = waste friction angle

K_o = coefficient of earth pressure at rest

σ_v = vertical stress of waste lift

$$T_w = K_o \sigma_v \tan \Phi_w h_w + K_o \sigma_v \tan \Phi_s h_s$$

$$T_w = (1 - \sin 33) 1/2(74)(8) \tan(33)(8) + (1 - \sin(33))(1/2(110)(2)) \tan(33)(2)$$

$$T_w = 700 \text{ lbs/ft} + 65 \text{ lbs/ft}$$

$$T_w = 765 \text{ lbs/ft}$$

$$W_{net} = W_w - T_w$$

Where:

W_{net} = net weight of waste

$W_{net} = 10,349 \text{ lbs/ft} - 765 \text{ lbs/ft}$

$W_{net} = 9,584 \text{ lbs/ft}$

Given the net weight, we can find the normal and shear force of the weight.

$$N = W_{net} \cos\beta = (9,584 \text{ lb/ft})\cos(14.04)$$

$$P = W_{net} \sin\beta = (9,584 \text{ lb/ft})\sin(14.04)$$

$$N = 9,297.7 \text{ lb/ft}$$

$$P = 2,323 \text{ lb/ft}$$

The critical interface of the liner system occurs at the geocomposite to double-sided textured HDPE interface. F_1 is calculated for geocomposite to protective soil and F_2 is calculated for geocomposite to double-sided textured HDPE.

$$F_1 = N \tan\delta_1 = 9,297.7 \tan(32)$$

$$F_2 = N \tan\delta_2 = 9,297.2 \tan(26.3)$$

$$F_1 = 5,809.8 \text{ lbs/ft}$$

$$F_2 = 4,595.2 \text{ lbs/ft}$$

$$F_1 - F_2 = 5,809.8 \text{ lbs/ft} - 4,595.2 \text{ lbs/ft} = 1,212.6 \text{ lbs/ft} = 101.2 \text{ lbs/in}$$

According to Reference 10, there is a direct relationship between the CBR puncture resistance value and the wide width tensile strength of geotextiles. The equation below shows the relationship.

$$T_f = F_p / \pi r$$

Where:

T_f = tensile force per unit width of fabric

F_p = puncture breaking force = 575 lbs for GSE 8oz/yd² geotextile

r = radius of puncturing rod = 25 mm = 0.98 in

$$T_f = 575 \text{ lbs}/\pi(0.98 \text{ in}) = 186.76 \text{ lbs/in}$$

$$F.S. = (T_f)/(F_1 - F_2) = 186.76 \text{ lbs/in}/101.2 \text{ lbs/in} = 1.85$$

The Factor of Safety for the critical interface is 1.85, therefore the liner system is adequate.

3.3 Calculation of Tensile Stresses in Geosynthetics due to Equipment Loading

A Caterpillar D6E dozer or equivalent will be used to place protective soil layer up the sideslope a sufficient distance to accommodate an approximate 10-foot lift of waste placed on the landfill floor.

- Unit weight of protective soil = 110 lbs/ft³ dry density
- Internal friction angle of protective soil = 33°
- Critical liner interface friction angle occurs between the HDPE geonet and the double-sided textured HDPE liner = 26.3°
- Equipment loading assuming a D6N dozer:
 - Weight = 36,943 lbs
 - Track width = 24 in = 2 feet
 - Pressure distribution, assume a 2H:IV distribution; therefore, width acting on geomembrane = 20 feet
- Tensile forces acting on geomembrane:
 - Protective soil layer, F_{soil}
 - D6E dozer, F_{dozer}
- Total resisting forces:
 - Geonet interface friction, F_{geonet}
 - Soil buttress friction at toe of slope, F_{buttress}

The minimum interface friction angle for the liner system is 26.3° and occurs between the geocomposite and the double-sided textured geomembrane.

Tensile forces acting on geomembrane:

$$F_{\text{soil}} = h_{\text{lift}} (\text{unsupported slope length}) (\text{unit weight of protective soil}) (\sin(\text{slope angle}))$$

$$F_{\text{soil}} = (2 \text{ ft})(70 \text{ ft})(110 \text{ lbs/ft}^3)(\sin(14.04^\circ))$$

$$F_{\text{soil}} = 3,736 \text{ lbs/ft}$$

$$F_{\text{dozer}} = [(\text{dozer weight}) / (\text{width acting on geocomposite})] (\sin(14.04^\circ))$$

$$F_{\text{dozer}} = [0.5(36,943 \text{ lbs}) / 20 \text{ ft}] (\sin(14.04^\circ))$$

$$F_{\text{dozer}} = 448 \text{ lbs/ft}$$

$$\text{Total tensile force acting on geocomposite} = 3,736 \text{ lbs/ft} + 448 \text{ lbs/ft} = 4,184 \text{ lbs/ft}$$

Total resisting forces acting on geomembrane:

$$F_{\text{geomembrane}} = (\text{weight of protective soil} + \text{weight of dozer}) (\cos(\text{slope angle})) (\tan(\text{interface friction angle}))$$

$$F_{\text{geomembrane}} = [(2 \text{ ft})(70 \text{ ft})(110 \text{ lbs/ft}^3) + (36,943 \text{ lbs} / 20 \text{ ft})] (\cos 14.04^\circ) (\tan 26.3^\circ)$$

$$F_{\text{geomembrane}} = 8,269 \text{ lbs/ft}$$

$$F_{\text{buttress}} = \left[\frac{\cos(\text{internal friction angle of soil})}{\cos(\text{internal friction angle of soil} + \text{slope angle})} \right] \left[\frac{(\text{unit weight of soil}) (\text{thickness of soil})^2}{\sin^2(\text{slope angle})} \right] \tan(\text{internal friction angle of soil})$$

$$F_{\text{buttress}} = \left[\frac{\cos(33^\circ)}{\cos(33^\circ + 14.04^\circ)} \right] \left[\frac{(110 \text{ lbs/ft}^3)(2 \text{ ft})^2}{\sin^2(14.04^\circ)} \right] [\tan(33^\circ)]$$

$$F_{\text{buttress}} = 747 \text{ lbs/ft}$$

$$\text{Total resisting force acting on geomembrane} = 8,269 \text{ lbs/ft} + 747 \text{ lbs/ft} = 9,016 \text{ lbs/ft}$$

To summarize, tensile stress in geocomposite = 4,184 lbs/ft - 9,016 lbs/ft = -4,832 lbs/ft. A negative tensile stress indicates the geocomposite is not in tension.

3.4 Anchor Trench Pullout Analysis

The anchor trench detail is shown in Attachment B, Figure 501 –Liner & Leachate Collection Details. To establish the static equilibrium equation, two imaginary and frictionless pulleys are assumed at the top edge and the bottom corner of the anchor trench. The friction force above a runout geosynthetic is always neglected in the anchor trench.

3.5 Geocomposite: Double-Sided Textured Geomembrane Interface

$\Sigma F_H = 0$ yields the following equation for the calculation of T (where T = geocomposite tensile force per unit width lbs/ft):

$$T = \frac{(Y_s)(d_{cs})(L_{ro})(\tan\delta_c) + [(1 - \sin\Theta)((Y_s)(d_{cs} + 0.5d_{AT}))d_{AT} + Y_s(d_{cs} + d_{AT})L_{AT}](\tan\delta_c + \tan\delta_f)}{\cos\beta - (\sin\beta)(\tan\delta_c)}$$

Where:

Y_s = unit weight of cover and backfill soil = 110 lbs/cf dry density

d_{cs} = depth of cover soil = 2 feet

L_{ro} = runout length = 2 feet

δ_c = friction angle between the GCC and underlying soil = 28.2°

Θ = internal friction angle of compacted backfill soil in anchor trench = 35°

d_{AT} = depth of anchor trench = 2 feet

L_{AT} = width of anchor trench = 2 feet

δ_f = interface friction angle between the geomembrane and the compacted backfill soil = 32°

β = sideslope angle, measured from horizontal = 14.04°

$$T = \frac{(110 \text{ lbs/cf})(2')(2')(\tan 28.2^\circ) + [(1 - \sin 35^\circ)((110 \text{ lbs/cf})(2' + 0.5(2'))(2') + 110 \text{ lbs/cf}(2' + 2')2')(\tan 28.2^\circ + \tan 32^\circ)}{\cos 14.04^\circ - (\sin 14.04^\circ)(\tan 28.2^\circ)}$$

$$T = 1,884 \text{ lbs/ft} = 157 \text{ lbs/in}$$

The anchor trench can withstand greater yield strength than the geomembrane.

3.6 Geosynthetic Slippage Analysis

To determine the factor of safety for slippage and subsequent tension in the liner geosynthetics, the method of active and passive wedges, shown in Reference 1, was used. This calculation utilizes the passive wedge which supports the sideslope active wedge, consistent with actual field conditions. These calculations were performed along the geomembrane covered slope. To be conservative, the lowest interface friction angles (residual strength values) for the sideslope liner system; and peak strength values for the floor liner system were used. These values taken are $\delta_A = 20.1^\circ$ for the interface friction angle between the geocomposite and double-sided textured HDPE geomembrane on the sideslope. Interface friction angle between the geonet and smooth HDPE geomembrane on the floor was used. The total height of the active wedge is the maximum height of waste over the liner system sloped portion.

For the purposes of this calculation, the following assumptions and nomenclature were used from the literature:

Table 3.3 – Translational Failure Analysis

$W_P =$	Total weight of the passive wedge
$N_P =$	Normal force acting on the bottom of the passive wedge
$F_P =$	Frictional force acting on the bottom of the passive wedge (parallel to the bottom of the passive wedge)
$E_{HP} =$	Normal force from the active wedge acting on the passive wedge
$E_{VP} =$	Frictional force acting on the side of the passive wedge
$FS_P =$	Factor of safety for the passive wedge
$\delta_P =$	Minimum interface friction angle of multi-layer liner components beneath the passive wedge = 10° (assumed interface friction angle between the geotextile of the GCL and the smooth HDPE geomembrane)
$\Phi_S =$	Friction angle of the solid waste = 33°
$a =$	Angle of the waste slope, measured from horizontal
$\Phi =$	Angle of the landfill cell subgrade, measured from horizontal = 1.15°
$W_A =$	Weight of the active wedge
$W_T =$	Total weight of active and passive wedges
$N_A =$	Normal force acting on the bottom of the active wedge
$F_A =$	Frictional force acting on the bottom of the active wedge (parallel to the bottom of the active wedge)
$E_{HA} =$	Normal force from the active wedge acting on the active wedge, $E_{HA} = E_{HP}$
$E_{VA} =$	Frictional force acting on the side of the active wedge, $E_{VA} = E_{VP}$
$FS_A =$	Factor of safety for the active wedge
$b =$	Horizontal length of active wedge (cell sideslope at maximum depth) = 280 ft

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$b_p =$	Horizontal length of the passive wedge = 420 feet
$h_t =$	Total height of the wedges = 140 feet
$\delta_A =$	Minimum interface friction angle of multi-layer liner components beneath the active wedge = 26.3°
$\beta =$	Angle of sideslope, measured from the horizontal = 14.04°
FS =	Factor of safety for the entire solid waste mass

The active wedge is considered first:

$$W_A = 1/2((b \cdot h_a \cdot \gamma) + (b \cdot h_b \cdot \gamma))$$

$$W_A = 1/2(280\text{ft} \cdot 70\text{ft} \cdot 74(\text{lbs}/\text{ft}^3) + 280\text{ft} \cdot 70\text{ft} \cdot 74(\text{lbs}/\text{ft}^3)) = 1,450,400 \text{ lbs}/\text{ft}$$

The passive wedge is then considered by multiplying the cross sectional area by the unit weight of waste:

$$W_P = 1/2(b_p \cdot h_t \cdot \gamma) = W_P = 1/2(420\text{ft} \cdot 140\text{ft} \cdot 74(\text{lbs}/\text{ft}^3)) = 2,175,600 \text{ lbs}/\text{ft}$$

$$W_T = 1,450,400 \text{ lbs}/\text{ft} + 2,175,600 \text{ lbs}/\text{ft} = 3,626,000 \text{ lbs}/\text{ft}$$

Factor of safety:

$$aFS^3 + bFS^2 + cFS + d = 0$$

Where:

$$a = W_A \sin \beta \cos \Theta + W_P \cos \beta \sin \Theta = 394,155 \text{ lbs}/\text{ft}$$

$$b = (W_A \tan \delta_P + W_P \tan \delta_A + W_T \tan \phi_S) \sin \beta \sin \Theta - (W_A \tan \delta_A + W_P \tan \delta_P) \cos \beta \cos \Theta = -1,049,414 \text{ lbs}/\text{ft}$$

$$c = -[W_T \tan \phi_S (\sin \beta \cos \Theta \tan \delta_P + \cos \beta \sin \Theta \tan \delta_A) + (W_A \cos \beta \sin \Theta + W_P \sin \beta \cos \Theta) \tan \delta_A \tan \delta_P] = -174,586 \text{ lbs}/\text{ft}$$

$$d = W_T \cos \beta \cos \Theta \tan \delta_A \tan \delta_P \tan \phi_S = 199,037 \text{ lbs}/\text{ft}$$

and:

$$\beta = 14.04^\circ - \text{sideslope angle}$$

$$\Theta = 1.15^\circ - \text{subgrade angle}$$

$$\delta_P = 10^\circ - \text{minimum friction angle of bottom liner system}$$

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$\delta_A = 26.3^\circ$ - minimum friction angle of sideslope liner system

$\phi_S = 33^\circ$ - friction angle of waste

$$aFS^3 + bFS^2 + cFS + d = 0$$

$$394,155FS^3 - 1,049,414FS^2 - 174,586FS + 199,037 = 0$$

This equation is then solved by trial and error using an Excel spreadsheet. Table 3.4 shows results:

**Table 3.4 – Translational Failure Analysis
Factor of Safety Summary**

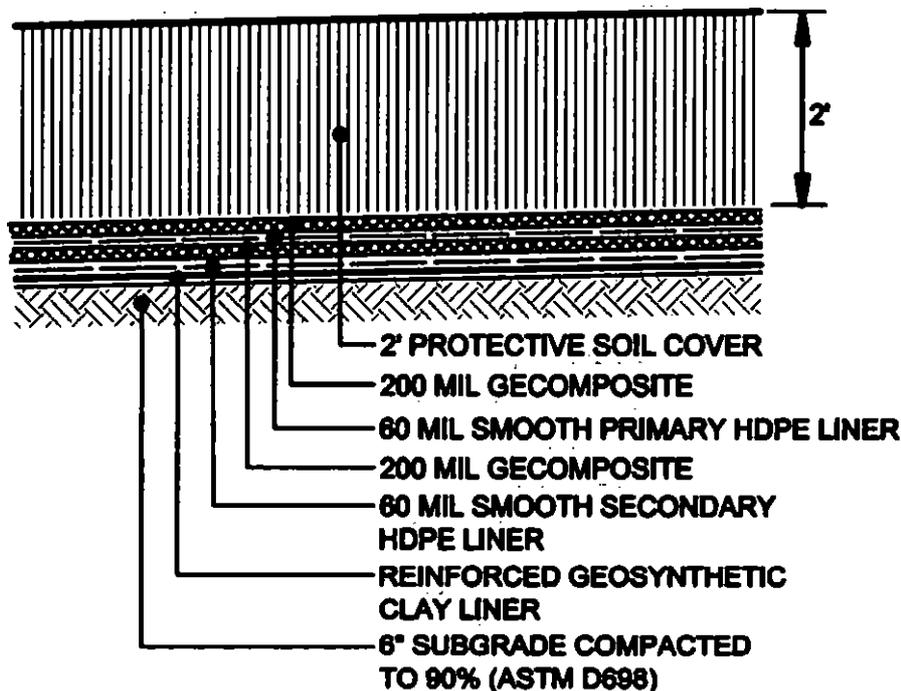
Assumed FS	Result
1	-630,808
2.75	20,075
2.76	-10,105

This factor of safety against translational geosynthetic failure considering active and passive soil wedges is 2.75. This indicates the passive wedge will support the sideslopes active wedge without slipping. Therefore, the geosynthetic liner system is not in tension, and the proposed liner system design is compatible with calculated external forces.

3.7 Minimum Liner Thickness

According to Reference 6, "liner deformation can result from differential setting of subgrade soils, from localized settlement of soft areas beneath the liner, or from other anomalous conditions, wherein settlement places the liner in tension. Adequate thickness must be provided to resist potential damaging deformation within a margin of safety."

The landfill is located on the west flank of a topographic high ridge, locally named Rattlesnake Ridge, otherwise known as the Dockum Red Bed Ridge or Red Bed Ridge. Given the stability of the location and the proposed engineered liner foundation, it is not anticipated that soft areas or sinkholes will be encountered. The landfill liner system consists of a multilayer system shown below. The foundation will be constructed with 6-inches recompacted subgrade (90% of ASTM D698) supporting the liner system. The following is the floor liner system:



For conservatism, only one layer of geomembrane was analyzed to determine the minimum thickness. As stated above, the liner system will be a multiple liner system and is therefore capable of withstanding more forces than just a single liner system. The resulting required thickness that is calculated for a single liner will be a conservative value given the landfill's multiple liner system.

"The required thickness for a synthetic liner can be calculated using the equation below for localized settlement. It is a one-dimensional force balance at equilibrium in the x - direction

with the geomembrane tension resolved into its horizontal and vertical components”, (Reference 6).

$$t_{reqd} = \frac{\sigma_n x (\tan \delta_u + \tan \delta_L)}{\sigma_{allow} (\cos \beta - \sin \beta \tan \delta_L)}$$

Where:

t = liner thickness (inches)

σ_n = applied overburden pressure = 81.7 psi (See calculations below)

β = angle of force applied to synthetic liner = 45° (Reference 6)

σ_{allow} = liner allowable stress at yield = 2100 psi (Reference 6)

x = mobilized liner deformation = 1.695 inches (See calculation below)

δ_u = friction angle between the liner and the upper interface = 10° (Table 3.2)

δ_L = friction angle between the liner and the lower interface = 12° (Table 3.2)

$$\sigma_n = H_w \gamma$$

$$\sigma_n = H_w \gamma_w + H_s \gamma_s$$

Where:

H_w = height of waste = 150 ft

γ_w = unit weight of waste

H_s = height of soil (protective cover, intermediate cover, and final cover)

γ_s = unit weight of waste

$$\sigma_n = (150 \text{ ft})(74 \text{ pcf}) + 6 \text{ ft} (110 \text{ pcf})$$

$$\sigma_n = 11,760 \text{ lbs/ft}^2 = 81.7 \text{ psi}$$

Using the equation given for 60-mil liner for embedment depth that is provided by Reference 6 we can use the following equation calculate a value for “x”.

$$x = 13.15e^{-0.0236\sigma_n}$$

Where:

x = mobilized liner deformation

σ_n = applied overburden pressure = 81.7 psi

$$x = 13.15e^{-0.0236(81.7)}$$

$$x = 1.91$$

Typical values for "x" can range from 2-inches to 10-inches; therefor, a value of $x = 2$ was used for the calculation. β was estimated to be 45° as the worst case scenario (Reference 6).

$$t_{reqd} = \frac{81.7 \text{ psi} * 2 \text{ in} * (\tan 10^\circ + \tan 12^\circ)}{2100 \text{ psi} * (\cos 45^\circ - \sin 45^\circ \tan 12^\circ)}$$
$$t_{reqd} = 0.0543 \text{ inches} = 54.3 \text{ mils}$$

Since the calculated minimum liner thickness of 54.3 mils is less than the 60 mils used to calculate embedment depth, the 60 mil liner thickness is acceptable.

$$FS = (t_{60 \text{ mil}}) / (t_{reqd}) = 60 \text{ mils} / 54.3 \text{ mils} = 1.10$$

The liner thickness calculation above only assumes a single liner system. The landfill is designed as a multiple Geosynthetic liner system which will add additional liner support.

4.0 EROSION CALCULATIONS

The purpose of erosion calculation is to determine potential soil losses due to wind and rainfall erosion during operations and following final cap installation. Erosion calculations project the soil loss from rainfall at approximately 4.51 tons/acre/year (t/a/y), which is below the NRCS established criterion of 5.0 t/a/y. The wind erosion loss from the site is estimated at 1.2 t/a/y, also below the NRCS established criterion of 2.5 t/a/y. The total soil loss from the site potentially caused by water and wind erosion is calculated at 5.71 t/a/y.

4.1 Rainfall Erosion Loss Calculations

Revised Universal Soil Loss Equations (RUSLE) was used to model rainfall erosion:

$$A = R \times K \times LS \times C$$

Where:

A = soil loss per unit area, typically in t/a/y

R = rainfall/runoff factor, which varies with location and climate

K = soil erodibility factor, which depends on soil type

LS = topographic factor that accounts for the site slope gradient and length

C = cover factor that accounts for ground cover (bare slope = 1)

	Final Cover Crown	Final Cover Sideslope	Total
RUSLE Soil Loss	0.19	4.32	4.51

Table 4.1			
RUSLE Equation			
R	-	Rainfall Value	
	=	45	for this area Fig 2-1 NRCS Agricultural Handbook #703
K	-	Soil Erodibility Factor	
		0.15	From Soil Survey local soils (silty clay loam) and table 8.4, page 261, Hann, Barfield text
L	-	Slope Length Factor	
	=	$(L/72.6)^M$	eq 4-1, NRCS Agricultural Handbook #703
		L = horizontal slope length in feet	
		L = 400	
		M = slope length exponent	table 8.6, page 263, Haan, Barfield text
		M = 0.64	
	=	2.98	
S	-	Slope Factor	
	=	$(16.8 \sin(Q)) - 0.5$	for slopes $\sin Q > 0.09$ eq. 4-5 NRCS Agricultural Handbook #703
		Q = slope angle	
		Q = 14.04 degrees	degrees = 0.24504423 radians
	=	3.58	
C	-	Covering Management Factor	
	=	0.06	see C factor calculation sheet
P	-	Support Practices Factor	
	=	1	Conservative Estimate
A	-	Calculated Soils loss in tons/acre-year	
	=	RKLSCP	
	=	4.32	tons/acre/year

Table 4.2			
C - Factor Calculation			
C_{PLU}	-	prior land use subfactor	
=	1	for rangeland	table 8-10.B, page 271, Hann, Barfield text
C_{CC}	-	canopy cover subfactor	From Soil Survey local soils (sand) and table 8.4, page 261, Hann, Barfield text
=	$1 - F_C \cdot \exp(-0.1H)$		eq 8.52, page 270, Hann, Barfield text
		F_C = fraction of surface covered by canopy	
	FC =	0.5	conservative estimate
		H = average canopy height in feet	
	H =	1	conservative estimate for root depth
	=	0.55	
C_{SC}	-	surface cover subfactor	
=	$\exp[-bR_C(6/6+R_G)^{0.08}]$		eq. 8.53, page 270, Hann, Barfield text
	b =	constant	
	b =	4.5	
	R_C =	fraction ground cover	conservative estimate taken and adjusted from value of 1.0 for complete rock covering
	R_C =	0.5	
		R_G = surface roughness variable	eq. 8.55, page 271, Haan, Barfield text
		$R_G = (25.4 \cdot R_R - 6) \cdot (1 - \exp(-0.0015R_G)) \cdot (\exp(-0.14P_T))$	
		R_R =	random roughness
	R_R =	0.8	conservative estimate - Ag. Handbook #703
		R_S =	total root and buried residue (lb/acre)
	R_S =	1200	Table 8.10, page 271, Haan, Barfield text
		P_T =	average yearly rainfall
	P_T =	11.72	inches National Weather Service Data
	R_G =	2.32	
	=	0.11	
C_{SR}	-	surface roughness subfactor	
=	$\exp(-0.026 \cdot R_G)$		eq. 8.62, page 273 in Haan, Barfield text see above for references and equation
	R_G =	2.32	
	=	0.94	
C_{SM}	-	soil moisture subfactor	
=	1	for rangeland	see page 273 in Haan, Barfield text
C	-	Cover Management Factor	
=	$C_{PLU} C_{CC} C_{SC} C_{SR} C_{SM}$		
=	0.06	**	

**Recommendations of George Foster of the Agricultural Research Service is to use a minimum value of 0.005. Therefore, if necessary, for conservative estimates, use a C value of 0.005

4.2 Wind Erosion Loss Calculations

Purpose: to estimate the quantity of soil loss as a result of wind using the Wind Erosion Equation (WEQ).

Wind Erosion Equation: $E = f(I, K, C, L, V)$

Where:

E = potential average annual soil loss (t/a/y)

I = soil erodibility index (t/a/y)

K = ridge roughness factor (0.5-1.0)

C = the climactic factor

L = unsheltered distance along prevailing wind erosion direction across area to be evaluated

V = equivalent vegetative cover

Find I:

The soil onsite primarily consists of silty sands of the soil type SM. The I value for silty sands is listed at 134 t/a/y.

$$I = 134$$

Find K:

The ridge roughness factor (K) is a measure of the effect from tilled ridges and planting implements. These reduce erosion by absorbing and deflecting wind energy and trapping blown particles. No wind-breaking ridges are planned for the final cover; therefore, a conservative K value of 1.0 has been chosen.

$$K = 1.0$$

Find C:

The climactic factor (C) is based on the average wind velocity and precipitation-evaporation index (PE index). The isolar map of New Mexico (Agronomy Tech Note 27, June 1992) was used to find the C-value of 150 for the site.

$$C = 150$$

Find L:

L represents the longest unsheltered distance along the prevailing wind direction for the area to be evaluated. The prevailing wind direction was determined using data obtained from the New Mexico Climate Center at Hobbs Lea County Airport. There, the prevailing wind is from the south. The longest unsheltered distance is approximately 2,300 feet; therefore,

$$L = 2,300 \text{ feet}$$

Find V:

The equivalent vegetative cover is a value that relates the kind, amount, and orientation of vegetative material to the equivalent in lbs/acre of a small grain residue reference condition. This reference condition is defined as 10-inch long stalks of small grain lying flat in rows spaced 10 inches apart, perpendicular to the direction of the wind.

The landfill vegetation plan required vegetation cover to be seeded per NRCS recommendations with blue and sideoats gramma grasses, as well as dropseed varieties. This plan will yield 1,500 – 2,000 lbs/acre of vegetative cover (assuming good germination and adequate precipitation). When this value is converted to the Blue Gamma equivalent, it yields an equivalent vegetative factor of over 10,000 lbs/acre. A highly conservative factor of 3,000 lbs/acre is therefore used for V.

$$V = 3,000 \text{ lbs/acre}$$

Solve for E:

Using the E-Table, a value of $E = 1.2 \text{ t/a/y}$ of soil loss due to wind erosion is expected. This value is less than the NRCS recommended maximum value of 2.5 t/a/y .

5.0 SETTLEMENT CALCULATIONS

The final cover slope, liner, and leachate collection piping after settlement must be consistent with the performance specifications for leachate collection and stormwater control. The following calculations show the designed grades for final cover and leachate collection system will allow adequate drainage even after settlement has occurred.

5.1 Foundation Soils Settlement

The methodology for estimating floor potential settlement involves selecting points along the landfill floor surface, then computing settlement at each point, and evaluating the resultant change in surface elevation. Points were conservatively selected from a cross-section where the waste and fill material is thickest. Reference 1 presents a method to determine landfill foundation settlement that evaluates elastic, primary, and secondary settlement. The foundation soils at the C.K. Disposal site are predominately a mixture of sand with varying amounts of fines and clay. Recent laboratory testing evaluated a mixture of sands and silty sand (i.e., USCS Classifications SM) in the excavation area. SM soil properties are used in the following equations.

$$Z_e = \left(\frac{\Delta\sigma}{M_s} \right) H_o$$

Where:

Z_e = elastic settlement of soil layer (ft)

H_o = initial thickness of soil layer (ft)

$\Delta\sigma$ = increment of vertical effective stress, lb/ft²

M_s = constrained modulus of soil, lb/ft²

The constrained modulus is provided in this equation:

$$M_s = \frac{E_s(1-\nu_s)}{(1+\nu_s)(1-2\nu_s)}$$

Where:

M_s = constrained modulus of soil, lb/ft²

E_s = elastic modulus of soil (lb/ft²) found using Reference 1

$E_s = (4,700 \text{ psi} + 1,600 \text{ psi}) / 2 = 10,350 (144) = 1,490,400 \text{ lbs/ft}^2$

ν_s = Poisson's Ratio for soil = 0.39, found using the same method to estimate the elastic modulus of soil

Elastic Foundation Soil Settlement

Thickness of Waste = 150 feet (assume entire thickness of waste from intermediate cover to top of protective soil layer; this provides a conservative analysis)

Unit Weight of Soil = 110 lb/ft³ dry density

Unit Weight of Waste = 74 lb/ft³

$\Delta\sigma =$ (waste effective stress) + (protective soil layer effective stress) + (intermediate cover effective stress) + (final cover effective stress)

$$\Delta\sigma = (150\text{ft})(74\text{lb/ft}^3) + (2\text{ft})(110\text{lbs/ft}^3) + (1\text{ft})(110\text{lbs/ft}^3) + (3.0\text{ft})(110\text{lbs/ft}^3) = 11,760\text{lbs/ft}^3$$

$$M_s = \frac{1,490,400 \text{ lb/ft}^2 (1-0.29)}{(1+0.29)(1-2*0.29)} = 1,953,090 \text{ lbs/ft}^2$$

H₀=150 ft the full thickness of the compressible SM soils; the compressible soil is considered incompressible at the depth of 40 feet.

$$Z_e = \left(\frac{11,760}{1,953,090} \right) 40\text{ft} = 0.241\text{ft}$$

The attached spreadsheet has settlement calculations for points shown in Figure 1. The required 2% slope of the leachate collection system is not adversely affected by foundation settlement. Table 5.1 summarizes the foundation soil settlement calculations.

5.2 Waste Settlement Calculations

Estimated waste settlement points on the final cover surface were selected and settlement was computed at each point. Points were selected from Cross-Sections A-A and B-B (Figure 1). Reference 1 presents a method for determining settlement in landfills. This method is based on developed soils consolidation theory, which relates settlement to layer thickness and changes in void ratio.

The primary settlement is estimated using this equation:

$$\Delta H_c = C_c \left(\frac{H_o}{1 + e_o} \right) \log \left(\frac{\sigma_i}{\sigma_o} \right)$$

Where:

ΔH_c = primary settlement

$C_c/(1+e_o) = 0.006$ (Reference 11, Appendix D)

H_o = initial thickness of the waste layer before settlement (assume entire thickness of waste from intermediate cover to the top of protective soil layer; this provides a conservative analysis) = 157 ft

σ_o = previously applied pressure in waste layer (assumed to equal the compaction pressure = 1,000 lbs/ft²)

σ_i = total overburden pressure applied at the mid-level of the waste layer (lbs/ft²)

Long-term secondary settlement is estimated by the equation below:

$$\Delta H_s = C_a \left(\frac{H_o}{1 + e_o} \right) \log \left(\frac{t_1}{t_o} \right)$$

Where:

ΔH_s = secondary settlement

$C_a = 1/3 [C_c/(1+e_o)] = 0.002$ (Reference 11, Appendix D)

H_o = waste thickness at start of secondary settlement = $H - H_c$

t_1 = starting time of secondary settlement (1 year)

t_2 = ending time of secondary settlement = assume 30 years

Settlement is estimated at key locations shown on the landfill Cross-Sections A-A and B-B (Figure 1). An example calculation is demonstrated as follows:

Primary Waste Settlement

Maximum Thickness of Waste = 150 feet

$$\Delta H_c = C_c \left(\frac{H_o}{1 + e_o} \right) \log \left(\frac{\sigma_i}{\sigma_o} \right)$$

Where:

$$C_c / (1 + e_o) = 0.006$$

$$H_o = 157 \text{ ft}$$

$$\sigma_o = 1,000 \text{ lbs/ft}^2$$

$$\sigma_i = 0.5[(157 \text{ ft})(74 \text{ lbs/ft}^3) + 4.0 \text{ ft}(110 \text{ lbs/ft}^2)] = 6,029 \text{ lbs/ft}^2$$

$$\Delta H_c = 0.006 \times 157 \times \log \frac{6,029 \text{ lb/ft}^2}{1,000 \text{ lbs/ft}^2}$$

$$\Delta H_c = 0.702 \text{ ft}$$

Secondary Waste Settlement

$$H_o = 157 \text{ ft} - 0.702 \text{ ft} = 156.298 \text{ ft}$$

$$\Delta H_s = 0.002 \times 156.298 \times \log \frac{30 \text{ years}}{1 \text{ year}} = 0.46 \text{ ft}$$

$$\text{Total waste settlement} = 0.735 \text{ ft} + 0.46 \text{ ft} = 1.2 \text{ ft}$$

The waste settlement is 1.2 ft, which has nominal impact on the corresponding calculations for slope, runoff, etc. A summary of potential waste settlement is provided in Table 5.2.

5.3 Soil Cover Settlement Calculations

The final cover soil layer consisting of vegetative, barrier, and intermediate cover layers will also experience nominal settlement due to its own weight. The method for evaluating settlement of the soil cover and cushion layers is based on this equation:

Primary Soil Settlement

$$\Delta H_p = C_c \left(\frac{H_p}{1 + e_s} \right) \log \left(\frac{P_o + \Delta P}{P_o} \right)$$

$$C_c/(1+e_o) = 0.0006$$

Thickness of Soil = (H) = 3.0 feet of final cover + 1 foot of intermediate cover soil
+ 2 feet of protective soil layer = 6 feet

Unit Weight of Soil = 110 lbs/ft³ Dry Density

$$\Delta P = (3.0 \text{ ft})(110 \text{ lbs/ft}^3) + (1 \text{ ft})(110 \text{ lbs/ft}^3) + (2.0 \text{ ft})(110 \text{ lbs/ft}^3) = 660.0 \text{ lbs/ft}^2$$

$$P_o = (H/2)(110 \text{ lbs/ft}^3) = 3.0(110) = 330 \text{ lbs/ft}^2$$

$$\Delta H_p = (0.006)(6.0 \text{ ft}) \log \left(\frac{330 \frac{\text{lbs}}{\text{ft}^2} + 660 \frac{\text{lbs}}{\text{ft}^2}}{330 \frac{\text{lbs}}{\text{ft}^2}} \right)$$

$$\Delta H_p = 0.017 \text{ ft}$$

Secondary Soil Settlement

$$\Delta H_s = C_s \left(\frac{H_o}{1 + e_s} \right) \log \left(\frac{t^2}{t^1} \right)$$

$$C_A = 1/3[C_c/(1+e_o)] = 0.002$$

$$H_o = 6.0 \text{ ft} - 0.017 \text{ ft} = 5.983 \text{ ft}$$

$$\Delta H_s = 0.002 (5.983 \text{ ft}) \log 30/1 = 0.018 \text{ ft}$$

The maximum settlement of the final cover is the sum of primary and secondary settlement at point A21. The soil final cover layer settlement is equal to 0.017 ft + 0.018 ft = 0.035 ft. Table 5.3 summarizes the settlement in the final cover.

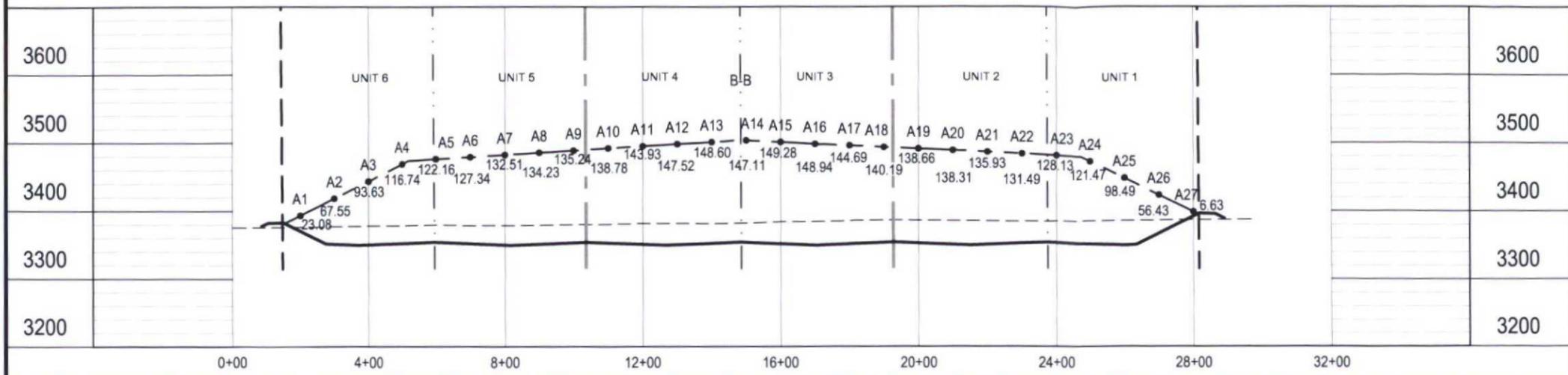
5.4 Conclusion

Settlement projections have been calculated for the landfill foundation, waste mass, and for landfill final soil cover. Settlement estimates include elastic deformation and both primary and secondary consolidation in the foundation soils, waste, and cover materials. The greatest value of projected settlement in both the foundation soils and waste occurs where waste thickness is greatest.

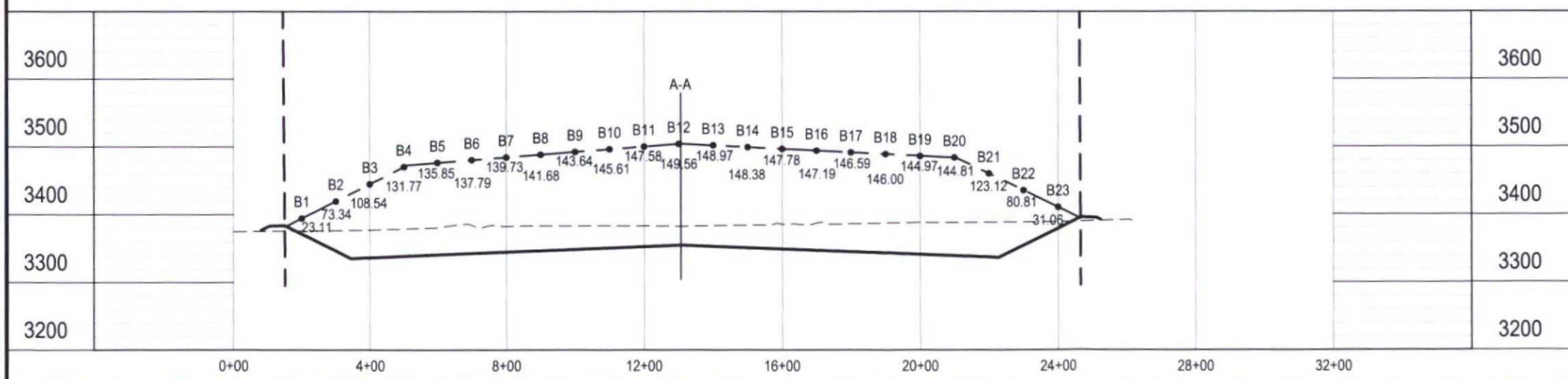
Maximum final settlement of landfill foundation, waste mass, and landfill cover is the sum of primary and secondary settlement. The foundation soil settlement is equal to 0.241 foot, waste settlement is equal to 1.2 feet, and final cover layer settlement is calculated at 0.035 foot. Maximum total settlement that could occur on the final cover is the sum of the foundation soil, waste, and cover settlement (i.e.: $0.241 \text{ ft} + 1.2 \text{ ft} + 0.035 \text{ ft} = 1.476 \text{ ft}$).

The final cover slope, liner, and leachate collection pipe after settlement is adequate and consistent with the performance specifications for leachate collection system and stormwater controls and the New Mexico Oil Conservation Division.

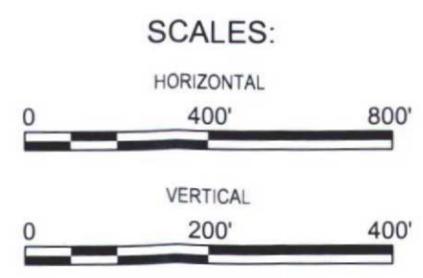
FILE NAME: \\Data11...s\2015\0580.15\BIM_CAD\09_PERMIT\Volume III\FIG.III.9.1 - SETTLEMENT POINTS.dwg
 UT NAME: FIG.III.9.1 PRINTED: Thursday, May 05, 2016 - 4:11pm USER: Tkrueger



A SECTION A-A
SCALE: 1" = 400'



B SECTION B-B
SCALE: 1" = 400'



LEGEND

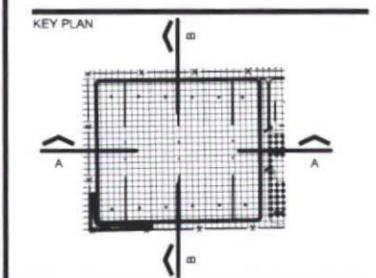
---	LIMIT OF WASTE
- - - -	EXISTING GRADE
—	BASE GRADE
— · —	TOP OF WASTE
•	SETTLEMENT POINT LOCATION
146.00	DEPTH OF WASTE

**C. K. DISPOSAL
E & P LANDFILL &
PROCESSING
FACILITY**

NMED PERMIT NO. _____

**NEW LANDFILL SITE
& PROCESSING FACILITY**

LEA COUNTY, NEW MEXICO



NO	DATE	ISSUE FOR REVIEW	DESCRIPTION
1	09/23/15	ISSUE FOR REVIEW	

ISSUING OFFICE: EL PASO PROJECT NO. 0580.15

**SETTLEMENT
POINTS**

FIGURE 1

Table 5.1

SETTLEMENT AND ANGULAR DISTORTION OF FOUNDATION SOILS BETWEEN POINTS; CROSS SECTION A-A								
Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction	Design Base Grade Elevation	Design Slope Between Points	Updated Base Grade Elevation	Update Slope Between Points
	(ft)	(ft)	(%)		(ft)	(%)	(ft)	(%)
A1	0.05				3371.16	25.00	3371.11	
		100	0.067	↑				2.43
A2	0.12				3351.85	2.50	3351.73	
		100	0.040	↑				2.46
A3	0.16				3350.94	2.50	3350.78	
		100	0.035	↑				2.46
A4	0.19				3353.01	2.50	3352.82	
		100	0.000	↓				2.50
A5	0.18				3354.84	2.50	3354.66	
		100	0.000	↑				2.50
A6	0.21				3352.76	2.50	3352.55	
		100	0.000	↑				2.50
A7	0.21				3350.67	2.50	3350.46	
		100	0.000	↑				2.50
A8	0.22				3352.05	2.50	3351.83	
		100	0.000	↑				2.50
A9	0.22				3354.13	2.50	3353.91	
		100	0.000	↑				2.50
A10	0.22				3353.68	2.50	3353.46	
		100	0.000	↑				2.50
A11	0.23				3351.62	2.50	3351.39	
		100	0.000	↑				2.50
A12	0.24				3351.12	2.50	3350.88	
		100	0.000	↑				2.50
A13	0.24				3353.13	2.50	3352.89	
		100	0.000	↓				2.50
A14	0.24				3354.46	2.50	3354.22	
		100	0.000	↑				2.50
A15	0.24				3352.32	2.50	3352.08	
		100	0.000	↓				2.50
A16	0.24				3350.18	2.50	3349.94	
		100	0.000	↓				2.50
A17	0.23				3351.95	2.50	3351.72	
		100	0.000	↓				2.50
A18	0.23				3353.98	2.50	3353.75	
		100	0.000	↓				2.50
A19	0.22				3353.03	2.50	3352.81	
		100	0.000	↓				2.50
A20	0.22				3350.91	2.50	3350.69	
		100	0.000	↓				2.50
A21	0.22				3350.81	2.50	3350.59	
		100	0.000	↓				2.50
A22	0.21				3352.77	2.50	3352.56	
		100	0.000	↓				2.50
A23	0.21				3353.65	2.50	3353.44	
		100	0.000	↓				2.50
A24	0.20				3351.62	2.50	3351.42	
		100	0.000	↓				2.50
A25	0.16				3349.62	2.50	3349.46	
		100	-0.001	↓				25.00
A26	0.10				3367.04	25.00	3366.94	
		100	-0.001	↓				25.00
A27	0.02				3392.04	25.00	3392.02	

Table 5.1 Continued

SETTLEMENT AND ANGULAR DISTORTION OF FOUNDATION SOILS BETWEEN POINTS; CROSS SECTION B-B

Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction	Design Base Grade Elevation	Design Slope Between Points	Updated Base Grade Elevation	Update Slope Between Points
	(ft)	(ft)	(%)		(ft)	(%)	(ft)	(%)
B1	0.13				3371.57	25	3371.44	
		100	0.203	↑				24.80
B2	0.34				3346.59	25.00	3346.25	
		100	0.142	↑				2.36
B3	0.48				3336.63	2.50	3336.15	
		100	0.094	↑				2.41
B4	0.57				3338.64	2.50	3338.07	
		100	0.016	↑				2.48
B5	0.59				3340.66	2.50	3340.07	
		100	0.008	↑				2.49
B6	0.60				3342.67	2.50	3342.07	
		100	0.008	↑				2.49
B7	0.60				3344.69	2.50	3344.09	
		100	0.008	↑				2.49
B8	0.61				3346.70	2.50	3346.09	
		100	0.008	↑				2.49
B9	0.62				3348.69	2.50	3348.07	
		100	0.008	↑				2.49
B10	0.63				3350.68	2.50	3350.05	
		100	0.008	↑				2.49
B11	0.64				3352.66	2.50	3352.02	
		100	0.008	↑				2.49
B12	0.64				3354.65	2.50	3354.01	
		100	-0.002	↓				2.50
B13	0.64				3352.96	2.50	3352.32	
		100	-0.002	↓				2.50
B14	0.64				3350.95	2.50	3350.31	
		100	-0.002	↓				2.50
B15	0.64				3348.93	2.50	3348.29	
		100	-0.002	↓				2.50
B16	0.63				3346.92	2.50	3346.29	
		100	-0.002	↓				2.50
B17	0.63				3344.90	2.50	3344.27	
		100	-0.002	↓				2.50
B18	0.63				3342.89	2.50	3342.26	
		100	-0.004	↓				2.50
B19	0.62				3340.87	2.50	3340.25	
		100	-0.001	↓				2.50
B20	0.62				3338.86	2.50	3338.24	
		100	-0.088	↓				2.59
B21	0.54				3336.84	2.50	3336.30	
		100	-0.171	↓				25.17
B22	0.37				3354.40	25.00	3354.03	
		100	-0.201	↓				25.20
B23	0.16				3379.40	25.00	3379.24	

Table 5.2				
WASTE SETTLEMENT AND ANGULAR DISTORTION BETWEEN POINTS; CROSS SECTION A-A				
Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction
	(ft)	(ft)	(%)	
A1	0.08	100	0.31	↑
A2	0.39	100	0.22	↑
A3	0.61	100	0.21	↑
A4	0.82	100	-0.04	↓
A5	0.78	100	0.14	↑
A6	0.92	100	0.05	↑
A7	0.97	100	0.02	↑
A8	0.99	100	0.01	↑
A9	1.00	100	0.03	↑
A10	1.03	100	0.05	↑
A11	1.08	100	0.04	↑
A12	1.12	100	0.01	↑
A13	1.13	100	0.26	↑
A14	1.39	100	-0.25	↓
A15	1.14	100	-0.003	↓
A16	1.13	100	-0.04	↓
A17	1.09	100	-0.04	↓
A18	1.05	100	-0.02	↓
A19	1.03	100	0.00	↓
A20	1.03	100	-0.02	↓
A21	1.00	100	-0.04	↓
A22	0.96	100	-0.03	↓
A23	0.93	100	-0.06	↓
A24	0.86	100	-0.21	↓
A25	0.65	100	-0.35	↓
A26	0.30	100	-0.29	↓
A27	0.01			

Table 5.2 Continued				
WASTE SETTLEMENT AND ANGULAR DISTORTION BETWEEN POINTS; CROSS SECTION B-B				
Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction
	(ft)	(ft)	(%)	
B1	0.08	100	0.32	↑
B2	0.40	100	0.29	↑
B3	0.69	100	0.21	↑
B4	0.90	100	0.038	↑
B5	0.94	100	0.018	↑
B6	0.96	100	0.018	↑
B7	0.97	100	0.018	↑
B8	0.99	100	0.018	↑
B9	1.01	100	0.019	↑
B10	1.03	100	0.019	↑
B11	1.05	100	0.019	↑
B12	1.07	100	-0.006	↓
B13	1.06	100	-0.006	↓
B14	1.06	100	-0.006	↓
B15	1.05	100	-0.006	↓
B16	1.04	100	-0.006	↓
B17	1.04	100	-0.006	↓
B18	1.03	100	-0.010	↓
B19	1.02	100	-0.002	↓
B20	1.02	100	-0.20	↓
B21	0.82	100	-0.36	↓
B22	0.46	100	-0.35	↓
B23	0.11			

Table 5.3				
SOIL COVER SETTLEMENT AND ANGULAR DISTORTION BETWEEN POINTS; CROSS SECTION A-A				
Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction
	(ft)	(ft)	(%)	
A1	0.13	100	0.26	↑
A2	0.39	100	0.15	↑
A3	0.54	100	0.13	↑
A4	0.68	100	-0.03	↓
A5	0.65	100	0.27	↑
A6	0.92	100	-0.15	↓
A7	0.77	100	0.01	↑
A8	0.78	100	0.01	↑
A9	0.79	100	0.02	↑
A10	0.81	100	0.03	↑
A11	0.84	100	0.02	↑
A12	0.86	100	0.01	↑
A13	0.86	100	0.15	↑
A14	1.01	100	-0.14	↓
A15	0.87	100	-0.144	↓
A16	0.87	100	0.00	↓
A17	0.84	100	-0.02	↓
A18	0.82	100	-0.03	↓
A19	0.81	100	-0.01	↓
A20	0.80	100	0.00	↓
A21	0.79	100	-0.01	↓
A22	0.76	100	-0.03	↓
A23	0.75	100	-0.02	↓
A24	0.71	100	-0.17	↓
A25	0.57	100	-0.24	↓
A26	0.33	100	-0.29	↓
A27	0.04			

Table 5.3 Continued				
SOIL COVER SETTLEMENT AND ANGULAR DISTORTION BETWEEN POINTS; CROSS SECTION B-B				
Point Location	Total Settlement	Distance Between Points	Angular Distortion	Distortion Direction
	(ft)	(ft)	(%)	
B1	0.13	100	0.29	↑
B2	0.43	100	0.20	↑
B3	0.63	100	0.14	↑
B4	0.77	100	0.024	↑
B5	0.79	100	0.011	↑
B6	0.80	100	0.011	↑
B7	0.81	100	0.011	↑
B8	0.82	100	0.011	↑
B9	0.84	100	0.011	↑
B10	0.85	100	0.011	↑
B11	0.86	100	0.012	↑
B12	0.87	100	-0.003	↓
B13	0.87	100	-0.003	↓
B14	0.86	100	-0.003	↓
B15	0.86	100	-0.003	↓
B16	0.86	100	-0.003	↓
B17	0.85	100	-0.003	↓
B18	0.85	100	-0.006	↓
B19	0.84	100	-0.001	↓
B20	0.84	100	-0.13	↓
B21	0.72	100	-0.25	↓
B22	0.47	100	-0.29	↓
B23	0.18			

6.0 GEONET COMPRESSION UNDER OVERBURDEN

C.K. Disposal will utilize a 200-mil geonet onsite for leachate collection. The site's leachate collection was modeled using the HELP Model. The HELP Model uses a hydraulic conductivity of 10 cm/sec for the estimated geocomposite flow rate. The geonet has a tendency to compress when subjected to weight and time. Table 6.1 shows how different loading on the geocomposite affects drainage. A sample calculation follows:

- 200-mil geonet
- $y_w = 74$ pcf
- $y_s = 110$ pcf
- Maximum height of waste over geocomposite = 160 feet
- 50% compressibility at 20,000 psf

$$t_o = t_i + (t_c - t_i)((P_o - P_i)/(P_t - P_i))$$

Where:

t_o = thickness after loading

t_c = thickness of geonet at 20,000 psf = 0.1 inch

t_i = initial thickness = 0.2 inch

P_o = loading on geocomposite = (160 ft)(74 pcf) + (6 ft)(110 pcf) = 12,500 lbs/ft²

P_i = initial loading

P_t = total compressibility

$$t_o = t_i + (t_c - t_i)((P_o - P_i) / (P_t - P_i))$$

$$t_o = 0.2 + (0.1 - 0.2)((12,500 - 0) / (20,000 - 0))$$

$$t_o = 0.1375 \text{ inch}$$

A factor of safety was assumed to be 1.5 to account for geotextile intrusion, creep deformation, chemical clogging, and biological clogging.

6.1 Transmissivity

$$T_{FS} = T/FS$$

Where:

T_{FS} = transmissivity with factor of safety

T = transmissivity of geocomposite

$$FS = 1.5$$

$$T_{FS} = ((5.76E -4 (\text{Tenax Geocomposite testing})) / (1.5))$$

$$T_{FS} = 3.84E -4$$

With maximum soil and waste profile weight applied to the geocomposite, a new hydraulic conductivity value is calculated.

$$K = T_{FS} / t$$

$$K = (3.84E - 04m^2/s) / (0.1375 \text{ in})$$

$$K = 10.99 \text{ cm/s}$$

6.2 Summary

The assumed hydraulic conductivity of 10 cm/sec used in the HELP model is less than the value calculated after the geocomposite is subjected to the loading of the waste and cover soil. Therefore, the 10 cm/sec is a conservative representation of the C.K. Disposal leachate collection system. Table 6.1 is a detailed summary of the geocomposite compression calculation.

Base/Design Geocomposite:

GSE Fabrinet HF

T = 9.00E-05 m2/s @ 10,000 psf
 t = 0.2 in @ unloaded

1. Geocomposite Thickness

Assume the geocomposite will undergo linear compression due to the weight of soil and waste.

Unloaded geocomposite thickness = 0.2 in
 Compressibility at 20,000 psf = 50 %

Unit weight of waste = 74.0 pcf = 1,998 lb/CY
 Unit weight of soil = 110 pcf

Fill Condition	d_w^1 (ft)	d_s^2 (ft)	P^3 (psf)	t^4 (in)
Interim	40	3	3290	0.22
Interim	80	3	6250	0.17
Interim	120	3	9210	0.15
Final	160	6	12500	0.14

- d_w is the depth of waste above the geocomposite
- d_s is the depth of soil above the geocomposite
- P is the pressure on the geocomposite due to the weight of the waste and soil.
- t is the thickness of the geocomposite after being subjected to linear compression.

2. Factors of safety for Strength and Environmental Conditions.

Factor of Safety	Fill Condition			
	Interim (40' Waste)	Interim (80' Waste)	Interim (120' Waste)	Final (160' Waste)
Geotextile Intrusion	1.0	1.10	1.10	1.25
Creep Deformation	1.0	1.00	1.00	1.00
Chemical Clogging	1.0	1.10	1.10	1.10
Biological Clogging	1.0	1.10	1.10	1.10
FS Factor	1.00	1.33	1.33	1.50

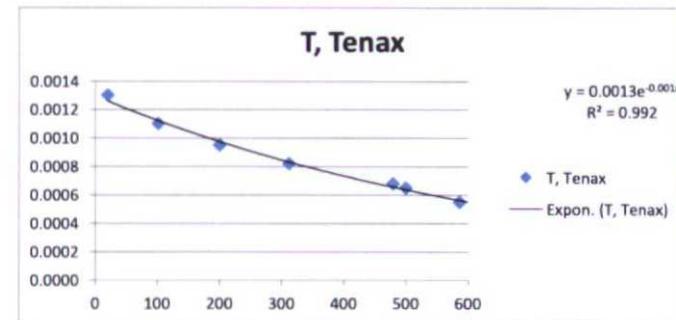
3. Compute the hydraulic conductivity

Fill Condition	d_w (ft)	P (psf)	t (in)	T^1 (m^2/s)	FS	T_{FS}^2 (m^2/s)	k^3 (cm/s)
Interim	40	3290	0.22	8.10E-04	1.00	8.10E-04	14.73
Interim	80	6250	0.17	7.08E-04	1.33	5.32E-04	12.41
Interim	120	9210	0.15	6.04E-04	1.33	4.54E-04	11.60
Final	160	12500	0.14	5.76E-04	1.50	3.84E-04	10.99

- T is the geocomposite Transmissivity value.
 - T_{FS} is the geocomposite Transmissivity taking into account the FS.
 - k is the geocomposite hydraulic conductivity input
- $k = T_{FS}/t$

$$y = y_0 + (y_1 - y_0) \frac{x - x_0}{x_1 - x_0}$$

dw	kpa	psf	T, Tenax	T, GSE
0	0.05	1	0.0013	
0	1	21	0.0013	
5	20	418	0.0013	
40	102	2,120	0.0011	0.000809
80	200	4,177	0.00095	
140	312	6,520	0.00082	0.000603
219	479	10,000	0.00068	0.0005
229	500	10,443	0.00065	
270	586	12,240	0.00055	0.000404



7.0 GEOTEXTILE RETENTION

Retention design is typically based on an upper limit to the largest geotextile opening size. According to Carrol (1983), the design of the geotextile should have the following relationship:

$$O_{95} < (2-3) d_{85}$$

Where:

O_{95} = apparent opening size

d_{85} = soil particle size in which 85% of the material by weight is finer

Based on the onsite soil testing, the d_{85} for the soil is approximately 0.2 mm. According to GSE documentation, the apparent opening size for the 8 oz geotextile is 0.1 mm to 0.2 mm.

$$O_{95} < (2-3) d_{85}$$

$$0.2 < (2.5)(0.2)$$

$$0.2 < 0.5$$

7.1 Permittivity

Permittivity is defined by ASTM D4491 as "the volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions in the normal direction through a geotextile." Designers rely primarily on the hydraulic conductivity of the geotextile, which is related to permittivity by the following equation:

$$\Psi = K/t$$

Where:

Ψ = permittivity of the geotextile (sec^{-1})

K = hydraulic conductivity of the geotextile (m/sec)

t = thickness of the geotextile (m)

According to GSE product specifications for the FabriNet 200-mil geocomposite, they specify the geotextile has a water flow rate of 95 gpm/ft²

$$K = (95 \text{ gpm/ft}^2)(0.133681 \text{ ft}^2/\text{gal})(1 \text{ min} / 60 \text{ sec})(0.3048 / 1 \text{ ft})$$

$$K = 0.06 \text{ m/s}$$

$$\text{Geotextile thickness} = 100 \text{ mil} = 0.00254 \text{ meter}$$

$$\Psi = K/t = (0.06 \text{ m/s} / 0.00254 \text{ m}) = 23.6 \text{ sec}^{-1}$$

7.2 Porosity (Reference 7)

Reference 7 show that the porosity of geotextiles, geonets or geocomposites can be calculated by the equation below:

$$n = 1 - (M/pt)$$

Where:

n = porosity

m = mass per unit area = 8 oz/yd² = 0.027 g/cm²

p = density of polymeric compound = 0.94

t = thickness of geosynthetic material = 0.254 cm

Since the density of high density polyethylene is approximately constant around 0.94 g/cm³, porosity of the material primarily depends on its thickness and mass per unit area. In general, the higher the M/t ratio, the higher the geosynthetic porosity.

$$n = 1 - (M/pt)$$

$$n = 1 - ((0.027 \text{ g/cm}^2) / (0.94 \text{ g/cm}^3)(0.254 \text{ cm}))$$

$$n = 0.887$$

8.0 GEOTECHNICAL DESIGN – SLOPE STABILITY

Final cover slope stability was analyzed under static and pseudo-static conditions for the CK Disposal Facility. Both scenarios were analyzed for circular failure using Bishop and Janbu simplified calculation methods. Janbu simplified analysis was selected as a redundant check of the Bishop simplified method. Both static and pseudo-static scenarios were analyzed using Slide 7.0, a RocScience program. A summary table (below) of the analyses run on the critical cross section of the landfill shows that final cover slope design is adequate for static and pseudo-static conditions.

Table 8.0 – Factor of Safety

	Bishop Simplified	Janbu Simplified
Static		
East Slope	2.544	2.635
West Slope	2.598	2.590
Pseudo-static		
East Slope	1.926	1.919
West Slope	1.900	1.894

8.1 Model Input Parameters

Grab samples from geotechnical drilling investigations were obtained from the site and tested by Terra Testing, LLC in Lubbock, Texas. These soils were identified as “Caliche” Silty Sand, “Red Bed” Sand, and “Sand” Silty Sand. Drilling logs, from the monitor wells drilled at the site, identified clayey sand, silty sand, and claystone. In order to construct the in-situ soil profile, both clayey sand and silty sand were considered to be “Caliche” Silty Sand, which is non-plastic and has a dry density of 102.2-pcf. The full depth of excavation will take place in this soil. Because excavated soil will be used as final cover on side slopes and top slopes, the same soil parameters were applied to final cover slopes. Side slopes will have 4-feet of cover, and top slopes will have 5-feet of cover. A unit weight of 2,000 pounds per cubic yard was converted to 74-pcf and used for waste properties. This value is used consistently throughout this permit application. Because no cohesion information was known about waste profile in final slope conditions, a cohesion value of 0-psf was used for waste analysis.

Reference 8 presented a table outlining descriptive properties of rock. This table listed the typical density of clastic sedimentary rock as 130 to 150-pcf. A typical value of 140-pcf was assumed for claystone identified at this site. A very conservative cohesion value of 2,000-psf was input into the model for the cohesion value of claystone. Reference 8 is attached to this report in Appendix C.

8.2 Static Slope Stability

The East-West cross section of the landfill site was identified as the critical cross section for slope stability analysis. This cross section is also representative of the entire landfill, as

geometry is specified as uniform across all side slopes. RocScience Slide 7.0 was used to analyze the east and west side slopes of the East-West cross section. Although side slopes are specified as uniform, slight variations in perimeter drainage channels and transport roadways at the toe of slope warranted that each slope be checked for stability. Detailed Slide 7.0 model input information for static slope stability can be seen in Appendix A, along with Slide 7.0 output graphics.

8.3 Pseudo-static Slope Stability

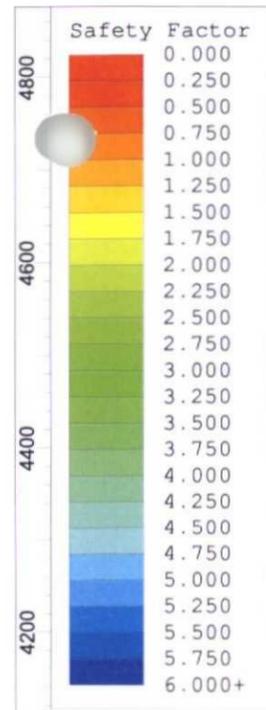
The model input geometry and slopes identified for static slope stability were utilized for pseudo-static slope stability as well. The mapped Peak Ground Acceleration (PGA) at the site is 0.116 g (where $g = 32.2 \text{ ft/s}^2$). A detailed report showing seismic properties of the location was generated at earthquake.usgs.gov and is attached in Appendix C. Per Reference 6 a typical horizontal seismic loading coefficient of $0.5 \cdot \text{PGA}$ was used. A conservative k_H of $0.8 \cdot \text{PGA}$ was used for this design. A vertical seismic loading coefficient of $0.66 \cdot k_H$ was also applied to the model.

The resulting seismic loading coefficients are $k_H = 0.8$ and $k_v = 0.5$. When these parameters were input to the static slope stability model in Slide 7.0, Factors of Safety greater than 2.0 were resultant for both slopes. A minimum accepted Factor of Safety is 1.1 for pseudo-static slope stability. Detailed Slide 7.0 model input information for pseudo-static slope stability can be seen in Appendix A, along with Slide 7.0 output graphics

REFERENCES

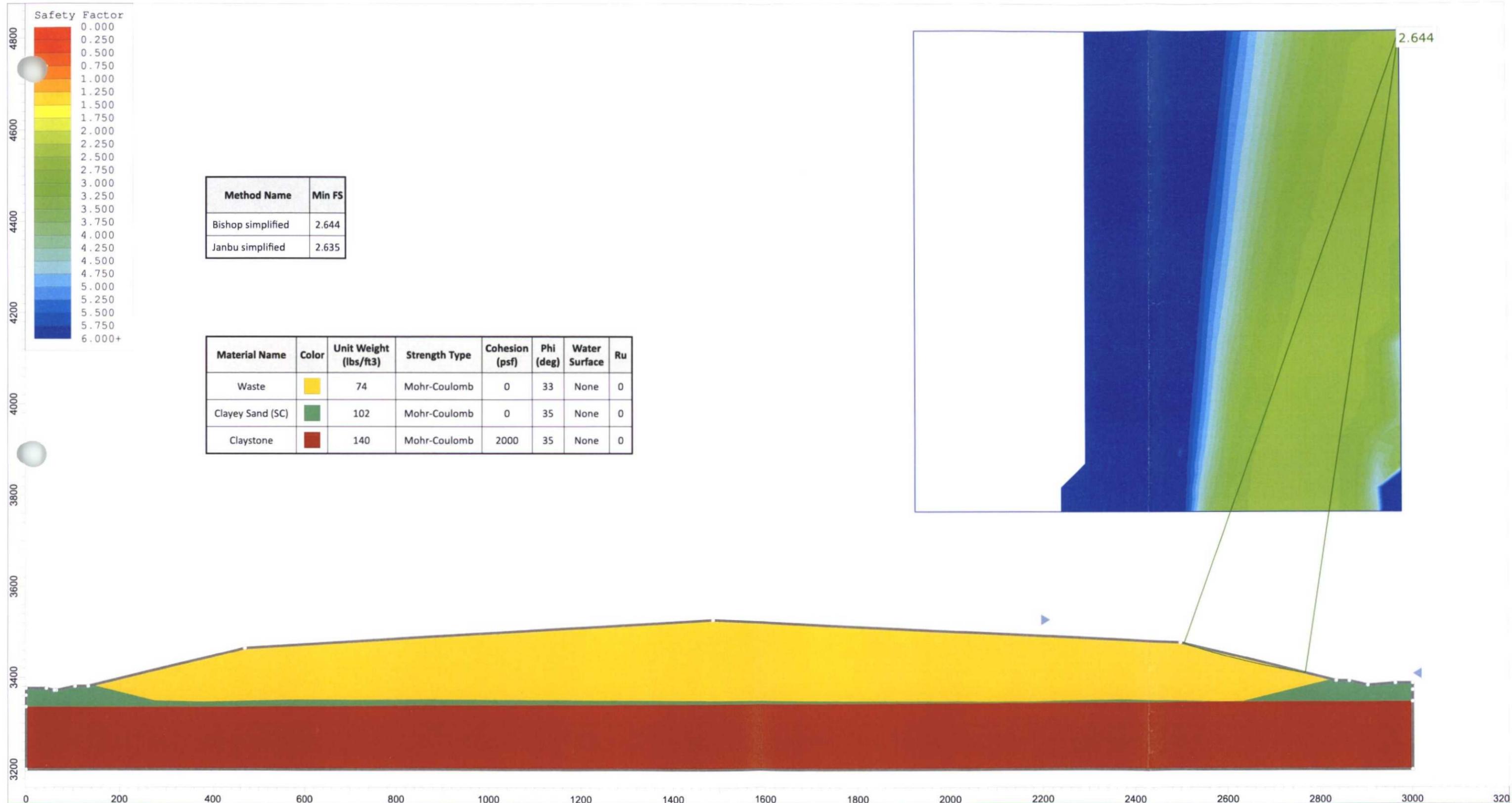
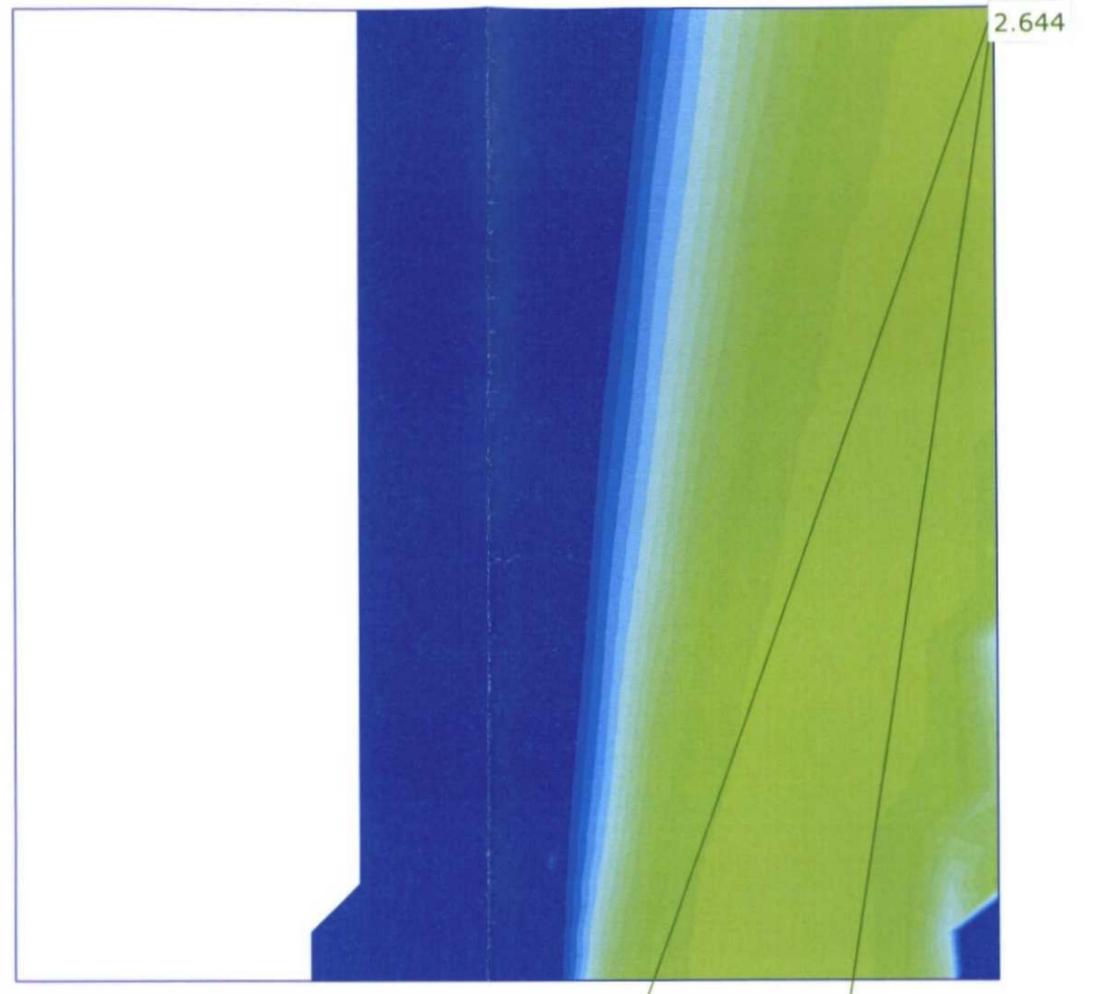
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APPENDIX A
STATIC MODEL INPUTS AND OUTPUTS

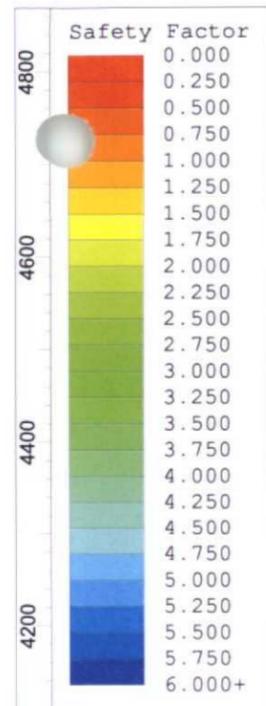


Method Name	Min FS
Bishop simplified	2.644
Janbu simplified	2.635

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0

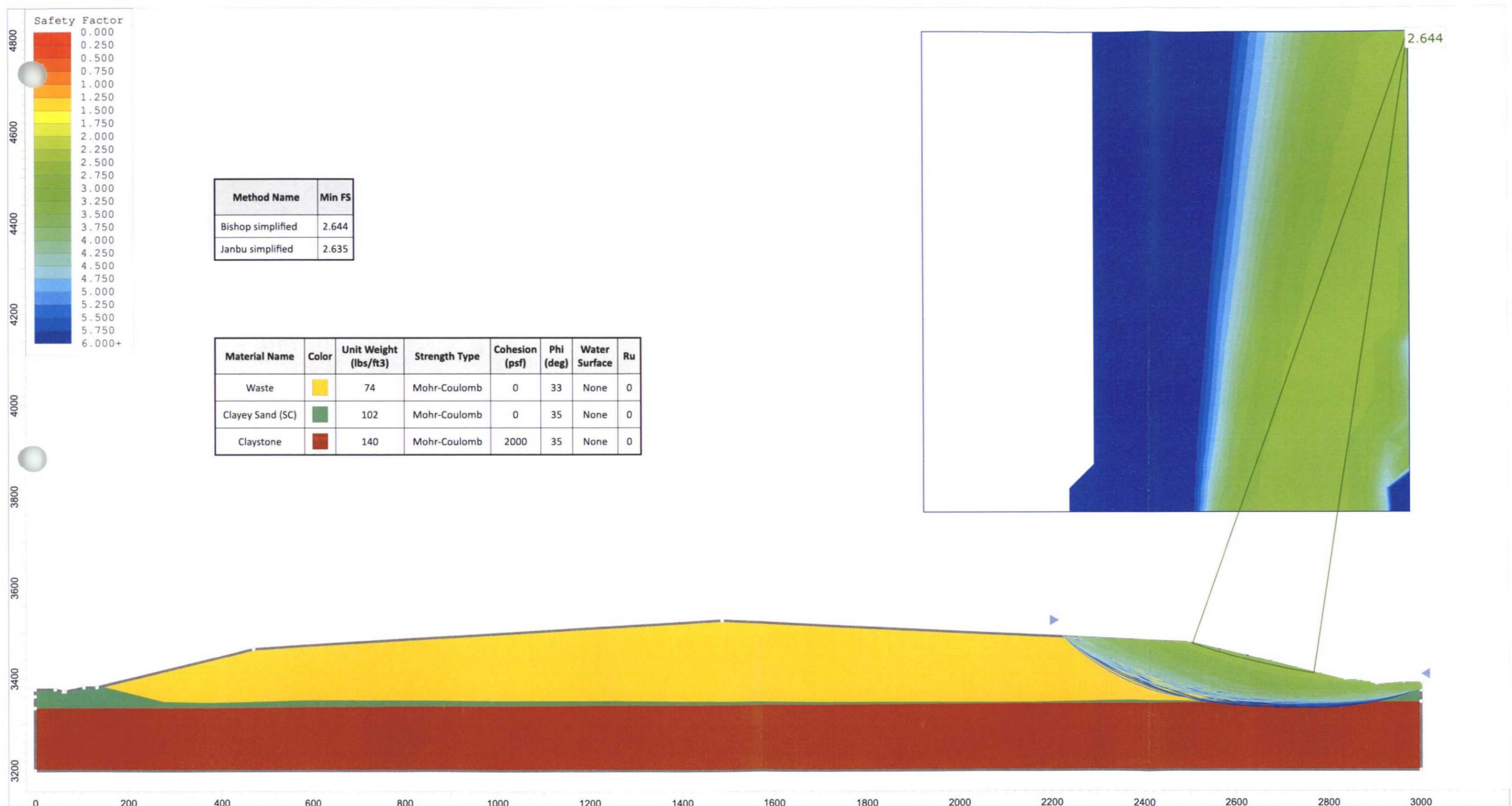
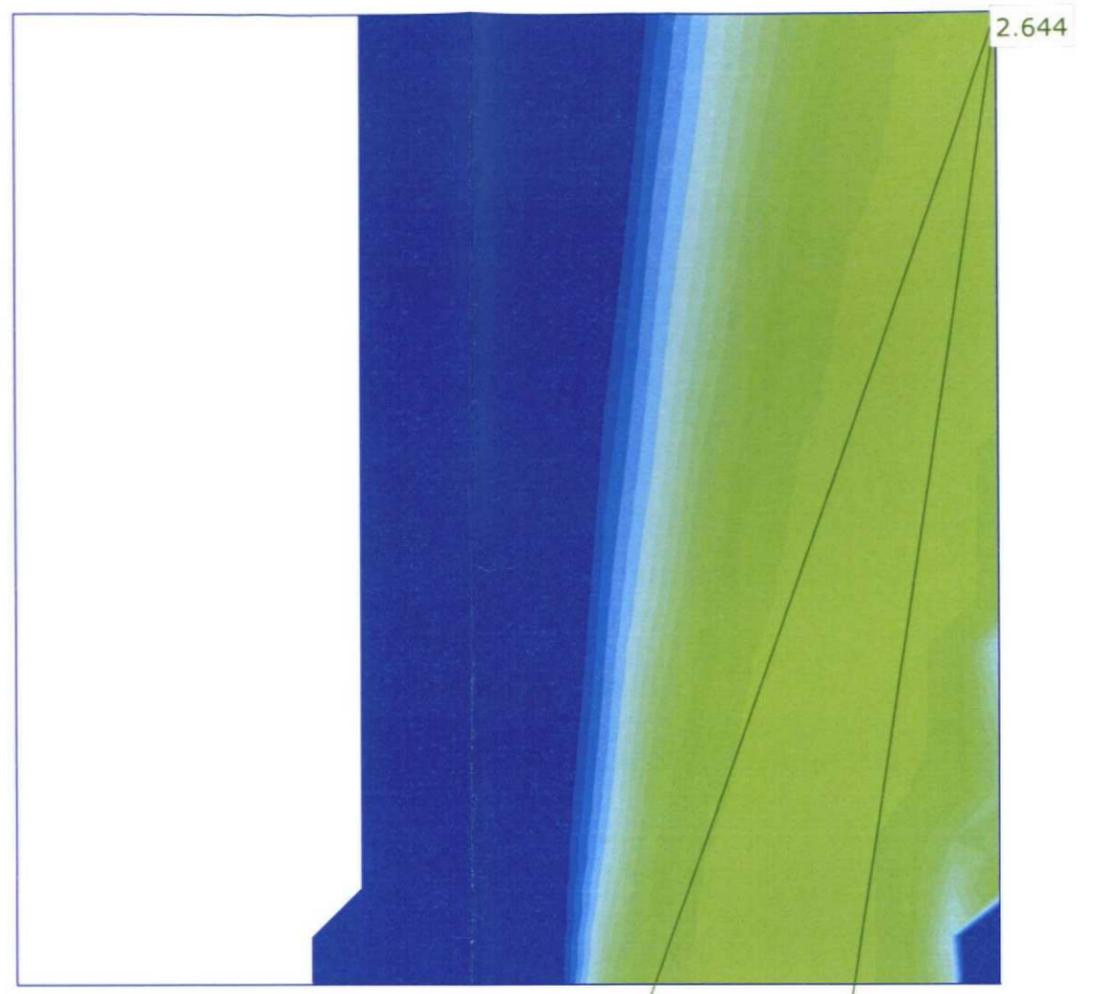


Project				CK Disposal Facility, East Slope			
Analysis Description				Final Cover			
Drawn By		Scale		Company		Parkhill, Smith & Cooper Inc.	
Date		4/19/2016, 5:02:51 PM		File Name		EAST SLOPE STATIC.slim	



Method Name	Min FS
Bishop simplified	2.644
Janbu simplified	2.635

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project				CK Disposal Facility, East Slope			
Analysis Description				Final Cover			
Drawn By		Scale		Company		Parkhill, Smith & Cooper Inc.	
Date		4/19/2016, 5:02:51 PM		File Name		EAST SLOPE STATIC.slim	

Slide Analysis Information

CK Disposal Facility, East Slope

Project Summary

File Name: EAST SLOPE STATIC
 Slide Modeler Version: 7.014
 Project Title: CK Disposal Facility, East Slope
 Analysis: Final Cover
 Company: Parkhill, Smith & Cooper Inc.
 Date Created: 4/19/2016, 5:02:51 PM

General Settings

Units of Measurement: Imperial Units
 Time Units: days
 Permeability Units: feet/second
 Failure Direction: Left to Right
 Data Output: Standard
 Maximum Material Properties: 20
 Maximum Support Properties: 20

Analysis Options

Slices Type: Vertical

Analysis Methods Used

Bishop simplified
 Janbu simplified

Number of slices: 50
 Tolerance: 0.005
 Maximum number of iterations: 75
 Check $\alpha < 0.2$: Yes
 Create Interslice boundaries at intersections with water tables and piezos: Yes
 Initial trial value of FS: 1
 Steffensen Iteration: Yes

Groundwater Analysis

Groundwater Method: Water Surfaces
 Pore Fluid Unit Weight [lbs/ft³]: 62.4
 Advanced Groundwater Method: None

Random Numbers

Pseudo-random Seed: 10116
 Random Number Generation Method: Park and Miller v.3

Surface Options

Surface Type: Circular
 Search Method: Grid Search
 Radius Increment: 5
 Composite Surfaces: Disabled
 Reverse Curvature: Invalid Surfaces
 Minimum Elevation: Not Defined
 Minimum Depth: Not Defined
 Minimum Area: Not Defined
 Minimum Weight: Not Defined

Seismic

Advanced seismic analysis: No
 Staged pseudostatic analysis: Yes
 Staged pseudostatic method: Effective Stress

Material Properties

Property	Waste	Clayey Sand (SC)	Claystone
Color			
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft ³]	74	102	140
Cohesion [psf]	0	0	2000
Friction Angle [deg]	33	35	35
Water Surface	None	None	None
Ru Value	0	0	0

Global Minimums

Method: bishop simplified

FS	2.643640
Center:	2976.733, 4816.811
Radius:	1421.530
Left Slip Surface Endpoint:	2505.464, 3475.672
Right Slip Surface Endpoint:	2767.289, 3410.795
Resisting Moment:	9.04137e+007 lb-ft
Driving Moment:	3.42005e+007 lb-ft
Total Slice Area:	1153.23 ft ²
Surface Horizontal Width:	261.825 ft
Surface Average Height:	4.40459 ft

Method: janbu simplified

FS	2.634950
Center:	2976.733, 4711.511
Radius:	1323.079
Left Slip Surface Endpoint:	2502.035, 3476.522
Right Slip Surface Endpoint:	2819.884, 3397.762
Resisting Horizontal Force:	112374 lb
Driving Horizontal Force:	42647.6 lb
Total Slice Area:	2221 ft ²
Surface Horizontal Width:	317.85 ft
Surface Average Height:	6.98758 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 1741
 Number of Invalid Surfaces: 905

Error Codes:

Error Code -102 reported for 6 surfaces
 Error Code -106 reported for 35 surfaces
 Error Code -107 reported for 12 surfaces
 Error Code -1000 reported for 852 surfaces

Method: janbu simplified

Number of Valid Surfaces: 1741
 Number of Invalid Surfaces: 905

Error Codes:

Error Code -102 reported for 6 surfaces
 Error Code -106 reported for 35 surfaces
 Error Code -107 reported for 12 surfaces
 Error Code -1000 reported for 852 surfaces

Error Codes

The following errors were encountered during the computation:

- 102 = Two surface / slope intersections, but resulting arc is actually outside soil region.
- 106 = Average slice width is less than 0.0001 * (maximum horizontal extent of soil region). This limitation is imposed to avoid numerical errors which may result from too many slices, or too small a slip region.
- 107 = Total driving moment or total driving force is negative. This will occur if the wrong failure direction is specified, or if high external or anchor loads are applied against the failure direction.
- 1000 = No valid slip surfaces are generated at a grid center. Unable to draw a surface.

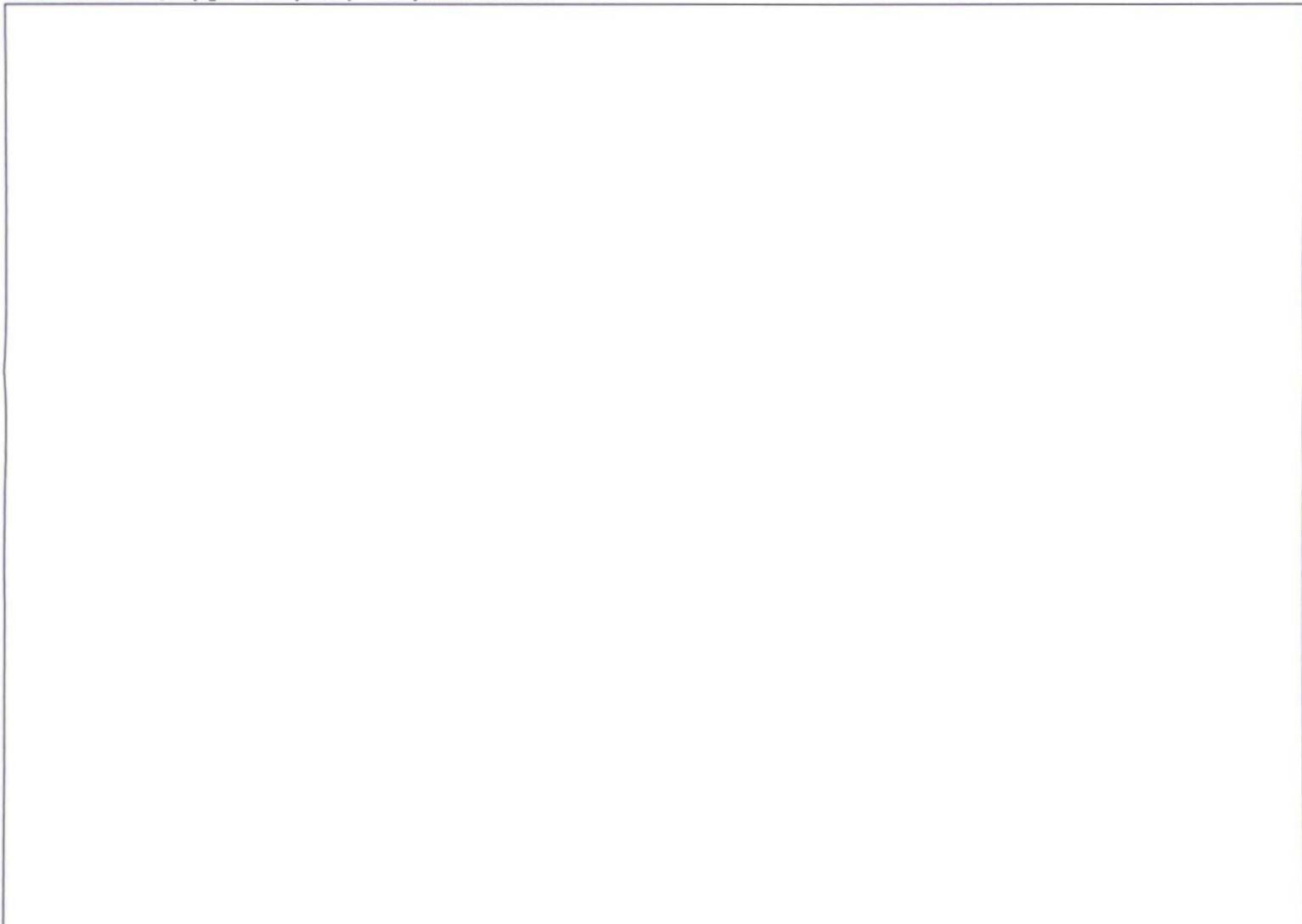
Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.64364

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Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	4.77986	118.392	-19.2592	Clayey Sand (SC)	15.875	0	6.00498	15.875	22.6708	0	22.6708
2	4.77986	350.528	-19.0552	Clayey Sand (SC)	47.0472	0	17.7964	47.0472	67.1874	0	67.1874
3	4.77986	573.385	-18.8515	Clayey Sand (SC)	77.0329	0	29.139	77.0329	110.01	0	110.01
4	4.77986	786.997	-18.648	Clayey Sand (SC)	105.833	0	40.0331	105.833	151.138	0	151.138
5	4.77986	991.396	-18.4448	Clayey Sand (SC)	133.448	0	50.4789	133.448	190.575	0	190.575
6	5.31874	1299.76	-18.2304	Waste	146.824	0	55.5386	146.824	226.08	0	226.08
7	5.31874	1466.05	-18.0049	Waste	165.773	0	62.7063	165.773	255.258	0	255.258
8	5.31874	1623.24	-17.7796	Waste	183.729	0	69.4985	183.729	282.907	0	282.907
9	5.31874	1771.36	-17.5546	Waste	200.691	0	75.9146	200.691	309.026	0	309.026
10	5.31874	1910.44	-17.3299	Waste	216.661	0	81.9556	216.661	333.617	0	333.617
11	5.31874	2040.51	-17.1055	Waste	231.64	0	87.6216	231.64	356.682	0	356.682
12	5.31874	2161.62	-16.8813	Waste	245.627	0	92.9124	245.627	378.219	0	378.219
13	5.31874	2273.79	-16.6574	Waste	258.625	0	97.8291	258.625	398.234	0	398.234
14	5.31874	2377.04	-16.4338	Waste	270.633	0	102.371	270.633	416.724	0	416.724
15	5.31874	2471.42	-16.2104	Waste	281.651	0	106.539	281.651	433.69	0	433.69
16	5.31874	2556.96	-15.9873	Waste	291.681	0	110.333	291.681	449.134	0	449.134
17	5.31874	2633.68	-15.7644	Waste	300.722	0	113.753	300.722	463.057	0	463.057
18	5.31874	2701.61	-15.5418	Waste	308.776	0	116.8	308.776	475.457	0	475.457
19	5.31874	2760.78	-15.3194	Waste	315.842	0	119.472	315.842	486.339	0	486.339
20	5.31874	2811.22	-15.0972	Waste	321.921	0	121.772	321.921	495.7	0	495.7
21	5.31874	2852.96	-14.8753	Waste	327.014	0	123.698	327.014	503.541	0	503.541
22	5.31874	2886.02	-14.6536	Waste	331.119	0	125.251	331.119	509.862	0	509.862
23	5.31874	2910.44	-14.4321	Waste	334.238	0	126.431	334.238	514.666	0	514.666
24	5.31874	2926.22	-14.2109	Waste	336.371	0	127.238	336.371	517.951	0	517.951
25	5.31874	2933.42	-13.9898	Waste	337.518	0	127.672	337.518	519.715	0	519.715
26	5.31874	2932.03	-13.769	Waste	337.678	0	127.732	337.678	519.964	0	519.964
27	5.31874	2922.1	-13.5484	Waste	336.853	0	127.42	336.853	518.692	0	518.692
28	5.31874	2903.65	-13.328	Waste	335.041	0	126.735	335.041	515.904	0	515.904
29	5.31874	2876.69	-13.1078	Waste	332.243	0	125.676	332.243	511.596	0	511.596
30	5.31874	2841.26	-12.8878	Waste	328.459	0	124.245	328.459	505.769	0	505.769
31	5.31874	2797.37	-12.6679	Waste	323.689	0	122.441	323.689	498.424	0	498.424
32	5.31874	2745.04	-12.4483	Waste	317.932	0	120.263	317.932	489.56	0	489.56
33	5.31874	2684.31	-12.2289	Waste	311.189	0	117.712	311.189	479.177	0	479.177
34	5.31874	2615.18	-12.0096	Waste	303.458	0	114.788	303.458	467.273	0	467.273
35	5.31874	2537.68	-11.7905	Waste	294.74	0	111.49	294.74	453.848	0	453.848
36	5.31874	2451.84	-11.5716	Waste	285.035	0	107.819	285.035	438.904	0	438.904
37	5.31874	2357.66	-11.3529	Waste	274.341	0	103.774	274.341	422.438	0	422.438
38	5.31874	2255.17	-11.1343	Waste	262.659	0	99.3551	262.659	404.449	0	404.449
39	5.31874	2144.39	-10.9159	Waste	249.988	0	94.562	249.988	384.939	0	384.939
40	5.31874	2025.34	-10.6976	Waste	236.328	0	89.3949	236.328	363.905	0	363.905
41	5.31874	1898.03	-10.4796	Waste	221.678	0	83.8533	221.678	341.346	0	341.346
42	5.31874	1762.48	-10.2616	Waste	206.037	0	77.9369	206.037	317.261	0	317.261
43	5.31874	1618.71	-10.0438	Waste	189.404	0	71.6452	189.404	291.651	0	291.651
44	5.31874	1466.74	-9.82619	Waste	171.78	0	64.9786	171.78	264.512	0	264.512
45	5.31874	1306.58	-9.6087	Waste	153.164	0	57.9368	153.164	235.847	0	235.847
46	5.03522	1052.78	-9.39713	Clayey Sand (SC)	140.256	0	53.0541	140.256	200.301	0	200.301
47	5.03522	835.203	-9.19148	Clayey Sand (SC)	111.374	0	42.129	111.374	159.055	0	159.055
48	5.03522	608.108	-8.98595	Clayey Sand (SC)	81.1668	0	30.7027	81.1668	115.916	0	115.916
49	5.03522	371.507	-8.78054	Clayey Sand (SC)	49.633	0	18.7745	49.633	70.8819	0	70.8819
50	5.03522	125.416	-8.57524	Clayey Sand (SC)	16.7711	0	6.34394	16.7711	23.9512	0	23.9512

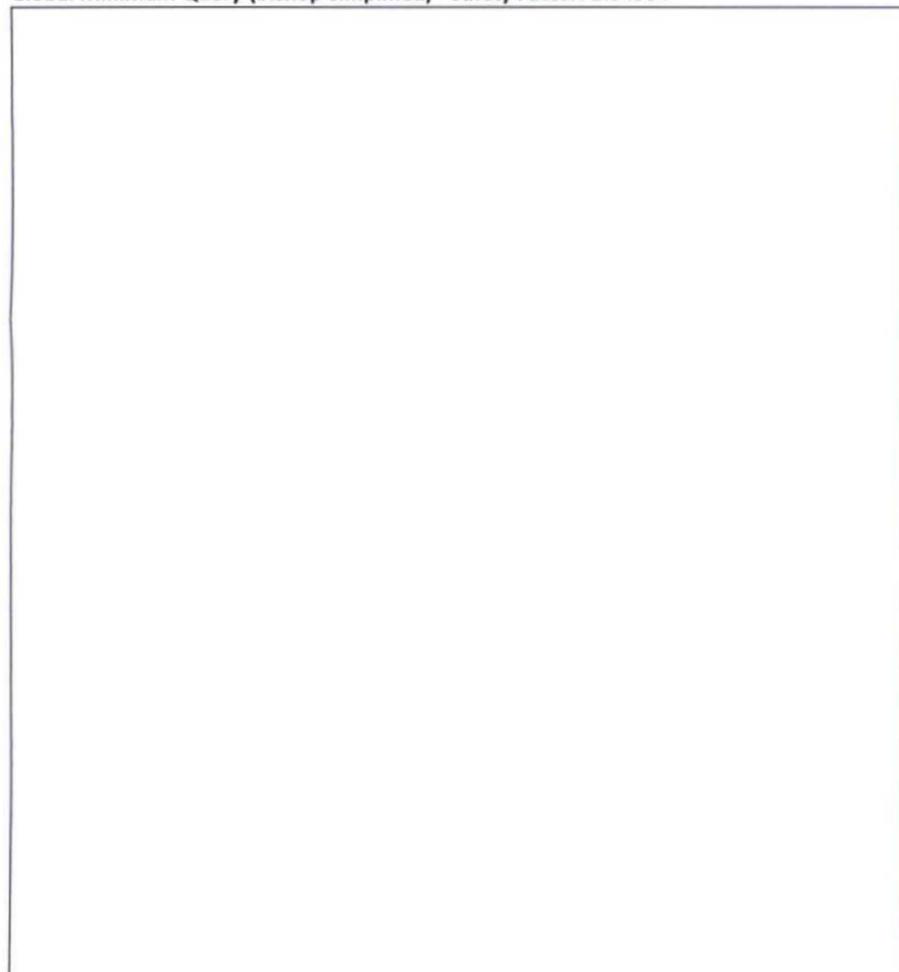
Global Minimum Query (janbu simplified) - Safety Factor: 2.63495



Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	5.80225	229.894	-20.891	Clayey Sand (SC)	25.1884	0	9.55935	25.1884	35.9701	0	35.9701
2	5.80225	680.472	-20.6223	Clayey Sand (SC)	74.6527	0	28.3317	74.6527	106.607	0	106.607
3	5.80225	1112.68	-20.3541	Clayey Sand (SC)	122.227	0	46.3868	122.227	174.545	0	174.545
4	6.40397	1640.05	-20.0724	Waste	152.572	0	57.9032	152.572	234.925	0	234.925
5	6.40397	1988.25	-19.7775	Waste	185.209	0	70.2894	185.209	285.177	0	285.177
6	6.40397	2318.82	-19.483	Waste	216.285	0	82.0832	216.285	333.029	0	333.029
7	6.40397	2631.86	-19.1891	Waste	245.805	0	93.2864	245.805	378.482	0	378.482
8	6.40397	2927.46	-18.8957	Waste	273.769	0	103.899	273.769	421.541	0	421.541
9	6.40397	3205.71	-18.6029	Waste	300.179	0	113.922	300.179	462.208	0	462.208
10	6.40397	3466.71	-18.3105	Waste	325.039	0	123.357	325.039	500.486	0	500.486
11	6.40397	3710.55	-18.0186	Waste	348.348	0	132.203	348.348	536.378	0	536.378
12	6.40397	3937.3	-17.7273	Waste	370.11	0	140.462	370.11	569.886	0	569.886
13	6.40397	4147.05	-17.4363	Waste	390.325	0	148.134	390.325	601.014	0	601.014
14	6.40397	4339.89	-17.1459	Waste	408.996	0	155.22	408.996	629.762	0	629.762
15	6.40397	4515.89	-16.8559	Waste	426.123	0	161.72	426.123	656.135	0	656.135
16	6.40397	4675.14	-16.5663	Waste	441.707	0	167.634	441.707	680.132	0	680.132
17	6.40397	4817.7	-16.2772	Waste	455.751	0	172.964	455.751	701.757	0	701.757
18	6.40397	4943.66	-15.9885	Waste	468.254	0	177.709	468.254	721.009	0	721.009
19	6.40397	5053.08	-15.7002	Waste	479.218	0	181.87	479.218	737.893	0	737.893
20	6.40397	5146.03	-15.4124	Waste	488.643	0	185.447	488.643	752.406	0	752.406
21	6.40397	5222.59	-15.1249	Waste	496.531	0	188.44	496.531	764.552	0	764.552
22	6.40397	5282.83	-14.8378	Waste	502.881	0	190.85	502.881	774.331	0	774.331
23	6.40397	5326.8	-14.5511	Waste	507.695	0	192.677	507.695	781.744	0	781.744
24	6.40397	5354.57	-14.2648	Waste	510.973	0	193.921	510.973	786.792	0	786.792
25	6.40397	5366.21	-13.9788	Waste	512.714	0	194.582	512.714	789.474	0	789.474
26	6.40397	5361.77	-13.6932	Waste	512.919	0	194.66	512.919	789.791	0	789.791
27	6.40397	5341.31	-13.4079	Waste	511.589	0	194.155	511.589	787.744	0	787.744
28	6.40397	5304.89	-13.123	Waste	508.723	0	193.067	508.723	783.332	0	783.332
29	6.40397	5252.57	-12.8384	Waste	504.321	0	191.397	504.321	776.553	0	776.553
30	6.40397	5184.41	-12.5541	Waste	498.382	0	189.143	498.382	767.409	0	767.409
31	6.40397	5100.44	-12.2702	Waste	490.906	0	186.306	490.906	755.899	0	755.899
32	6.40397	5000.74	-11.9865	Waste	481.894	0	182.885	481.894	742.023	0	742.023
33	6.40397	4885.34	-11.7032	Waste	471.343	0	178.881	471.343	725.778	0	725.778
34	6.40397	4754.29	-11.4201	Waste	459.254	0	174.293	459.254	707.163	0	707.163
35	6.40397	4607.65	-11.1373	Waste	445.626	0	169.121	445.626	686.178	0	686.178
36	6.40397	4445.46	-10.8548	Waste	430.457	0	163.364	430.457	662.823	0	662.823
37	6.40397	4267.75	-10.5726	Waste	413.747	0	157.023	413.747	637.092	0	637.092
38	6.40397	4074.59	-10.2906	Waste	395.494	0	150.095	395.494	608.988	0	608.988
39	6.40397	3866	-10.0088	Waste	375.698	0	142.583	375.698	578.505	0	578.505
40	6.40397	3642.04	-9.72736	Waste	354.356	0	134.483	354.356	545.644	0	545.644
41	6.40397	3402.73	-9.4461	Waste	331.468	0	125.797	331.468	510.401	0	510.401
42	6.40397	3148.12	-9.16508	Waste	307.032	0	116.523	307.032	472.774	0	472.774
43	6.40397	2878.24	-8.88428	Waste	281.046	0	106.661	281.046	432.761	0	432.761
44	6.40397	2593.13	-8.6037	Waste	253.508	0	96.2098	253.508	390.358	0	390.358
45	6.40397	2292.82	-8.32332	Waste	224.416	0	85.169	224.416	345.561	0	345.561
46	6.40397	1977.35	-8.04314	Waste	193.769	0	73.538	193.769	298.371	0	298.371
47	6.40397	1646.75	-7.76316	Waste	161.564	0	61.3158	161.564	248.781	0	248.781
48	6.22271	1206.06	-7.48732	Clayey Sand (SC)	131.131	0	49.766	131.131	187.27	0	187.27
49	6.22271	736.949	-7.21561	Clayey Sand (SC)	80.2256	0	30.4467	80.2256	114.571	0	114.571
50	6.22271	248.818	-6.94406	Clayey Sand (SC)	27.1203	0	10.2925	27.1203	38.7309	0	38.7309

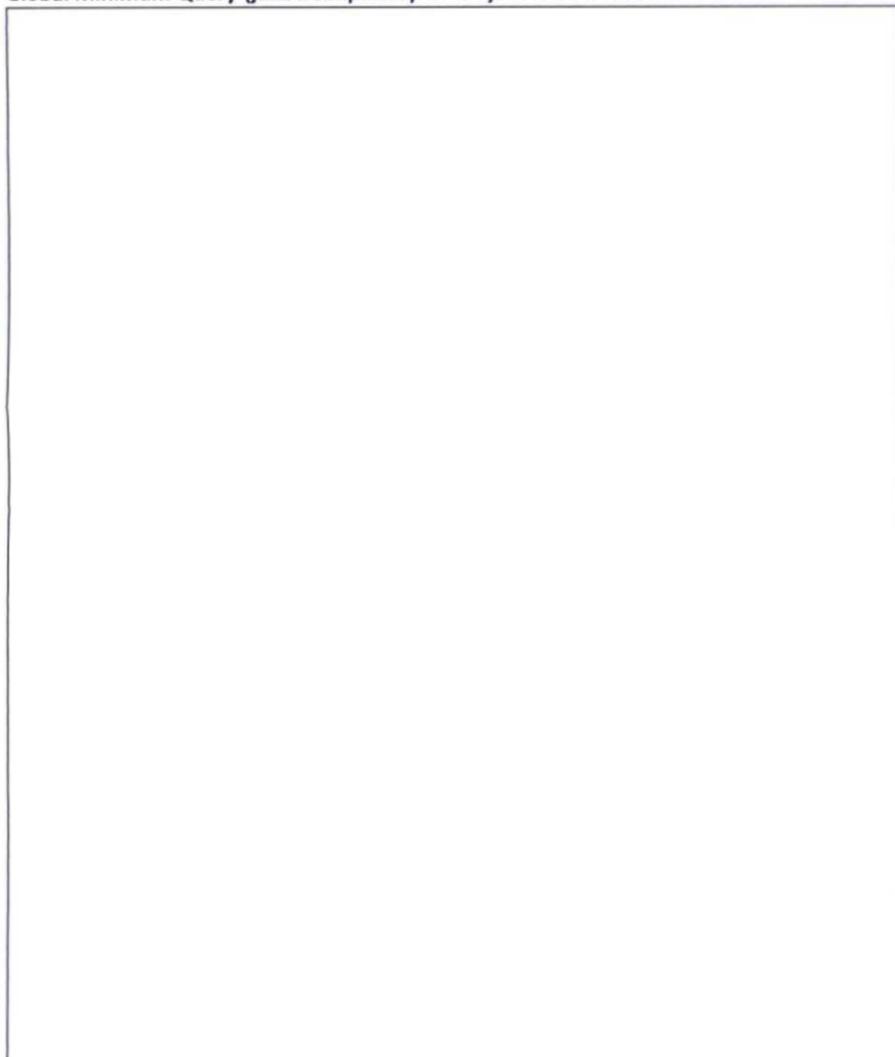
Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.64364



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	2505.46	3475.67	0	0	0
2	2510.24	3474	9.15869	0	0
3	2515.02	3472.35	35.0204	0	0
4	2519.8	3470.72	75.2752	0	0
5	2524.58	3469.11	127.719	0	0
6	2529.36	3467.51	190.253	0	0
7	2534.68	3465.76	290.916	0	0
8	2540	3464.03	398.653	0	0
9	2545.32	3462.33	511.527	0	0
10	2550.64	3460.64	627.714	0	0
11	2555.96	3458.98	745.5	0	0
12	2561.28	3457.35	863.285	0	0
13	2566.59	3455.73	979.577	0	0
14	2571.91	3454.14	1092.99	0	0
15	2577.23	3452.57	1202.26	0	0
16	2582.55	3451.03	1306.22	0	0
17	2587.87	3449.5	1403.8	0	0
18	2593.19	3448	1494.04	0	0
19	2598.51	3446.52	1576.11	0	0
20	2603.83	3445.06	1649.25	0	0
21	2609.14	3443.63	1712.82	0	0
22	2614.46	3442.22	1766.28	0	0
23	2619.78	3440.83	1809.19	0	0
24	2625.1	3439.46	1841.21	0	0
25	2630.42	3438.11	1862.11	0	0
26	2635.74	3436.79	1871.74	0	0
27	2641.06	3435.48	1870.06	0	0
28	2646.38	3434.2	1857.14	0	0
29	2651.69	3432.94	1833.13	0	0
30	2657.01	3431.7	1798.28	0	0
31	2662.33	3430.48	1752.96	0	0
32	2667.65	3429.29	1697.6	0	0
33	2672.97	3428.12	1632.74	0	0
34	2678.29	3426.96	1559.04	0	0
35	2683.61	3425.83	1477.21	0	0
36	2688.93	3424.72	1388.1	0	0
37	2694.24	3423.63	1292.62	0	0
38	2699.56	3422.56	1191.79	0	0
39	2704.88	3421.52	1086.73	0	0
40	2710.2	3420.49	978.629	0	0
41	2715.52	3419.49	868.798	0	0
42	2720.84	3418.5	758.623	0	0
43	2726.16	3417.54	649.589	0	0
44	2731.48	3416.6	543.271	0	0
45	2736.79	3415.68	441.339	0	0
46	2742.11	3414.78	345.551	0	0
47	2747.15	3413.94	245.327	0	0
48	2752.18	3413.13	162.79	0	0
49	2757.22	3412.33	100.492	0	0
50	2762.25	3411.55	61.0858	0	0
51	2767.29	3410.79	0	0	0

Global Minimum Query (Janbu simplified) - Safety Factor: 2.63495



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	2502.03	3476.52	0	0	0
2	2507.84	3474.31	24.1516	0	0
3	2513.64	3472.12	92.4141	0	0
4	2519.44	3469.97	198.775	0	0
5	2525.85	3467.63	377.41	0	0
6	2532.25	3465.33	583.618	0	0
7	2538.65	3463.06	812.074	0	0
8	2545.06	3460.83	1057.75	0	0
9	2551.46	3458.64	1315.9	0	0
10	2557.87	3456.49	1582.09	0	0
11	2564.27	3454.37	1852.14	0	0
12	2570.67	3452.28	2122.18	0	0
13	2577.08	3450.24	2388.6	0	0
14	2583.48	3448.23	2648.07	0	0
15	2589.89	3446.25	2897.53	0	0
16	2596.29	3444.31	3134.18	0	0
17	2602.69	3442.4	3355.49	0	0
18	2609.1	3440.53	3559.19	0	0
19	2615.5	3438.7	3743.27	0	0
20	2621.9	3436.9	3905.97	0	0
21	2628.31	3435.13	4045.78	0	0
22	2634.71	3433.4	4161.46	0	0
23	2641.12	3431.71	4251.99	0	0
24	2647.52	3430.04	4316.62	0	0
25	2653.92	3428.42	4354.82	0	0
26	2660.33	3426.82	4366.32	0	0
27	2666.73	3425.26	4351.09	0	0
28	2673.14	3423.74	4309.33	0	0
29	2679.54	3422.24	4241.46	0	0
30	2685.94	3420.78	4148.17	0	0
31	2692.35	3419.36	4030.36	0	0
32	2698.75	3417.96	3889.16	0	0
33	2705.16	3416.6	3725.94	0	0
34	2711.56	3415.28	3542.31	0	0
35	2717.96	3413.98	3340.07	0	0
36	2724.37	3412.72	3121.28	0	0
37	2730.77	3411.5	2888.22	0	0
38	2737.18	3410.3	2643.4	0	0
39	2743.58	3409.14	2389.52	0	0
40	2749.98	3408.01	2129.56	0	0
41	2756.39	3406.91	1866.68	0	0
42	2762.79	3405.84	1604.27	0	0
43	2769.2	3404.81	1345.97	0	0
44	2775.6	3403.81	1095.6	0	0
45	2782	3402.84	857.227	0	0
46	2788.41	3401.9	635.144	0	0
47	2794.81	3401	433.852	0	0
48	2801.22	3400.13	258.081	0	0
49	2807.44	3399.31	101.319	0	0
50	2813.66	3398.52	1.97501	0	0
51	2819.88	3397.76	0	0	0

List Of Coordinates

External Boundary

X	Y
105.01	3381.21
65	3372.05
61	3372.02
43.9	3376.3
0	3376.3
0	3361
0	3336
0	3200
3000	3200
3000	3349
3000	3374
3000	3389.22
2962.33	3389.22
2902.33	3384.3
2862.33	3393.92
2834.14	3394.23
2497.32	3477.69
1486.5	3527.15
470.02	3466.33
133.49	3381.5

Material Boundary



X	Y
133.49	3381.5
142.75	3381.59
149.94	3381.66
232.606	3361
275.18	3350.36
372.35	3348.37
594.61	3352.96
2150.52	3347.83
2372.79	3352.2
2595.06	3347.69
2633	3348.48
2735.51	3374
2817.33	3394.37
2824.68	3394.31
2834.14	3394.23

Material Boundary

X	Y
142.75	3381.59
142.75	3381.59
146.998	3382.66
468.81	3463.72
1486.54	3524.64
2498.75	3475.1
2820.46	3395.36
2824.68	3394.31

Material Boundary

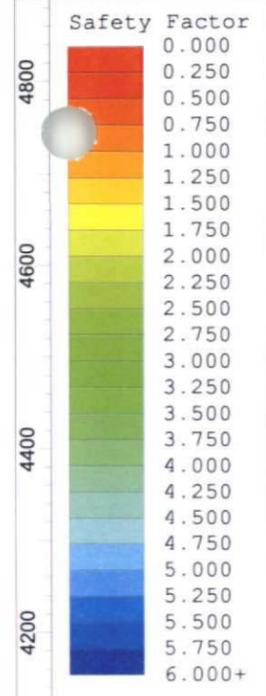
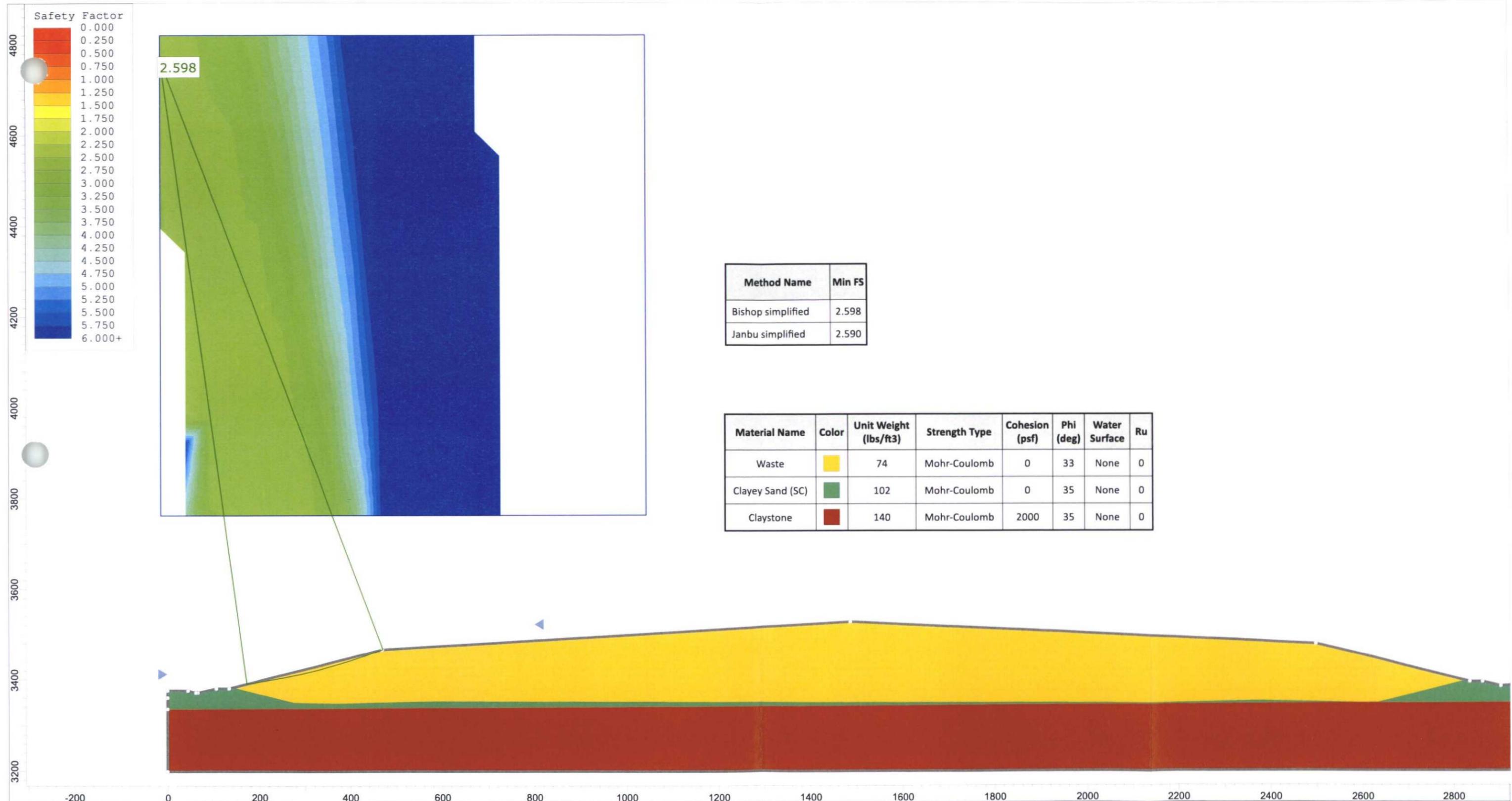
X	Y
594.53	3353.96
594.61	3352.96

Material Boundary

X	Y
2150.44	3348.83
2150.52	3347.83

Material Boundary

X	Y
0	3336
3000	3349

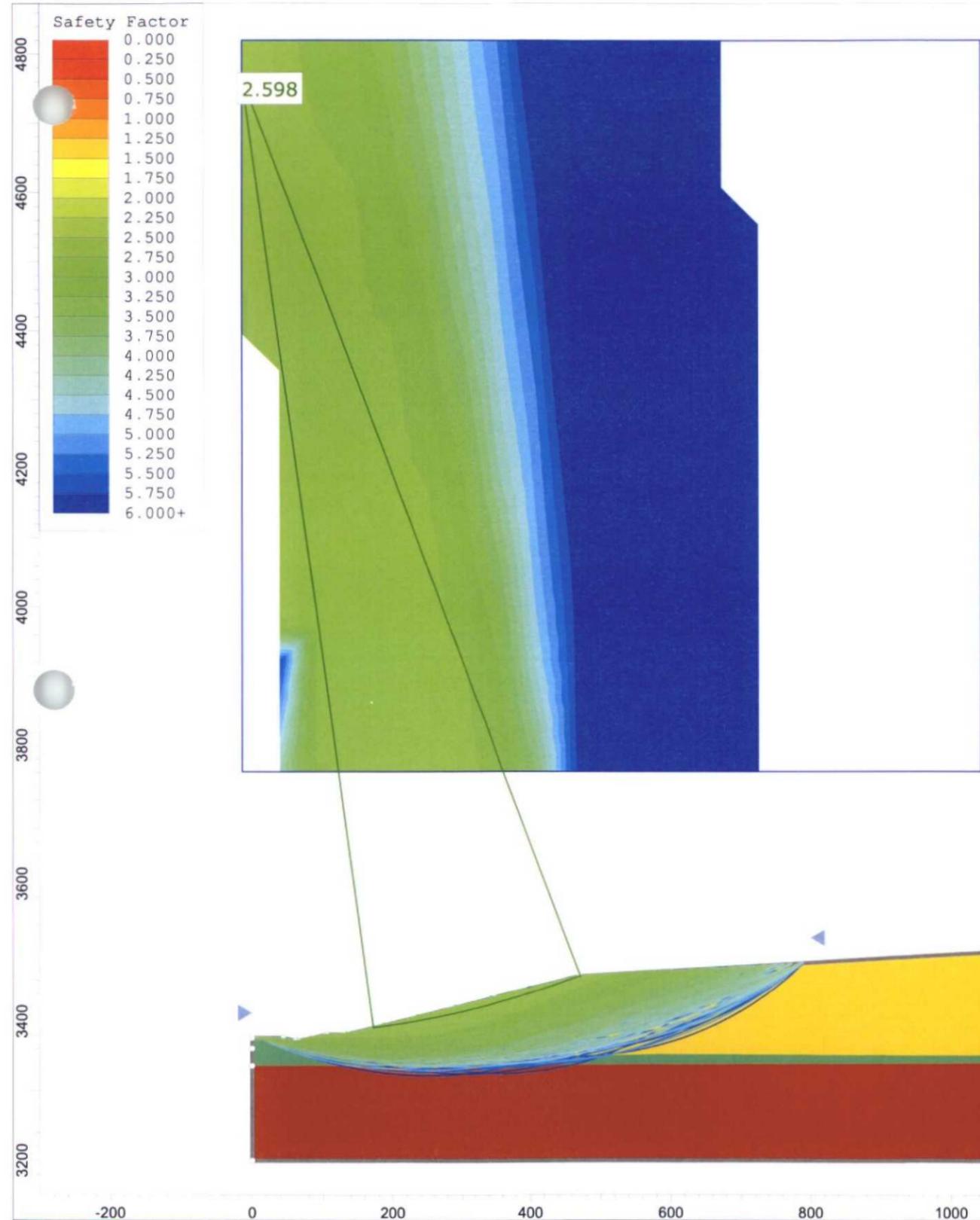


Method Name	Min FS
Bishop simplified	2.598
Janbu simplified	2.590

Material Name	Color	Unit Weight (lbs/ft ³)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project				CK Disposal Facility, West Slope			
Analysis Description				Final Cover			
Drawn By		Scale		Company		Parkhill, Smith & Cooper Inc.	
Date		4/19/2016, 5:02:51 PM		File Name		WEST SLOPE STATIC.slim	



Method Name	Min FS
Bishop simplified	2.598
Janbu simplified	2.590

Material Name	Color	Unit Weight (lbs/ft ³)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project				CK Disposal Facility, West Slope			
Analysis Description				Final Cover			
Drawn By		Scale		Company		Parkhill, Smith & Cooper Inc.	
		1:2375					
Date				File Name		WEST SLOPE STATIC.slim	
4/19/2016, 5:02:51 PM							

Slide Analysis Information

CK Disposal Facility, West Slope

Project Summary

File Name: WEST SLOPE STATIC
 Slide Modeler Version: 7.014
 Project Title: CK Disposal Facility, West Slope
 Analysis: Final Cover
 Company: Parkhill, Smith & Cooper Inc.
 Date Created: 4/19/2016, 5:02:51 PM

General Settings

Units of Measurement: Imperial Units
 Time Units: days
 Permeability Units: feet/second
 Failure Direction: Right to Left
 Data Output: Standard
 Maximum Material Properties: 20
 Maximum Support Properties: 20

Analysis Options

Slices Type: Vertical

Analysis Methods Used

Bishop simplified
 Janbu simplified

Number of slices: 50
 Tolerance: 0.005
 Maximum number of iterations: 75
 Check $\alpha < 0.2$: Yes
 Create Interslice boundaries at intersections with water tables and piezos: Yes
 Initial trial value of FS: 1
 Steffensen Iteration: Yes

Groundwater Analysis

Groundwater Method: Water Surfaces
 Pore Fluid Unit Weight [lbs/ft³]: 62.4
 Advanced Groundwater Method: None

Random Numbers

Pseudo-random Seed: 10116
 Random Number Generation Method: Park and Miller v.3

Surface Options

Surface Type: Circular
 Search Method: Grid Search
 Radius Increment: 5
 Composite Surfaces: Disabled
 Reverse Curvature: Invalid Surfaces
 Minimum Elevation: Not Defined
 Minimum Depth: Not Defined
 Minimum Area: Not Defined
 Minimum Weight: Not Defined

Seismic

Advanced seismic analysis: No
 Staged pseudostatic analysis: Yes
 Staged pseudostatic method: Effective Stress

Material Properties



Property	Waste	Clayey Sand (SC)	Claystone
Color			
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft ³]	74	102	140
Cohesion [psf]	0	0	2000
Friction Angle [deg]	33	35	35
Water Surface	None	None	None
Ru Value	0	0	0

Global Minimums

Method: bishop simplified

FS	2.597510
Center:	-13.434, 4766.460
Radius:	1387.612
Left Slip Surface Endpoint:	172.744, 3391.395
Right Slip Surface Endpoint:	471.742, 3466.433
Resisting Moment:	1.33558e+008 lb-ft
Driving Moment:	5.14179e+007 lb-ft
Total Slice Area:	1814.38 ft ²
Surface Horizontal Width:	298.998 ft
Surface Average Height:	6.06821 ft

Method: janbu simplified

FS	2.589740
Center:	-13.434, 4713.609
Radius:	1336.888
Left Slip Surface Endpoint:	158.650, 3387.842
Right Slip Surface Endpoint:	463.490, 3464.684
Resisting Horizontal Force:	99219 lb
Driving Horizontal Force:	38312.4 lb
Total Slice Area:	1944.05 ft ²
Surface Horizontal Width:	304.84 ft
Surface Average Height:	6.37728 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 1761
 Number of Invalid Surfaces: 885

Error Codes:

Error Code -102 reported for 9 surfaces
 Error Code -106 reported for 47 surfaces
 Error Code -107 reported for 1 surface
 Error Code -1000 reported for 828 surfaces

Method: janbu simplified

Number of Valid Surfaces: 1761
 Number of Invalid Surfaces: 885

Error Codes:

Error Code -102 reported for 9 surfaces
 Error Code -106 reported for 47 surfaces
 Error Code -107 reported for 1 surface
 Error Code -1000 reported for 828 surfaces

Error Codes

The following errors were encountered during the computation:

- 102 = Two surface / slope intersections, but resulting arc is actually outside soil region.
- 106 = Average slice width is less than 0.0001 * (maximum horizontal extent of soil region). This limitation is imposed to avoid numerical errors which may result from too many slices, or too small a slip region.
- 107 = Total driving moment or total driving force is negative. This will occur if the wrong failure direction is specified, or if high external or anchor loads are applied against the failure direction.
- 1000 = No valid slip surfaces are generated at a grid center. Unable to draw a surface.

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.59751



Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	6.89156	276.425	7.85437	Clayey Sand (SC)	27.0793	0	10.4251	27.0793	38.6725	0	38.6725
2	6.89156	816.889	8.14172	Clayey Sand (SC)	79.9182	0	30.7672	79.9182	114.133	0	114.133
3	6.89156	1332.55	8.42929	Clayey Sand (SC)	130.194	0	50.1226	130.194	185.931	0	185.931
4	5.93104	1492.46	8.69699	Waste	157.397	0	60.5953	157.397	242.366	0	242.366
5	5.93104	1744.86	8.94482	Waste	183.82	0	70.7678	183.82	283.052	0	283.052
6	5.93104	1985.71	9.19282	Waste	208.971	0	80.4505	208.971	321.78	0	321.78
7	5.93104	2215	9.44099	Waste	232.852	0	89.6443	232.852	358.553	0	358.553
8	5.93104	2432.7	9.68935	Waste	255.464	0	98.3496	255.464	393.372	0	393.372
9	5.93104	2638.79	9.93788	Waste	276.809	0	106.567	276.809	426.239	0	426.239
10	5.93104	2833.23	10.1866	Waste	296.888	0	114.297	296.888	457.157	0	457.157
11	5.93104	3016	10.4355	Waste	315.701	0	121.54	315.701	486.125	0	486.125
12	5.93104	3187.07	10.6846	Waste	333.25	0	128.296	333.25	513.148	0	513.148
13	5.93104	3346.41	10.934	Waste	349.535	0	134.565	349.535	538.224	0	538.224
14	5.93104	3494.01	11.1835	Waste	364.559	0	140.349	364.559	561.358	0	561.358
15	5.93104	3629.81	11.4332	Waste	378.32	0	145.647	378.32	582.547	0	582.547
16	5.93104	3753.8	11.6832	Waste	390.82	0	150.459	390.82	601.795	0	601.795
17	5.93104	3865.94	11.9334	Waste	402.06	0	154.787	402.06	619.103	0	619.103
18	5.93104	3966.2	12.1838	Waste	412.041	0	158.629	412.041	634.47	0	634.47
19	5.93104	4054.55	12.4345	Waste	420.762	0	161.987	420.762	647.899	0	647.899
20	5.93104	4130.95	12.6854	Waste	428.224	0	164.859	428.224	659.389	0	659.389
21	5.93104	4195.37	12.9365	Waste	434.428	0	167.248	434.428	668.941	0	668.941
22	5.93104	4247.77	13.188	Waste	439.373	0	169.152	439.373	676.555	0	676.555
23	5.93104	4288.11	13.4396	Waste	443.061	0	170.571	443.061	682.235	0	682.235
24	5.93104	4316.36	13.6915	Waste	445.491	0	171.507	445.491	685.975	0	685.975
25	5.93104	4332.48	13.9437	Waste	446.664	0	171.959	446.664	687.781	0	687.781
26	5.93104	4336.43	14.1962	Waste	446.579	0	171.926	446.579	687.65	0	687.65
27	5.93104	4328.16	14.449	Waste	445.236	0	171.409	445.236	685.581	0	685.581
28	5.93104	4307.64	14.702	Waste	442.635	0	170.407	442.635	681.576	0	681.576
29	5.93104	4274.83	14.9553	Waste	438.777	0	168.922	438.777	675.635	0	675.635
30	5.93104	4229.68	15.209	Waste	433.66	0	166.952	433.66	667.755	0	667.755
31	5.93104	4172.15	15.4629	Waste	427.285	0	164.498	427.285	657.938	0	657.938
32	5.93104	4102.19	15.7172	Waste	419.651	0	161.559	419.651	646.183	0	646.183
33	5.93104	4019.75	15.9717	Waste	410.757	0	158.135	410.757	632.487	0	632.487
34	5.93104	3924.79	16.2266	Waste	400.604	0	154.226	400.604	616.853	0	616.853
35	5.93104	3817.27	16.4819	Waste	389.19	0	149.832	389.19	599.278	0	599.278
36	5.93104	3697.12	16.7374	Waste	376.515	0	144.952	376.515	579.76	0	579.76
37	5.93104	3564.3	16.9933	Waste	362.578	0	139.587	362.578	558.299	0	558.299
38	5.93104	3418.77	17.2496	Waste	347.378	0	133.735	347.378	534.894	0	534.894
39	5.93104	3260.46	17.5062	Waste	330.915	0	127.397	330.915	509.545	0	509.545
40	5.93104	3089.32	17.7632	Waste	313.187	0	120.572	313.187	482.247	0	482.247
41	5.93104	2905.3	18.0205	Waste	294.194	0	113.26	294.194	453.001	0	453.001
42	5.93104	2708.34	18.2782	Waste	273.934	0	105.46	273.934	421.804	0	421.804
43	5.93104	2498.38	18.5363	Waste	252.407	0	97.1727	252.407	388.656	0	388.656
44	5.93104	2275.37	18.7948	Waste	229.61	0	88.3962	229.61	353.554	0	353.554
45	5.93104	2039.24	19.0537	Waste	205.543	0	79.1308	205.543	316.495	0	316.495
46	5.93104	1789.94	19.313	Waste	180.205	0	69.3761	180.205	277.48	0	277.48
47	5.93104	1527.4	19.5727	Waste	153.594	0	59.1312	153.594	236.503	0	236.503
48	5.78585	1173.42	19.8297	Clayey Sand (SC)	129.432	0	49.8293	129.432	184.84	0	184.84
49	5.78585	794.249	20.0838	Clayey Sand (SC)	87.5006	0	33.6863	87.5006	124.958	0	124.958
50	5.78585	368.807	20.3384	Clayey Sand (SC)	40.5804	0	15.6228	40.5804	57.9519	0	57.9519

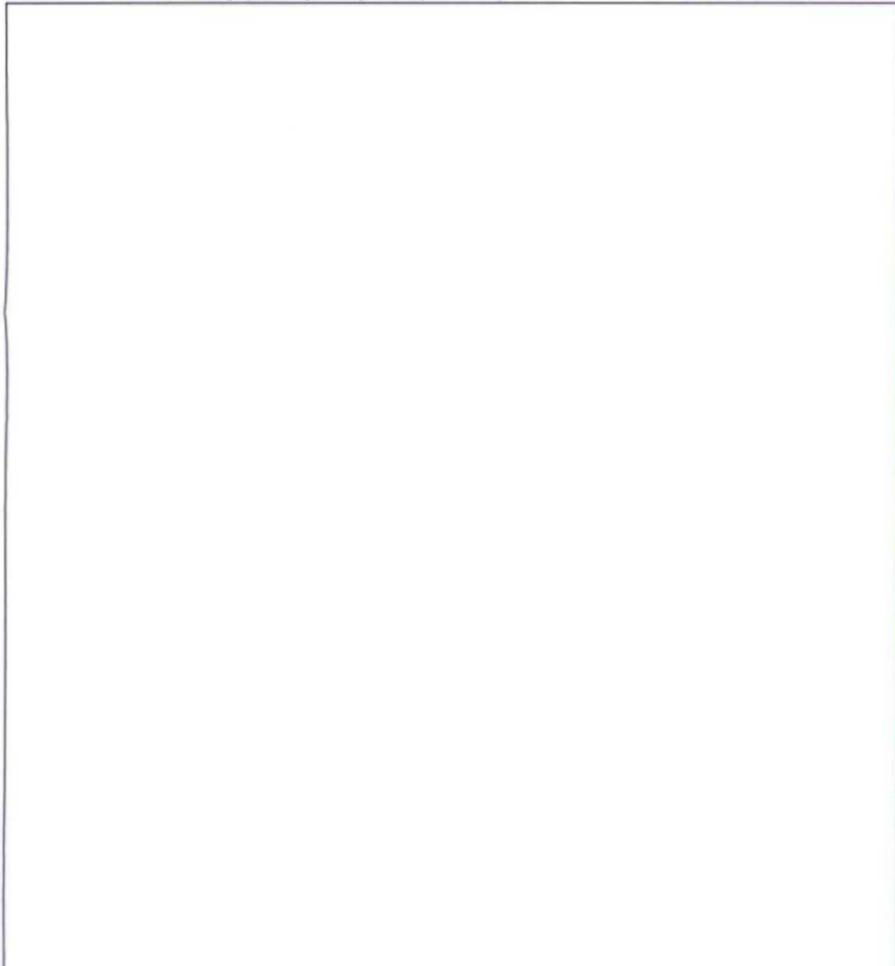
Global Minimum Query (janbu simplified) - Safety Factor: 2.58974



Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	6.5392	261.182	7.53699	Clayey Sand (SC)	27.001	0	10.4261	27.001	38.5604	0	38.5604
2	6.5392	772.586	7.81978	Clayey Sand (SC)	79.7654	0	30.8005	79.7654	113.914	0	113.914
3	6.5392	1262.05	8.10277	Clayey Sand (SC)	130.129	0	50.2479	130.129	185.839	0	185.839
4	6.05072	1531.26	8.37536	Waste	158.495	0	61.2011	158.495	244.054	0	244.054
5	6.05072	1809.16	8.63757	Waste	187.048	0	72.2266	187.048	288.02	0	288.02
6	6.05072	2074.38	8.89995	Waste	214.225	0	82.7207	214.225	329.868	0	329.868
7	6.05072	2326.87	9.16253	Waste	240.029	0	92.6846	240.029	369.6	0	369.6
8	6.05072	2566.63	9.4253	Waste	264.46	0	102.118	264.46	407.22	0	407.22
9	6.05072	2793.61	9.68827	Waste	287.521	0	111.023	287.521	442.73	0	442.73
10	6.05072	3007.79	9.95144	Waste	309.213	0	119.399	309.213	476.131	0	476.131
11	6.05072	3209.13	10.2148	Waste	329.537	0	127.247	329.537	507.424	0	507.424
12	6.05072	3397.62	10.4784	Waste	348.494	0	134.567	348.494	536.615	0	536.615
13	6.05072	3573.2	10.7423	Waste	366.086	0	141.36	366.086	563.702	0	563.702
14	6.05072	3735.86	11.0063	Waste	382.313	0	147.626	382.313	588.688	0	588.688
15	6.05072	3885.55	11.2706	Waste	397.177	0	153.366	397.177	611.576	0	611.576
16	6.05072	4022.24	11.5352	Waste	410.678	0	158.579	410.678	632.364	0	632.364
17	6.05072	4145.89	11.8	Waste	422.817	0	163.266	422.817	651.056	0	651.056
18	6.05072	4256.48	12.065	Waste	433.596	0	167.428	433.596	667.652	0	667.652
19	6.05072	4353.95	12.3303	Waste	443.013	0	171.065	443.013	682.153	0	682.153
20	6.05072	4438.26	12.5959	Waste	451.071	0	174.176	451.071	694.559	0	694.559
21	6.05072	4509.39	12.8618	Waste	457.77	0	176.763	457.77	704.873	0	704.873
22	6.05072	4567.28	13.1279	Waste	463.11	0	178.825	463.11	713.094	0	713.094
23	6.05072	4611.9	13.3943	Waste	467.091	0	180.362	467.091	719.223	0	719.223
24	6.05072	4643.2	13.661	Waste	469.713	0	181.375	469.713	723.262	0	723.262
25	6.05072	4661.13	13.9281	Waste	470.977	0	181.863	470.977	725.206	0	725.206
26	6.05072	4665.65	14.1954	Waste	470.883	0	181.826	470.883	725.061	0	725.061
27	6.05072	4656.72	14.463	Waste	469.43	0	181.265	469.43	722.823	0	722.823
28	6.05072	4634.28	14.731	Waste	466.619	0	180.18	466.619	718.494	0	718.494
29	6.05072	4598.28	14.9993	Waste	462.449	0	178.57	462.449	712.074	0	712.074
30	6.05072	4548.68	15.2679	Waste	456.921	0	176.435	456.921	703.56	0	703.56
31	6.05072	4485.42	15.5369	Waste	450.033	0	173.775	450.033	692.953	0	692.953
32	6.05072	4408.45	15.8062	Waste	441.785	0	170.59	441.785	680.252	0	680.252
33	6.05072	4317.71	16.0759	Waste	432.177	0	166.88	432.177	665.456	0	665.456
34	6.05072	4213.15	16.346	Waste	421.207	0	162.645	421.207	648.566	0	648.566
35	6.05072	4094.72	16.6164	Waste	408.877	0	157.883	408.877	629.58	0	629.58
36	6.05072	3962.35	16.8872	Waste	395.184	0	152.596	395.184	608.495	0	608.495
37	6.05072	3815.98	17.1584	Waste	380.127	0	146.782	380.127	585.31	0	585.31
38	6.05072	3655.56	17.43	Waste	363.706	0	140.441	363.706	560.025	0	560.025
39	6.05072	3481.01	17.702	Waste	345.92	0	133.573	345.92	532.639	0	532.639
40	6.05072	3292.29	17.9745	Waste	326.768	0	126.178	326.768	503.147	0	503.147
41	6.05072	3089.32	18.2473	Waste	306.248	0	118.254	306.248	471.552	0	471.552
42	6.05072	2872.03	18.5206	Waste	284.359	0	109.802	284.359	437.847	0	437.847
43	6.05072	2640.36	18.7943	Waste	261.1	0	100.821	261.1	402.032	0	402.032
44	6.05072	2394.23	19.0684	Waste	236.469	0	91.3099	236.469	364.107	0	364.107
45	6.05072	2133.58	19.343	Waste	210.465	0	81.2688	210.465	324.065	0	324.065
46	6.05072	1858.34	19.6181	Waste	183.085	0	70.6963	183.085	281.907	0	281.907
47	6.05072	1568.42	19.8936	Waste	154.329	0	59.5925	154.329	237.63	0	237.63
48	6.33036	1249.59	20.176	Clayey Sand (SC)	125.727	0	48.5481	125.727	179.542	0	179.542
49	6.33036	766.236	20.4653	Clayey Sand (SC)	76.9857	0	29.7272	76.9857	109.939	0	109.939
50	6.33036	259.346	20.7552	Clayey Sand (SC)	26.0203	0	10.0475	26.0203	37.1578	0	37.1578

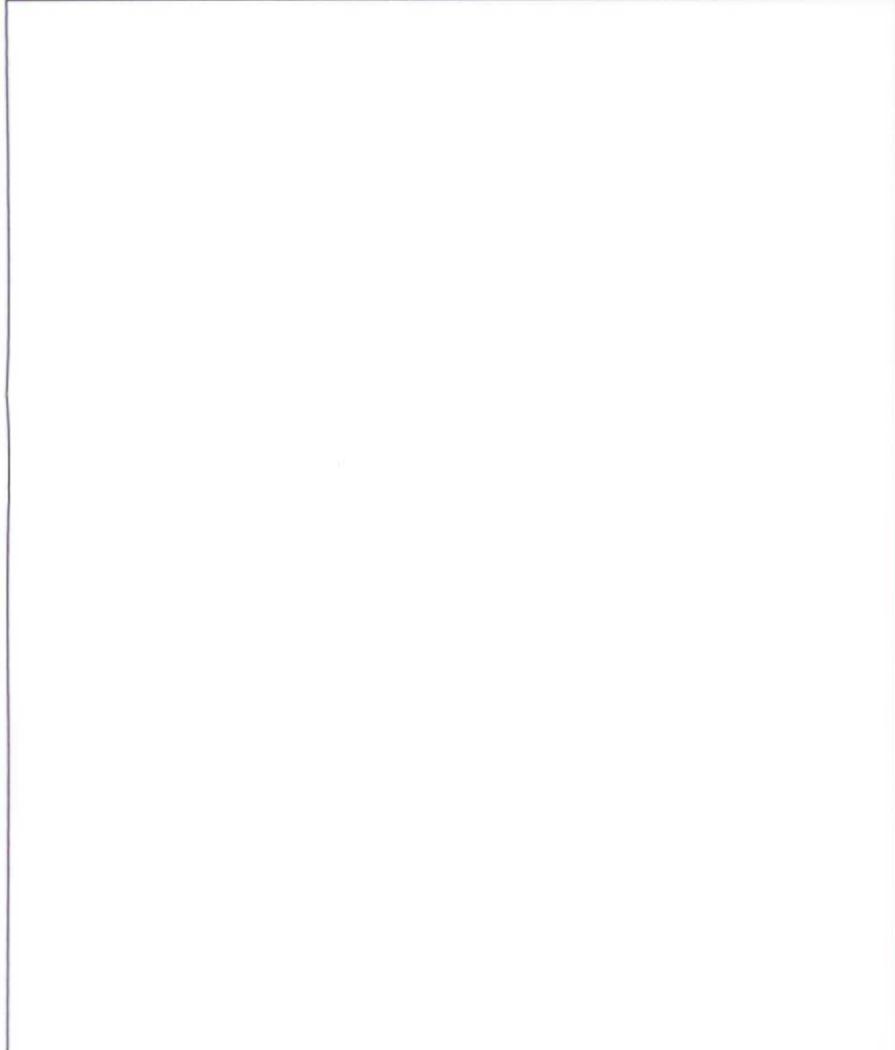
Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.59751



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	172.744	3391.39	0	0	0
2	179.636	3392.35	35.0798	0	0
3	186.528	3393.33	134.587	0	0
4	193.419	3394.35	290.125	0	0
5	199.35	3395.26	429.631	0	0
6	205.281	3396.19	585.119	0	0
7	211.212	3397.15	753.412	0	0
8	217.143	3398.14	931.478	0	0
9	223.074	3399.15	1116.44	0	0
10	229.005	3400.19	1305.55	0	0
11	234.936	3401.26	1496.25	0	0
12	240.867	3402.35	1686.09	0	0
13	246.798	3403.47	1872.79	0	0
14	252.73	3404.61	2054.21	0	0
15	258.661	3405.79	2228.38	0	0
16	264.592	3406.99	2393.46	0	0
17	270.523	3408.21	2547.77	0	0
18	276.454	3409.47	2689.79	0	0
19	282.385	3410.75	2818.13	0	0
20	288.316	3412.05	2931.58	0	0
21	294.247	3413.39	3029.07	0	0
22	300.178	3414.75	3109.68	0	0
23	306.109	3416.14	3172.65	0	0
24	312.04	3417.56	3217.38	0	0
25	317.971	3419	3243.43	0	0
26	323.902	3420.48	3250.5	0	0
27	329.833	3421.98	3238.48	0	0
28	335.764	3423.51	3207.38	0	0
29	341.695	3425.06	3157.4	0	0
30	347.626	3426.65	3088.9	0	0
31	353.557	3428.26	3002.4	0	0
32	359.488	3429.9	2898.57	0	0
33	365.419	3431.57	2778.27	0	0
34	371.35	3433.27	2642.5	0	0
35	377.281	3434.99	2492.46	0	0
36	383.212	3436.75	2329.5	0	0
37	389.143	3438.53	2155.15	0	0
38	395.074	3440.34	1971.1	0	0
39	401.005	3442.18	1779.23	0	0
40	406.937	3444.06	1581.6	0	0
41	412.868	3445.96	1380.42	0	0
42	418.799	3447.88	1178.13	0	0
43	424.73	3449.84	977.299	0	0
44	430.661	3451.83	780.72	0	0
45	436.592	3453.85	591.356	0	0
46	442.523	3455.9	412.362	0	0
47	448.454	3457.98	247.084	0	0
48	454.385	3460.09	99.063	0	0
49	460.171	3462.17	1.71541	0	0
50	465.957	3464.29	-67.7247	0	0
51	471.742	3466.43	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 2.58974



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	158.65	3387.84	0	0	0
2	165.189	3388.71	34.8704	0	0
3	171.729	3389.61	134.14	0	0
4	178.268	3390.54	289.969	0	0
5	184.319	3391.43	443.162	0	0
6	190.369	3392.35	615.798	0	0
7	196.42	3393.29	804.161	0	0
8	202.471	3394.27	1004.71	0	0
9	208.521	3395.27	1214.06	0	0
10	214.572	3396.31	1429.03	0	0
11	220.623	3397.37	1646.58	0	0
12	226.674	3398.46	1863.88	0	0
13	232.724	3399.58	2078.24	0	0
14	238.775	3400.73	2287.16	0	0
15	244.826	3401.9	2488.32	0	0
16	250.876	3403.11	2679.58	0	0
17	256.927	3404.34	2858.95	0	0
18	262.978	3405.61	3024.64	0	0
19	269.029	3406.9	3175.03	0	0
20	275.079	3408.22	3308.69	0	0
21	281.13	3409.58	3424.34	0	0
22	287.181	3410.96	3520.92	0	0
23	293.231	3412.37	3597.51	0	0
24	299.282	3413.81	3653.4	0	0
25	305.333	3415.28	3688.06	0	0
26	311.384	3416.78	3701.12	0	0
27	317.434	3418.31	3692.44	0	0
28	323.485	3419.87	3662.01	0	0
29	329.536	3421.46	3610.06	0	0
30	335.586	3423.08	3536.98	0	0
31	341.637	3424.74	3443.35	0	0
32	347.688	3426.42	3329.95	0	0
33	353.739	3428.13	3197.77	0	0
34	359.789	3429.87	3047.96	0	0
35	365.84	3431.65	2881.89	0	0
36	371.891	3433.45	2701.14	0	0
37	377.942	3435.29	2507.45	0	0
38	383.992	3437.16	2302.82	0	0
39	390.043	3439.06	2089.4	0	0
40	396.094	3440.99	1869.59	0	0
41	402.144	3442.95	1645.98	0	0
42	408.195	3444.95	1421.37	0	0
43	414.246	3446.98	1198.78	0	0
44	420.297	3449.03	981.454	0	0
45	426.347	3451.13	772.85	0	0
46	432.398	3453.25	576.648	0	0
47	438.449	3455.41	396.757	0	0
48	444.499	3457.6	237.314	0	0
49	450.83	3459.92	127.247	0	0
50	457.16	3462.29	55.855	0	0
51	463.49	3464.68	0	0	0

List Of Coordinates

External Boundary

X	Y
105.01	3381.21
65	3372.05
61	3372.02
43.9	3376.3
0	3376.3
0	3361
0	3336
0	3200
3000	3200
3000	3349
3000	3374
3000	3389.22
2962.33	3389.22
2902.33	3384.3
2862.33	3393.92
2834.14	3394.23
2497.32	3477.69
1486.5	3527.15
470.02	3466.33
133.49	3381.5

Material Boundary

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X	Y
133.49	3381.5
142.75	3381.59
149.94	3381.66
232.606	3361
275.18	3350.36
372.35	3348.37
594.61	3352.96
2150.52	3347.83
2372.79	3352.2
2595.06	3347.69
2633	3348.48
2735.51	3374
2817.33	3394.37
2824.68	3394.31
2834.14	3394.23

Material Boundary

X	Y
142.75	3381.59
142.75	3381.59
146.998	3382.66
468.81	3463.72
1486.54	3524.64
2498.75	3475.1
2820.46	3395.36
2824.68	3394.31

Material Boundary

X	Y
594.53	3353.96
594.61	3352.96

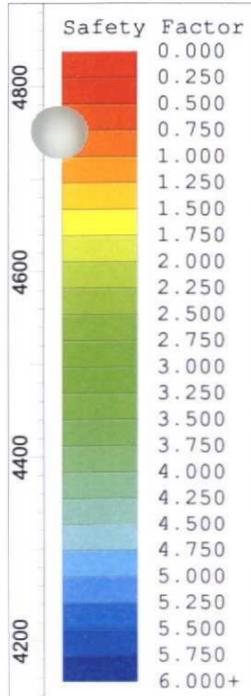
Material Boundary

X	Y
2150.44	3348.83
2150.52	3347.83

Material Boundary

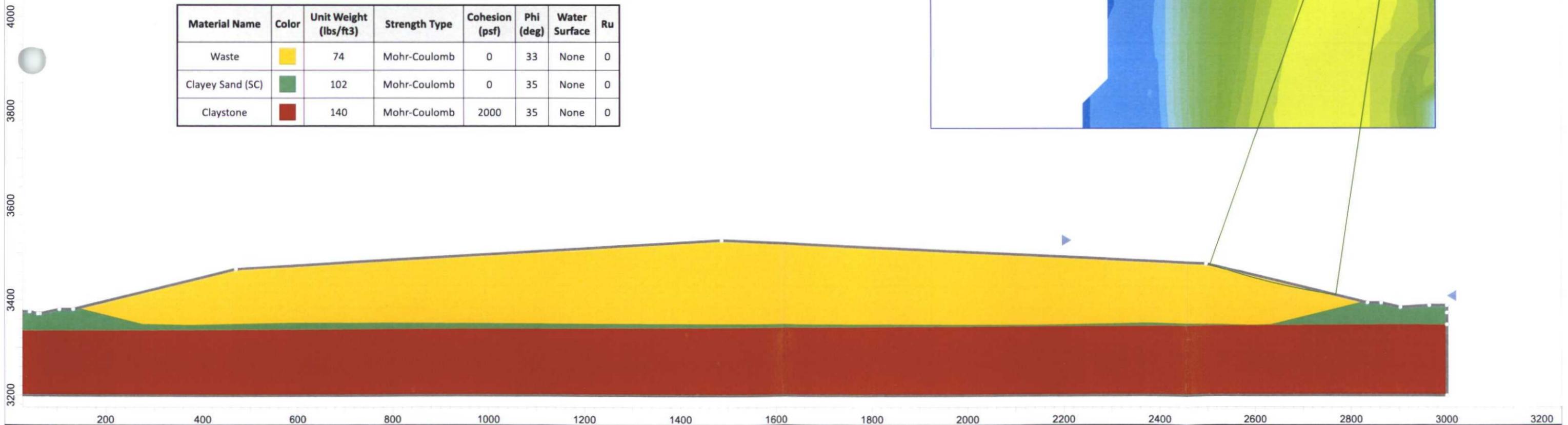
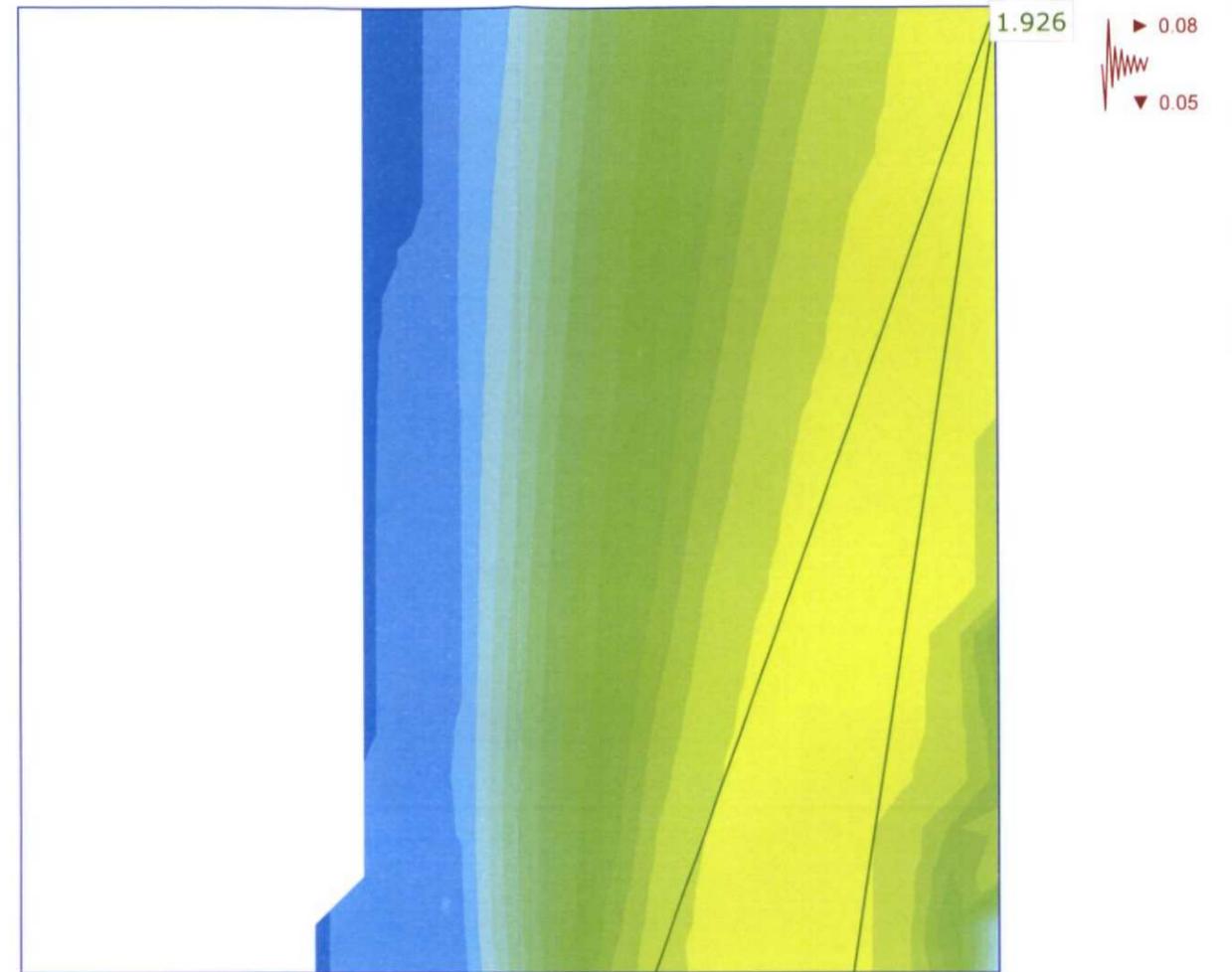
X	Y
0	3336
3000	3349

APPENDIX B
PSEUDO - STATIC MODEL INPUTS AND OUTPUTS

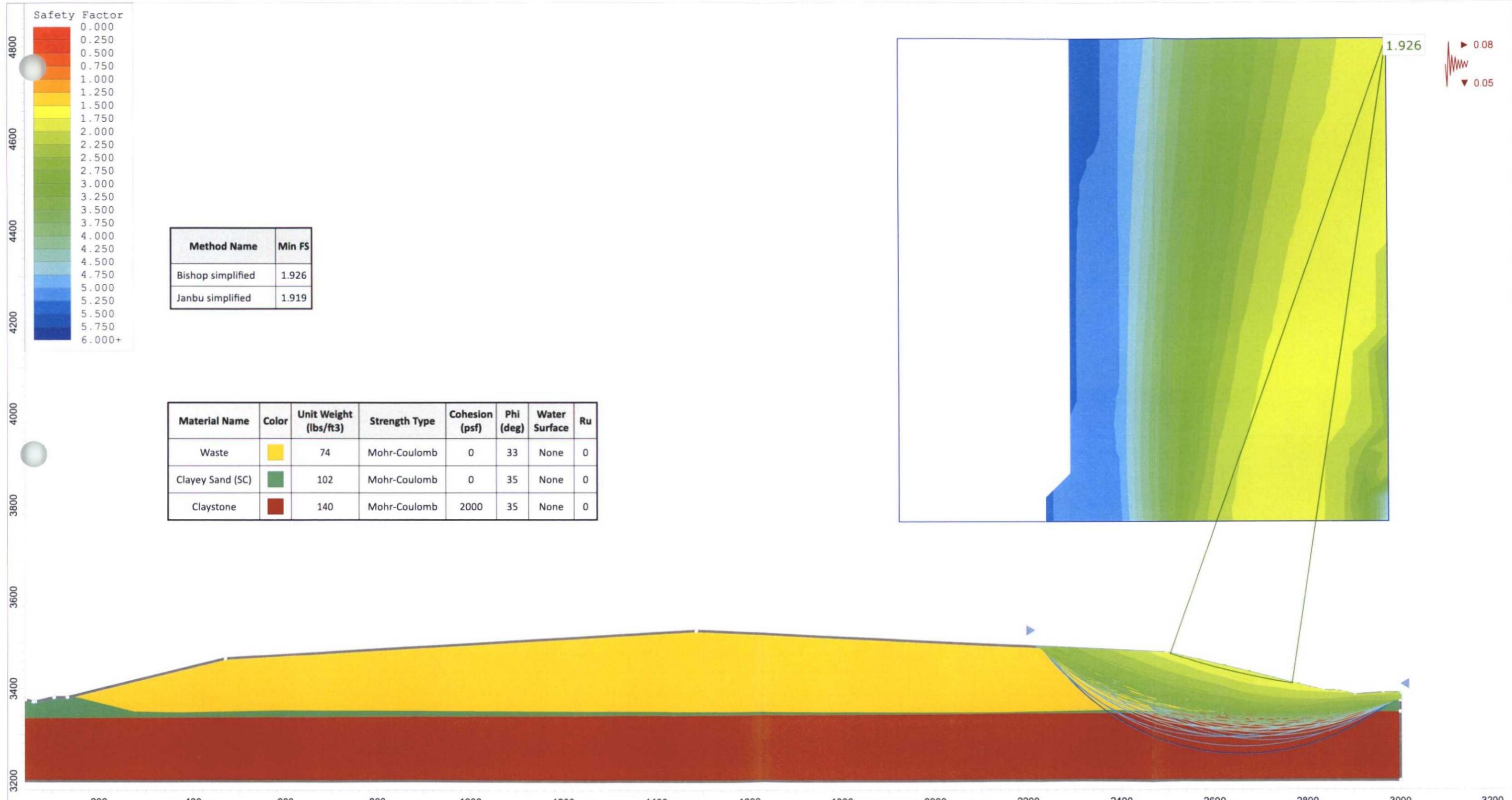


Method Name	Min FS
Bishop simplified	1.926
Janbu simplified	1.919

Material Name	Color	Unit Weight (lbs/ft ³)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project				CK Disposal Facility, East Slope			
Analysis Description				Final Cover			
Drawn By		Scale		Company		Parkhill, Smith & Cooper Inc.	
Date		4/19/2016, 5:02:51 PM		File Name		EAST SLOPE SEISMIC.slim	



Method Name	Min FS
Bishop simplified	1.926
Janbu simplified	1.919

Material Name	Color	Unit Weight (lbs/ft ³)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project		CK Disposal Facility, East Slope	
Analysis Description		Final Cover	
Drawn By	Scale	Company	Parkhill, Smith & Cooper Inc.
Date	4/19/2016, 5:02:51 PM	File Name	EAST SLOPE SEISMIC.slim

Slide Analysis Information

CK Disposal Facility, East Slope

Project Summary

File Name: EAST SLOPE SEISMIC
 Slide Modeler Version: 7.014
 Project Title: CK Disposal Facility, East Slope
 Analysis: Final Cover
 Company: Parkhill, Smith & Cooper Inc.
 Date Created: 4/19/2016, 5:02:51 PM

General Settings

Units of Measurement: Imperial Units
 Time Units: days
 Permeability Units: feet/second
 Failure Direction: Left to Right
 Data Output: Standard
 Maximum Material Properties: 20
 Maximum Support Properties: 20

Analysis Options

Slices Type: Vertical

Analysis Methods Used

Bishop simplified
 Janbu simplified

Number of slices: 50
 Tolerance: 0.005
 Maximum number of iterations: 75
 Check $\alpha < 0.2$: Yes
 Create Interslice boundaries at intersections with water tables and piezos: Yes
 Initial trial value of FS: 1
 Steffensen Iteration: Yes

Groundwater Analysis

Groundwater Method: Water Surfaces
 Pore Fluid Unit Weight [lbs/ft³]: 62.4
 Advanced Groundwater Method: None

Random Numbers

Pseudo-random Seed: 10116
 Random Number Generation Method: Park and Miller v.3

Surface Options

Surface Type: Circular
 Search Method: Grid Search
 Radius Increment: 5
 Composite Surfaces: Disabled
 Reverse Curvature: Invalid Surfaces
 Minimum Elevation: Not Defined
 Minimum Depth: Not Defined
 Minimum Area: Not Defined
 Minimum Weight: Not Defined

Seismic

Advanced seismic analysis: No
 Staged pseudostatic analysis: Yes
 Staged pseudostatic method: Effective Stress

Loading

Seismic Load Coefficient (Horizontal): 0.08
 Seismic Load Coefficient (Vertical): 0.05

Material Properties

Property	Waste	Clayey Sand (SC)	Claystone
Color			
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft ³]	74	102	140
Cohesion [psf]	0	0	2000
Friction Angle [deg]	33	35	35
Water Surface	None	None	None
Ru Value	0	0	0

Global Minimums

Method: bishop simplified

FS	1.925620
Center:	2976.733, 4816.811
Radius:	1421.530
Left Slip Surface Endpoint:	2505.464, 3475.672
Right Slip Surface Endpoint:	2767.289, 3410.795
Resisting Moment:	9.04137e+007 lb-ft
Driving Moment:	4.6953e+007 lb-ft
Total Slice Area:	1153.23 ft ²
Surface Horizontal Width:	261.825 ft
Surface Average Height:	4.40459 ft

Method: janbu simplified

FS	1.919220
Center:	2976.733, 4711.511
Radius:	1323.079
Left Slip Surface Endpoint:	2502.035, 3476.522
Right Slip Surface Endpoint:	2819.884, 3397.762
Resisting Horizontal Force:	112374 lb
Driving Horizontal Force:	58552 lb
Total Slice Area:	2221 ft ²
Surface Horizontal Width:	317.85 ft
Surface Average Height:	6.98758 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 1741
 Number of Invalid Surfaces: 905

Error Codes:

Error Code -102 reported for 6 surfaces
 Error Code -106 reported for 35 surfaces
 Error Code -107 reported for 12 surfaces
 Error Code -1000 reported for 852 surfaces

Method: janbu simplified

Number of Valid Surfaces: 1741
 Number of Invalid Surfaces: 905

Error Codes:

Error Code -102 reported for 6 surfaces
 Error Code -106 reported for 35 surfaces
 Error Code -107 reported for 12 surfaces
 Error Code -1000 reported for 852 surfaces

Error Codes

The following errors were encountered during the computation:

- 102 = Two surface / slope intersections, but resulting arc is actually outside soil region.
- 106 = Average slice width is less than 0.0001 * (maximum horizontal extent of soil region). This limitation is imposed to avoid numerical errors which may result from too many slices, or too small a slip region.
- 107 = Total driving moment or total driving force is negative. This will occur if the wrong failure direction is specified, or if high external or anchor loads are applied against the failure direction.
- 1000 = No valid slip surfaces are generated at a grid center. Unable to draw a surface.

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.92562

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	4.77986	118.392	-19.2592	Clayey Sand (SC)	15.875	0	8.2441	15.875	23.127	0	23.127
2	4.77986	350.528	-19.0552	Clayey Sand (SC)	47.0472	0	24.4322	47.0472	68.5621	0	68.5621
3	4.77986	573.385	-18.8515	Clayey Sand (SC)	77.0329	0	40.0042	77.0329	112.298	0	112.298
4	4.77986	786.997	-18.648	Clayey Sand (SC)	105.833	0	54.9605	105.833	154.333	0	154.333
5	4.77986	991.396	-18.4448	Clayey Sand (SC)	133.448	0	69.3013	133.448	194.668	0	194.668
6	5.31874	1299.76	-18.2304	Waste	146.824	0	76.2477	146.824	231.479	0	231.479
7	5.31874	1466.05	-18.0049	Waste	165.773	0	86.0881	165.773	261.441	0	261.441
8	5.31874	1623.24	-17.7796	Waste	183.729	0	95.4129	183.729	289.857	0	289.857
9	5.31874	1771.36	-17.5546	Waste	200.691	0	104.221	200.691	316.723	0	316.723
10	5.31874	1910.44	-17.3299	Waste	216.661	0	112.515	216.661	342.041	0	342.041
11	5.31874	2040.51	-17.1055	Waste	231.64	0	120.294	231.64	365.808	0	365.808
12	5.31874	2161.62	-16.8813	Waste	245.627	0	127.557	245.627	388.026	0	388.026
13	5.31874	2273.79	-16.6574	Waste	258.625	0	134.307	258.625	408.693	0	408.693
14	5.31874	2377.04	-16.4338	Waste	270.633	0	140.543	270.633	427.81	0	427.81
15	5.31874	2471.42	-16.2104	Waste	281.651	0	146.265	281.651	445.373	0	445.373
16	5.31874	2556.96	-15.9873	Waste	291.681	0	151.474	291.681	461.385	0	461.385
17	5.31874	2633.68	-15.7644	Waste	300.722	0	156.169	300.722	475.841	0	475.841
18	5.31874	2701.61	-15.5418	Waste	308.776	0	160.351	308.776	488.742	0	488.742
19	5.31874	2760.78	-15.3194	Waste	315.842	0	164.021	315.842	500.09	0	500.09
20	5.31874	2811.22	-15.0972	Waste	321.921	0	167.178	321.921	509.879	0	509.879
21	5.31874	2852.96	-14.8753	Waste	327.014	0	169.823	327.014	518.11	0	518.11
22	5.31874	2886.02	-14.6536	Waste	331.119	0	171.954	331.119	524.782	0	524.782
23	5.31874	2910.44	-14.4321	Waste	334.238	0	173.574	334.238	529.893	0	529.893
24	5.31874	2926.22	-14.2109	Waste	336.371	0	174.682	336.371	533.445	0	533.445
25	5.31874	2933.42	-13.9898	Waste	337.518	0	175.278	337.518	535.432	0	535.432
26	5.31874	2932.03	-13.769	Waste	337.678	0	175.361	337.678	535.855	0	535.855
27	5.31874	2922.1	-13.5484	Waste	336.853	0	174.932	336.853	534.713	0	534.713
28	5.31874	2903.65	-13.328	Waste	335.041	0	173.991	335.041	532.005	0	532.005
29	5.31874	2876.69	-13.1078	Waste	332.243	0	172.538	332.243	527.727	0	527.727
30	5.31874	2841.26	-12.8878	Waste	328.459	0	170.573	328.459	521.879	0	521.879
31	5.31874	2797.37	-12.6679	Waste	323.689	0	168.096	323.689	514.46	0	514.46
32	5.31874	2745.04	-12.4483	Waste	317.932	0	165.106	317.932	505.466	0	505.466
33	5.31874	2684.31	-12.2289	Waste	311.189	0	161.605	311.189	494.898	0	494.898
34	5.31874	2615.18	-12.0096	Waste	303.458	0	157.59	303.458	482.752	0	482.752
35	5.31874	2537.68	-11.7905	Waste	294.74	0	153.062	294.74	469.027	0	469.027

36	5.31874	2451.84	-11.5716	Waste	285.035	0	148.022	285.035	453.721	0	453.721
37	5.31874	2357.66	-11.3529	Waste	274.341	0	142.469	274.341	436.833	0	436.833
38	5.31874	2255.17	-11.1343	Waste	262.659	0	136.402	262.659	418.359	0	418.359
39	5.31874	2144.39	-10.9159	Waste	249.988	0	129.822	249.988	398.298	0	398.298
40	5.31874	2025.34	-10.6976	Waste	236.328	0	122.728	236.328	376.647	0	376.647
41	5.31874	1898.03	-10.4796	Waste	221.678	0	115.12	221.678	353.406	0	353.406
42	5.31874	1762.48	-10.2616	Waste	206.037	0	106.998	206.037	328.569	0	328.569
43	5.31874	1618.71	-10.0438	Waste	189.404	0	98.36	189.404	302.137	0	302.137
44	5.31874	1466.74	-9.82619	Waste	171.78	0	89.2076	171.78	274.105	0	274.105
45	5.31874	1306.58	-9.6087	Waste	153.164	0	79.5401	153.164	244.473	0	244.473
46	5.03522	1052.78	-9.39713	Clayey Sand (SC)	140.256	0	72.8368	140.256	207.482	0	207.482
47	5.03522	835.203	-9.19148	Clayey Sand (SC)	111.374	0	57.838	111.374	164.807	0	164.807
48	5.03522	608.108	-8.98595	Clayey Sand (SC)	81.1668	0	42.151	81.1668	120.144	0	120.144
49	5.03522	371.507	-8.78054	Clayey Sand (SC)	49.633	0	25.7751	49.633	73.4895	0	73.4895
50	5.03522	125.416	-8.57524	Clayey Sand (SC)	16.7711	0	8.70945	16.7711	24.8398	0	24.8398

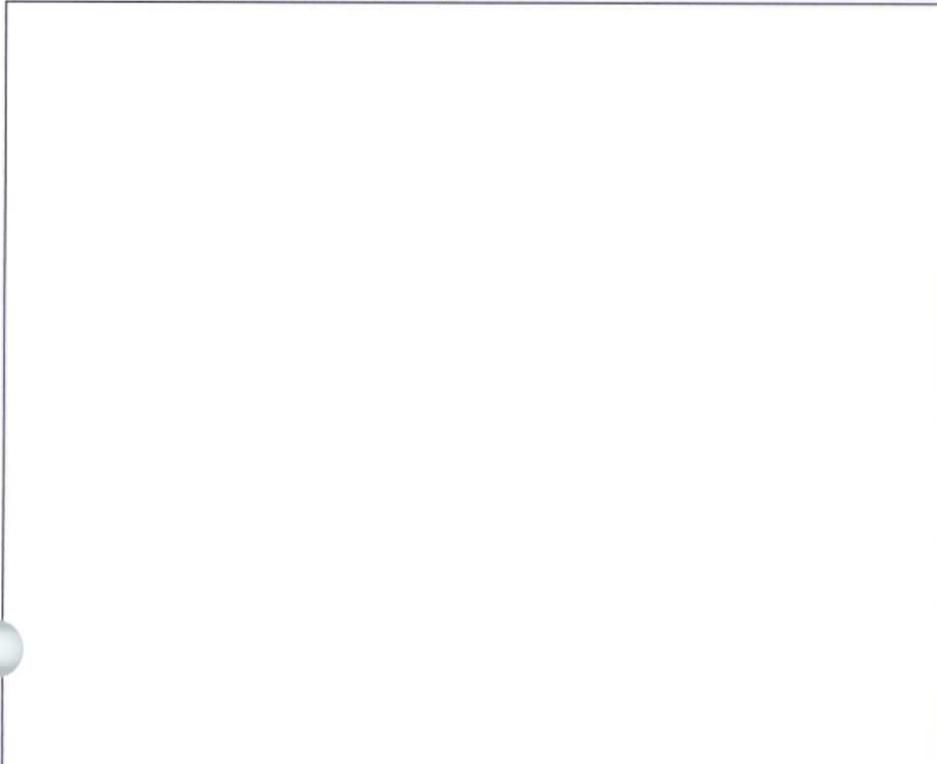
Global Minimum Query (janbu simplified) - Safety Factor: 1.91922

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	5.80225	229.894	-20.891	Clayey Sand (SC)	25.1884	0	13.1243	25.1884	36.5921	0	36.5921
2	5.80225	680.472	-20.6223	Clayey Sand (SC)	74.6527	0	38.8974	74.6527	108.5	0	108.5
3	5.80225	1112.68	-20.3541	Clayey Sand (SC)	122.227	0	63.6858	122.227	177.723	0	177.723
4	6.40397	1640.05	-20.0724	Waste	152.572	0	79.4969	152.572	239.848	0	239.848
5	6.40397	1988.25	-19.7775	Waste	185.209	0	96.5022	185.209	291.287	0	291.287
6	6.40397	2318.82	-19.483	Waste	216.285	0	112.694	216.285	340.316	0	340.316
7	6.40397	2631.86	-19.1891	Waste	245.805	0	128.075	245.805	386.937	0	386.937
8	6.40397	2927.46	-18.8957	Waste	273.769	0	142.646	273.769	431.15	0	431.15
9	6.40397	3205.71	-18.6029	Waste	300.179	0	156.407	300.179	472.954	0	472.954
10	6.40397	3466.71	-18.3105	Waste	325.039	0	169.36	325.039	512.347	0	512.347
11	6.40397	3710.55	-18.0186	Waste	348.348	0	181.505	348.348	549.33	0	549.33
12	6.40397	3937.3	-17.7273	Waste	370.11	0	192.844	370.11	583.903	0	583.903
13	6.40397	4147.05	-17.4363	Waste	390.325	0	203.377	390.325	616.063	0	616.063
14	6.40397	4339.89	-17.1459	Waste	408.996	0	213.105	408.996	645.81	0	645.81
15	6.40397	4515.89	-16.8559	Waste	426.123	0	222.029	426.123	673.142	0	673.142
16	6.40397	4675.14	-16.5663	Waste	441.707	0	230.149	441.707	698.059	0	698.059
17	6.40397	4817.7	-16.2772	Waste	455.751	0	237.467	455.751	720.56	0	720.56
18	6.40397	4943.66	-15.9885	Waste	468.254	0	243.981	468.254	740.641	0	740.641
19	6.40397	5053.08	-15.7002	Waste	479.218	0	249.694	479.218	758.303	0	758.303
20	6.40397	5146.03	-15.4124	Waste	488.643	0	254.605	488.643	773.542	0	773.542
21	6.40397	5222.59	-15.1249	Waste	496.531	0	258.715	496.531	786.357	0	786.357
22	6.40397	5282.83	-14.8378	Waste	502.881	0	262.024	502.881	796.745	0	796.745
23	6.40397	5326.8	-14.5511	Waste	507.695	0	264.532	507.695	804.705	0	804.705
24	6.40397	5354.57	-14.2648	Waste	510.973	0	266.24	510.973	810.233	0	810.233
25	6.40397	5366.21	-13.9788	Waste	512.714	0	267.147	512.714	813.329	0	813.329
26	6.40397	5361.77	-13.6932	Waste	512.919	0	267.254	512.919	813.988	0	813.988

27	6.40397	5341.31	-13.4079	Waste	511.589	0	266.561	511.589	812.207	0	812.207
28	6.40397	5304.89	-13.123	Waste	508.723	0	265.068	508.723	807.985	0	807.985
29	6.40397	5252.57	-12.8384	Waste	504.321	0	262.774	504.321	801.316	0	801.316
30	6.40397	5184.41	-12.5541	Waste	498.382	0	259.679	498.382	792.198	0	792.198
31	6.40397	5100.44	-12.2702	Waste	490.906	0	255.784	490.906	780.629	0	780.629
32	6.40397	5000.74	-11.9865	Waste	481.894	0	251.088	481.894	766.603	0	766.603
33	6.40397	4885.34	-11.7032	Waste	471.343	0	245.591	471.343	750.117	0	750.117
34	6.40397	4754.29	-11.4201	Waste	459.254	0	239.292	459.254	731.169	0	731.169
35	6.40397	4607.65	-11.1373	Waste	445.626	0	232.191	445.626	709.752	0	709.752
36	6.40397	4445.46	-10.8548	Waste	430.457	0	224.287	430.457	685.862	0	685.862
37	6.40397	4267.75	-10.5726	Waste	413.747	0	215.581	413.747	659.496	0	659.496
38	6.40397	4074.59	-10.2906	Waste	395.494	0	206.07	395.494	630.65	0	630.65
39	6.40397	3866	-10.0088	Waste	375.698	0	195.756	375.698	599.317	0	599.317
40	6.40397	3642.04	-9.72736	Waste	354.356	0	184.635	354.356	565.492	0	565.492
41	6.40397	3402.73	-9.4461	Waste	331.468	0	172.71	331.468	529.173	0	529.173
42	6.40397	3148.12	-9.16508	Waste	307.032	0	159.977	307.032	490.351	0	490.351
43	6.40397	2878.24	-8.88428	Waste	281.046	0	146.438	281.046	449.022	0	449.022
44	6.40397	2593.13	-8.6037	Waste	253.508	0	132.089	253.508	405.181	0	405.181
45	6.40397	2292.82	-8.32332	Waste	224.416	0	116.931	224.416	358.823	0	358.823
46	6.40397	1977.35	-8.04314	Waste	193.769	0	100.962	193.769	309.938	0	309.938
47	6.40397	1646.75	-7.76316	Waste	161.564	0	84.1821	161.564	258.523	0	258.523
48	6.22271	1206.06	-7.48732	Clayey Sand (SC)	131.131	0	68.3252	131.131	194.525	0	194.525
49	6.22271	736.949	-7.21561	Clayey Sand (SC)	80.2256	0	41.8011	80.2256	119.057	0	119.057
50	6.22271	248.818	-6.94406	Clayey Sand (SC)	27.1203	0	14.1309	27.1203	40.2632	0	40.2632

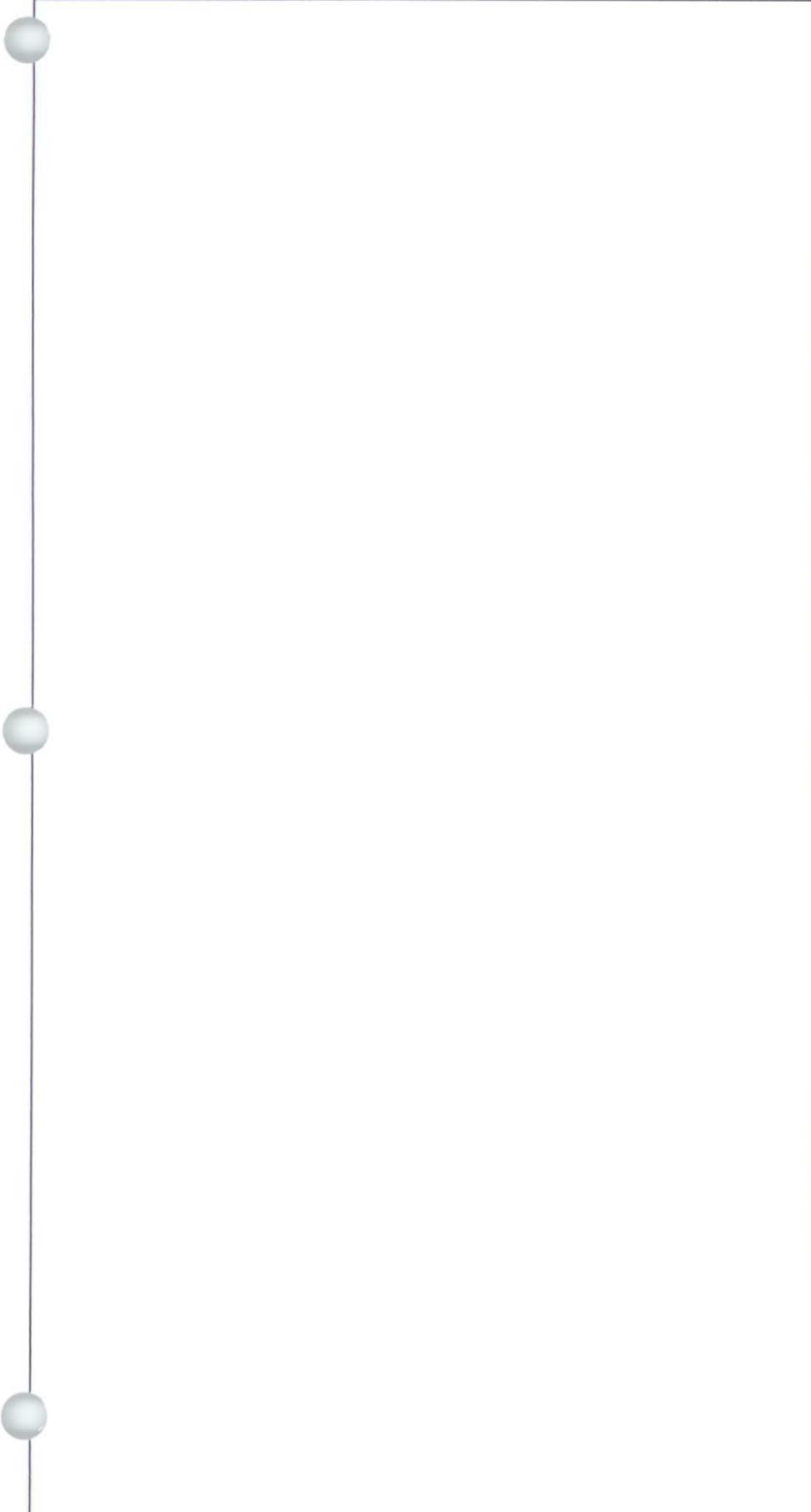
Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.92562



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	2505.46	3475.67	0	0	0
2	2510.24	3474	8.68912	0	0
3	2515.02	3472.35	33.1441	0	0
4	2519.8	3470.72	71.0697	0	0
5	2524.58	3469.11	120.276	0	0
6	2529.36	3467.51	178.678	0	0
7	2534.68	3465.76	282.631	0	0
8	2540	3464.03	393.978	0	0
9	2545.32	3462.33	510.733	0	0
10	2550.64	3460.64	631.023	0	0
11	2555.96	3458.98	753.088	0	0
12	2561.28	3457.35	875.28	0	0
13	2566.59	3455.73	996.063	0	0
14	2571.91	3454.14	1114.01	0	0
15	2577.23	3452.57	1227.81	0	0
16	2582.55	3451.03	1336.25	0	0
17	2587.87	3449.5	1438.24	0	0
18	2593.19	3448	1532.78	0	0
19	2598.51	3446.52	1618.98	0	0
20	2603.83	3445.06	1696.08	0	0
21	2609.14	3443.63	1763.39	0	0
22	2614.46	3442.22	1820.34	0	0
23	2619.78	3440.83	1866.48	0	0
24	2625.1	3439.46	1901.44	0	0
25	2630.42	3438.11	1924.95	0	0
26	2635.74	3436.79	1936.88	0	0
27	2641.06	3435.48	1937.15	0	0
28	2646.38	3434.2	1925.83	0	0
29	2651.69	3432.94	1903.06	0	0
30	2657.01	3431.7	1869.08	0	0
31	2662.33	3430.48	1824.25	0	0
32	2667.65	3429.29	1769.02	0	0
33	2672.97	3428.12	1703.93	0	0
34	2678.29	3426.96	1629.64	0	0
35	2683.61	3425.83	1546.9	0	0
36	2688.93	3424.72	1456.54	0	0
37	2694.24	3423.63	1359.51	0	0
38	2699.56	3422.56	1256.86	0	0
39	2704.88	3421.52	1149.72	0	0
40	2710.2	3420.49	1039.34	0	0
41	2715.52	3419.49	927.05	0	0
42	2720.84	3418.5	814.281	0	0
43	2726.16	3417.54	702.567	0	0
44	2731.48	3416.6	593.534	0	0
45	2736.79	3415.68	488.908	0	0
46	2742.11	3414.78	390.511	0	0
47	2747.15	3413.94	280.882	0	0
48	2752.18	3413.13	190.749	0	0
49	2757.22	3412.33	122.822	0	0
50	2762.25	3411.55	79.9151	0	0
51	2767.29	3410.79	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.91922



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	2502.03	3476.52	0	0	0
2	2507.84	3474.31	23.26	0	0
3	2513.64	3472.12	88.859	0	0
4	2519.44	3469.97	190.821	0	0
5	2525.85	3467.63	374.056	0	0
6	2532.25	3465.33	585.722	0	0
7	2538.65	3463.06	820.39	0	0
8	2545.06	3460.83	1072.93	0	0
9	2551.46	3458.64	1338.5	0	0
10	2557.87	3456.49	1612.55	0	0
11	2564.27	3454.37	1890.82	0	0
12	2570.67	3452.28	2169.32	0	0
13	2577.08	3450.24	2444.36	0	0
14	2583.48	3448.23	2712.5	0	0
15	2589.89	3446.25	2970.58	0	0
16	2596.29	3444.31	3215.73	0	0
17	2602.69	3442.4	3445.32	0	0
18	2609.1	3440.53	3657	0	0
19	2615.5	3438.7	3848.69	0	0
20	2621.9	3436.9	4018.53	0	0
21	2628.31	3435.13	4164.97	0	0
22	2634.71	3433.4	4286.69	0	0
23	2641.12	3431.71	4382.61	0	0
24	2647.52	3430.04	4451.93	0	0
25	2653.92	3428.42	4494.08	0	0
26	2660.33	3426.82	4508.74	0	0
27	2666.73	3425.26	4495.86	0	0
28	2673.14	3423.74	4455.59	0	0
29	2679.54	3422.24	4388.38	0	0
30	2685.94	3420.78	4294.87	0	0
31	2692.35	3419.36	4175.97	0	0
32	2698.75	3417.96	4032.83	0	0
33	2705.16	3416.6	3866.84	0	0
34	2711.56	3415.28	3679.6	0	0
35	2717.96	3413.98	3473	0	0
36	2724.37	3412.72	3249.12	0	0
37	2730.77	3411.5	3010.29	0	0
38	2737.18	3410.3	2759.1	0	0
39	2743.58	3409.14	2498.34	0	0
40	2749.98	3408.01	2231.05	0	0
41	2756.39	3406.91	1960.52	0	0
42	2762.79	3405.84	1690.26	0	0
43	2769.2	3404.81	1424	0	0
44	2775.6	3403.81	1165.74	0	0
45	2782	3402.84	919.68	0	0
46	2788.41	3401.9	690.281	0	0
47	2794.81	3401	482.226	0	0
48	2801.22	3400.13	300.437	0	0
49	2807.44	3399.31	130.739	0	0
50	2813.66	3398.52	23.3118	0	0
51	2819.88	3397.76	0	0	0

List Of Coordinates

External Boundary

X	Y
105.01	3381.21
65	3372.05
61	3372.02
43.9	3376.3
0	3376.3
0	3361
0	3336
0	3200
3000	3200
3000	3349
3000	3374
3000	3389.22
2962.33	3389.22
2902.33	3384.3
2862.33	3393.92
2834.14	3394.23
2497.32	3477.69
1486.5	3527.15
470.02	3466.33
133.49	3381.5

Material Boundary

X	Y
133.49	3381.5
142.75	3381.59
149.94	3381.66
232.606	3361
275.18	3350.36
372.35	3348.37
594.61	3352.96
2150.52	3347.83
2372.79	3352.2
2595.06	3347.69
2633	3348.48
2735.51	3374
2817.33	3394.37
2824.68	3394.31
2834.14	3394.23

Material Boundary

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X	Y
142.75	3381.59
142.75	3381.59
146.998	3382.66
468.81	3463.72
1486.54	3524.64
2498.75	3475.1
2820.46	3395.36
2824.68	3394.31

Material Boundary

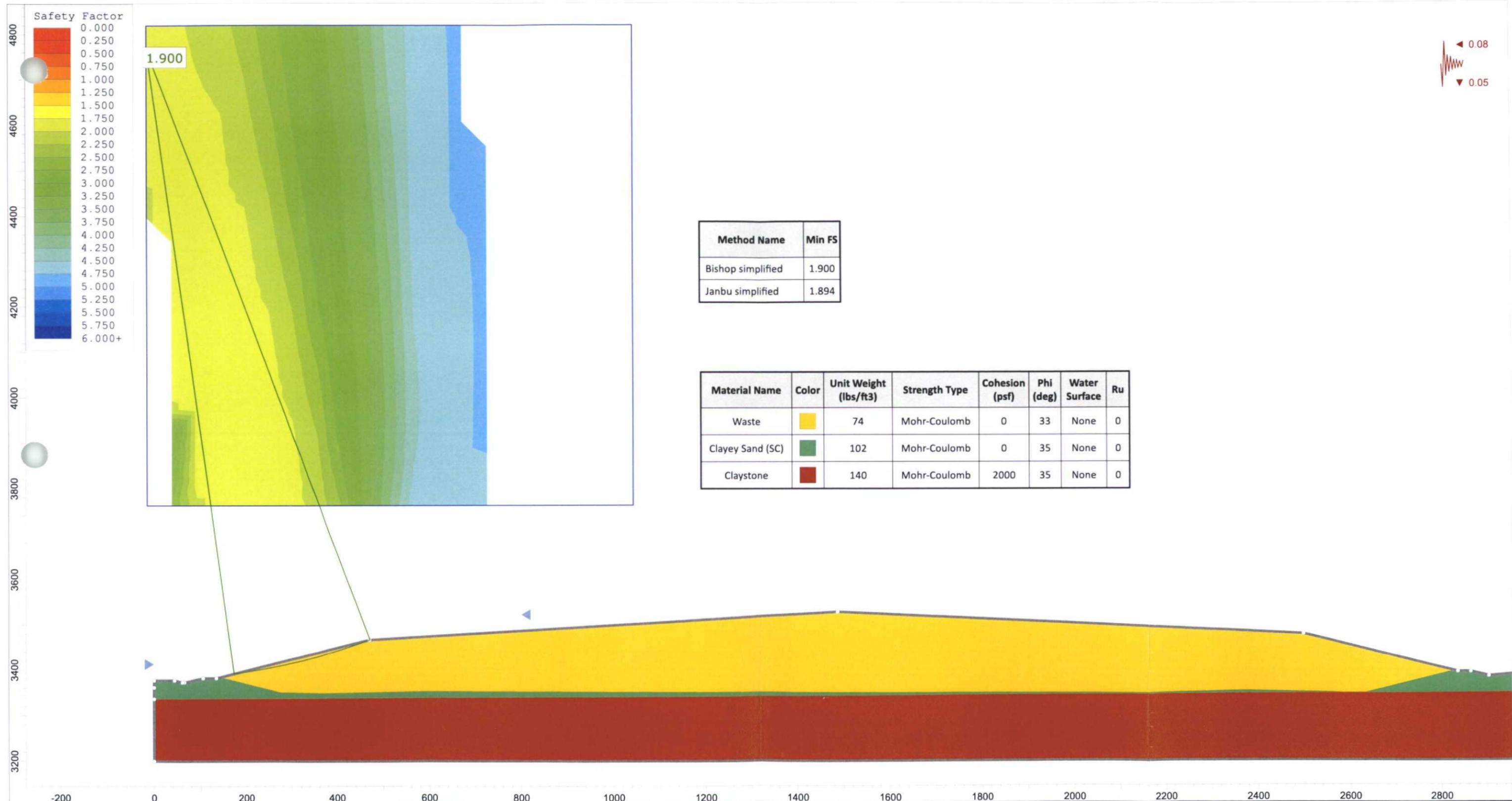
X	Y
594.53	3353.96
594.61	3352.96

Material Boundary

X	Y
2150.44	3348.83
2150.52	3347.83

Material Boundary

X	Y
0	3336
3000	3349



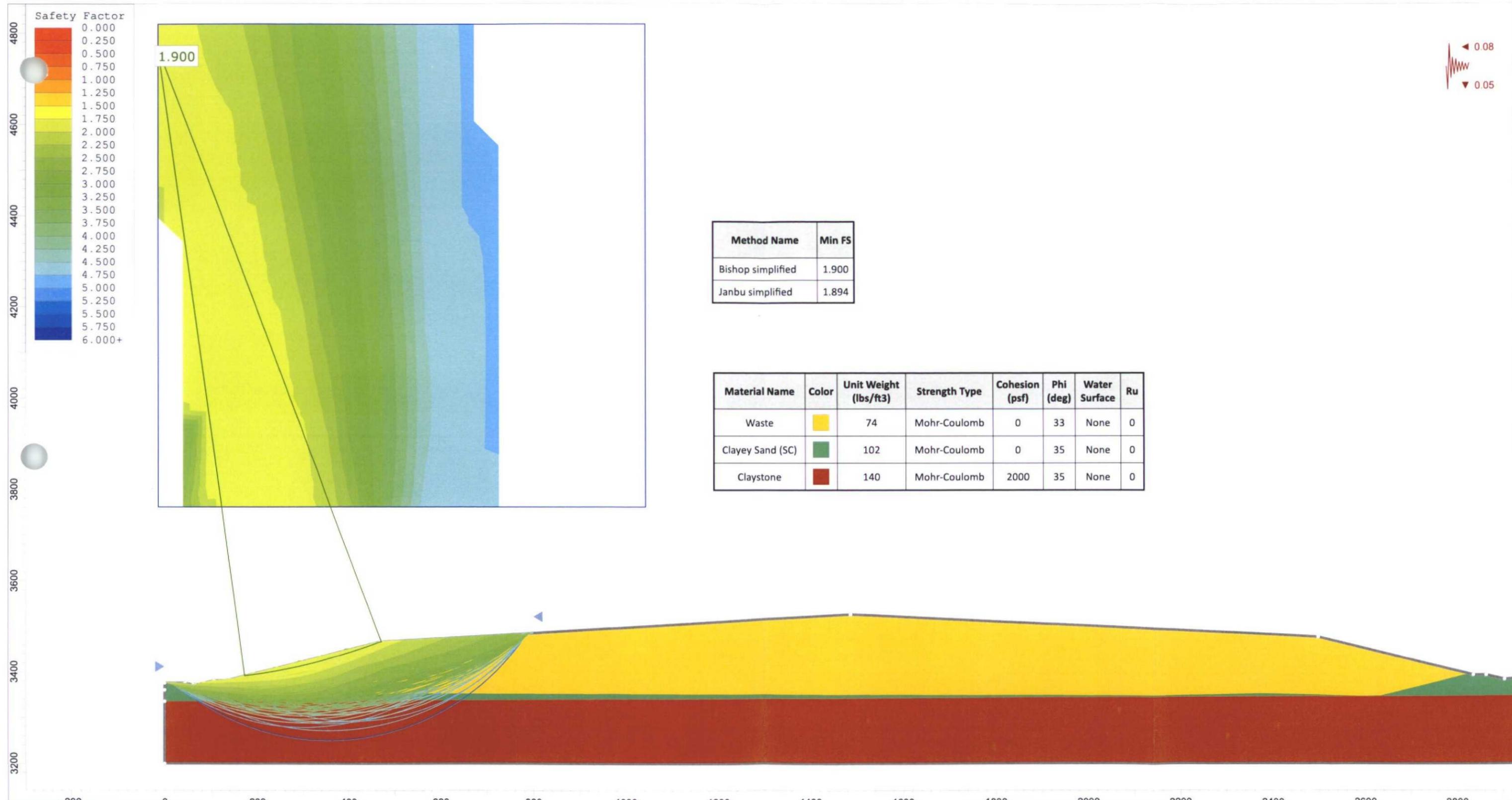
Method Name	Min FS
Bishop simplified	1.900
Janbu simplified	1.894

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



SLIDEINTERPRET 7.014

Project		CK Disposal Facility, West Slope	
Analysis Description		Final Cover	
Drawn By	Scale	Company	Parkhill, Smith & Cooper Inc.
Date	4/19/2016, 5:02:51 PM	File Name	WEST SLOPE SEISMIC.slim



Method Name	Min FS
Bishop simplified	1.900
Janbu simplified	1.894

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Ru
Waste	Yellow	74	Mohr-Coulomb	0	33	None	0
Clayey Sand (SC)	Green	102	Mohr-Coulomb	0	35	None	0
Claystone	Red	140	Mohr-Coulomb	2000	35	None	0



Project		CK Disposal Facility, West Slope	
Analysis Description		Final Cover	
Drawn By	Scale	Company	Parkhill, Smith & Cooper Inc.
Date	4/19/2016, 5:02:51 PM	File Name	WEST SLOPE SEISMIC.slim

Slide Analysis Information

CK Disposal Facility, West Slope

Project Summary

File Name: WEST SLOPE SEISMIC
 Slide Modeler Version: 7.014
 Project Title: CK Disposal Facility, West Slope
 Analysis: Final Cover
 Company: Parkhill, Smith & Cooper Inc.
 Date Created: 4/19/2016, 5:02:51 PM

General Settings

Units of Measurement: Imperial Units
 Time Units: days
 Permeability Units: feet/second
 Failure Direction: Right to Left
 Data Output: Standard
 Maximum Material Properties: 20
 Maximum Support Properties: 20

Analysis Options

Slices Type: Vertical

Analysis Methods Used

Bishop simplified
 Janbu simplified

Number of slices: 50
 Tolerance: 0.005
 Maximum number of iterations: 75
 Check malpha < 0.2: Yes
 Create Interslice boundaries at intersections with water tables and piezos: Yes
 Initial trial value of FS: 1
 Steffensen Iteration: Yes

Groundwater Analysis

Groundwater Method: Water Surfaces
 Pore Fluid Unit Weight [lbs/ft3]: 62.4
 Advanced Groundwater Method: None

Random Numbers

Pseudo-random Seed: 10116
 Random Number Generation Method: Park and Miller v.3

Surface Options

Surface Type: Circular
 Search Method: Grid Search
 Radius Increment: 5
 Composite Surfaces: Disabled
 Reverse Curvature: Invalid Surfaces
 Minimum Elevation: Not Defined
 Minimum Depth: Not Defined
 Minimum Area: Not Defined
 Minimum Weight: Not Defined

Seismic

Advanced seismic analysis: No
 Staged pseudostatic analysis: Yes
 Staged pseudostatic method: Effective Stress

Loading

Seismic Load Coefficient (Horizontal): 0.08
 Seismic Load Coefficient (Vertical): 0.05

Material Properties

Property	Waste	Clayey Sand (SC)	Claystone
Color			
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	74	102	140
Cohesion [psf]	0	0	2000
Friction Angle [deg]	33	35	35
Water Surface	None	None	None
Ru Value	0	0	0

Global Minimums

Method: bishop simplified

FS	1.899610
Center:	-13.434, 4766.460
Radius:	1387.612
Left Slip Surface Endpoint:	172.744, 3391.395
Right Slip Surface Endpoint:	471.742, 3466.433
Resisting Moment:	1.33558e+008 lb-ft
Driving Moment:	7.03084e+007 lb-ft
Total Slice Area:	1814.38 ft2
Surface Horizontal Width:	298.998 ft
Surface Average Height:	6.06821 ft

Method: janbu simplified

FS	1.893970
Center:	-13.434, 4713.609
Radius:	1336.888
Left Slip Surface Endpoint:	158.650, 3387.842
Right Slip Surface Endpoint:	463.490, 3464.684
Resisting Horizontal Force:	99219 lb
Driving Horizontal Force:	52386.9 lb
Total Slice Area:	1944.05 ft2
Surface Horizontal Width:	304.84 ft
Surface Average Height:	6.37728 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 1761
 Number of Invalid Surfaces: 885

Error Codes:

Error Code -102 reported for 9 surfaces
 Error Code -106 reported for 47 surfaces
 Error Code -107 reported for 1 surface
 Error Code -1000 reported for 828 surfaces

Method: janbu simplified

Number of Valid Surfaces: 1761
 Number of Invalid Surfaces: 885

Error Codes:

Error Code -102 reported for 9 surfaces
 Error Code -106 reported for 47 surfaces
 Error Code -107 reported for 1 surface
 Error Code -1000 reported for 828 surfaces

Error Codes

The following errors were encountered during the computation:

- 102 = Two surface / slope intersections, but resulting arc is actually outside soil region.
- 106 = Average slice width is less than 0.0001 * (maximum horizontal extent of soil region). This limitation is imposed to avoid numerical errors which may result from too many slices, or too small a slip region.
- 107 = Total driving moment or total driving force is negative. This will occur if the wrong failure direction is specified, or if high external or anchor loads are applied against the failure direction.
- 1000 = No valid slip surfaces are generated at a grid center. Unable to draw a surface.

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.89961

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Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	6.89156	276.425	7.85437	Clayey Sand (SC)	27.0793	0	14.2552	27.0793	40.1498	0	40.1498
2	6.89156	816.889	8.14172	Clayey Sand (SC)	79.9182	0	42.0708	79.9182	118.443	0	118.443
3	6.89156	1332.55	8.42929	Clayey Sand (SC)	130.194	0	68.5372	130.194	192.871	0	192.871
4	5.93104	1492.46	8.69699	Waste	157.397	0	82.8575	157.397	251.542	0	251.542
5	5.93104	1744.86	8.94482	Waste	183.82	0	96.7672	183.82	293.67	0	293.67
6	5.93104	1985.71	9.19282	Waste	208.971	0	110.007	208.971	333.737	0	333.737
7	5.93104	2215	9.44099	Waste	232.852	0	122.579	232.852	371.75	0	371.75
8	5.93104	2432.7	9.68935	Waste	255.464	0	134.482	255.464	407.712	0	407.712
9	5.93104	2638.79	9.93788	Waste	276.809	0	145.719	276.809	441.626	0	441.626
10	5.93104	2833.23	10.1866	Waste	296.888	0	156.289	296.888	473.496	0	473.496
11	5.93104	3016	10.4355	Waste	315.701	0	166.193	315.701	503.327	0	503.327
12	5.93104	3187.07	10.6846	Waste	333.25	0	175.431	333.25	531.123	0	531.123
13	5.93104	3346.41	10.934	Waste	349.535	0	184.004	349.535	556.884	0	556.884
14	5.93104	3494.01	11.1835	Waste	364.559	0	191.913	364.559	580.619	0	580.619
15	5.93104	3629.81	11.4332	Waste	378.32	0	199.157	378.32	602.325	0	602.325
16	5.93104	3753.8	11.6832	Waste	390.82	0	205.737	390.82	622.009	0	622.009
17	5.93104	3865.94	11.9334	Waste	402.06	0	211.654	402.06	639.675	0	639.675
18	5.93104	3966.2	12.1838	Waste	412.041	0	216.908	412.041	655.323	0	655.323
19	5.93104	4054.55	12.4345	Waste	420.762	0	221.499	420.762	668.956	0	668.956
20	5.93104	4130.95	12.6854	Waste	428.224	0	225.427	428.224	680.58	0	680.58
21	5.93104	4195.37	12.9365	Waste	434.428	0	228.693	434.428	690.195	0	690.195
22	5.93104	4247.77	13.188	Waste	439.373	0	231.296	439.373	697.804	0	697.804
23	5.93104	4288.11	13.4396	Waste	443.061	0	233.238	443.061	703.409	0	703.409
24	5.93104	4316.36	13.6915	Waste	445.491	0	234.517	445.491	707.014	0	707.014
25	5.93104	4332.48	13.9437	Waste	446.664	0	235.135	446.664	708.619	0	708.619
26	5.93104	4336.43	14.1962	Waste	446.579	0	235.09	446.579	708.227	0	708.227
27	5.93104	4328.16	14.449	Waste	445.236	0	234.383	445.236	705.843	0	705.843
28	5.93104	4307.64	14.702	Waste	442.635	0	233.014	442.635	701.464	0	701.464
29	5.93104	4274.83	14.9553	Waste	438.777	0	230.983	438.777	695.096	0	695.096
30	5.93104	4229.68	15.209	Waste	433.66	0	228.289	433.66	686.737	0	686.737
31	5.93104	4172.15	15.4629	Waste	427.285	0	224.933	427.285	676.392	0	676.392
32	5.93104	4102.19	15.7172	Waste	419.651	0	220.914	419.651	664.062	0	664.062
33	5.93104	4019.75	15.9717	Waste	410.757	0	216.232	410.757	649.747	0	649.747
34	5.93104	3924.79	16.2266	Waste	400.604	0	210.887	400.604	633.45	0	633.45
35	5.93104	3817.27	16.4819	Waste	389.19	0	204.879	389.19	615.171	0	615.171
36	5.93104	3697.12	16.7374	Waste	376.515	0	198.206	376.515	594.913	0	594.913
37	5.93104	3564.3	16.9933	Waste	362.578	0	190.87	362.578	572.676	0	572.676
38	5.93104	3418.77	17.2496	Waste	347.378	0	182.868	347.378	548.46	0	548.46
39	5.93104	3260.46	17.5062	Waste	330.915	0	174.202	330.915	522.267	0	522.267
40	5.93104	3089.32	17.7632	Waste	313.187	0	164.869	313.187	494.1	0	494.1
41	5.93104	2905.3	18.0205	Waste	294.194	0	154.871	294.194	463.956	0	463.956
42	5.93104	2708.34	18.2782	Waste	273.934	0	144.205	273.934	431.839	0	431.839
43	5.93104	2498.38	18.5363	Waste	252.407	0	132.873	252.407	397.748	0	397.748
44	5.93104	2275.37	18.7948	Waste	229.61	0	120.872	229.61	361.683	0	361.683
45	5.93104	2039.24	19.0537	Waste	205.543	0	108.203	205.543	323.646	0	323.646
46	5.93104	1789.94	19.313	Waste	180.205	0	94.8642	180.205	283.636	0	283.636
47	5.93104	1527.4	19.5727	Waste	153.594	0	80.8555	153.594	241.655	0	241.655
48	5.78585	1173.42	19.8297	Clayey Sand (SC)	129.432	0	68.1361	129.432	188.378	0	188.378
49	5.78585	794.249	20.0838	Clayey Sand (SC)	87.5006	0	46.0624	87.5006	127.296	0	127.296
50	5.78585	368.807	20.3384	Clayey Sand (SC)	40.5804	0	21.3625	40.5804	59.0115	0	59.0115

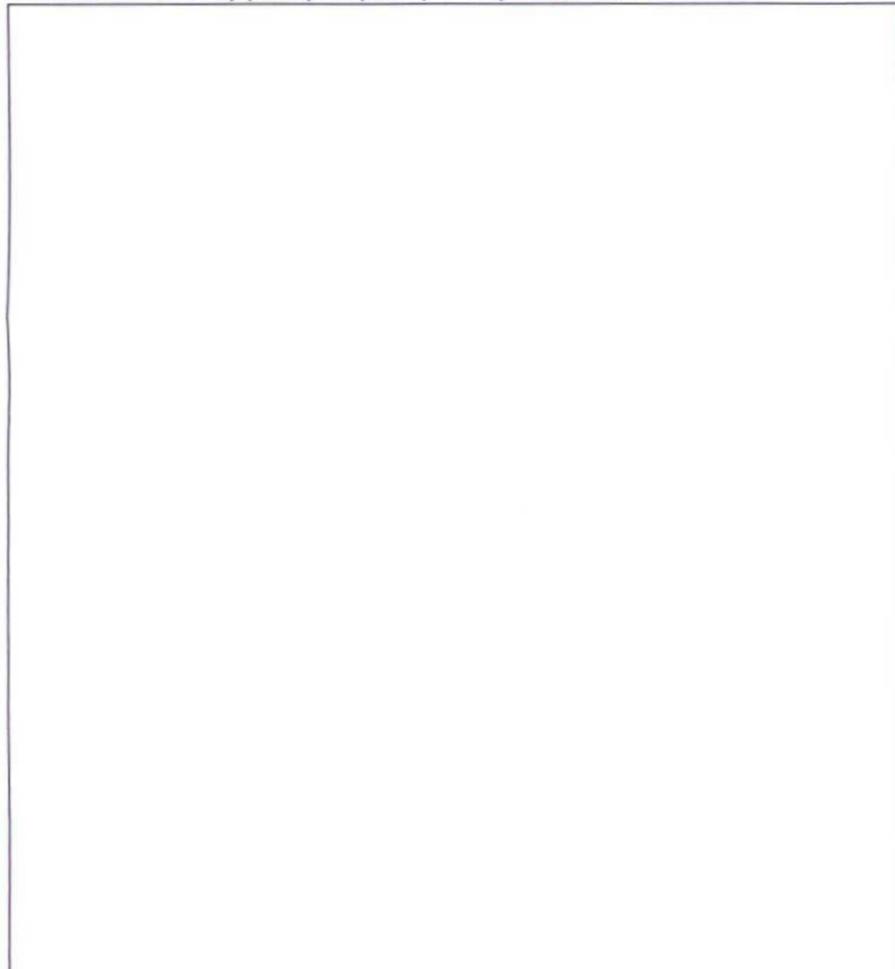
Global Minimum Query (janbu simplified) - Safety Factor: 1.89397



Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [degrees]	Base Material	Base Cohesion [psf]	Base Friction Angle [degrees]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]
1	6.5392	261.182	7.53699	Clayey Sand (SC)	27.001	0	14.2563	27.001	40.0513	0	40.0513
2	6.5392	772.586	7.81978	Clayey Sand (SC)	79.7654	0	42.1155	79.7654	118.269	0	118.269
3	6.5392	1262.05	8.10277	Clayey Sand (SC)	130.129	0	68.707	130.129	192.863	0	192.863
4	6.05072	1531.26	8.37536	Waste	158.495	0	83.684	158.495	253.402	0	253.402
5	6.05072	1809.16	8.63757	Waste	187.048	0	98.7597	187.048	298.945	0	298.945
6	6.05072	2074.38	8.89995	Waste	214.225	0	113.109	214.225	342.256	0	342.256
7	6.05072	2326.87	9.16253	Waste	240.029	0	126.733	240.029	383.343	0	383.343
8	6.05072	2566.63	9.4253	Waste	264.46	0	139.633	264.46	422.209	0	422.209
9	6.05072	2793.61	9.68827	Waste	287.521	0	151.809	287.521	458.86	0	458.86
10	6.05072	3007.79	9.95144	Waste	309.213	0	163.262	309.213	493.298	0	493.298
11	6.05072	3209.13	10.2148	Waste	329.537	0	173.993	329.537	525.531	0	525.531
12	6.05072	3397.62	10.4784	Waste	348.494	0	184.002	348.494	555.559	0	555.559
13	6.05072	3573.2	10.7423	Waste	366.086	0	193.29	366.086	583.39	0	583.39
14	6.05072	3735.86	11.0063	Waste	382.313	0	201.858	382.313	609.025	0	609.025
15	6.05072	3885.55	11.2706	Waste	397.177	0	209.706	397.177	632.468	0	632.468
16	6.05072	4022.24	11.5352	Waste	410.678	0	216.834	410.678	653.726	0	653.726
17	6.05072	4145.89	11.8	Waste	422.817	0	223.244	422.817	672.8	0	672.8
18	6.05072	4256.48	12.065	Waste	433.596	0	228.935	433.596	689.695	0	689.695
19	6.05072	4353.95	12.3303	Waste	443.013	0	233.907	443.013	704.411	0	704.411
20	6.05072	4438.26	12.5959	Waste	451.071	0	238.162	451.071	716.954	0	716.954
21	6.05072	4509.39	12.8618	Waste	457.77	0	241.699	457.77	727.329	0	727.329
22	6.05072	4567.28	13.1279	Waste	463.11	0	244.518	463.11	735.534	0	735.534
23	6.05072	4611.9	13.3943	Waste	467.091	0	246.62	467.091	741.576	0	741.576
24	6.05072	4643.2	13.661	Waste	469.713	0	248.004	469.713	745.456	0	745.456
25	6.05072	4661.13	13.9281	Waste	470.977	0	248.672	470.977	747.176	0	747.176
26	6.05072	4665.65	14.1954	Waste	470.883	0	248.622	470.883	746.739	0	746.739
27	6.05072	4656.72	14.463	Waste	469.43	0	247.855	469.43	744.149	0	744.149
28	6.05072	4634.28	14.731	Waste	466.619	0	246.371	466.619	739.407	0	739.407
29	6.05072	4598.28	14.9993	Waste	462.449	0	244.169	462.449	732.515	0	732.515
30	6.05072	4548.68	15.2679	Waste	456.921	0	241.25	456.921	723.477	0	723.477
31	6.05072	4485.42	15.5369	Waste	450.033	0	237.614	450.033	712.292	0	712.292
32	6.05072	4408.45	15.8062	Waste	441.785	0	233.259	441.785	698.962	0	698.962
33	6.05072	4317.71	16.0759	Waste	432.177	0	228.186	432.177	683.491	0	683.491
34	6.05072	4213.15	16.346	Waste	421.207	0	222.394	421.207	665.879	0	665.879
35	6.05072	4094.72	16.6164	Waste	408.877	0	215.884	408.877	646.128	0	646.128
36	6.05072	3962.35	16.8872	Waste	395.184	0	208.654	395.184	624.239	0	624.239
37	6.05072	3815.98	17.1584	Waste	380.127	0	200.704	380.127	600.215	0	600.215
38	6.05072	3655.56	17.43	Waste	363.706	0	192.034	363.706	574.055	0	574.055
39	6.05072	3481.01	17.702	Waste	345.92	0	182.643	345.92	545.76	0	545.76
40	6.05072	3292.29	17.9745	Waste	326.768	0	172.531	326.768	515.334	0	515.334
41	6.05072	3089.32	18.2473	Waste	306.248	0	161.696	306.248	482.774	0	482.774
42	6.05072	2872.03	18.5206	Waste	284.359	0	150.139	284.359	448.083	0	448.083
43	6.05072	2640.36	18.7943	Waste	261.1	0	137.859	261.1	411.262	0	411.262
44	6.05072	2394.23	19.0684	Waste	236.469	0	124.854	236.469	372.31	0	372.31
45	6.05072	2133.58	19.343	Waste	210.465	0	111.124	210.465	331.229	0	331.229
46	6.05072	1858.34	19.6181	Waste	183.085	0	96.6673	183.085	288.018	0	288.018
47	6.05072	1568.42	19.8936	Waste	154.329	0	81.4844	154.329	242.678	0	242.678
48	6.33036	1249.59	20.176	Clayey Sand (SC)	125.727	0	66.3828	125.727	182.867	0	182.867
49	6.33036	766.236	20.4653	Clayey Sand (SC)	76.9857	0	40.6478	76.9857	111.92	0	111.92
50	6.33036	259.346	20.7552	Clayey Sand (SC)	26.0203	0	13.7385	26.0203	37.8093	0	37.8093

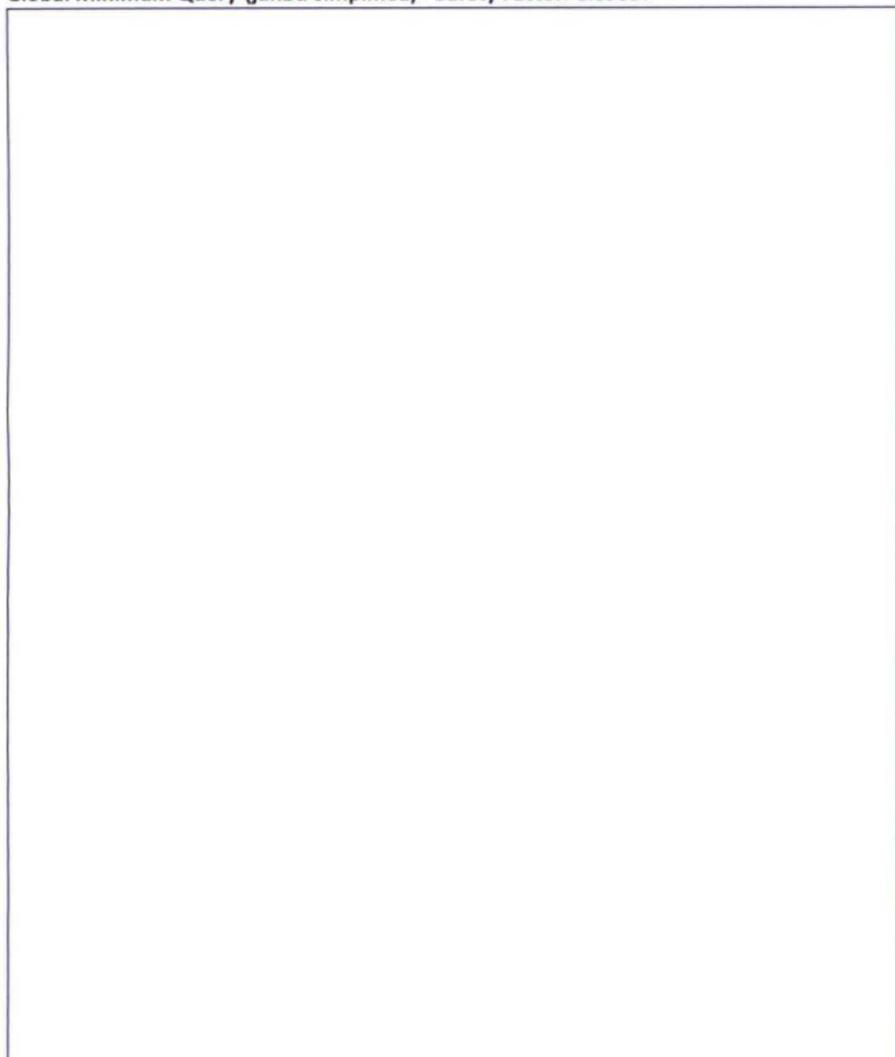
Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.89961



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	172.744	3391.39	0	0	0
2	179.636	3392.35	37.9568	0	0
3	186.528	3393.33	145.764	0	0
4	193.419	3394.35	314.516	0	0
5	199.35	3395.26	458.339	0	0
6	205.281	3396.19	618.532	0	0
7	211.212	3397.15	791.794	0	0
8	217.143	3398.14	974.981	0	0
9	223.074	3399.15	1165.11	0	0
10	229.005	3400.19	1359.35	0	0
11	234.936	3401.26	1555.03	0	0
12	240.867	3402.35	1749.63	0	0
13	246.798	3403.47	1940.81	0	0
14	252.73	3404.61	2126.36	0	0
15	258.661	3405.79	2304.25	0	0
16	264.592	3406.99	2472.59	0	0
17	270.523	3408.21	2629.66	0	0
18	276.454	3409.47	2773.9	0	0
19	282.385	3410.75	2903.9	0	0
20	288.316	3412.05	3018.41	0	0
21	294.247	3413.39	3116.36	0	0
22	300.178	3414.75	3196.82	0	0
23	306.109	3416.14	3259.03	0	0
24	312.04	3417.56	3302.38	0	0
25	317.971	3419	3326.44	0	0
26	323.902	3420.48	3330.93	0	0
27	329.833	3421.98	3315.74	0	0
28	335.764	3423.51	3280.93	0	0
29	341.695	3425.06	3226.72	0	0
30	347.626	3426.65	3153.48	0	0
31	353.557	3428.26	3061.79	0	0
32	359.488	3429.9	2952.36	0	0
33	365.419	3431.57	2826.07	0	0
34	371.35	3433.27	2684.01	0	0
35	377.281	3434.99	2527.4	0	0
36	383.212	3436.75	2357.66	0	0
37	389.143	3438.53	2176.36	0	0
38	395.074	3440.34	1985.27	0	0
39	401.005	3442.18	1786.33	0	0
40	406.937	3444.06	1581.66	0	0
41	412.868	3445.96	1373.55	0	0
42	418.799	3447.88	1164.49	0	0
43	424.73	3449.84	957.133	0	0
44	430.661	3451.83	754.345	0	0
45	436.592	3453.85	559.159	0	0
46	442.523	3455.9	374.806	0	0
47	448.454	3457.98	204.706	0	0
48	454.385	3460.09	52.476	0	0
49	460.171	3462.17	-40.2074	0	0
50	465.957	3464.29	-106.529	0	0
51	471.742	3466.43	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.89397



Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	158.65	3387.84	0	0	0
2	165.189	3388.71	37.7016	0	0
3	171.729	3389.61	145.153	0	0
4	178.268	3390.54	314.039	0	0
5	184.319	3391.43	472.275	0	0
6	190.369	3392.35	650.486	0	0
7	196.42	3393.29	844.808	0	0
8	202.471	3394.27	1051.56	0	0
9	208.521	3395.27	1267.24	0	0
10	214.572	3396.31	1488.53	0	0
11	220.623	3397.37	1712.32	0	0
12	226.674	3398.46	1935.64	0	0
13	232.724	3399.58	2155.74	0	0
14	238.775	3400.73	2370.04	0	0
15	244.826	3401.9	2576.15	0	0
16	250.876	3403.11	2771.85	0	0
17	256.927	3404.34	2955.12	0	0
18	262.978	3405.61	3124.11	0	0
19	269.029	3406.9	3277.19	0	0
20	275.079	3408.22	3412.86	0	0
21	281.13	3409.58	3529.87	0	0
22	287.181	3410.96	3627.1	0	0
23	293.231	3412.37	3703.65	0	0
24	299.282	3413.81	3758.8	0	0
25	305.333	3415.28	3792.03	0	0
26	311.384	3416.78	3802.99	0	0
27	317.434	3418.31	3791.54	0	0
28	323.485	3419.87	3757.72	0	0
29	329.536	3421.46	3701.77	0	0
30	335.586	3423.08	3624.12	0	0
31	341.637	3424.74	3525.41	0	0
32	347.688	3426.42	3406.44	0	0
33	353.739	3428.13	3268.26	0	0
34	359.789	3429.87	3112.08	0	0
35	365.84	3431.65	2939.32	0	0
36	371.891	3433.45	2751.62	0	0
37	377.942	3435.29	2550.8	0	0
38	383.992	3437.16	2338.91	0	0
39	390.043	3439.06	2118.19	0	0
40	396.094	3440.99	1891.1	0	0
41	402.144	3442.95	1660.31	0	0
42	408.195	3444.95	1428.7	0	0
43	414.246	3446.98	1199.37	0	0
44	420.297	3449.03	975.641	0	0
45	426.347	3451.13	761.056	0	0
46	432.398	3453.25	559.375	0	0
47	438.449	3455.41	374.591	0	0
48	444.499	3457.6	210.922	0	0
49	450.83	3459.92	105.918	0	0
50	457.16	3462.29	37.5923	0	0
51	463.49	3464.68	0	0	0

List Of Coordinates

External Boundary

X	Y
105.01	3381.21
65	3372.05
61	3372.02
43.9	3376.3
0	3376.3
0	3361
0	3336
0	3200
3000	3200
3000	3349
3000	3374
3000	3389.22
2962.33	3389.22
2902.33	3384.3
2862.33	3393.92
2834.14	3394.23
2497.32	3477.69
1486.5	3527.15
470.02	3466.33
133.49	3381.5

Material Boundary

--	--

X	Y
133.49	3381.5
142.75	3381.59
149.94	3381.66
232.606	3361
275.18	3350.36
372.35	3348.37
594.61	3352.96
2150.52	3347.83
2372.79	3352.2
2595.06	3347.69
2633	3348.48
2735.51	3374
2817.33	3394.37
2824.68	3394.31
2834.14	3394.23

Material Boundary

X	Y
142.75	3381.59
142.75	3381.59
146.998	3382.66
468.81	3463.72
1486.54	3524.64
2498.75	3475.1
2820.46	3395.36
2824.68	3394.31

Material Boundary

X	Y
594.53	3353.96
594.61	3352.96

Material Boundary

X	Y
2150.44	3348.83
2150.52	3347.83

Material Boundary

X	Y
0	3336
3000	3349

APPENDIX C
ROC SCIENCE SUPPORTING DOCUMENTATION

USGS Design Maps Detailed Report

2009 NEHRP Recommended Seismic Provisions (32.43212°N, 103.12518°W)

Class D – “Stiff Soil”, Risk Category I/II/III

Section 11.4.1 — Mapped Acceleration Parameters and Risk Coefficients

Note: Ground motion values contoured on Figures 22-1, 2, 5, & 6 below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_{SUH} and S_{SD}) and 1.3 (to obtain S_{1UH} and S_{1D}). Maps in the Proposed 2015 NEHRP Provisions are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

Figure 22-1: Uniform-Hazard (2% in 50-Year) Ground Motions of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

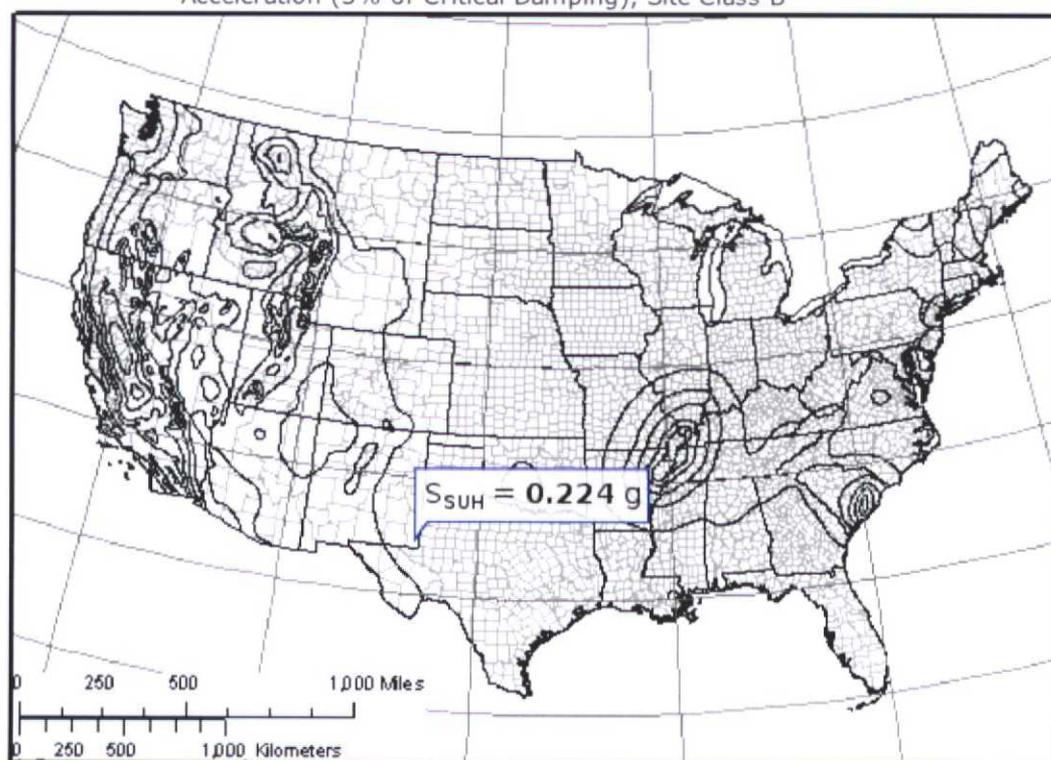


Figure 22-2: Uniform-Hazard (2% in 50-Year) Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

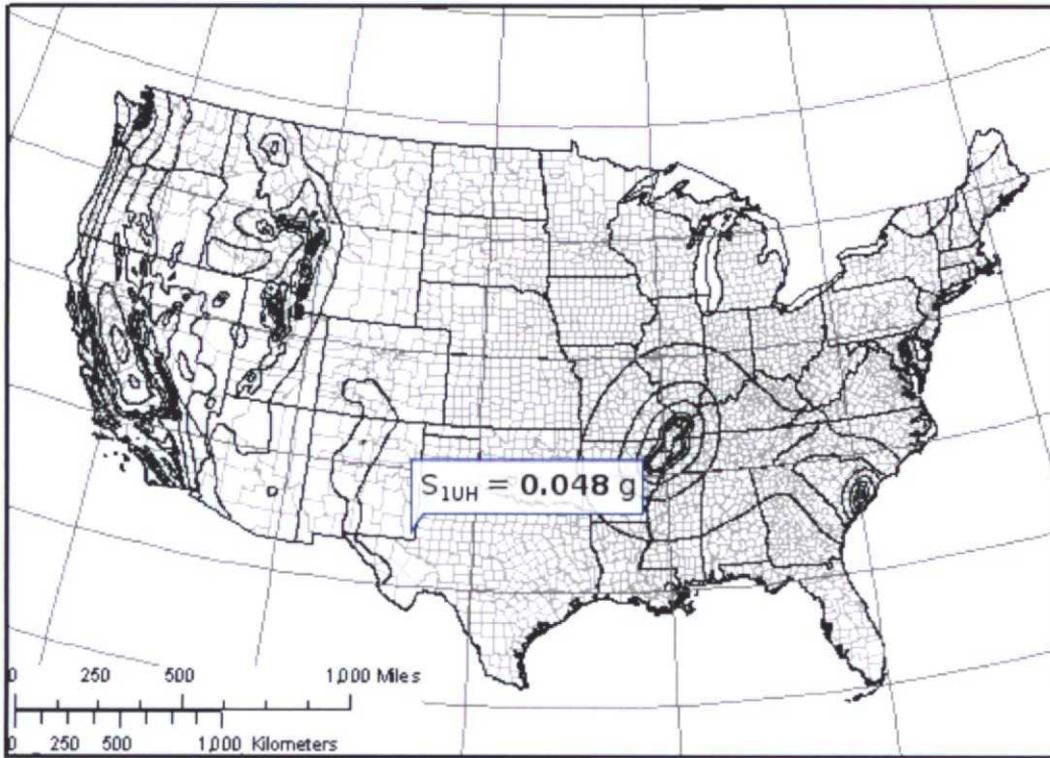


Figure 22-3: Risk Coefficient at 0.2-Second Spectral Response Period

CRS = 0.871



Figure 22-4: Risk Coefficient at 1.0-Second Spectral Response Period

CR1 = 0.907

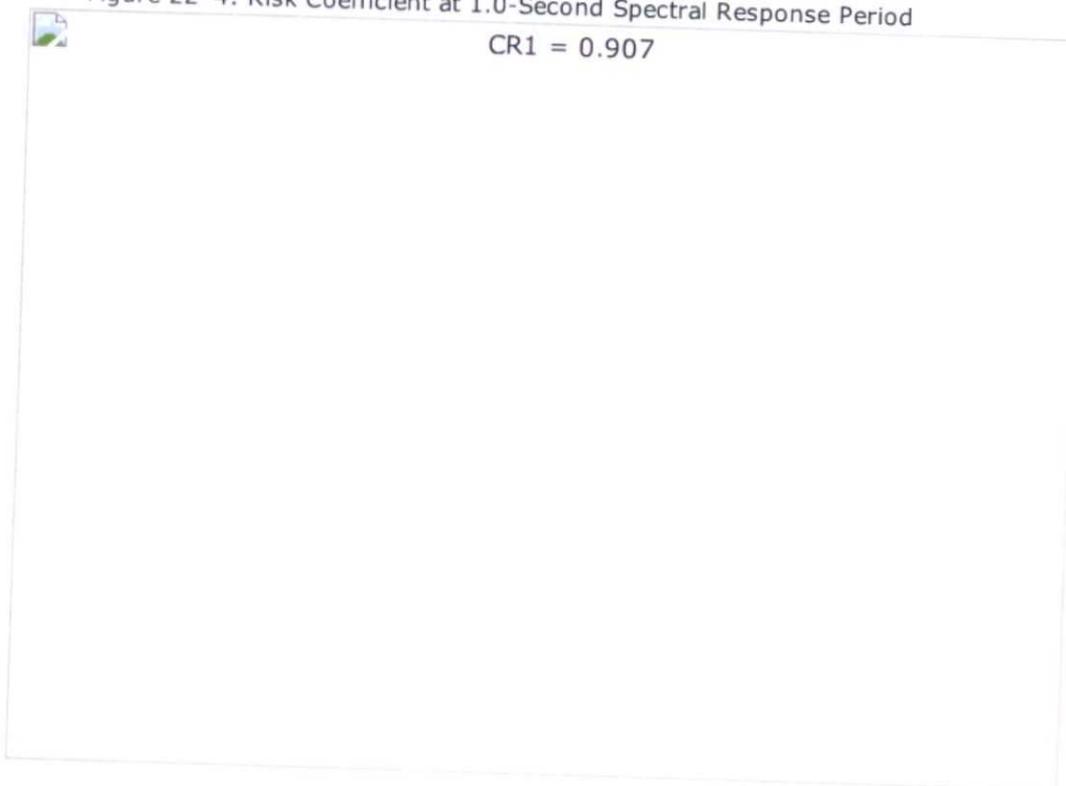


Figure 22-5: Deterministic Ground Motions of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

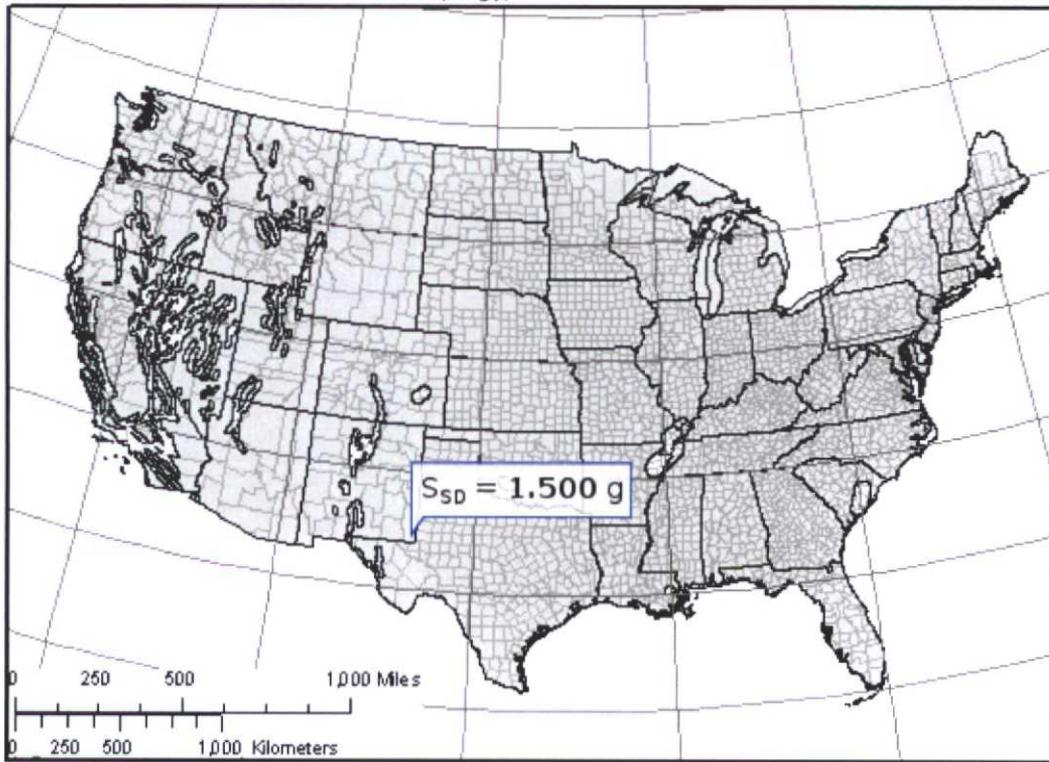
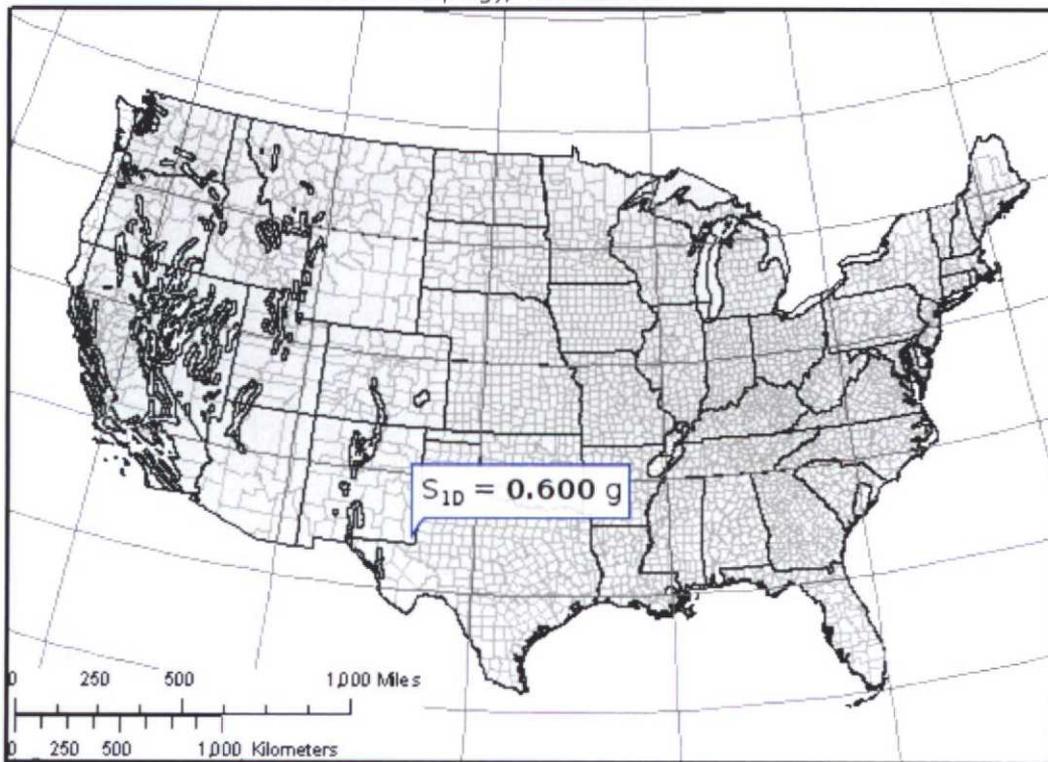


Figure 22-6: Deterministic Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B



Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the consultant has classified the site as Site Class D, based on the site soil properties in accordance with Chapter 20.

Table 20.3-1 Site Classification

Site Class	\bar{v}_s	\bar{N} or \bar{N}_{ch}	\bar{s}_u
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf

Any profile with more than 10 ft of soil having the characteristics:

- Plasticity index $PI > 20$,
- Moisture content $w \geq 40\%$, and
- Undrained shear strength $\bar{s}_u < 500$ psf

F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		
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For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients, Risk Coefficients, and Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Equation (11.4-1): $C_{RS}S_{SUH} = 0.871 \times 0.224 = 0.195$ g

Equation (11.4-2): $S_{SD} = 1.500$ g

$S_s \equiv$ "Lesser of values from Equations (11.4-1) and (11.4-2)" = 0.195 g

Equation (11.4-3): $C_{R1}S_{1UH} = 0.907 \times 0.048 = 0.044$ g

Equation (11.4-4): $S_{1D} = 0.600$ g

$S_1 \equiv$ "Lesser of values from Equations (11.4-3) and (11.4-4)" = 0.044 g



Table 11.4-1: Site Coefficient F_a

Site Class	Spectral Response Acceleration Parameter at Short Period				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_s

For Site Class = D and $S_s = 0.195$ g, $F_a = 1.600$

Table 11.4-2: Site Coefficient F_v

Site Class	Spectral Response Acceleration Parameter at 1-Second Period				
	$S_1 \leq 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \geq 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_1

For Site Class = D and $S_1 = 0.044$ g, $F_v = 2.400$

Equation (11.4-5):

$$S_{MS} = F_a S_s = 1.600 \times 0.195 = 0.312 \text{ g}$$

Equation (11.4-6):

$$S_{M1} = F_v S_1 = 2.400 \times 0.044 = 0.105 \text{ g}$$

Section 11.4.4 — Design Spectral Acceleration Parameters

Equation (11.4-7):

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} \times 0.312 = 0.208 \text{ g}$$

Equation (11.4-8):

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3} \times 0.105 = 0.070 \text{ g}$$

Section 11.4.5 — Design Response Spectrum

Figure 22-7: Long-period Transition Period, T_L (s)

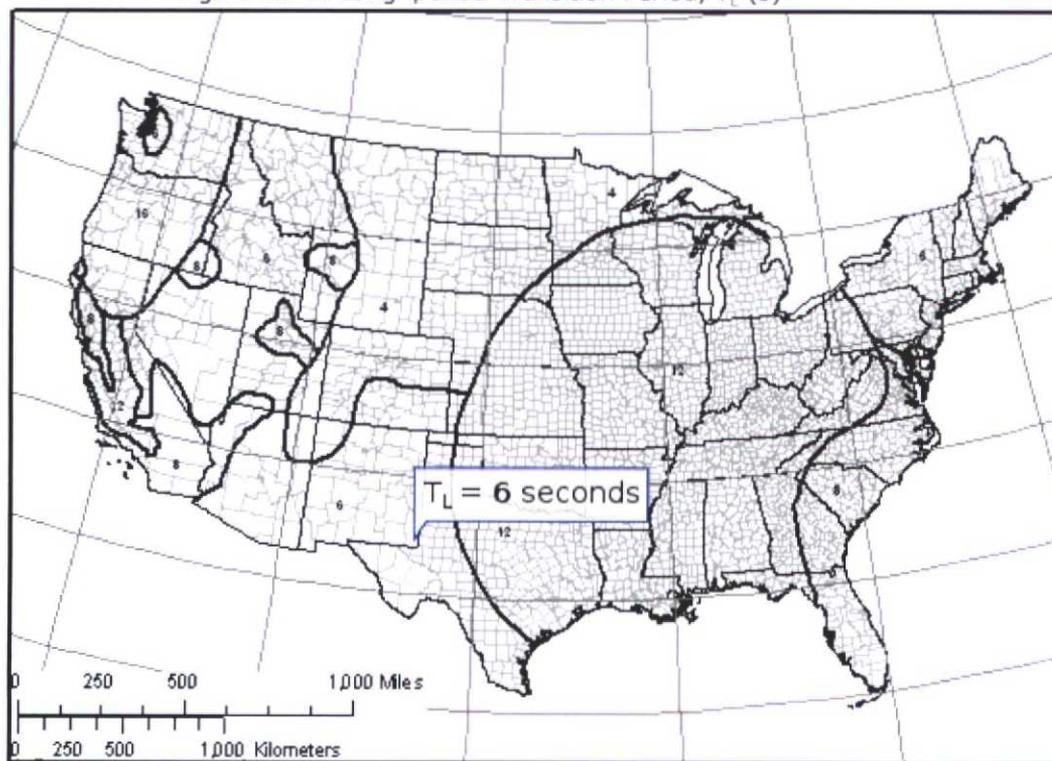
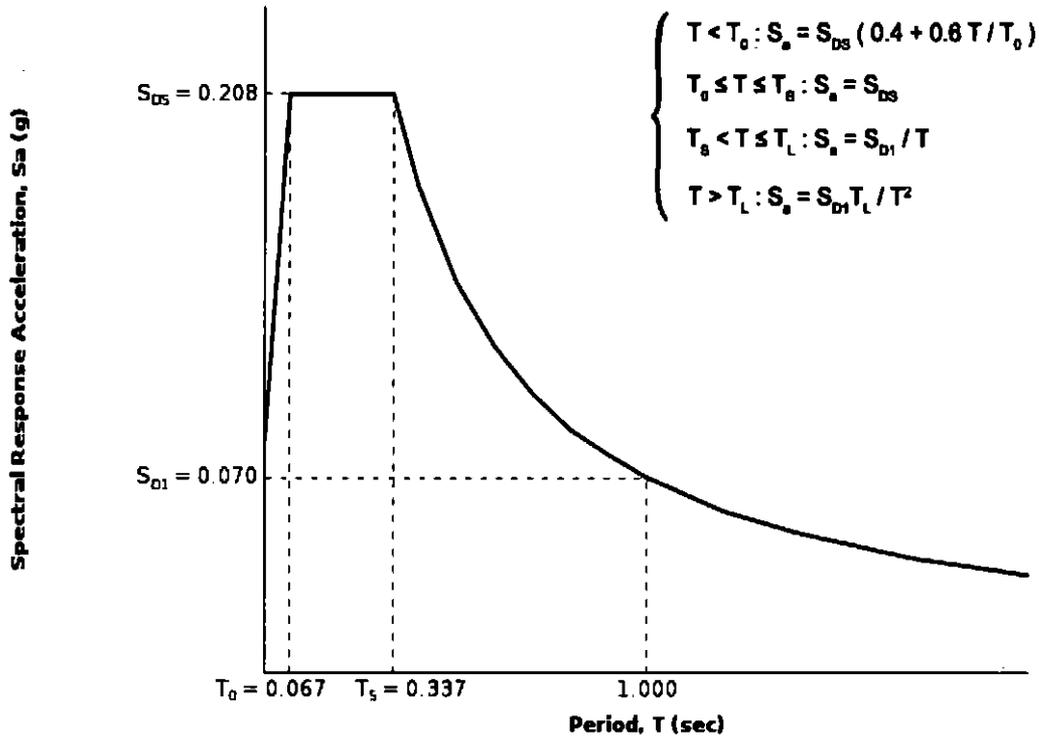
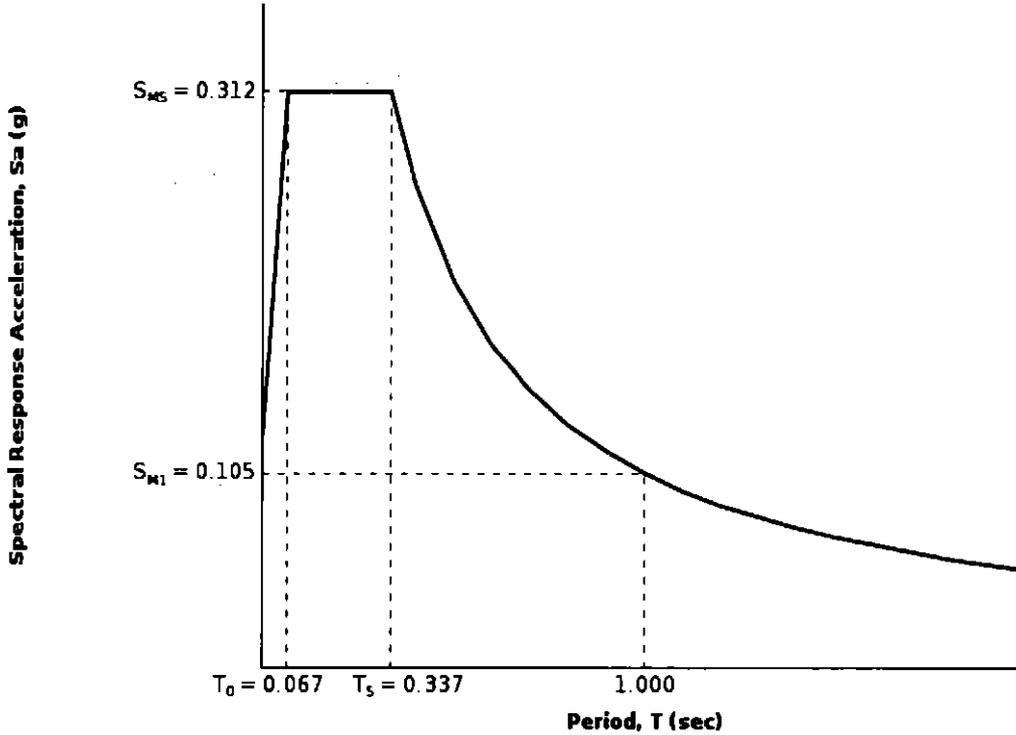


Figure 11.4-1: Design Response Spectrum



Section 11.4.6 — MCE_R Response Spectrum

The MCE_R response spectrum is determined by multiplying the design response spectrum above by 1.5.



Section 11.8.3 — Additional Geotechnical Investigation Report Requirements for Seismic Design Categories D through F

Table 11.8-1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of PGA

For Site Class = D and PGA = 0.116 g, $F_{PGA} = 1.567$

Mapped PGA

PGA = 0.116 g

Equation (11.8-1):

$$PGA_M = F_{PGA} PGA = 1.567 \times 0.116 = 0.183 \text{ g}$$

Geotechnical Properties of Geologic Materials

by

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INTRODUCTION

Engineering geologists and geotechnical engineers are an integral part of the design team for virtually all modern engineering projects that involve site characterization and geotechnical design. Evaluation of alternative project sites or specific site selection usually requires data collection, analysis and explanation of physical site conditions to other members of a project design team. Because of the need to develop a mutual understanding of geologic conditions and the resulting implications for design criteria, a common understanding of the relationship between geologic origin and geotechnical properties is essential. It is imperative that the geologist and engineer work in close cooperation to assure the best product quality.

Traditionally, the geologist's role has focused on identification of the geologic origin and distribution of earth materials. This includes both physical classification and interpretation of the processes of emplacement and modification. The product of a geologist's work within a project design team is often primarily qualitative, usually a map with appropriate descriptions. Such data must be translated into a quantitative form usable in engineering analysis and in design development and evaluation. The translation and quantification of geologic data for engineering purposes occurs over a wide range of scales. Discussion of the distribution of geologic materials and processes commonly involves a megascopic scale of feet or miles, while many engineering properties are discussed in microscopic context. A mutual understanding of terms, units and properties is essential for geologists and engineers to communicate effectively.

This paper relates the geologic characteristics and origin of earth materials commonly found in Washington to certain geotechnical properties. Four tables are presented in which descriptive and interpretive properties of soil and rock materials are correlated with their genetic classification.

The information presented in the tables is useful to indicate the general range of values for typical geotechnical properties, but is no substitute for site-specific laboratory and field information. The tables will be of some direct benefit to students and to geotechnical professionals who are new to the Pacific Northwest; among those with local experience they will serve mainly as a basis for ongoing argument.

The properties indicated in the tables are those most relevant to geotechnical considerations. The

values presented in the tables are based on a compilation of published and unpublished information and do not represent original research. These data have been compiled from field and laboratory tests performed over many years by engineers, geologists and geophysicists in both the government and private sectors.

Because of the extremely variable nature of geologic materials, the ranges presented in the tables should be considered representative, but not necessarily all inclusive. Where ranges are indicated, we estimate that roughly two-thirds of field or laboratory observations will fall within the indicated ranges. Some geologic categories are not described in the tables; for example, the tables include no discussion of fill materials or landslide deposits because it is the writers' opinion that these materials are too variable to be meaningfully included. Not all pertinent geotechnical properties are listed and some engineering projects will require information on properties not included in the tables. The design team collectively must evaluate what geological conditions might affect, or be affected by, the engineering project.

DESCRIPTION OF TABLES

The four tables include summaries of descriptive and interpretive properties of soil and rock. The vertical organization of the tables is based on the genetic classification of the materials; descriptive and interpretive properties of general interest for engineering considerations are presented in the horizontal headings. Unified Soil Classification System (USCS) symbols are shown for soil materials and Unified Rock Classification System (URCS) symbols are indicated for rock materials. These classification systems are summarized in Figures 1 and 2. A generalized explanation of terms is presented below, but is not intended to rigorously define either the geologic categories or the geotechnical properties.

Table 1. Descriptive properties of soil; see Table 5 for classification

Classification		Grain	Sorting	Dry	Friction	Cohesion	Permeability	Storage	Seismic	Resistivity
Geologic	USCS	Size		Density	angle			capacity	velocity	
				(pcf)	(deg)	(psf)	(fpm)		(fps x 1000)	(ohm-m x 1000)
ALLUVIAL										
High Energy	GW,GP,GM	Med-Coarse	Med-Good	115-130	30-35	0	0.01-10	0.1-0.3	1.5-5dry 5-7.5wet	0.3-30dry 0.2-20wet
Low Energy	ML,SM,SP,SW	Fine-Med	Med-Good	90-115	15-30	0-500	0.0001-0.1	0.05-0.2	1-4dry 3.5-6wet	0.01-10dry 0.001-1wet
COLLUVIAL Variable Reflects parent material									
EOLIAN										
Dune Sand	SP	Medium	Very Good	90-110	30-35	0	0.01-0.1	0.1-0.3	1-2.5	0.5-100
Loess	ML, SM	Fine	Med-Good	80-100	20-30	500-1000	0.001-0.01	0.05-0.1	0.75-2.5	0.01-2
GLACIAL										

Till	SM, ML	Fine-Med	Poor	120-140	35-45	1000-4000	0-0.001	0-0.01	3.5-10	0.01-5
Outwash	GW,GP,SW,SP,SM	Med-Coarse	Poor-Good	115-130	30-40	0-1000	0.01-10	0.01-0.3	4-6dry 5-8.5wet	0.2-10dry 0.1-5wet
Glaciolacustrine	ML,SM,SP	Fine-Med	Good	100-120	15-35	0-3000	0-0.1	0-0.1	2.5-8.5	0.001-2
LACUSTRINE										
Inorganic	ML,SM,MH	Fine	Good	70-100	5-20	0-200	0.0001-0.1	0.05-0.3	1-2.5	0.001-0.5
Organic	OL, PT	Fine-Med	Poor-Good	10-70	0-10	0-200	0.0001-1.0	0.05-0.8	0.5-1.5	0.001-0.5
MARINE										
High Energy	SW,GW,SP	Med-Coarse	Med-Good	115-130	25-35	0	0.001-1.0	0.1-0.3	5-6	0-2
Low Energy	ML,SM,MH	Fine-Med	Med-Good	70-115	0-25	0-200	0.0001-0.1	0.05-0.3	2.5-5	0-0.5
RESIDUAL Variable Reflects parent material									
VOLCANIC										
Tephra	ML,SM	Fine-Med	Poor-Good	80-120	20-35	0-1000	0.0001-0.1	0.05-0.2	0.5-6	0.5-100
Lahar	SM,SW,GM	Fine-Coarse	Poor	80-130	25-40	0-1000	0.001-0.1	0.05-0.2	3.5-9	0.01-5

Table 2. Interpretive properties of soil; see Table 5 for classification

Classification		Relative	Excavation	Moisture	Foundation	Cut	Seismic	Common
Geologic	USCS	erodibility	difficulty	sensitivity	support	slopes	hazards	uses
					(psf)	(%)		
ALLUVIAL								
High Energy	GW,GP,GM	Low	Low	Low	1500-2000	50-65	Low-Med	Aggregate, Fill
Low Energy	ML,SM,SP,SW	Med-High	Low	Med-High	500-1500	25-50	Med-High	Fill
COLLUVIAL Variable Reflects parent material								
EOLIAN								
Dune Sand	SP	High	Low	Low	500-1000	20-30	Low-Med	Fill, Industrial
Loess	ML,SM	Very High	Low	High	500-1000	25-50	Low-Med	
GLACIAL								
Till	SM,ML	Low-Med	Med-High	High	1500-5000	50-100	Low	Fill
Outwash	GW,GP,SW,SP,SM	Low-Med	Low-Med	Low-Med	1500-3000	50-70	Low	Aggregate, Fill

Glaciolacustrine	ML,SM, SP	Med-High	Medium	High	1000-2000	25-50	Med-High	Fill, Industrial
LACUSTRINE	ML,SM, MH,OL, PT	High	Low	High	0-500	0-25	High	PT: Soil additive
MARINE								
High Energy	SW,GW, SP	Medium	Low	Low	1000-2000	25-60	Low-Med	Fill
Low Energy	ML,SM, MH	High	Low	Med-High	0-500	0-25	High	Fill
RESIDUAL Variable Reflects parent material							
VOLCANIC								
Tephra	ML,SM	Low-High	Low	Low-High	500-1500	20-50	Low-Med	Fill, Industrial
Lahar	SM,GM	Med-High	Low-Med	Low-High	500-1500	25-50	Low-Med	Fill

Table 3. Descriptive properties of rock; see Table 6 for classification

Classification		Density	Compressive	Discontinuities	Permeability	Storage	Seismic	Resistivity
Geologic	URCS		strength			capacity	velocity	
		(pcf)	(psi x 1000)				(fps x 1000)	(ohm-m x 1000)
IGNEOUS								
Intrusive	<u>OAAA</u> - <u>OCEB</u>	150-200	3-30	Joints	Low	Low	12-20	0.5-20
Extrusive	<u>OAAA</u> - <u>ODEE</u>	120-200	1-30	Joints, Voids, Flow Features	Low-High	Low-High	6-18	0.01-5
METAMORPHIC								
High Grade	<u>OAAA</u> - <u>OCED</u>	150-200	3-25	Joints, Foliation	Low	Low	12-20	0.05-20
Low Grade	<u>OBAA</u> - <u>OEEE</u>	150-200	0.5-15	Joints, Foliation	Low	Low	2.5-14	0.001-10
SEDIMENTARY								
Clastic	<u>OBCC</u> - <u>OEEE</u>	130-150	1-15	Joints, Bedding	Low-Med	Low-Med	5-14	0.001-10
Chemical	<u>OBCB</u> - <u>ODEC</u>	140-160	2-15	Joints, Bedding, Voids	Low-High	Low	4-15	0.05-50
Organic	<u>OCCD</u> - <u>ODEE</u>	80-100	0.5-5	Joints, Bedding, Voids	Low-Med	Low	1.5-5.5	0.05-1

Table 4. Interpretive properties of rock; see Table 6 for classification

Classification		Excavation	Resistance	Foundation	Stability	Common
Geologic	URCS	difficulty	to weathering	support	in cuts	uses
IGNEOUS						
Intrusive	<u>OAAA - OCEB</u>	High	High	Good	Good	Riprap, Aggregate, Building stone
Extrusive	<u>OAAA - ODEE</u>	Med-High	Med-High	Usually Good	Med-Good	Riprap, Aggregate, Building stone
METAMORPHIC						
High Grade	<u>OAAA - OCED</u>	High	High	Good	Good	Riprap, Aggregate, Building stone, Industrial
Low Grade	<u>OBAA - OEEE</u>	Low-High	Low-Med	Usually Good	Poor-Good	Fill
SEDIMENTARY						
Clastic	<u>OBCC - OEEE</u>	Low-High	Low-Med	Usually Good	Poor-Good	Building stone, Industrial
Chemical	<u>OBCB - ODEC</u>	Med-High	Low-High	Usually Good	Poor-Good	Riprap, Aggregate, Industrial, Building stone
Organic	<u>OCED - ODEE</u>	Low-Med	Low	Poor	Poor	Fuel

Table 5. Unified Soil Classification System; from American Society for Testing and Materials, 1985

MAJOR DIVISIONS			GROUP SYMBOL	GROUP NAME
COARSE GRAINED SOILS MORE THAN 50% RETAINED ON NO.200 SIEVE	GRAVEL MORE THAN 50% OF COARSE FRACTION RETAINED ON NO.4 SIEVE	CLEAN GRAVEL	GW	WELL-GRADED GRAVEL, FINE TO COARSE GRAVEL
		GRAVEL WITH FINES	GP	POORLY-GRADED GRAVEL
			GM	SILTY GRAVEL
			GC	CLAYEY GRAVEL
	SAND MORE THAN 50% OF COARSE FRACTION PASSES NO.4 SIEVE	CLEAN SAND	SW	WELL-GRADED SAND, FINE TO COARSE SAND
		SAND WITH FINES	SP	POORLY-GRADED SAND
			SM	SILTY SAND
			SC	CLAYEY SAND
FINE GRAINED SOILS	SILT AND CLAY LIQUID LIMIT LESS THAN 50	INORGANIC	ML	SILT
			CL	CLAY
		ORGANIC	OL	ORGANIC SILT, ORGANIC CLAY

MORE THAN 50% PASSES NO.200 SIEVE	SILT AND CLAY	INORGANIC	MH	SILT OF HIGH PLASTICITY, ELASTIC SILT
	LIQUID LIMIT 50 OR MORE		CH	CLAY OF HIGH PLASTICITY, FAT CLAY
			ORGANIC	OH
HIGHLY ORGANIC SOILS			PT	PEAT

Table 6. Unified Rock Classification System, from Williamson, 1984

DEGREE OF WEATHERING	REPRESENTATIVE		A	Micro Fresh State (MFS)	
			B	Visually Fresh State (VFS)	
	ALTERED		C	Stained State (STS)	
	WEATHERED	>GRAVEL SIZE	D	Partly Decomposed State (PDS)	
		<SAND SIZE	E	Completely Decomposed State (CDS)	
ESTIMATED STRENGTH	REACTION TO IMPACT OF 1 LB BALLPEEN HAMMER		A	"Rebounds" (Elastic) (RQ)	>15000 psi (2)
			B	"Pits" (Tensional) (PQ)	8000 - 15000 psi (2)
			C	"Dents" (Compression) (DQ)	3000 - 8000 psi (2)
			D	"Craters" (Shears) (CQ)	1000 - 3000 psi (2)
	REMOLDING (1)		E	"Moldable" (Friable) (MQ)	<1000 psi (2)
DISCONTINUITIES	VERY LOW PERMEABILITY		A	Solid (Random Breakage) (SRB)	
			B	Solid (Preferred Breakage) (SPB)	
			C	Solid (Latant Planes of Separation) (LPS)	
	MAY TRANSMIT WATER		D	Nonintersecting Open Planes (2-D)	
			E	Intersecting Open Planes (3-D)	
UNIT WEIGHT			A	Greater than 160 pcf	
			B	150 - 160 pcf	
			C	140 - 150 pcf	
			D	130 - 140 pcf	
			E	Less than 130 pcf	
(1) Strength estimated by soil mechanics techniques			(2) Approximate unconfined compressive strength		
SYMBOL NOTATION: <u>AAAA</u> IN ORDER WEATHERING, STRENGTH, DISCONTINUITIES, WEIGHT					

"O" IS USED AS A POSITION HOLDER

EXPLANATION OF TERMS

Soils

- o Alluvial: Sediment deposited by streams.
 - High Energy: Generally coarse sediment such as coarse sand, gravel, cobbles and boulders that have been deposited by fast moving water.
 - Low Energy: Generally fine-grained soil such as fine sand and silt deposited by slow moving water.
- o Colluvial: Generally heterogeneous soil aggregates that have been transported and deposited by mass wasting processes such as landslides, rockfalls and avalanches.
- o Eolian: Sediment transported and deposited by wind.
 - Dune Sand: Sand-size sediment; typically deposited in dune forms.
 - Loess: Fine-grained sediment; generally fine sand and silt.
- o Glacial: Material deposited by or in association with glaciers.
 - Till: Heterogeneous mixture of various particle sizes deposited directly by glacial ice.
 - Outwash: High-energy sediment deposited by glacial meltwater.
 - Glaciolacustrine: Low-energy sediment deposited in ice-marginal lakes.
- o Lacustrine: Sediment deposited in lakes.
 - Nonorganic: Sediment composed primarily of silt, sand and clay.
 - Organic: Peat and other predominantly organic sediment.
- o Marine: Sediment deposited in a marine environment.
 - High Energy: Generally coarse-grained material such as gravel and sand deposited by strong waves or currents.
 - Low Energy: Generally fine-grained material such as silt and sand.
- o Residual: Soil developed in place as the result of weathering or chemical decomposition of parent material.
- o Volcanic: Deposits derived from volcanoes or other eruptive sources.

- Tephra: Airborne volcanic ejecta such as volcanic bombs, cinders and ash.
- Lahar: Mudflow composed largely of volcanic debris, or having primarily a volcanic origin.

Bedrock

- o **Igneous:** Rock formed by solidification from a molten state.
 - **Intrusive:** Rock such as granite that has solidified from a molten state below the ground surface.
 - **Extrusive:** Rock such as basalt that has solidified after reaching the ground surface.
- o **Metamorphic:** Rock derived from pre-existing rock by mineralogical and textural changes.
 - **High Grade:** Metamorphic rock that has little resemblance to the original parent rock type.
 - **Low Grade:** Metamorphic rock that is similar to the original parent rock type.
- o **Sedimentary:** Rock deposited as sediment and subsequently lithified.
 - **Clastic:** Rock such as shale, sandstone and conglomerate formed from fragments of pre-existing rocks.
 - **Chemical:** Rock such as limestone formed by chemical precipitation.
 - **Organic:** Rock such as coal formed largely or exclusively from organic material.

Descriptive Properties

- o **USCS:** Unified Soil Classification System (ASTM D 2487).
- o **URCS:** Unified Rock Classification System (Williamson, 1984).
- o **Grain Size:** The general category of particle sizes corresponding to terms used in the USCS.
- o **Sorting:** Segregation by grain sizes. "Poor" means a wide range of grain sizes such as silty sandy gravel; "good" means a narrow range of grain sizes such as sand. No specific percentages are implied.
- o **Dry Density:** Dry weight in pounds per cubic foot.
- o **Friction Angle:** Angle of internal shearing resistance (ϕ) expressed in degrees.
- o **Cohesion:** That part of the shear strength of soil or rock which does not depend on interparticle friction.
- o **Permeability (Hydraulic Conductivity):** The ease with which water will move through soil interstices, expressed in feet per minute. For rock, variability is so great that it is expressed in the tables in dimensionless relative terms only. Negligible permeability is expressed as 0.
- o **Storage Capacity (Specific Yield):** The volume of water that will drain from a unit volume of an unconfined aquifer.

- o Seismic Velocity: Compressional seismic wave velocity in thousands of feet per second.
- o Resistivity: Electrical resistance to direct current expressed in terms of thousands of ohm-meters.
- o Compressive Strength: Load per unit area under which an unconfined block of rock fails (unconfined compressive strength), expressed in pounds per square inch.
- o Discontinuities: Surfaces or voids that interrupt otherwise homogeneous rock masses.

Interpretive Properties

- o Relative Erodibility: Susceptibility to erosion in terms of sediment yield per unit area.
- o Excavation Difficulty: The relative difficulty of excavation by heavy equipment.
- o Moisture Sensitivity: Susceptibility to significant changes in physical properties due to changes in water content. In general, sensitivity increases with increasing silt or clay content.
- o Foundation Support: Typical allowable bearing value for shallow spread foundations, expressed in pounds per square foot. Assumes conventional cast-in-place concrete footings with embedment adequate for frost protection. Expressed in dimensionless relative terms only for rock.
- o Cut Slopes (Soil): Typical maximum inclination for permanent cut slopes less than 15 feet in height. Assumes no destabilizing factors such as adverse structural/stratigraphic or ground water conditions.
- o Stability in Cut Slopes (Rock): Relative stability of permanent cut slopes. Assumes no destabilizing factors such as adverse structural/stratigraphic or ground water conditions.
- o Seismic Hazards: Relative association with earthquake-induced damage.
- o Common Uses: Typical applications of economic importance.
- o Resistance to Weathering: Relative resistance to mechanical or chemical deterioration.

DISCUSSION

Descriptive Properties

- o The Unified Soil Classification System (USCS) does not recognize particles larger than 3 inches in diameter. Common usage extends it to materials including cobbles (3 to 12 inches) and boulders (greater than 12 inches).
- o Cohesion is the result of soil structure and/or cementation. Some finite cohesion is generally present in loess, due to its unique granular structure and the common occurrence of minor cementation. Cohesion in till is a result of ice consolidation and a wide range of particle sizes, including a significant fraction of silt.
- o Permeability differences reflect variations in gradation between geologic materials. Very high permeability is associated with high-energy alluvial deposits or glacial outwash where coarse, open-work gravel is common. Permeability in these deposits can vary greatly over short horizontal and

vertical distances. Extremely low permeability is associated with poorly to moderately sorted materials that are ice-consolidated and contain a substantial fraction of silt and clay.

o Storage capacity reflects the volume of void space and the content of silt or clay within a soil deposit. Storage capacity is very small for poorly sorted or ice-consolidated, fine-grained materials such as till and glaciolacustrine deposits.

o Seismic velocities in soil can be affected by water content. Coarse-grained soils display significantly higher velocities when water saturated. Less velocity increase is associated with finer-grained soils. The electrical resistivity of soil and rock decreases with water content. Geophysical values are differentiated between wet and dry conditions where differences are significant and data is available.

Interpretive Properties

o Erodibility is closely related to slope, vegetative cover, water concentration and numerous other factors in addition to geologic characteristics.

o Excavation difficulty is discussed in more detail in handbooks published by Caterpillar, Inc. (1987a, b). Note that the table entries for this category refer to unrestricted excavation. Restricted excavations such as trenches are normally more difficult than open cuts. Substantial variations from the indicated values should be expected based on site-specific factors.

o Satisfactory foundation performance includes consideration of numerous factors in addition to the indicated bearing values. These factors include settlement performance, general stability and effects of and on adjacent manmade or natural features.

o The design of safe cut slopes must consider site-specific details of soil and water conditions and their relationship to risk. For example, a maintenance risk is much less significant than a life-threatening risk. Therefore, rather than relying on physical properties, risk will often dictate slope design.

o Seismic hazards can be manifested in the form of ground shaking, liquefaction, ground rupture or displacement (e.g., landslides induced by seismic shaking). The extent to which the indicated geologic classifications are associated with seismic hazards is expressed in relative terms.

o Moisture sensitivity varies considerably within each geologic classification. For example, low-energy alluvial deposits characterized by clean, free-draining sand are not particularly moisture-sensitive while low-energy alluvial soils containing a substantial fraction of silt are extremely moisture-sensitive. Although not included as a specific interpretive category for rock, moisture sensitivity can also be important. The moisture sensitivity of rock is generally proportional to the amount of clay or silt produced by mechanical or chemical decomposition.

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APPENDIX D
GEOTECHNICAL ENGINEERING PRINCIPLES AND PRACTICES EXCERPT

TABLE 10.4 Typical Consolidation Properties of Saturated Normally Consolidated Sandy Soils at Various Relative Densities^a

Soil Type	$C_c/(1+e_0)$					
	$D_r = 0\%$	$D_r = 20\%$	$D_r = 40\%$	$D_r = 60\%$	$D_r = 80\%$	$D_r = 100\%$
Medium to coarse sand, some fine gravel (SW)	-	-	0.005	-	-	-
Medium to coarse sand (SW/SP)	0.010	0.008	0.006	0.005	0.003	0.002
Fine to coarse sand (SW)	0.011	0.009	0.007	0.005	0.003	0.002
Fine to medium sand (SW/SP)	0.013	0.010	0.008	0.006	0.004	0.003
Fine sand (SP)	0.015	0.013	0.010	0.008	0.005	0.003
Fine sand with trace fine to coarse silt (SP-SM)	-	-	0.011	-	-	-
Fine sand with little fine to coarse silt (SM)	0.017	0.014	0.012	0.009	0.006	0.003
Fine sand with some fine to coarse silt (SM)	-	-	0.014	-	-	-

^aAdapted from Burmister, 1962.

tests on samples reconstituted to various relative densities. Engineers can estimate the in situ relative density using the methods described in Chapter 4, then select an appropriate $C_c/(1 + e_0)$ from this table. Note that all of these values are "very slightly compressible" as defined in Table 10.2.

For saturated overconsolidated sands, $C_c/(1 + e_0)$ is typically about one-third of the values listed in Table 10.4, which makes such soils nearly incompressible. Compacted fills can be considered to be overconsolidated, as can soils that have clear geologic evidence of preloading, such as glacial tills. Therefore, many settlement analyses simply consider the compressibility of such soils to be zero. If it is unclear whether a soil is normally consolidated or overconsolidated, it is conservative to assume it is normally consolidated.

Very few consolidation tests have been performed on gravelly soils, but the compressibility of these soils is probably equal to or less than those for sand, as listed in Table 10.4.

Another characteristic of sands and gravels is their high hydraulic conductivity, which means any excess pore water drains very quickly. Thus, the rate of consolidation is very fast, and typically occurs nearly as fast as the load is applied. Thus, if the load is due to a newly placed fill, the consolidation of these soils may have little practical significance.

However, there are at least two cases where consolidation of coarse-grained soils can be very important and needs more careful consideration:

1. **Loose sandy soils subjected to dynamic loads, such as those from an earthquake.** They can experience very large and irregular settlements that can cause serious damage. Kramer (1996) discusses methods of evaluating this problem.