# NM - 61

## Attachment M - ECP

May 2016

**APPENDICES**



**TABLES**

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

Where:

$W_{net}$ = net weight of waste

$W_{net}$ = 10,349 lbs/ft – 765 lbs/ft

$W_{net}$ = 9,584 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 lb/ft

P = 2,323 lb/ft

The critical interface of the liner system occurs at the geocomposite to double-sided textured HDPE interface. $F_1$ is calculated for gecomposite 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 lbs/ft

$F_2$ = 4,595.2 lbs/ft

$F_1 - F_2$ = 5,809.8 lbs/ft – 4,595.2 lbs/ft = 1,212.6 lbs/ft = 101.2 lbs/in

1,212.6 lbs/ft = 101.2 lbs/in

$\sigma_{actual}$ = (101.2 lbs/in)/(0.06 in) = 1,678 lbs/in$^2$

$\sigma_{allow}$ = (126 lbs/in)/(0.06 in) = 2,100 lbs/in$^2$

FS = (2,100 lbs/in$^2$)/(1,687 lbs/in$^2$) = 1.2

The Factor of Safety for the critical interface is 1.2, therefore the liner system is adequate.

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/yd$^2$ geotextile

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

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

F.S. = $(T_f)/(F_1 – F_2)$ = 186.76 lbs/in/101.2 lbs/in = 1.85

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

## 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:

$\Delta H_C$ = primary settlement

$C_C/(1+e_o)$ = 0.006 (~~Geotechnical Engineering Principals and Practices~~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

$\sigma_o$ = previously applied pressure in waste layer (assumed to equal the compaction pressure = 1,000 lbs/ft$^2$)

$\sigma_i$ = total overburden pressure applied at the mid-level of the waste layer (lbs/ft$^2$)

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

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

Where:

$\Delta H_S$ = 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:

REFERENCES

1. Gray, Donald, Robert M. Koerner, and Xian Quede, *Geotechnical Aspects of Landfill Design and Construction*. New York: Prentice Hall, 2002. Print.
2. *Handbook of PVC Design*. Uni-Bell PVC Pipe Association, 2001. Print.
3. Parametrix, Inc. *Solid Waste Landfill Design Manual*. Washington State Department of Ecology. June 1987. Web. 3 May 2016. <https://fortress.wa.gov/ecy/publications/documents/87013.pdf>.
4. Driscopipe, Inc., *Polyethylene Piping Systems Manual*. 2008.
5. Chevron Phillips Chemical Company LP. *The Performance Pipe Engineering Manual*. CPChem Performance Pipe. Chevron Phillips, 2002. Web. 3 May 2016. <http://www.cpchem.com/en-us/Pages/default.aspx>.
6. Richardson, Clinton P., *Municipal Landfill Design Calculations: An Entry Level Manual of Practice*. California: UBuildABook, LLC, 2009. Print.
7. Bachus, Robert, Mengjia Li, Dhani Narejo, Richard Thiel, and Te-Yang Soong, *GSE Drainage Design Manual*. GSE Environmental, June 2007. Web. 3 May 2016. <https://www.gseworld.com/content/documents/product-sheets/Drainage_Design_Manual.pdf>
8. Koloski, Jon, Signmund Schwarz, and Donald Tubbs. *Geotechnical Properties of Geologic Materials*. Geotechnical Properties of Geologic Materials. 1989. Web. 3 May 2016. http://www.tubbs.com/geotech/geotech.htm
9. Sangeeta, Lewis P., and Hari D. Sharma, *Waste Containment Systems, Waste Stabilization and Landfills: Design and Evaluation*. New York: John Wiley and Sons. 1994. Print.
10. Koerner, Robert M., *Designing with Geosynthetics*. 6th ed., Vol. 1. 2012. Print.
~~9.~~11. Coduto, Donald P., Man-chu R. Yeung, and William A. Kitch. *Geotechnical Engineering Principles and Practices*. 2nd ed. Upper Saddle River: Pearson Higher Education, 2011. Print.

.

# APPENDIX C
# ROC SCIENCE SUPPORTING DOCUMENTATION

# APPENDIX D

# GEOTECHNICAL ENGINEERING PRINCIPLES AND PRACTICES EXCERPT

# Permit Application

Lea County, New Mexico

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

Permit No. TBD

## Attachment M

## Engineering Design Calculations

Robert H. Holder
ROBERT H. HOLDER
NEW MEXICO
20239
PROFESSIONAL ENGINEER
05/12/2016

May 2016 REVISION 2

PSC Project # 01058015

PSC PARKHILLSMITH&COOPER

**ATTACHMENT M – ENGINEERING DESIGN CALCULATIONS**

**APPENDICES**



**TABLES**

# 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 ($yd^3$). 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<br>(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 ($W_c$):

$W_c = (P_T)(D_O)/(1-((n)(d)/12))$ (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 psi)(6.625)]/[1-((12)(0.5 in)/12)]

$W_c$ = 1,094.45 lbs/in = 13,133.4 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:

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

Where:

$\Delta X$ = 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 piper per unit of pipe length (1,094.45 lbs/in).

r = mean radius of the pipe (OD – t) = ((6.625 in – 0.432 in)/2) = 3.1 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)

[Continued on the next page]

[Continued from previous page]

I = moment of inertia of pipe wall per unit of length ($in^4/in$); for any round pipe

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

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

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

$$\Delta X = 0.5\ in$$

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

$$\%RD = [\Delta X/(D_i+t)]x100$$

Where:

$D_i$ = Internal Pipe Diameter

t = Pipe Wall Thickness

%RD = [0.5/(5.76+0.432)]x100

%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:

$P_{cr} = 2 \times \{[(E')/(1-v^2)][(E)(I)/r^3]\}^{0.5}$ (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

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

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

t = pipe wall thickness = 0.432 in

r = mean radius of pipe = 3.1 in

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

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

$P_{cr}$ = 1,123.3 psi

<u>The factor of safety is then determined</u>:

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

FS = 1,123.3 psi / 82.6 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 $\text{inches}^2$ = 0.50 $\text{foot}^2$

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 ($\text{lbs/ft}^2$)

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 ft / 2(3 ft) = 0.25
- M/2H = 0.33 ft / 2(3 ft) = 0.055

Therefore:

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

$W_{SD}$ = 2,287 lbs/ft = 190 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 ($W_c$):

$W_c = (P_T)(D_O)/(1-((n)(d)/12))$ (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 psi)(6.625)]/[1-((12)(0.5 in)/12)]

$W_c$ = 1,094.45 lbs/in = 13,133.4 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 psi

### 2.10 HDPE Deflection

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

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

Where:

$\Delta X$ = 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 in – 0.602 in)/2) = 3.0 in

[Continued on next page]

[Continued from previous page]

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

I = moment of inertia = $t^3/12$ ($in^4/in$) = $((0.602)^3/12)$ = 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:

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

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

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

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):

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

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

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

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

Where:

$P_{cb}$ = critical buckling pressure

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

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

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

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

For a SDR of 11.0 the actual compressive stress is:

$S_A = ((11.0-1)/2) \times 182.4 = 912$ 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 psi/910 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.

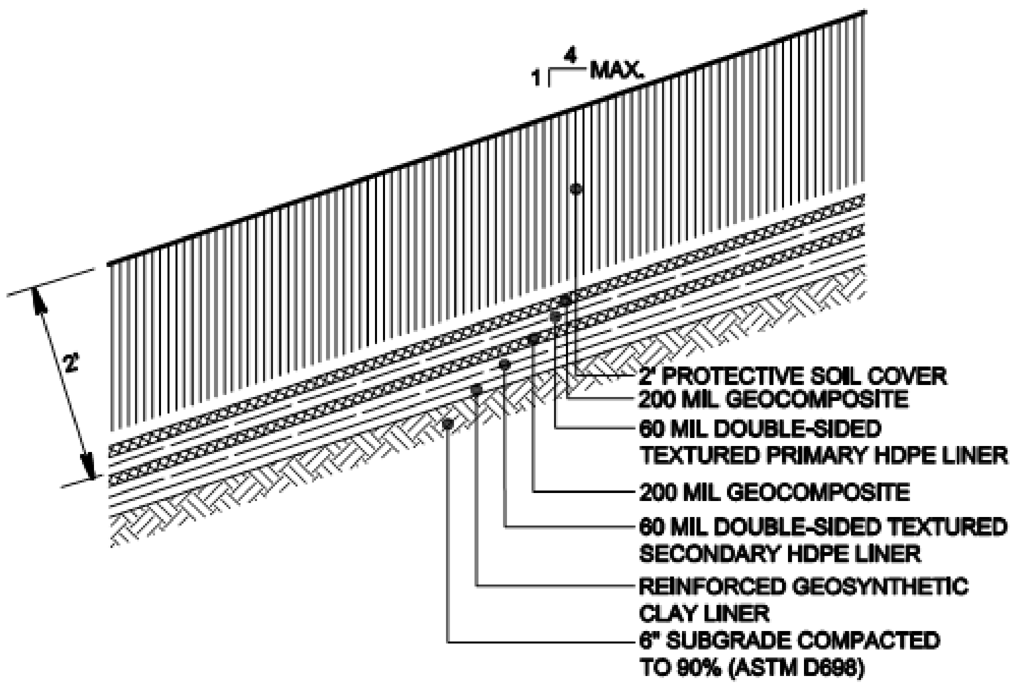
**Table 2.4 – SDR 11.0 HDPE Pipe Results Dncs Environmental Solutions**

| 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 |

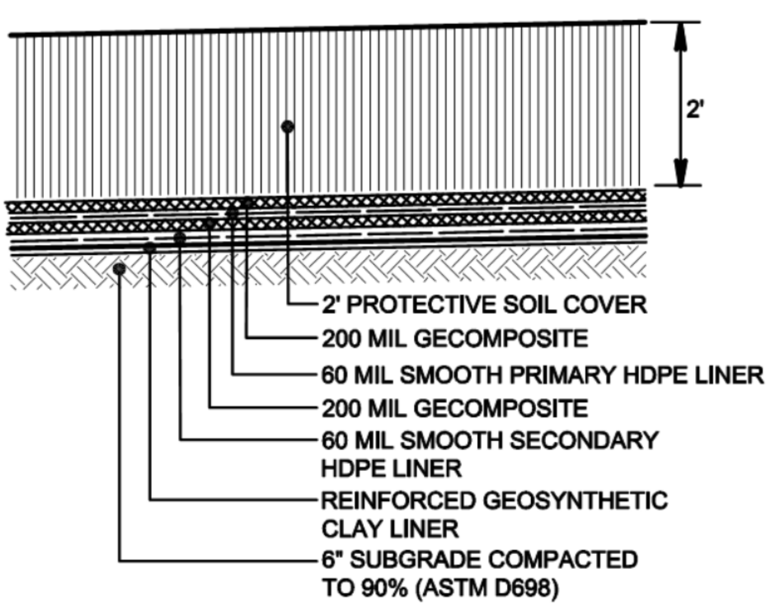
As shown, for each limiting design criterion, the factor of safety is greater than design criteria, thus the performance standard for the HDPE pipes is adequate.

# 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°<br>Average = 10° | 0 |
| Geonet to Smooth HDPE FML [1] | 5° - 19°<br>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.

$$W_w = ½\gamma_w H(H/\tan\beta) + ½\gamma_s H(H/\tan\beta)$$

Where:

$W_w$ = weight of lift per unit width

H = lift height

$\beta$ = slope angle

$\gamma_w$ = unit weight of waste

$$W_w = ½(74)(8)(8/\tan 14.04) + ½(110)(2)(2/\tan 14.04) = 10{,}349 \text{ lbs/ft}$$

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

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

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

Where:

$T_w$ = frictional resistance force per unit width

$\sigma_h$ = horizontal stress of waste lift

$\Phi_w$ = waste friction angle

$K_o$ = coefficient of earth pressure at rest

$\sigma_v$ = 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 lbs/ft + 65 lbs/ft

$T_w$ = 765 lbs/ft

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

Where:

$W_{net}$ = net weight of waste

$W_{net}$ = 10,349 lbs/ft – 765 lbs/ft

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

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

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

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

N = 9,297.7 lb/ft

P = 2,323 lb/ft

The critical interface of the liner system occurs at the geocomposite to double-sided textured HDPE interface. $F_1$ is calculated for gecomposite 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 lbs/ft

$F_2$ = 4,595.2 lbs/ft

$F_1 - F_2$ = 5,809.8 lbs/ft – 4,595.2 lbs/ft = 1,212.6 lbs/ft = 101.2 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/yd$^2$ geotextile

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

$T_f$ = 575 lbs/π(0.98 in) = 186.76 lbs/in

F.S. = $(T_f)/(F_1 - F_2)$ = 186.76 lbs/in/101.2 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/ft$^3$ 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.

<u>Tensile forces acting on geomembrane</u>:

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

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

Fsoil = 3,736 lbs/ft

$F_{dozer}$ = [(dozer weight) / (width acting on geocomposite)] (sin(14.04°))

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

$F_{dozer}$ = 448 lbs/ft

Total tensile force acting on geocomposite = 3,736 lbs/ft + 448 lbs/ft = 4,184 lbs/ft

Total resisting forces acting on geomembrane:

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

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

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

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

$F_{buttress}$ = [[cos(33°) / cos(33° + 14.04°)] [(110 lbs/ft$^3$(2 ft)$^2$) / sin(2(14.04°))] [tan(33°)]

$F_{buttress}$ = 747 lbs/ft

Total resisting force acting on geomembrane = 8,269 lbs/ft + 747 lbs/ft = 9,016 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

$\delta_c$ = friction angle between the GCC and underlying soil = 28.2°

$\Theta$ = 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

$\delta_f$ = interface friction angle between the geomembrane and the compacted backfill soil = 32°

$\beta$ = sideslope angle, measured from horizontal = 14.04°

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

T = 1,884 lbs/ft = 157 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 sidelsope 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° 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 |

[Continued on next page]

[Continued from previous page]

| | |
|---|---|
| $b_P$ = | 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:

$W_A = 1/2((b*h_a*y)+(b*h_b*y))$

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

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

$W_P = 1/2(b_P*h_t*y)=W_P=1/2(420ft*140ft*74(lbs/ft^3))=2,175,600\ lbs/ft$

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

Factor of safety:

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

Where:

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

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

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

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

and:

$\beta$ = 14.04° - sideslope angle

$\Theta$ = 1.15° - subgrade angle

$\delta_P$ = 10° - minimum friction angle of bottom liner system

[Continued on next page]

[Continued from previous page]

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

$\varnothing_S$ = 33° - 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**

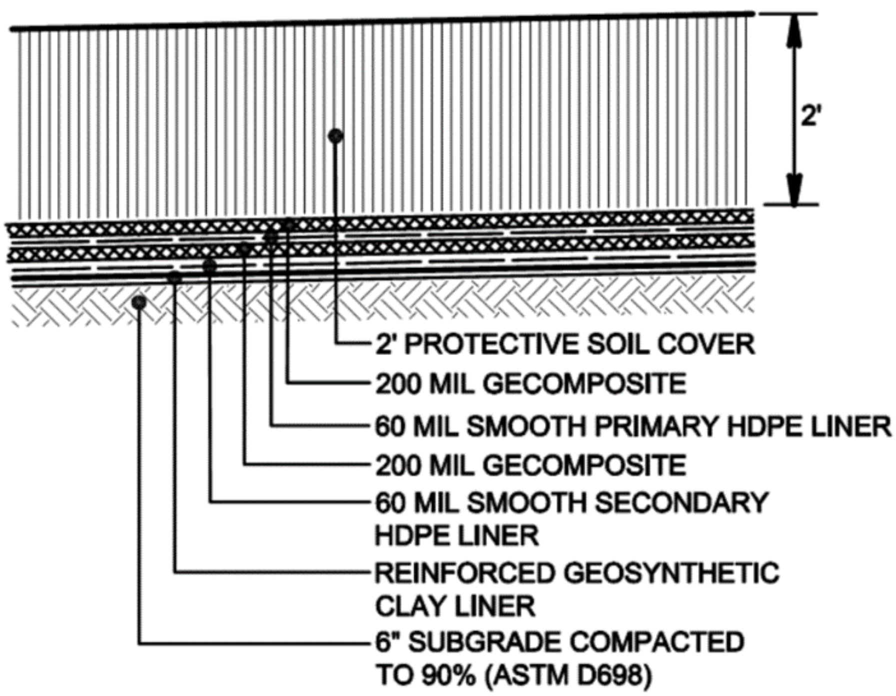
| Assumed FS | Result |
|---|---|
| 1 | -630,808 |
| 2.75 | 20,075 |
| 2.76 | -10,105 |

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)

$\sigma_n$ = applied overburden pressure = 81.7 psi (See calculations below)

$\beta$ = angle of force applied to synthetic liner = 45° (Reference 6)

$\sigma_{allow}$ = liner allowable stress at yield = 2100 psi (Reference 6)

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

$\delta_U$ = friction angle between the liner and the upper interface = 10° (Table 3.2)

$\delta_L$ = 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

$\gamma_w$ = unit weight of waste

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

$\gamma_s$ = 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

$\sigma_n$ = 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).

$$t_{reqd} = \frac{81.7\text{psi} * 2\text{in} * (\tan 10° + \tan 12°)}{2100\text{ psi} * (\cos 45° - \sin 45° \tan 12°)}$$

$$t_{reqd} = 0.0543\text{ inches} = 54.3\text{ mils}$$

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 = $(t_{60mil})/(t_{reqd})$ = 60 mils/54.3 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 x K x LS x 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 | | From Soil Survey local soils (silty clay loam) and table 8.4, page 261, Hann, Barfield text |
| | | 0.15 | | |
| 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 |
| | = | $1\text{-}F_C * \exp(-0.1H)$ | | 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 |
| | | | $R_G = (25.4 * R_R\text{-}6)*(1\text{-}\exp(-0.0015R_S))*(\exp(-0.14P_T))$ | |
| | | | $R_R$ = | 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 roughnes subfactor | | |
| | = | $\exp(-0.026*R_G)$ | $R_G$ = surface roughness variable | eq. 8.62, page 273 in Haan, Barfield text see above for references and equation |
| | | $R_G$ = | 2.32 | |
| | = | 0.94 | | |
| $C_{SR}$ | - | 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 isolinear 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 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 lbs/acre

Solve for E:

Using the E-Table, a value of E = 1.2 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.

$$\mathrm{Ze} = \left(\frac{\Delta\sigma}{\mathrm{Ms}}\right)\mathrm{Ho}$$

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/ft$^2$

Ms = constrained modulus of soil, lb/ft$^2$

The constrained modulus is provided in this equation:

$$M_S = \frac{E_S(1-v_s)}{(1+v_s)(1-2*v_s)}$$

Where:

$M_S$ = constrained modulus of soil, lb/ft$^2$

$E_S$ = elastic modulus of soil (lb/ft$^2$) found using Reference 1

$E_S$ = (4,700 psi + 1,600 psi) / 2 = 10,350 (144) = 1,490,400 lbs/ft$^2$

$v_s$ = 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/ft$^3$ dry density

Unit Weight of Waste = 74 lb/ft$^3$

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

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

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

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

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

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:

$\Delta H_C$ = 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

$\sigma_o$ = previously applied pressure in waste layer (assumed to equal the compaction pressure = 1,000 lbs/ft$^2$)

$\sigma_i$ = total overburden pressure applied at the mid-level of the waste layer (lbs/ft$^2$)

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

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

Where:

$\Delta H_S$ = 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:

<u>Primary Waste Settlement</u>

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 ft

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

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

<u>Secondary Waste Settlement</u>

$H_O$ = 157 ft – 0.702 ft = 156.298 ft

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

Total waste settlement = 0.735 ft + 0.46 ft = 1.2 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

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

$C_C/(1+e_o) = 0.0006$

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 $lbs/ft^3$ Dry Density

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

$P_O = (H/2)(110\ lbs/ft^3) = 3.0(110) = 330\ lbs/ft^2$

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

$\Delta H_P = 0.017$ ft

Secondary Soil Settlement

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

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

$H_O = 6.0\ ft – 0.017\ ft = 5.983\ ft$

$\Delta H_S = 0.002\ (5.983\ ft)\ \log 30/1 = 0.018\ ft$

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.

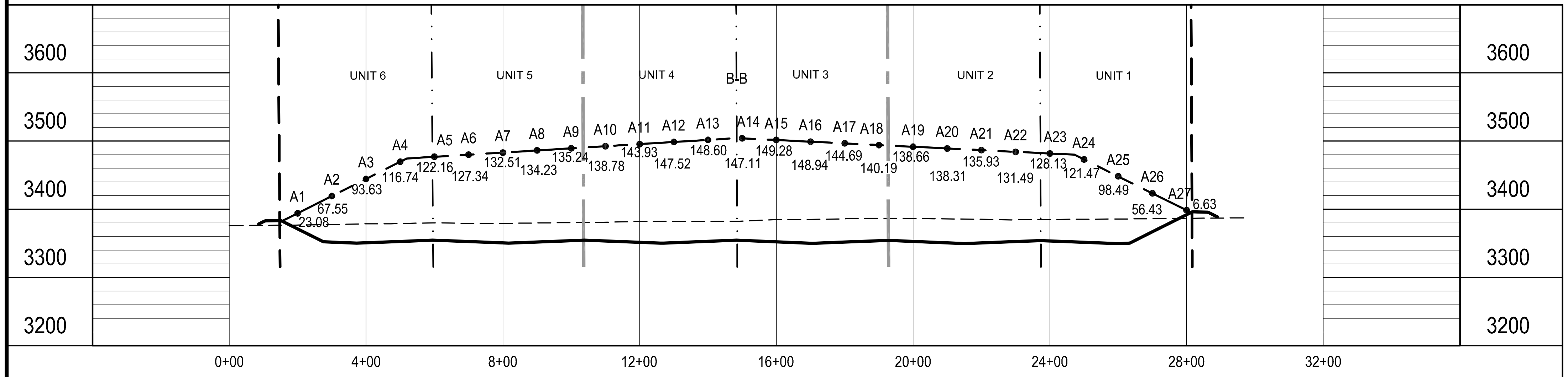
## 5.4 Conclusion

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 ft + 1.2 ft + 0.035 ft = 1.476 ft).

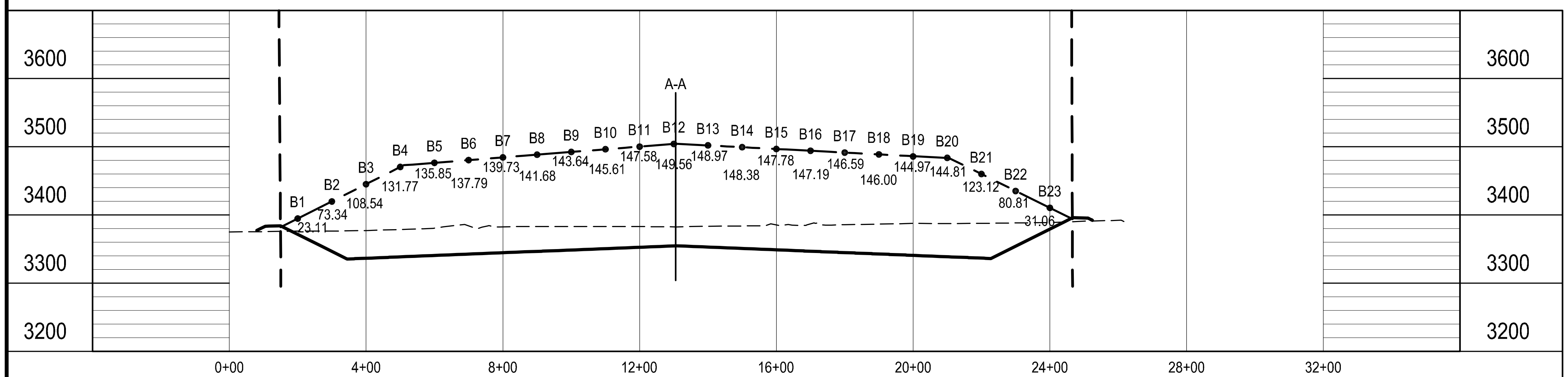
The final cover slope, liner, and leachate collection pipe after settlement is adequate and consistent with the performance specifications for leachate collection system and stormwater controls and the New Mexico Oil Conservation Division.

FILE NAME: \\Data1\Projects\2015\0580.15\BIM_CAD\09_PERMIT\Volume III\FIG.III.9.1 - SETTLEMENT POINTS.dwg LAYOUT 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'

SCALES:

HORIZONTAL

0 400' 800'

VERTICAL

0 200' 400'

LEGEND

LIMIT OF WASTE

EXISTING GRADE

BASE GRADE

TOP OF WASTE

B4 SETTLEMENT POINT LOCATION

146.00 DEPTH OF WASTE

PSC PARKHILL SMITH & COOPER

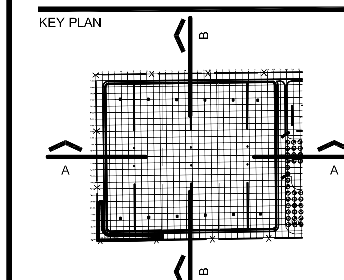
# C. K. DISPOSAL E & P LANDFILL & PROCESSING FACILITY

NMED PERMIT NO. ___

NEW LANDFILL SITE & PROCESSING FACILITY

LEA COUNTY, NEW MEXICO

KEY PLAN




| NO | DATE | 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/ft$^2$

$P_i$ = 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 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 (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 valve is calculated.

K = $T_{FS}$ / t

K = (3.84E – 04$m^2$/s) / (0.1375 in)

K = 10.99 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:

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

GSE Fabrinet HF

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

| 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 |

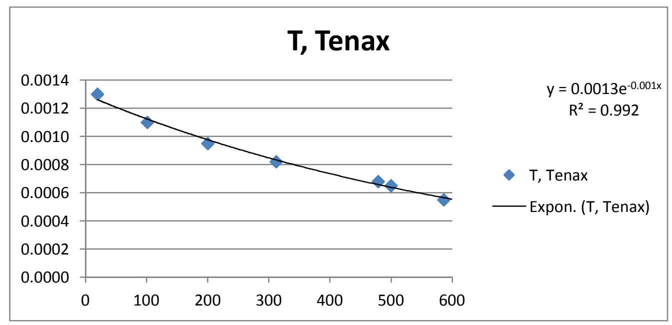
1. Geocomposite Thickness

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 |




1. $d_w$ is the depth of waste above the geocomposite
2. $d_s$ is the depth of soil above the geocomposite
3. P is the pressure on the geocomposite due to the weight of the waste and soil.
4. 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 |

1. T is the geocomposite Transmissivity value.
2. $T_{FS}$ is the geocomposite Transmissivity taking into account the FS.
3. k is the geocomposite hydraulic conductivity input

$k = T_{FS}/t$

# 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:

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

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.

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

$0.2 < (2.5)(0.2)$

$0.2 < 0.5$

## 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:

$\Psi$ = 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 $gpm/ft^2$

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

K = 0.06 m/s

Geotextile thickness = 100 mil = 0.00254 meter

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

### 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/yd$^2$ = 0.027 g/cm$^2$

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/cm$^3$, 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 g/cm$^2$) / (0.94 g/cm$^3$)(0.254 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 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*PGA was used. A conservative $k_H$ of 0.8*PGA was used for this design. A vertical seismic loading coefficient of 0.66*$k_H$ was also applied to the model.

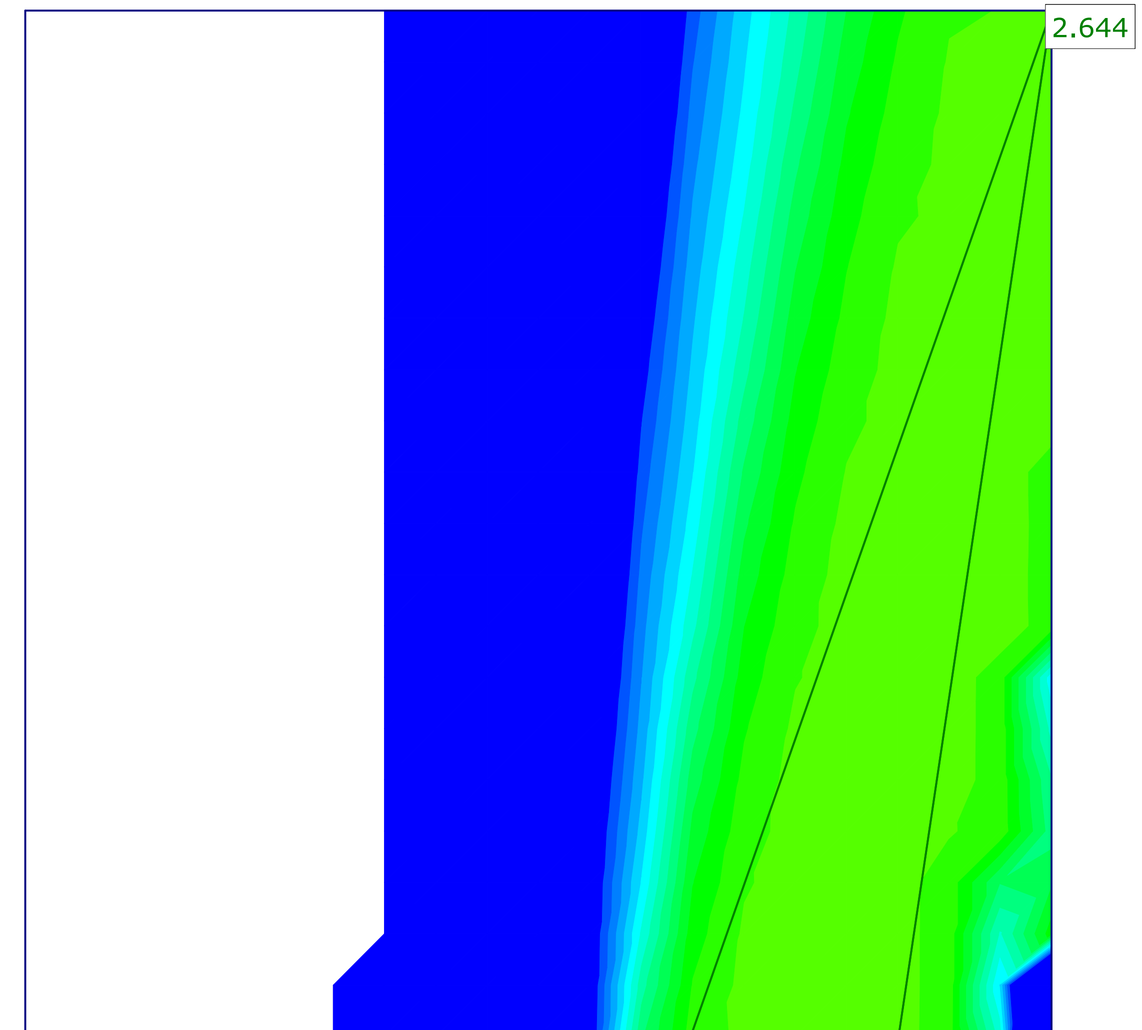
The resulting seismic loading coefficients are $k_H$ = 0.8 and $k_v$ = 0.5. When these parameters were input to the static slope stability model in Slide 7.0, Factors of Safety greater than 2.0 were resultant for both slopes. A minimum accepted Factor of Safety is 1.1 for pseudo-static slope stability.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

1. Gray, Donald, Robert M. Koerner, and Xian Quede, *Geotechnical Aspects of Landfill Design and Construction*. New York: Prentice Hall, 2002. Print.
2. *Handbook of PVC Design*. Uni-Bell PVC Pipe Association, 2001. Print.
3. Parametrix, Inc. *Solid Waste Landfill Design Manual.* Washington State Department of Ecology. June 1987. Web. 3 May 2016. <https://fortress.wa.gov/ecy/publications/documents/87013.pdf>.
4. Driscopipe, Inc., *Polyethylene Piping Systems Manual*. 2008.
5. Chevron Phillips Chemical Company LP. *The Performance Pipe Engineering Manual.* CPChem Performance Pipe. Chevron Phillips, 2002. Web. 3 May 2016. <http://www.cpchem.com/en-us/Pages/default.aspx>.
6. Richardson, Clinton P., *Municipal Landfill Design Calculations: An Entry Level Manual of Practice*. California: UBuildABook, LLC, 2009. Print.
7. Bachus, Robert, Mengjia Li, Dhani Narejo, Richard Thiel, and Te-Yang Soong, *GSE Drainage Design Manual.* GSE Environmental, June 2007. Web. 3 May 2016. <https://www.gseworld.com/content/documents/product-sheets/Drainage_Design_Manual.pdf>
8. Koloski, Jon, Signmund Schwarz, and Donald Tubbs. *Geotechnical Properties of Geologic Materials*. Geotechnical Properties of Geologic Materials. 1989. Web. 3 May 2016. http://www.tubbs.com/geotech/geotech.htm
9. Sangeeta, Lewis P., and Hari D. Sharma, *Waste Containment Systems, Waste Stabilization and Landfills: Design and Evaluation.* New York: John Wiley and Sons. 1994. Print.
10. Koerner, Robert M., *Designing with Geosynthetics*. 6th ed., Vol. 1. 2012. Print.
11. Coduto, Donald P., Man-chu R. Yeung, and William A. Kitch. *Geotechnical Engineering Principles and Practices*. 2nd ed. Upper Saddle River: Pearson Higher Education, 2011. Print.

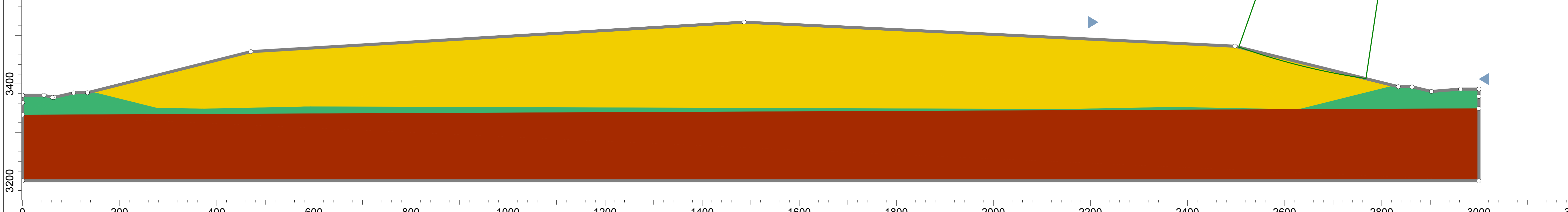
.

# APPENDIX A
## STATIC MODEL INPUTS AND OUTPUTS



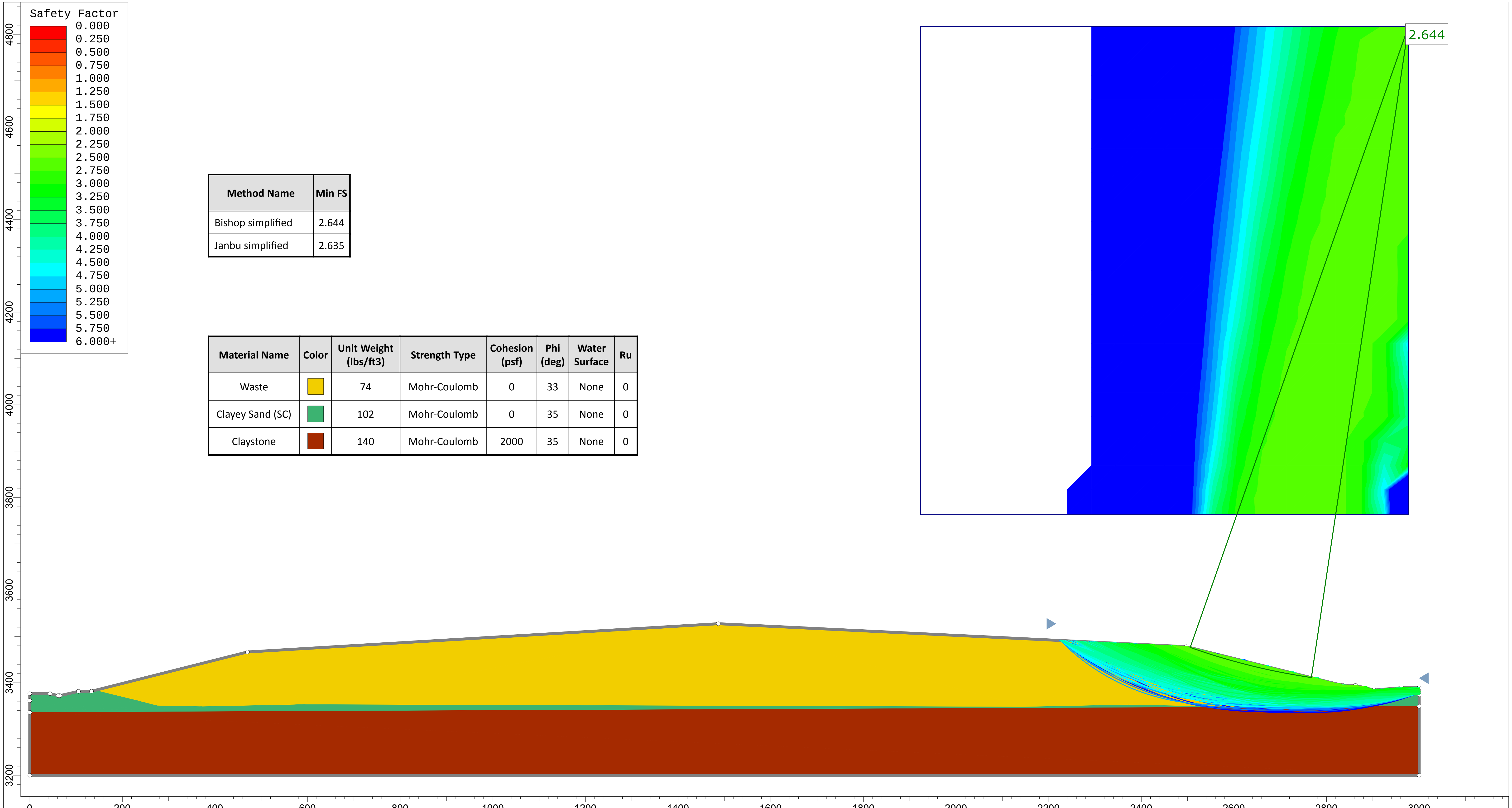

| Method Name | Min FS |
|---|---|
| Bishop simplified | 2.644 |
| Janbu simplified | 2.635 |

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




| | |
|---|---|
| *Project* | CK Disposal Facility, East Slope |
| *Analysis Description* | Final Cover |
| *Drawn By* | |
| *Scale* | 1:2364 |
| *Company* | Parkhill, Smith & Cooper Inc. |
| *Date* | 4/19/2016, 5:02:51 PM |
| *File Name* | EAST SLOPE STATIC.slim |

SLIDEINTERPRET 7.014




| 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 | | 74 | Mohr-Coulomb | 0 | 33 | None | 0 |
| Clayey Sand (SC) | | 102 | Mohr-Coulomb | 0 | 35 | None | 0 |
| Claystone | | 140 | Mohr-Coulomb | 2000 | 35 | None | 0 |

| | |
|---|---|
| *Project* | CK Disposal Facility, East Slope |
| *Analysis Description* | Final Cover |
| *Drawn By* | |
| *Scale* | 1:2364 |
| *Company* | Parkhill, Smith & Cooper Inc. |
| *Date* | 4/19/2016, 5:02:51 PM |
| *File Name* | EAST SLOPE STATIC.slim |

SLIDEINTERPRET 7.014

# 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 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 |

## 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 | 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 ft2 |
| 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 ft2 |
| 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

| 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

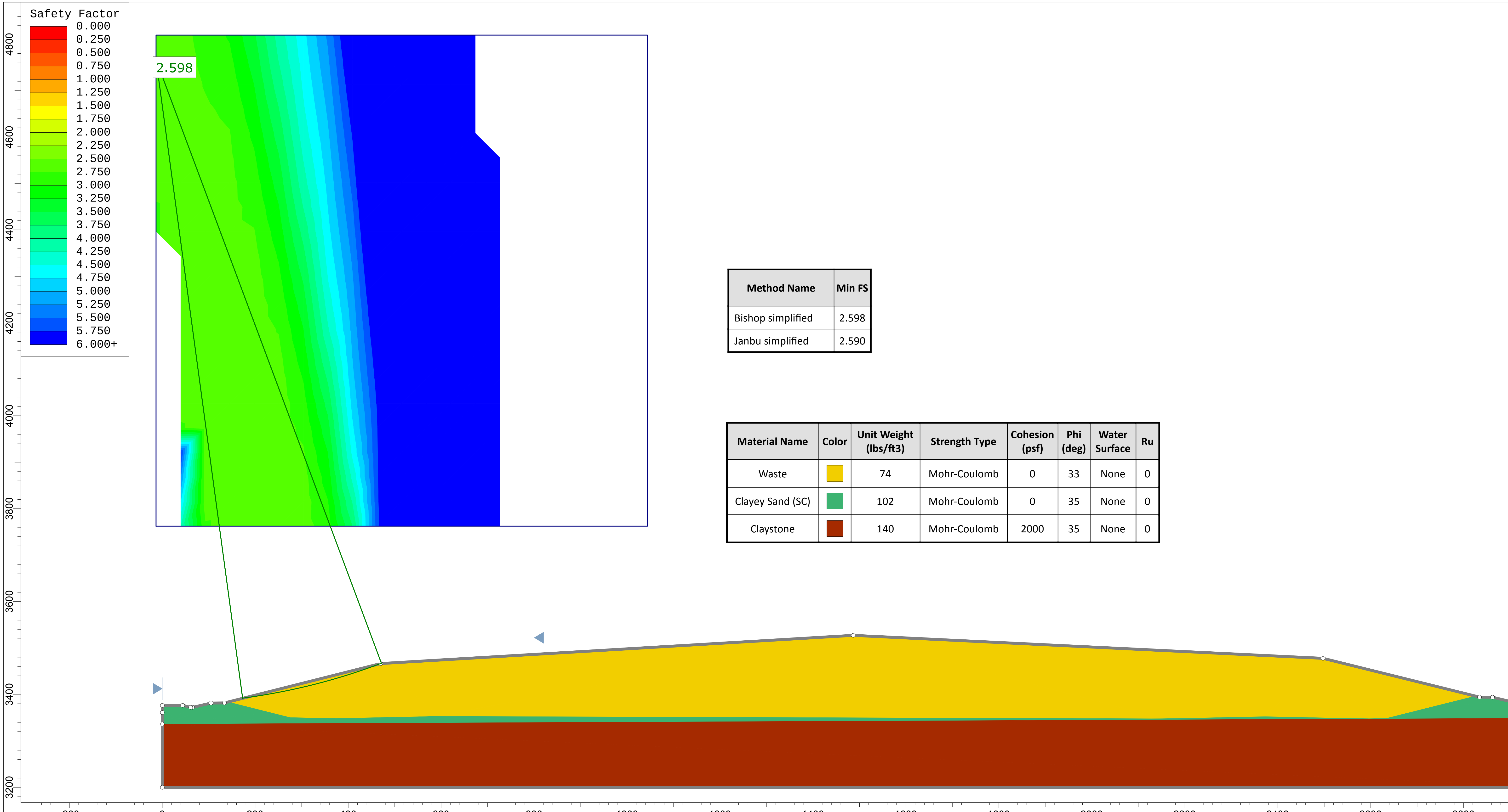
| X | Y |
|---|---|
| 594.53 | 3353.96 |
| 594.61 | 3352.96 |

### Material Boundary

| X | Y |
|---|---|
| 2150.44 | 3348.83 |
| 2150.52 | 3347.83 |

### Material Boundary

| X | Y |
|---|---|
| 0 | 3336 |
| 3000 | 3349 |

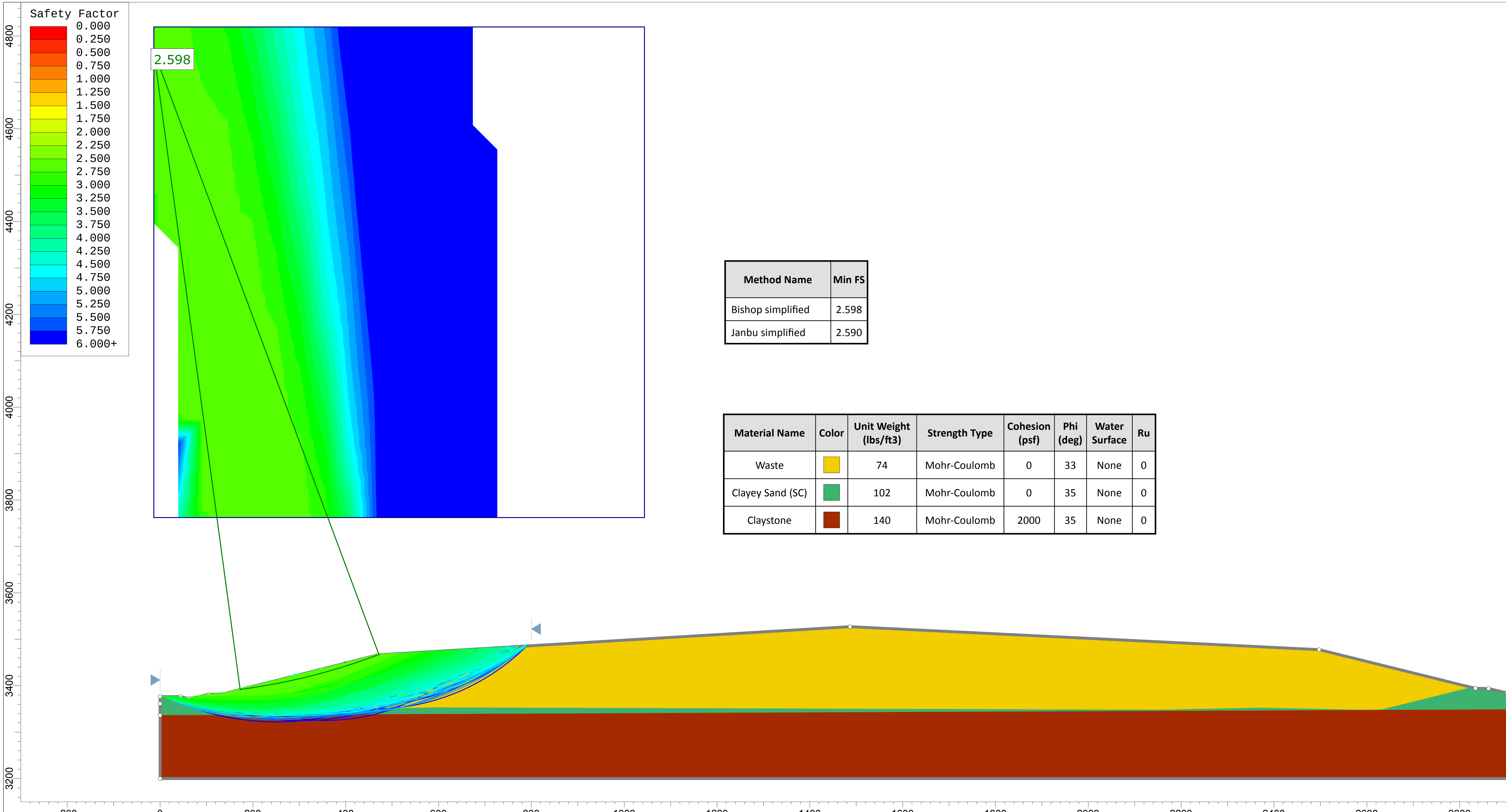



| Method Name | Min FS |
|---|---|
| Bishop simplified | 2.598 |
| Janbu simplified | 2.590 |

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

SLIDEINTERPRET 7.014

| | | | |
|---|---|---|---|
| Project | CK Disposal Facility, West Slope | | |
| Analysis Description | Final Cover | | |
| Drawn By | | Scale | 1:2375 |
| 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/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | Water Surface | Ru |
|---|---|---|---|---|---|---|---|
| Waste | | 74 | Mohr-Coulomb | 0 | 33 | None | 0 |
| Clayey Sand (SC) | | 102 | Mohr-Coulomb | 0 | 35 | None | 0 |
| Claystone | | 140 | Mohr-Coulomb | 2000 | 35 | None | 0 |

rocscience

SLIDEINTERPRET 7.014

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

# 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 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 |

## 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 | 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 ft2 |
| 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 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**: 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

| 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

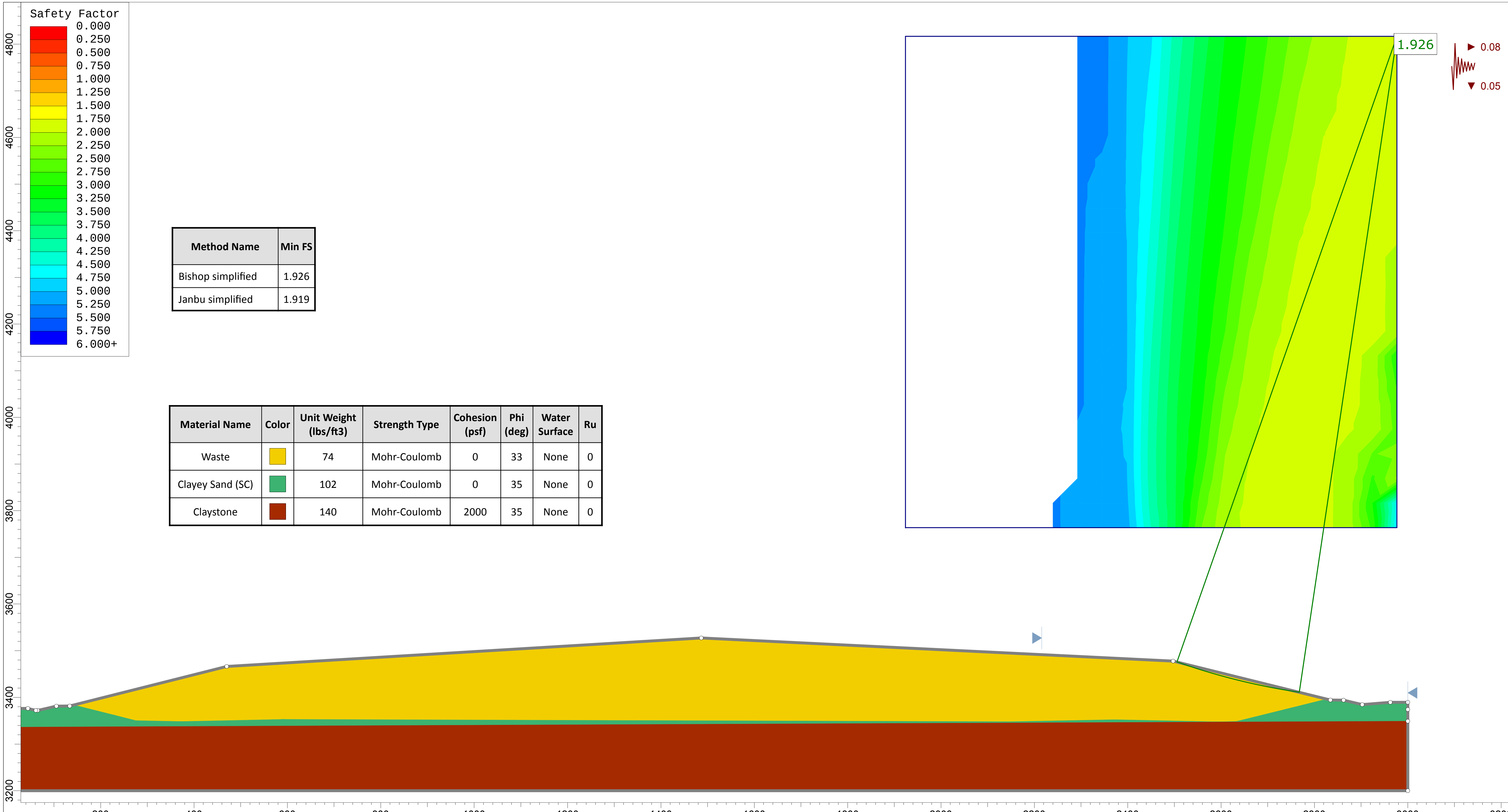
| X | Y |
|---|---|
| 2150.44 | 3348.83 |
| 2150.52 | 3347.83 |

## Material Boundary

| X | Y |
|---|---|
| 0 | 3336 |
| 3000 | 3349 |

# APPENDIX B

# PSEUDO – STATIC MODEL INPUTS AND OUTPUTS

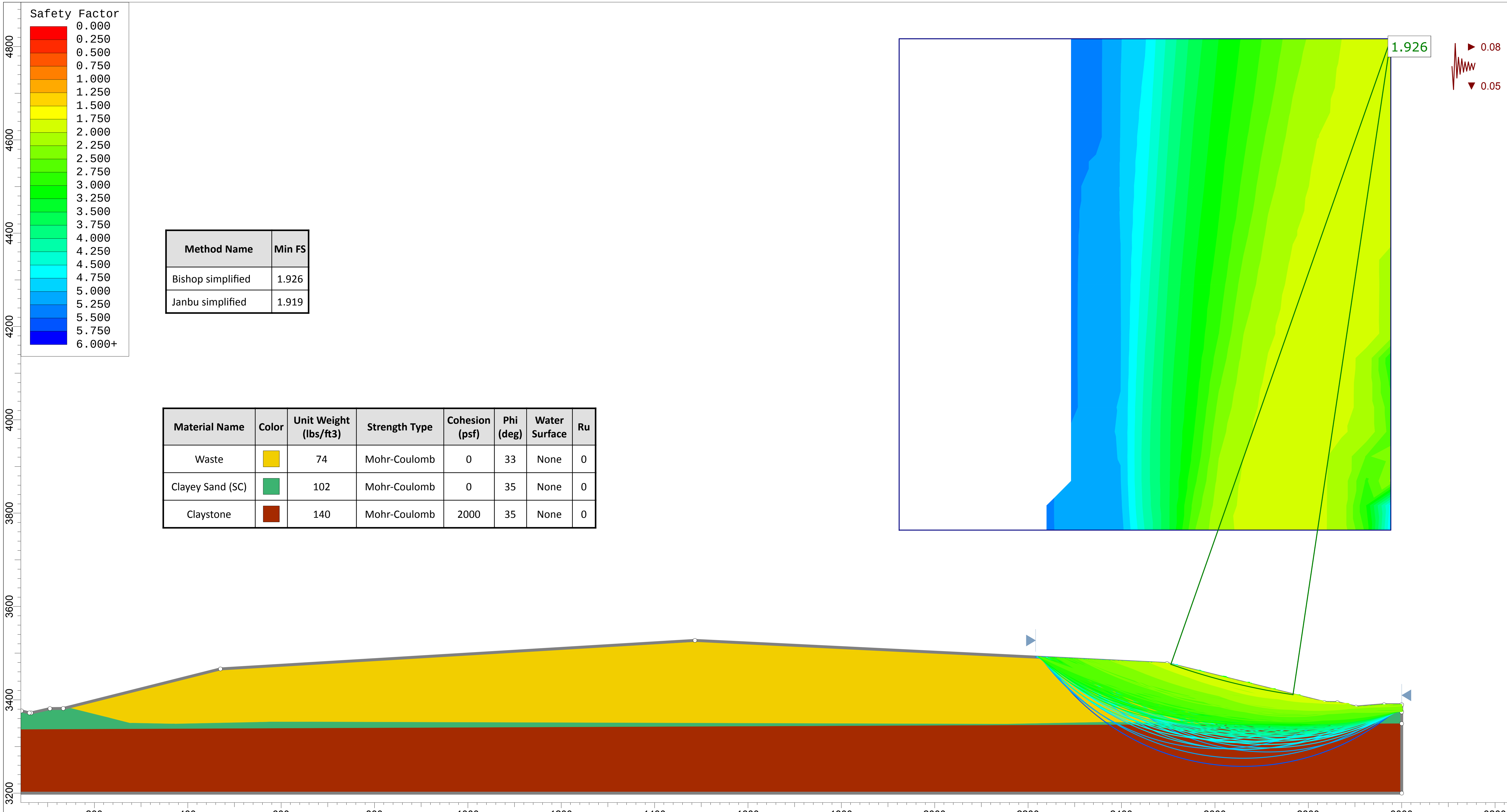



| Method Name | Min FS |
|---|---|
| Bishop simplified | 1.926 |
| Janbu simplified | 1.919 |

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

SLIDEINTERPRET 7.014

| | | | |
|---|---|---|---|
| *Project* | CK Disposal Facility, East Slope | | |
| *Analysis Description* | Final Cover | | |
| *Drawn By* | | *Scale* 1:2364 | *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/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | Water Surface | Ru |
|---|---|---|---|---|---|---|---|
| Waste | | 74 | Mohr-Coulomb | 0 | 33 | None | 0 |
| Clayey Sand (SC) | | 102 | Mohr-Coulomb | 0 | 35 | None | 0 |
| Claystone | | 140 | Mohr-Coulomb | 2000 | 35 | None | 0 |

| | | | |
|---|---|---|---|
| *Project* | CK Disposal Facility, East Slope | | |
| *Analysis Description* | Final Cover | | |
| *Drawn By* | | *Scale* 1:2364 | *Company* Parkhill, Smith & Cooper Inc. |
| *Date* | 4/19/2016, 5:02:51 PM | | *File Name* EAST SLOPE SEISMIC.slim |

SLIDEINTERPRET 7.014

# 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 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 | 1.925620 |
|---|---|
| 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 ft2 |
| 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 ft2 |
| 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

| 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

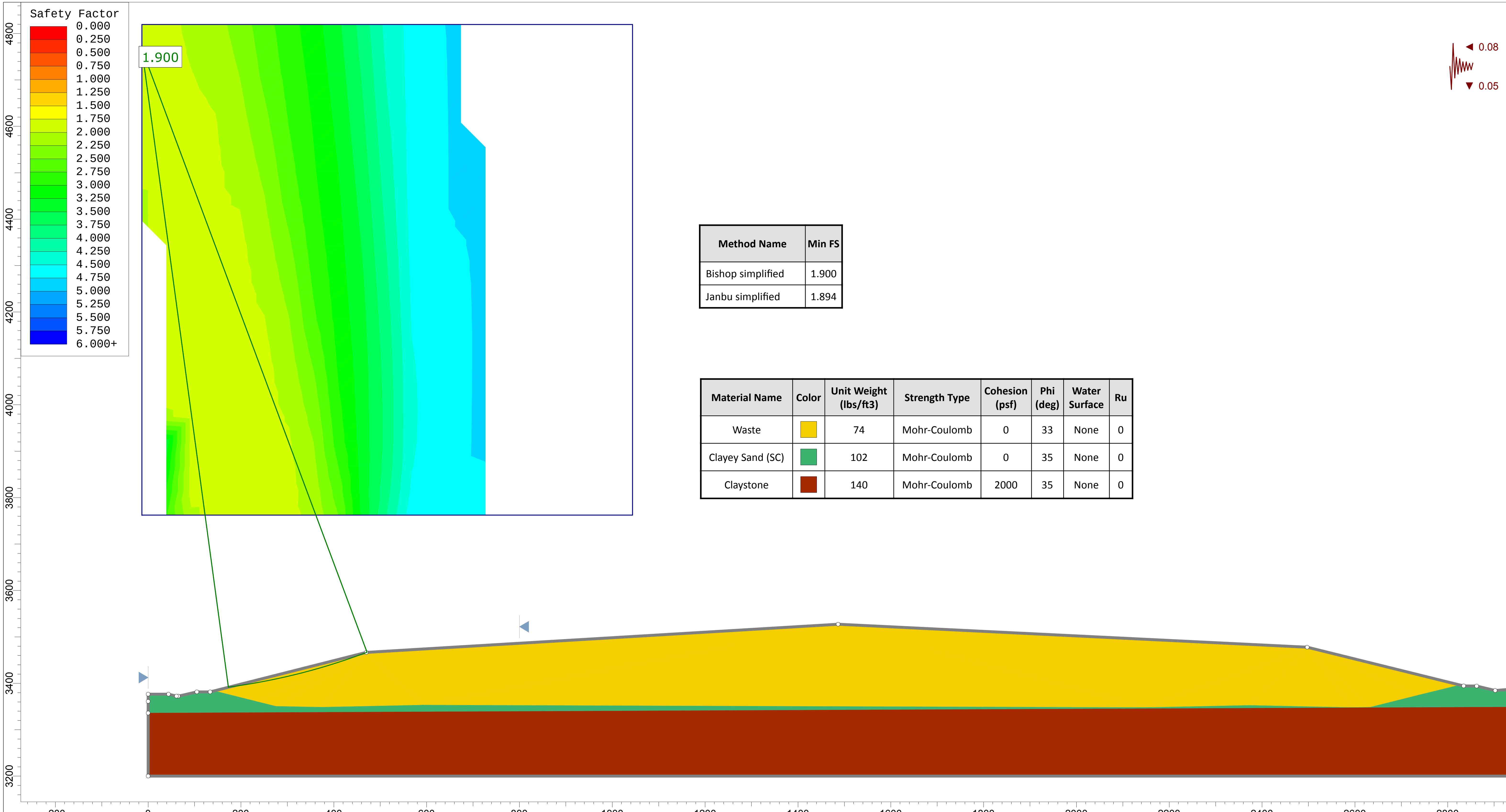
| X | Y |
|---|---|
| 594.53 | 3353.96 |
| 594.61 | 3352.96 |

## Material Boundary

| X | Y |
|---|---|
| 2150.44 | 3348.83 |
| 2150.52 | 3347.83 |

## Material Boundary

| X | Y |
|---|---|
| 0 | 3336 |
| 3000 | 3349 |

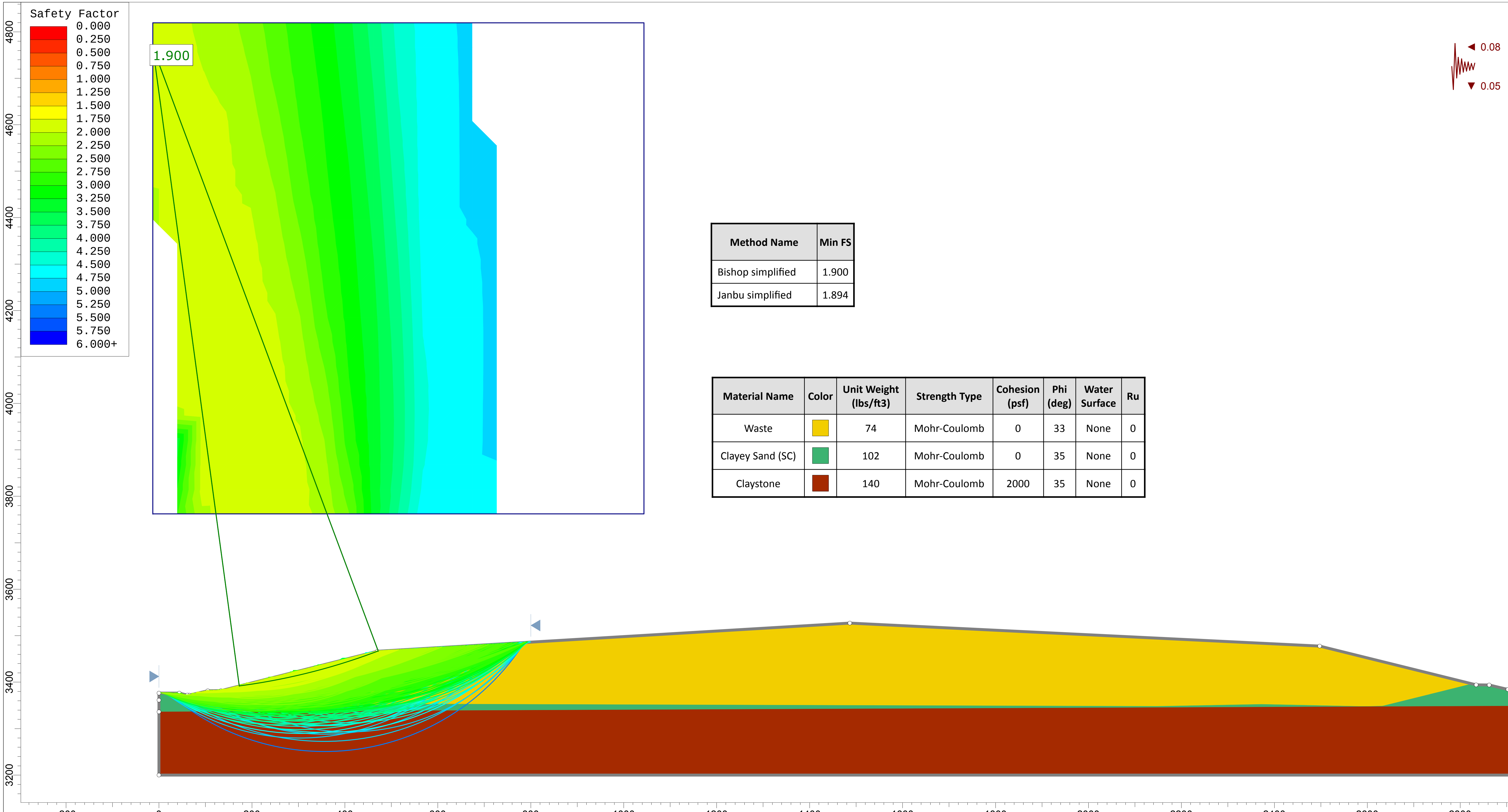



| Method Name | Min FS |
|---|---|
| Bishop simplified | 1.900 |
| Janbu simplified | 1.894 |

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

SLIDEINTERPRET 7.014

| | |
|---|---|
| *Project* | CK Disposal Facility, West Slope |
| *Analysis Description* | Final Cover |
| *Drawn By* | |
| *Scale* | 1:2375 |
| *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 | | 74 | Mohr-Coulomb | 0 | 33 | None | 0 |
| Clayey Sand (SC) | | 102 | Mohr-Coulomb | 0 | 35 | None | 0 |
| Claystone | | 140 | Mohr-Coulomb | 2000 | 35 | None | 0 |

rocscience

SLIDEINTERPRET 7.014

| | |
|---|---|
| *Project* | CK Disposal Facility, West Slope |
| *Analysis Description* | Final Cover |
| *Drawn By* | |
| *Scale* | 1:2375 |
| *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

| 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

# Design Maps Detailed Report

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

Site 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

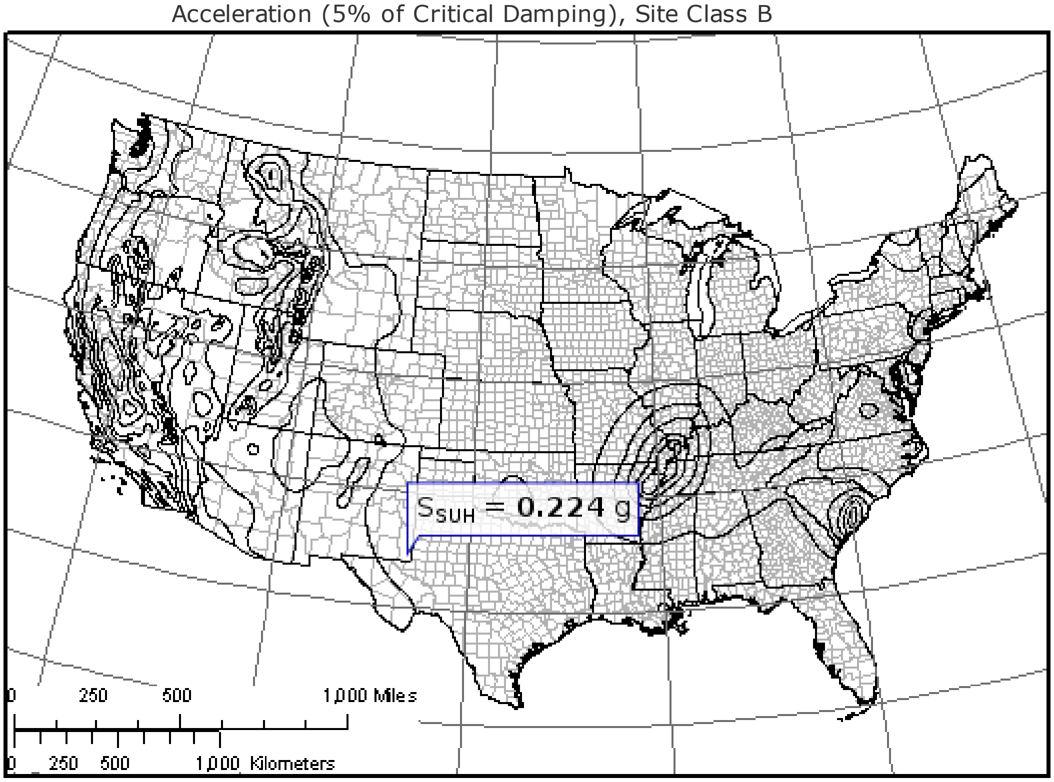



Figure 22–2: Uniform–Hazard (2% in 50–Year) Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B

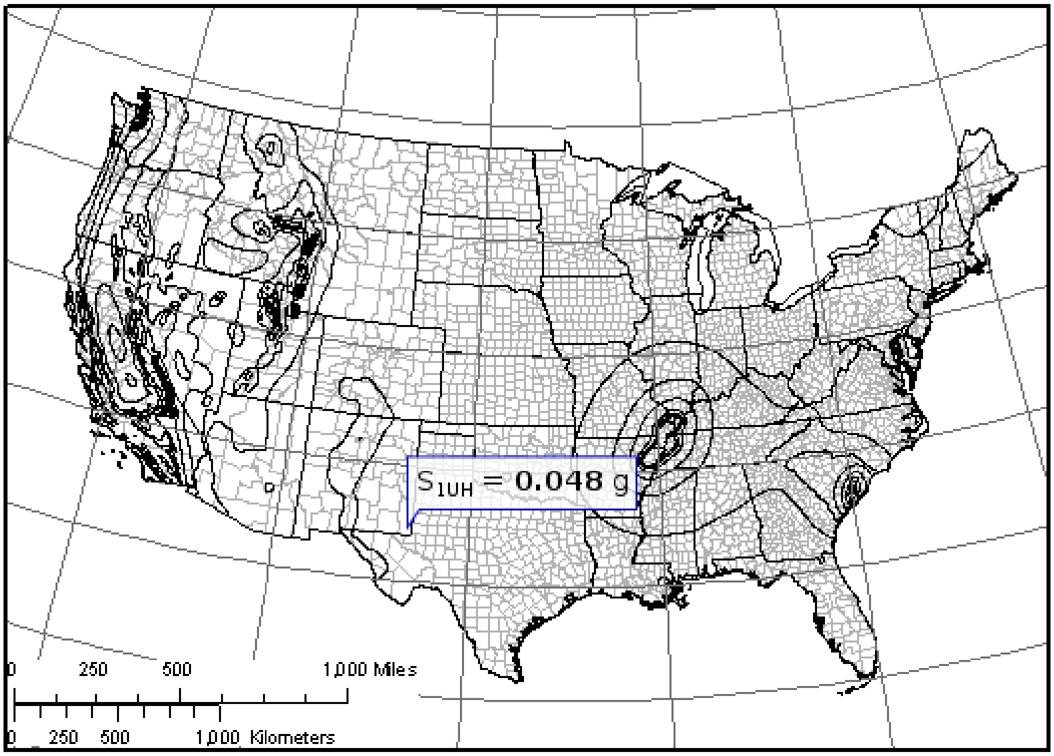

$S_{1UH}$ = 0.048 g
0 250 500 1,000 Miles
0 250 500 1,000 Kilometers

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

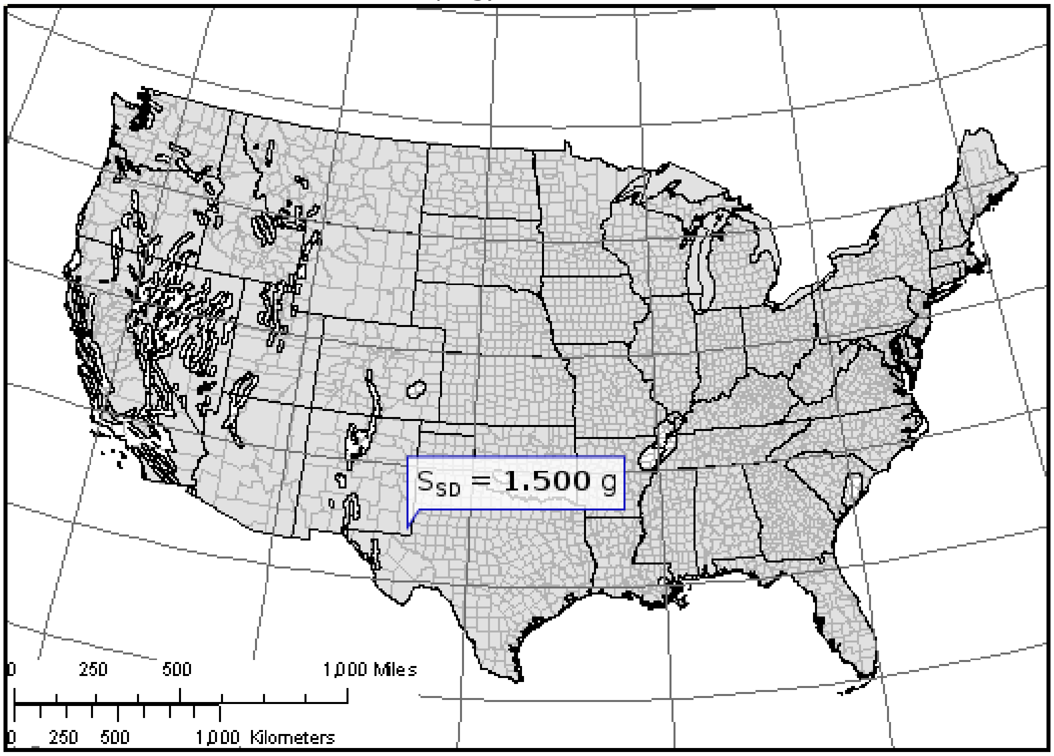
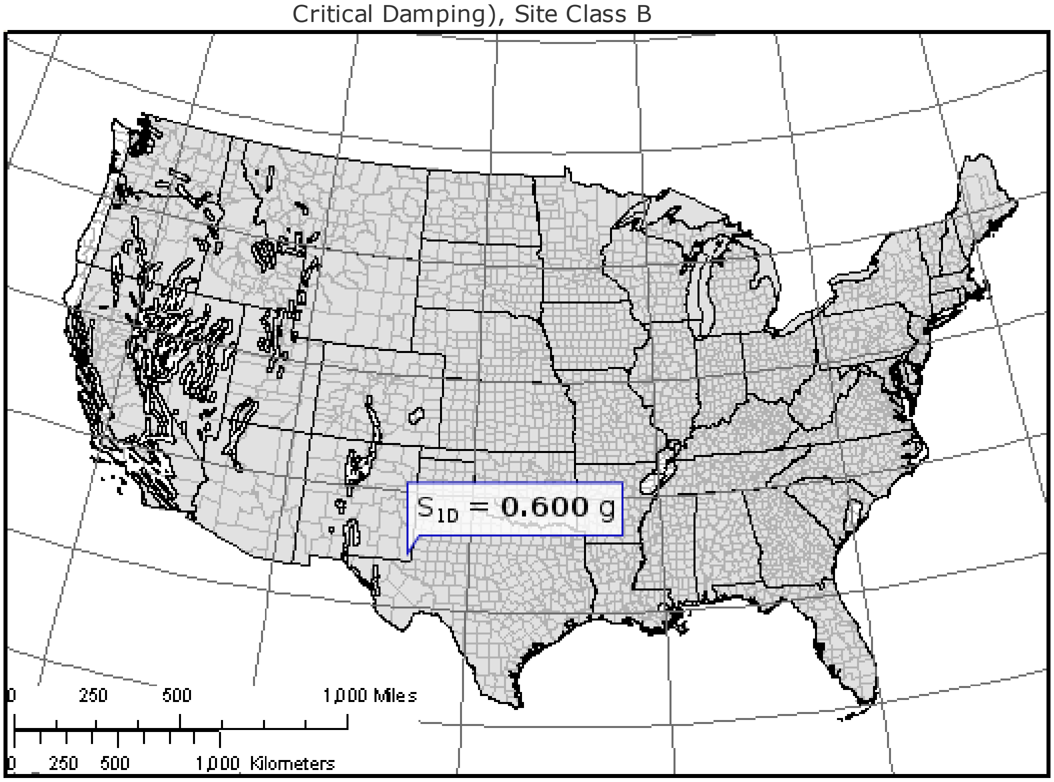



Figure 22–6: Deterministic Ground Motions of 1.0-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B



## Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default 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* ≥ 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 | | |

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 x 0.224 = 0.195 g

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

$S_S$ ≡ “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 x 0.048 = 0.044 g

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

$S_1$ ≡ “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 | | | | |
|---|---|---|---|---|---|
| | $S_S \le 0.25$ | $S_S = 0.50$ | $S_S = 0.75$ | $S_S = 1.00$ | $S_S \ge 1.25$ |
| 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 | | | | |
|---|---|---|---|---|---|
| | $S_1 \le 0.10$ | $S_1 = 0.20$ | $S_1 = 0.30$ | $S_1 = 0.40$ | $S_1 \ge 0.50$ |
| 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):** $S_{MS} = F_a S_S = 1.600 \times 0.195 = 0.312$ g

**Equation (11.4–6):** $S_{M1} = F_v S_1 = 2.400 \times 0.044 = 0.105$ g

## Section 11.4.4 — Design Spectral Acceleration Parameters

**Equation (11.4–7):** $S_{DS} = ⅔ S_{MS} = ⅔ \times 0.312 = 0.208$ g

**Equation (11.4–8):** $S_{D1} = ⅔ S_{M1} = ⅔ \times 0.105 = 0.070$ g

## Section 11.4.5 — Design Response Spectrum

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

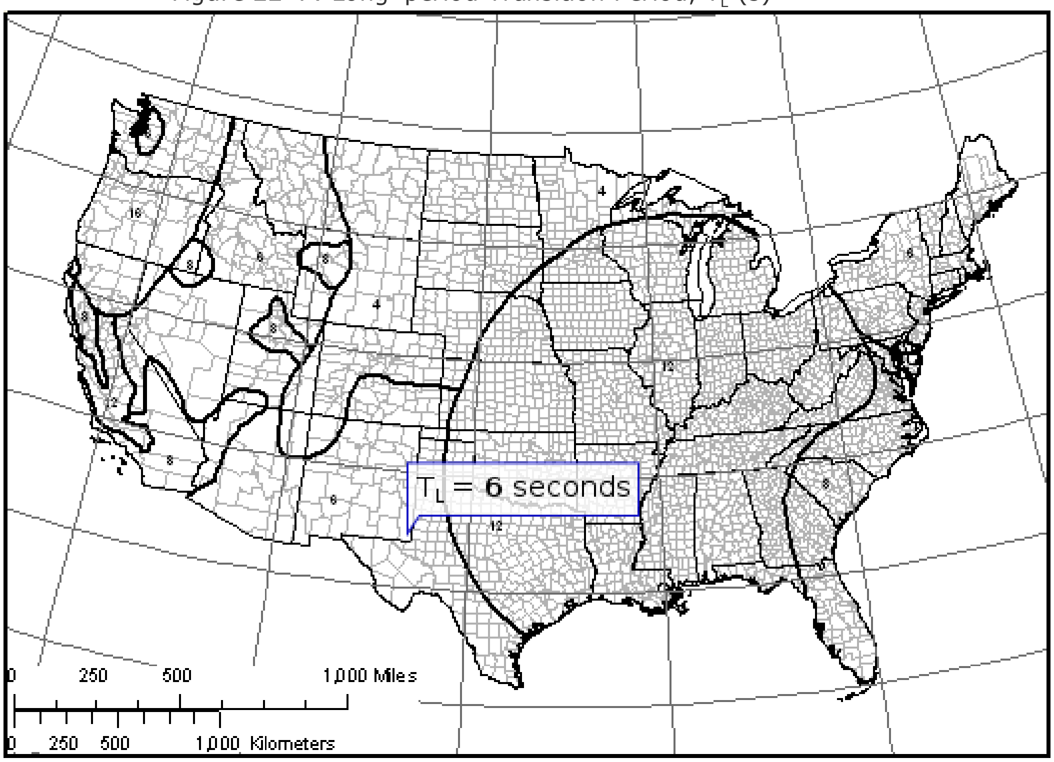
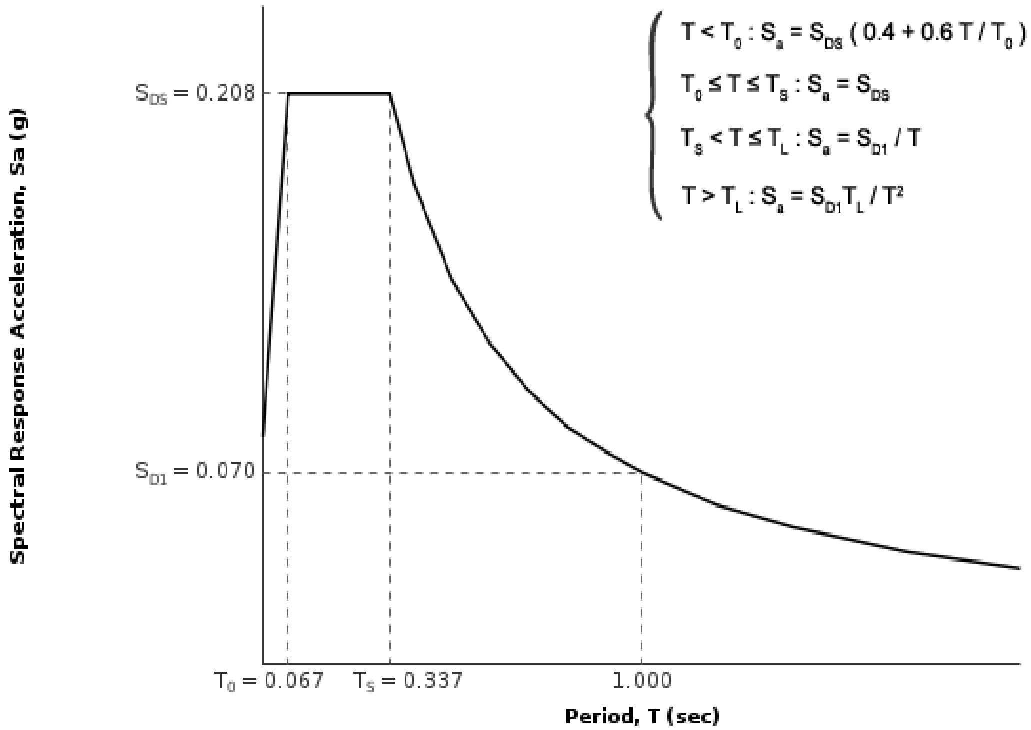
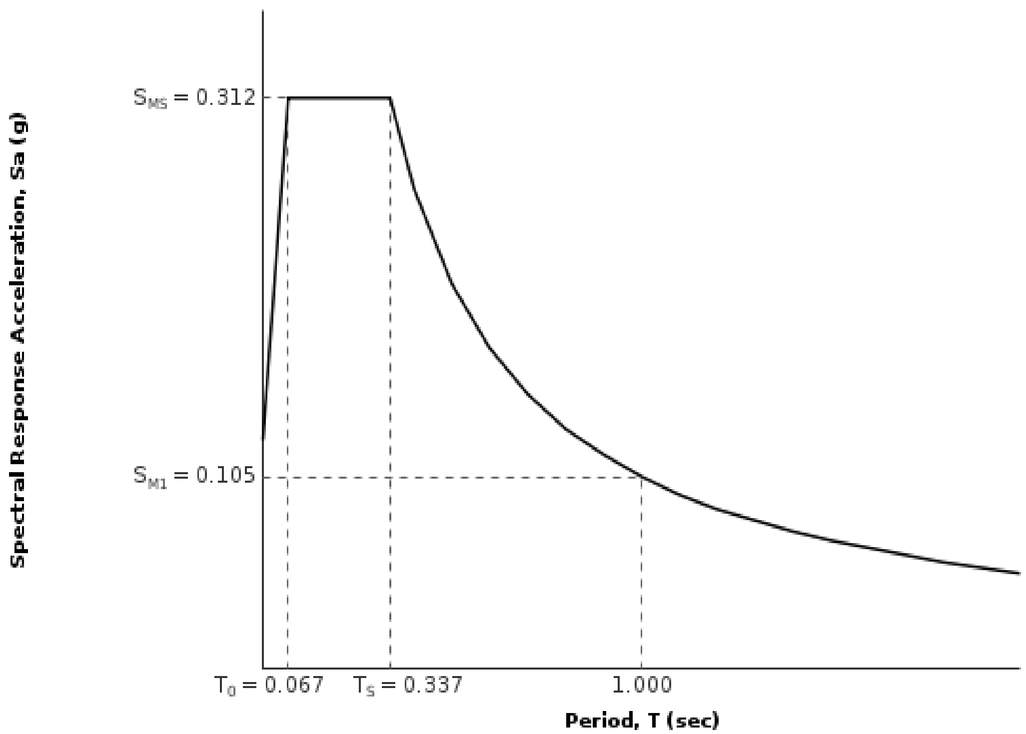


Figure 11.4–1: Design Response Spectrum




## 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):** | $PGA_M = F_{PGA}PGA = 1.567 \times 0.116 = 0.183$ g |

**Engineering Geology in Washington, Volume 1**

**Washington Division of Geology and Earth Resources Bulletin 78, 1989**

# Geotechnical Properties of Geologic Materials

by

**JON W. KOLOSKI, GeoEngineers, Inc.**

**SIGMUND D. SCHWARZ, S D Schwarz and Associates**

**DONALD W. TUBBS, Tubbs Geosciences**

## INTRODUCTION

Engineering geologists and geotechnical engineers are an intregal 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 | OAAA - OCEB | 150-200 | 3-30 | Joints | Low | Low | 12-20 | 0.5-20 |
| Extrusive | OAAA - ODEE | 120-200 | 1-30 | Joints, Voids, Flow Features | Low-High | Low-High | 6-18 | 0.01-5 |
| METAMORPHIC | | | | | | | | |
| High Grade | OAAA - OCED | 150-200 | 3-25 | Joints, Foliation | Low | Low | 12-20 | 0.05-20 |
| Low Grade | OBAA - OEEE | 150-200 | 0.5-15 | Joints, Foliation | Low | Low | 2.5-14 | 0.001-10 |
| SEDIMENTARY | | | | | | | | |
| Clastic | OBCC - OEEE | 130-150 | 1-15 | Joints, Bedding | Low-Med | Low-Med | 5-14 | 0.001-10 |
| Chemical | OBCB - ODEC | 140-160 | 2-15 | Joints, Bedding, Voids | Low-High | Low | 4-15 | 0.05-50 |
| Organic | OCCD - ODEE | 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 | OAAA - OCEB | High | High | Good | Good | Riprap, Aggregate, Building stone |
| Extrusive | OAAA - ODEE | Med-High | Med-High | Usually Good | Med-Good | Riprap, Aggregate, Building stone |
| METAMORPHIC | | | | | | |
| High Grade | OAAA - OCED | High | High | Good | Good | Riprap, Aggregate, Building stone, Industrial |
| Low Grade | OBAA - OEEE | Low-High | Low-Med | Usually Good | Poor-Good | Fill |
| SEDIMENTARY | | | | | | |
| Clastic | OBCC - OEEE | Low-High | Low-Med | Usually Good | Poor-Good | Building stone, Industrial |
| Chemical | OBCB - ODEC | Med-High | Low-High | Usually Good | Poor-Good | Riprap, Aggregate, Industrial, Building stone |
| Organic | OCCD - ODEE | 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 |
| | | | GP | POORLY-GRADED GRAVEL |
| | | GRAVEL WITH FINES | 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 |
| | | | SP | POORLY-GRADED SAND |
| | | SAND WITH FINES | 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<br>LIQUID LIMIT 50 OR MORE | INORGANIC | MH | SILT OF HIGH PLASTICITY, ELASTIC SILT |
| | | | CH | CLAY OF HIGH PLASTICITY, FAT CLAY |
| | | ORGANIC | OH | ORGANIC CLAY, ORGANIC SILT |
| 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: AAAA 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 (phi) 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.

## ACKNOWLEDGEMENTS

The writers wish to express appreciation to their colleagues in the geotechnical professions who over the years have shared information regarding geotechnical properties of geologic materials. Several organizations (GeoEngineers, Inc., Geo-Recon International Ltd., Shannon & Wilson, Inc., and the U.S. Army Corps of Engineers) made available to us specific information from their files. GeoEngineers, Inc., also provided assistance in manuscript preparation.

We are particularly grateful to Mr. George Yamane for his helpful review and comments during the

preparation of this paper.

## REFERENCES

American Society for Testing and Materials, 1985, D 2487-83, Classification of Soils for Engineering Purposes: Annual Book of ASTM Standards, Vol. 04.08, pp 395-408.

Caterpillar Inc., 1987a, Caterpillar Performance Handbook, Edition 18: Caterpillar Inc., Peoria, 768 p.

Caterpillar Inc., 1987b, Caterpillar Performance Handbook, Hydraulic Excavators: Caterpillar Inc., Peoria, 176 p.

Williamson, D.A., 1984, Unified Rock Classification System: Bulletin, Association of Engineering Geologists, Vol. 21, No. 3, pp 345-354.

Return to Tubbs Geosciences' Library

# 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 | – | – | – |
| Find 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 | – | – | – |

[a]Adapted 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, $C_r/(1 + e_0)$ 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.