ATLANTIC COAST
CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

RECEIVED

APR 19 2017

SOLID WASTE
MANAGEMENT PROGRAM

April 17, 2017

Mr. William Cook
Solid Waste Management Program
Georgia Environmental Protection Division
4244 International Parkway, Suite 104
Atlanta, Georgia 30354

RE: Waste Management of Metro Atlanta, Inc.
Pine Bluff MSWLF
Minor Modification – Coal Combustion Residuals (CCR) Management Plan: Local Government Notifications
Permit Number: 028-039D (SL)

Dear William,

Please find enclosed copies of the notifications that were sent on behalf of Waste Management of Metro Atlanta, Inc to local governments regarding the submission of the proposed Coal Combustion Residuals (CCR) Management Plan Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill. These notifications were given in accordance with EPD's Solid Waste Management Rule 391-3-4-.07(5) as well as the EPD guidance document issued December 22, 2016.

Please let me know if you have any questions.

Sincerely,

ATLANTIC COAST CONSULTING, INC.

Marc Liverman, P.E.
Project Engineer

cc: Shawn Carroll, WM
Robert Brown, ACC

ATLANTIC COAST
CONSULTING, INC.

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April 14, 2017

Jerry Cooper
County Manager
Cherokee County
1130 Bluffs Parkway
Canton, Georgia 30114

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mr. Cooper,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST
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Suite 801
Savannah, GA 31401
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April 14, 2017

Jeffery S. Moon
City Manager
City of Woodstock
Cherokee County
12453 Hwy. 92
Woodstock, Georgia 30188

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mr. Moon,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST
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Suite 801
Savannah, GA 31401
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April 14, 2017

Oma Lou Stewart
City Clerk/Manager
City of Waleska
Cherokee County
8891 Fincher St.
Waleska, Georgia 30183

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mrs. Stewart,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST
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7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
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April 14, 2017

Robert H. Logan
City Manager
City of Holly Springs
Cherokee County
3237 Holly Springs Parkway
Holly Springs, Georgia 30115

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mr. Logan,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

April 14, 2017

Eric Wilmarth
City Manager
City of Ball Ground
Cherokee County
215 Valley Street
Ball Ground , Georgia 30107

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mr. Wilmarth,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

7 E. Congress Street
Suite 801
Savannah, GA 31401
(912) 236-3471
www.atlcc.net

April 14, 2017

Billy Peppers
City Manager
City of Canton
Cherokee County
151 Elizabeth Street
Canton , Georgia 30114

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Metro Atlanta, Inc.- Pine Bluff Municipal Solid Waste Landfill
Cherokee County, Georgia

Dear Mr. Peppers,

Rules and regulations of the State of Georgia (391-3-4-.07(5)) require that you be notified of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for solid waste disposal facilities permitted by the Georgia Department of Natural Resources Environmental Protection Division (EPD). On April 5, 2017, a Minor Modification Permit Application for Pine Bluff Municipal Solid Waste Landfill was submitted to EPD. On behalf of Waste Management of Metro Atlanta, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
ATLANTIC COAST CONSULTING

Marc Liverman, P.E.

Cc: Shawn Carroll, WM
File

ATLANTIC COAST
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Suite 801
Savannah, GA 31401
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April 5, 2017

Mr. William Cook
Solid Waste Management Program
Georgia Environmental Protection Division
4244 International Parkway, Suite 104
Atlanta, Georgia 30354

RE: Waste Management of Metro Atlanta, Inc.
Pine Bluff MSWLF
Minor Modification – Coal Combustion Residuals (CCR) Management Plans
Permit Number: 028-039D (SL)

Dear William,

Please find enclosed an executed minor modification form and four copies of revised Plan Sheets Cover, 38, 43, 43A, 44, 47, 50A, and C05 along with two copies of the modified design calculations for the above referenced facility. This proposed modification to the permit revises the Design and Operation Plan to incorporate a CCR Management Plan in accordance with EPD's Solid Waste Management Rule 391-3-4-.07(5) as well as the EPD guidance document issued December 22, 2016. Below is a summary of the revisions incorporated into the current D&O plan for compliance with the CCR Management Plan Guidance.

<u>CCR Guidance General Requirements</u>

1) *The CCR Management Plan shall be submitted as a request for modification to the facility's Design and Operational (D&O) Plan. Modifications which substantially alter the design of the facility, management practices, the types of wastes being handled, or the method of waste handling, and due to the nature of the changes would likely have an impact on the ability of the facility to adequately protect human health and the environment will require a major modification.*

   <u>Response:</u> The Pine Bluff facility is currently accepting CCR material. This request for modification will not substantially alter the design, management, types of waste or methods of waste handling. Therefore, it is being submitted as a minor modification to the facility's current permit.

2) *CCR Management Plans will be approved for a duration of one year. Facilities must submit a sealed professional engineer's Annual CCR Management and Dust Control Review describing activities, issues and any non-compliance*

from the prior year (for more on Fugitive Dust Control requirements, see below). Based on the annual review, Georgia EPD will either issue written approval to continue CCR management under the existing plan or will request the facility to amend their Plan. Amendments to the plan shall include any changes necessitated by the prior year's operations. The facility shall place the written EPD approval in the facility operating record. Facilities requested to amend their CCR Management Plan must obtain an approved amended Plan within 30 days of EPD's request or cease receipt of CCR until such approval is granted.

Revision: **Section 38 has been added to the Operational Narrative on Sheet 43A to define the annual reporting requirements related to CCR management and fugitive dust control.**

The current source of CCR for this facility is defined in Section 3 of the Operational Narrative on Sheet 43. This section also requires that EPD approval be obtained prior to accepting new types of CCR or increases in ash ratio.

3) *Plan sheets should be the same size (24"x30" to 24"x36") and have a standard title block.*

Response: **All plan sheets match the size of the current D&O plan and have a standard title block.**

4) *A professional engineer registered to practice in Georgia must stamp and sign all sheets*

Response: **All modified plan sheets are stamped and signed by a Georgia Registered Professional Engineer.**

CCR Management Plan Components

1) *The estimated total amount of CCR to be accepted on annual basis and the daily maximum amount of CCR to be accepted must be listed in the Plan.*

For sites that will dispose of comingled CCR and MSW, the amount of MSW received and the maximum ratio of CCR to MSW for placement in the landfill must be listed in the Plan. The facility must be designed to address Section 4, Design Consistency, for comingling waste up to this maximum ratio. The facility may not dispose of comingled waste at a ratio that exceeds the maximum considered in the design calculations. Dedicated CCR cells that were previously approved for MSW disposal must also be redesigned to address the requirements of section 4. Design Consistency.

Revision: **Section 1 of the Operational Narrative on Sheet 43 has been modified to define the estimated daily and annual tonnages of CCR to be**

accepted at the facility. Additionally, Section 1 defines the estimated maximum ratio of MSW to CCR for co-mingled areas.

The design calculations that are affected by the CCR waste stream are included as attachments to this submittal.

2) *Procedures for waste placement, cover, and recovery*
The CCR Management Plan must include the following:

a. *A description of how the working face will be managed at facilities where CCR and other wastes will be comingled, or identification of proposed CCR monofill cells.*

Revision: Section 2 of the Operational Narrative on Sheet 43 has been modified to define the procedures governing the controlled unloading of CCR material at the working face and co-mingling with MSW. There are no CCR monofill cells designated for this facility.

b. *Description of waste placement procedures including (but not limited to):*

i. *the initial layer placement of CCR above the liner and leachate collection system,*

Revision: Section 34 of the Operational Narrative on Sheet 43A has been modified to state that no CCR material will be co-mingled in the initial lift.

ii. *placement and compaction requirements of CCR lifts to maintain stability,*

Response: The CCR will be co-mingled with MSW. Therefore, no amendments to the plan are required to define placement and compaction of CCR only lifts.

iii. *placement and compaction procedures for comingled wastes.*

Revision: The procedures currently in-place to spread and compact co-mingled MSW and CCR will remain the same as areas receiving MSW only. Section 5 of the Operational Narrative on Sheet 43 has been amended to define these procedures for co-mingled waste areas.

c. *Procedures and criteria for daily cover of comingled CCR and MSW.*

Revision: Section 6 of the Operational Narrative on Sheet 43 has been modified to require daily cover of co-mingled MSW and CCR in accordance with current procedures.

d. *The working face must be maintained at a size that is compatible with the facility's available equipment for spreading and compacting waste, and for suppressing dust. Describe the proposed maximum working face area and the equipment needed to manage a working face of this area.*

<u>Revision:</u> Section 2 of the Operational Narrative on Sheet 43 has been revised to describe co-mingling of CCR and MSW at the working face. Additionally, Section 21 on Sheet 43A has been modified to define dust control procedures for a working face receiving co-mingled wastes.

e. *Operator inspection procedures for maintaining and documenting compliance with the CCR Management Plan must be given.*

<u>Revision:</u> Section 2 of the Operational Narrative on Sheet 43 has been revised to specify operator training related to CCR waste streams.

f. *If applicable, procedures for onsite liquid waste solidification operations using CCR.*

<u>Revision:</u> Sheet 05 (Solidification Narrative) has been modified to clarify that CCR waste streams will not be used as bulking agents or solidification reagents.

g. *If applicable, procedures must be given for recovery of previously disposed CCR for beneficial reuse. EPD must be notified prior to disturbing and excavating previously disposed CCR for beneficial reuse*

<u>Response:</u> The D&O plan does not allow recovery of previously disposed CCR material for beneficial re-use.

3) *Fugitive Dust Control*

The CCR Management Plan must include measures that will minimize CCR from becoming airborne at the facility. Potential CCR fugitive dust emissions originating from CCR disposal units, roads, conditioning areas, and other CCR management and material handling activities must be minimized.

a. *Performance Standard: The percent opacity from CCR and any other fugitive dust source listed in Air Quality Rule 391-3-1-.02(2)(n)1 shall not exceed the limits set therein.*

<u>Revision</u>: Section 21 of the Operational Narrative on Sheet 43A has been modified to require compliance with Air Quality Rule 391-3-1-.02(2)(n)1.

b. *The Dust Control Plan must describe measures that the owner or operator will use to minimize CCR from becoming airborne, such as the following:*

   i. *locating CCR inside an enclosure/partial enclosure*

ii. *operating a water spray or fogging system*
iii. *reducing fall distances at material drop points*
iv. *using wind barriers, compaction, or vegetative covers*
v. *establishing vehicle speed limits*
vi. *paving and sweeping roads*
vii. *covering trucks transporting CCR*
viii. *reducing or halting operations during high wind events*
ix. *applying daily cover or more frequent cover as needed*

Revision: Section 21 of the Operational Narrative on Sheet 43A has been modified to require wetting of CCR disposal areas with a water truck to control dust, if needed.

c. *The Dust Control Plan must provide an explanation of how the selected measures are applicable and appropriate for the existing site conditions.*

Response: The use of a water truck to provide dust control was selected as it is equipment currently available at the facility. See Section 16 of Sheet 43.

d. *The Dust Control Plan must provide procedures to emplace CCR with adequate moisture content or other suppressants added to minimize dust.*

Revision: Section 21 of the Operational Narrative on Sheet 43A has been modified to require wetting of CCR disposal areas with a water truck to control dust, if needed.

e. *Citizen Complaints: Procedures to log citizen complaints received by the owner or operator must be described in the Plan.*

Revision: Section 21 of the Operational Narrative on Sheet 43A has been modified to specify the use of Waste Management's 1-800 citizen comment number for documenting citizen CCR complaints.

f. *An "Annual Fugitive Dust Control Report" report will be due 12 months after the approval of the CCR Management Plan, and one year later for each subsequent report. The report shall include a description of the actions taken to control fugitive dust, a record of all citizen complaints, a summary of any corrective measures taken and, if applicable, recommendations to improve the dust control measures in the future.*

Revision: Section 21 of the Operational Narrative on Sheet 43A has been modified to require preparation and submission of an annual dust control report. Additionally, Section 38 on Sheet 43A was added to allow for the annual fugitive dust report to be included with the annual CCR management plan renewal requirements.

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4. *Design Consistency*
   The CCR Management Plan must address the following landfill design considerations:

   a. *A demonstration that the design grades of the landfill are stable (i.e., for short operations and long-term static and seismic conditions).*

      Revision: A revised stability analysis is included as an attachment to demonstrate that the facility's waste mass will remain stable with the addition of a CCR waste stream.

   b. *A demonstration that the liner system is designed to account for chemical exposure to CCR-generated leachate.*

      Revision: CCR are defined by the EPA as a solid waste to be regulated under Subtitle D (EO 12866 CCR 2050-AE81). CCR waste material accepted for disposal at the landfill will not require non-hazardous certification. Additionally, CCR generated leachate will not subject the liner system to additional chemical exposure beyond what it endures from typical MSW.

   c. *The cell floor grading and construction plans shall account for settlement caused by the weight of the CCR or the comingled waste. Cell floor subsidence and leachate collection pipe crushing shall be evaluated, and a demonstration of adequate post-settlement cell floor grades, leachate pipe grades, and resistance to crushing shall be provided in the design calculations.*

      Revision: Revised base grade settlement analysis and pipe crushing calculations are included as an attachment to demonstrate that the integrity of the facility's base grades and leachate collection piping are adequate. Appropriate revisions to the D&O detail sheet 38 and the CQA plan (sheet 47) are included with this submittal.

   d. *The Leachate Collection and Removal System (LCRS) shall continue to maintain its functionality and limit the head of leachate on the liner system to a maximum of 30 centimeters. Drainage nets, filter fabrics, and other features of the LCRS must be demonstrated to be compatible with CCR. Pipes must be able to support the weight of the CCR without damage.*

      Revision: Revisions to the geocomposite design calculations are included with this submittal. Appropriate revisions to the CQA plan (sheet 47) are included with this submittal.

   e. *The landfill gas collection system design shall account for comingling of MSW and CCR waste.*

Revision: Standard MSWL GCCS systems are designed to account for gas produced from a mixed waste mass of MSW, C&D, and other inert materials (like CCR). Therefore, the current GCCS system design will not be affected by the co-mingling of CCR.

f. *Construction, operation, and maintenance of waste units to be used for CCR disposal shall remain consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR to be disposed.*

Revision: The estimated maximum ratio of MSW to CCR of 10:1 means that the majority of the waste stream will be typical MSW. Therefore, co-mingling of CCR does not require revisions to the D&O plan's specified construction, operation or maintenance of the waste units other than those issues addressed herein. .

g. *The plan must define any events or circumstances that represent a safety emergency, along with a description of the procedures that will be followed to detect a safety emergency in a timely manner.*

Revision: CCR does not present any significant safety concern beyond what is typically experienced at the site on a daily basis. The site has existing onsite safety procedures, contingency plans, and training materials to address routine emergencies. Section 10 of the Operational Narrative on Sheet 43 has been amended to require regular training of facility employees that will enable them to better detect and respond to safety emergencies.

h. *The plan must provide a detailed description of leachate and contact water management that demonstrates surface water contacting MSW or CCR will not be discharged into the stormwater management system. Describe or provide details for any required structures (such as chimney drains) and any management practices such as placement of diversion berms between the working face or exposed CCR and the stormwater collection ditches.*

Revision: Co-mingling of CCR does not require revisions to the D&O plan specified leachate or stormwater management requirements. Co-mingled MSW and CCR waste leachate and contact water will be managed in accordance with established practices that govern MSW only waste streams.

i. *Design calculations supporting the CCR Management Plan are to be performed by or be done under the direction of a Professional Engineer and shall be submitted as auxiliary materials to the Plan.*

Revision: Design calculations are included with this submittal and are sealed and signed by a Professional Engineer.

j. *CCR shall not be placed in any previously constructed cell, either comingled or as a monofill, without a demonstration that the cell, as constructed, was designed or can be retrofitted (e.g., lowering of final grades) to accommodate CCR disposal.*

Revision: As noted in the pipe design calculations, existing cells in Phase 1, Phase 2 cell 3, and Phase 3 cells 6 and 9 will not include additional CCR materials.

5. *Waste Compatibility Analysis*
The Plan must show that CCR waste is compatible (non-reactive) with MSW or industrial waste streams received at the facility, and that different CCR waste streams received are compatible with one another. In demonstrating compatibility, the plan shall contain at a minimum the following components:
   a. *List of source(s) of CCR waste streams*

   Revision: Section 3 of the Operational Narrative on Sheet 43 has been modified to specify the sources of CCR waste.

   b. *Chemical analyses of CCR waste streams*

   Revision: CCR are defined by the EPA as a solid waste to be regulated under Subtitle D (EO 12866 CCR 2050-AE81). CCR waste material accepted for disposal at the landfill will not require non-hazardous certification. The current list of sources of CCR waste streams and pre-acceptance chemical analysis are detailed in Section 3 of the Operational Narrative on Sheet 43.

   c. *Documentation of compatibility analyses for use in a solidification process, if applicable*

   Revision: CCR material will not be used in the solidification process.

The chemical analyses may be submitted as auxiliary materials to the Plan. If a new type of CCR is proposed for disposal, a plan modification application must be submitted if, based on the above analyses, acceptance of the new CCR material necessitates changes to the facility's design or operations.

Revision: The current source of CCR for this facility is defined in Section 3 of the Operational Narrative on Sheet 43. This section also requires that EPD approval be obtained prior to accepting new types of CCR.

6. *Closure and Post-Closure Care Impacts*
The CCR Management Plan shall evaluate impacts to the landfill's closure and post-closure care cost estimates. If CCR management changes either or both of these estimates, these plan sections must be revised to comply with 391-3-4-.11 or 391-3-4-.12. Groundwater monitoring costs should be updated to

ATLANTIC COAST CONSULTING, INC.

reflect the additional constituents monitored for landfills that have accepted CCR. If the largest open waste-accepting area increases due to CCR acceptance, closure cost estimates must be updated accordingly.

<u>Revision:</u> The Closure/Post Closure Care Plan on Sheet 44 has been revised to address the additional groundwater monitoring costs during post closure care. The closure costs and largest waste accepting area open are unaffected by the CCR management plan.

7. *Groundwater Monitoring*
   Appendix III and IV constituents (including boron) must be incorporated into the facility's groundwater monitoring plan in accordance with 391-3-4-.14(21)(c) and 391-3-4-.14(25).

   <u>Revision:</u> Sheet 50A has been added to the Groundwater Monitoring Plan to address the additional groundwater monitoring requirements related to acceptance of CCR wastes.

8. *Modification Procedures*
   The CCR Management Plan must be modified and submitted for EPD's approval if changes in either operating procedures or the facility design are necessary to comply with the requirements for CCR management.

   <u>Revision:</u> Section 38 of the Operational Narrative on Sheet 43A has been revised to require submittal of revised plans if operating procedures or facility design are necessary due to changes in the CCR waste stream.

9. *Documentation of Notification to Local Governments*
   The owner or operator shall notify the local governing authorities of the county, and any city within the county, in which the landfill is located upon the initial submittal of a CCR Management Plan or upon submittal of an amended Plan to EPD. Copies of the correspondence to local governing authorities must be provided to EPD with the Plan submittal.

   <u>Revision:</u> Section 38 of the Operational Narrative on Sheet 43A has been revised to specify compliance with notification requirements. Documentation of notification to the local governing authority required as part of this initial submittal will be forwarded to EPD.

Please let me know if you have any questions.

Sincerely,

ATLANTIC COAST CONSULTING, INC.

Marc Liverman, P.E.
Project Engineer

cc: Shawn Carroll, WM
Robert Brown, ACC

WASTE MANAGEMENT

WASTE MANAGEMENT OF METRO ATLANTA, INC.

1850 PARK PLACE | MARIETTA, GEORGIA 30067

PINE BLUFF SOLID WASTE MANAGEMENT FACILITY
CCR MANAGEMENT & GROUNDWATER PLANS

PERMIT #: 028-039D(SL)

DESIGN CALCULATIONS

ATLANTIC COAST CONSULTING, INC.

APRIL 2017

APRIL 2017

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ATLANTIC COAST CONSULTING, INC.

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Design Calculations Notebook

IN THIS SECTION:

Stability Analysis

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Section 1
A. Global Slope Stability Analysis

OBJECTIVE: Verify the global stability of the final configuration of the waste mass of the Pine Bluff MSWLF with the addition of Combustible Coal Residual (CCR) material. The original stability calculations, as prepared by Jordan, Jones and Goulding, Inc and dated December 2000, will be analyzed with respect to failure surfaces passing through the liner system and the underlying subgrade. The stability of the waste mass was evaluated under both static and seismic conditions. .

METHOD: The waste mass global stability was evaluated with the circular surface search analysis under static and seismic conditions. For the purpose of this analysis, a critical slope was selected from the disposal area which represents the original cross-section evaluated (i.e. Section C from the D&O plans and noted as Section F in the original design calculations). The geometry of the landfill and subsurface soils along the analyzed cross sections are shown on Figure 2. The addition of CCR to the waste mass does not impact the design of the final cover system, therefore the final cover stability is not being re-evaluated.

To identify critical failure planes, the computer program SLIDE Version 7.022 was used to perform stability calculations utilizing the Janbu and Bishop method of slices for circular surfaces. SLIDE was utilized to search through the anticipated zone of failures for each phase to identify the critical failure planes with the lowest factor of safety.

To begin the evaluation, the cross-sectional geometry and soil/waste mass was input into SLIDE and static analyses was evaluated over the landfill mass. This allows for the identification of the critical failure planes with the lowest factor of safety. The potential for permanent deformations under seismic conditions was calculated by applying the Maximum Horizontal Acceleration (MHA) in lithified earth material expected for the site as horizontal acceleration.

DATA: The waste parameters used for the calculations were taken from a May 2000 technical paper "Municipal Solid Waste Slope Failure. I: Waste and Foundation Soil Properties", by Eid, Stark, Evans, and Sherry. The soil properties used are from onsite field test as well as specified soil properties for the landfill construction quality assurance plan. The geosynthetic properties are the minimum required by the construction quality assurance plan.

The following assumptions were also used in the preparation of the stability analysis:

- The seismic coefficient for the site is 0.22g (Ah-horizontal) and 0.0g (Av-vertical). *Note: the seismic coefficients are used to increase or decrease the weight of each slice in the vertical direction by (Av)W and introduce a horizontal force of magnitude (Ah)W into the calculations. The increased inertial forces are assumed to act through the static center of gravity of each slice. The seismic coefficients are generally not the same as the expected peak ground accelerations at the site. For a preliminary assessment, these coefficients are* *estimated at 50% of the anticipated peak ground acceleration expected at the site (i.e. 0.11 Ah & 0.0 Av). Ah is then iteratively increased up to evaluate a conservative scenario for stability during an expected seismic event. (Reference: Misc. Paper GL-84-13, US Army Corps of Engineers, WES, Vicksburg, MS)*.

- Fully drained conditions within the landfill due to the presence of a leachate collection system

Soil Layer Data: The following material properties were used based on experience with similar materials and the references cited above.

Co-mingled Municipal Solid Waste and CCR (10:1) (SLIDE material unit 1)
unit wt. = 74.5 pcf phi = 33 degrees c=500 psf

Textured HDPE Geomembrane Liner (SLIDE material unit 2)
unit wt. = 100 pcf phi = 15 degrees c = 0 psf

Smooth HDPE Geomembrane Liner (SLIDE material unit 3)
unit wt. = 100 pcf phi = 10 degrees c = 0 psf

Recompacted Liner Base (SLIDE material unit 4)
unit wt. = 130 pcf phi = 25 degrees c = 500 psf

Geosynthetic Clay Liner (SLIDE material unit 5)
unit wt. = 100 pcf phi = 15 degrees c = 0 psf

Geocomposite (SLIDE material unit 6)
unit wt. = 60 pcf phi = 15 degrees c = 0 psf

Protective Cover (SLIDE material unit 7)
unit wt. = 110 pcf phi = 20 degrees c = 500 psf

Fully drained conditions were assumed within the landfill due to the presence of the leachate collection system.

Recirculation of leachate will occur at this site. However, due to the restrictions on loading rates as discussed on the operational narrative, the above referenced MSW material properties will not be effected.

RESULTS: The SLIDE program outputs for the critical analysis show the geometry of the critical cross section evaluated for failure, the location of the critical failure surfaces and the associated factor of safety. The minimum factor of safety against failure for the evaluation scenario for each phase is as follows:

Static:
SLIDE selected critical failure planes:
Factor of Safety (Janbu Circular, static) = 2.404

Seismic:
SLIDE selected critical failure planes:
Factor of Safety (Janbu Circular, static) = 1.650

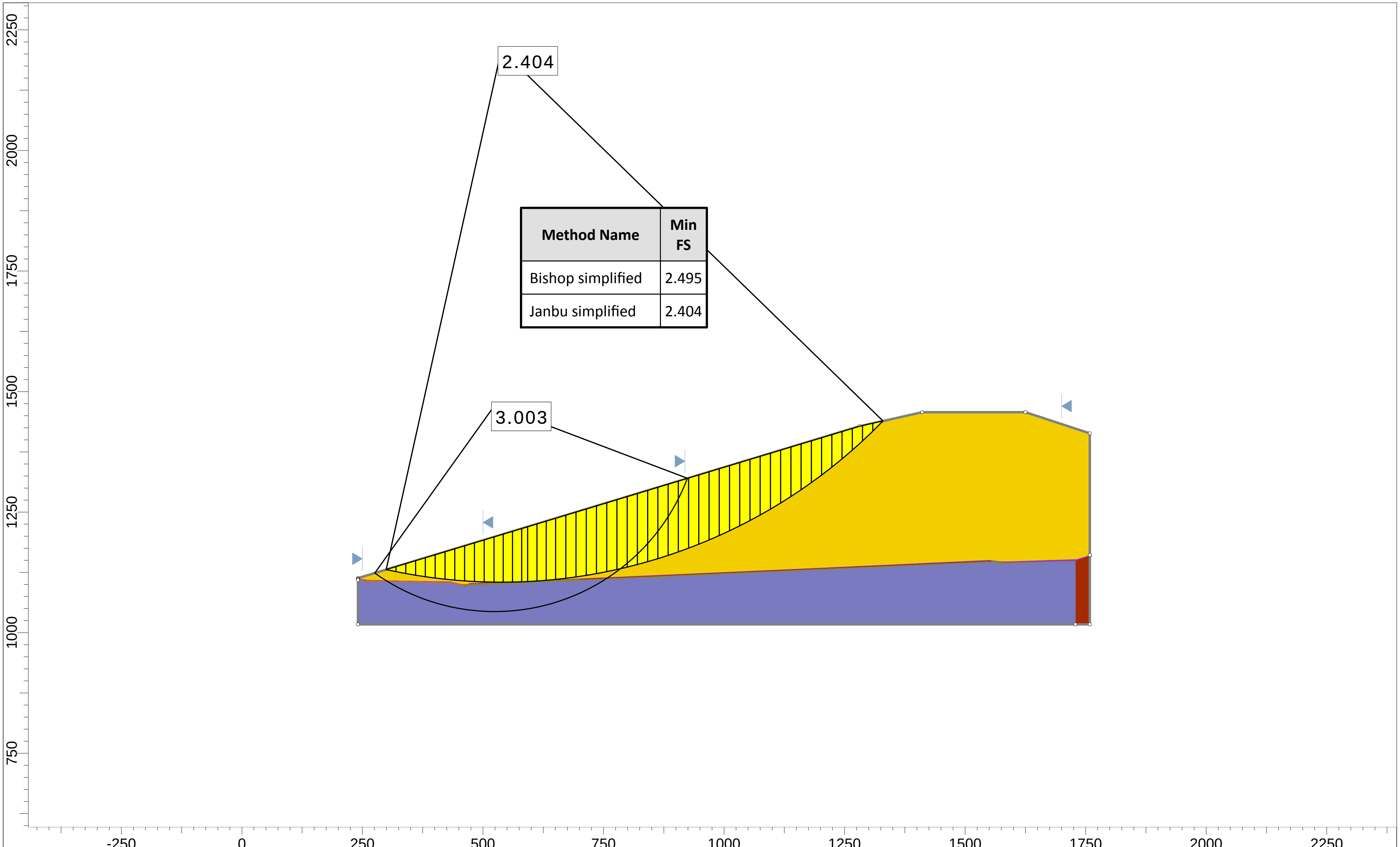
The calculated factors of safety for static and seismic conditions are greater than 1.5, and are therefore considered adequate in terms of long term stability.

CONCLUSION: The analysis indicates that the proposed landfill geometry is adequately designed in consideration of the global slope stability under static and seismic conditions.


G1
F1
F1
G1
LOCATION OF CRITICAL
STABILITY SECTIONS
ON FINAL GRADING PLAN
1" = 200'
PINE BLUFF MSWLF
1180-072 EGM

FIGURE 1

STATIC ANALYSIS



Method Name	Min FS
Bishop simplified	2.495
Janbu simplified	2.404

Project	Pine Bluff MSWLF - CCR Management Plan		
Analysis Description	Circular Static		
Drawn By Marc Liverman	*Scale* 1:3304	*Company*	Atlantic Coast Consulting
Date	3/31/17	*File Name*	PBL 4 CCR Circ Static.slim

SLIDEINTERPRET 7.022

Slide Analysis Information
Pine Bluff MSWLF - CCR Management Plan

Project Summary

File Name:	PBL 4 CCR Circ Static.slim
Slide Modeler Version:	7.022
Project Title:	Pine Bluff MSWLF - CCR Management Plan
Analysis:	Circular Static
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	3/31/17
Comments	
	Pine Bluff MSWLF
	Co-Mingled MSW and CCR Ratio 10:1 (by weight)

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
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:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Circular
Search Method:	Slope Search
Number of Surfaces:	5000
Upper Angle:	Not Defined
Lower Angle:	Not Defined
Composite Surfaces:	Disabled
Reverse Curvature:	Invalid Surfaces
Minimum Elevation [ft]:	1025
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis: No
Staged pseudostatic analysis: No

Material Properties

Property	MSW and CCR	Textured Liner	Smooth Liner	Recompacted Liner Base	GCL	Geocomposite	Protective Cover
Color							
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	74.5	100	100	130	100	60	110
Cohesion [psf]	500	0	0	500	0	0	500
Friction Angle [deg]	33	15	10	30	33	20	20
Water Surface	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	2.494880
Center:	485.699, 2726.150
Radius:	1623.078
Left Slip Surface Endpoint:	259.613, 1118.896
Right Slip Surface Endpoint:	1497.700, 1457.200
Resisting Moment:	1.06697e+010 lb-ft
Driving Moment:	4.27663e+009 lb-ft
Total Slice Area:	133991 ft2
Surface Horizontal Width:	1238.09 ft
Surface Average Height:	108.224 ft

Method: janbu simplified

FS	2.403600
Center:	538.109, 2208.833
Radius:	1104.092
Left Slip Surface Endpoint:	299.234, 1130.892
Right Slip Surface Endpoint:	1329.550, 1439.002
Resisting Horizontal Force:	4.82892e+006 lb
Driving Horizontal Force:	2.00904e+006 lb
Total Slice Area:	103393 ft2
Surface Horizontal Width:	1030.32 ft
Surface Average Height:	100.351 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Method: janbu simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.49488

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	26.9202	11740.5	-7.52774	MSW and CCR	500	33	325.113	811.117	479.078	0	479.078	436.116	436.116
2	26.9202	34763.4	-6.57015	MSW and CCR	500	33	553.124	1379.98	1355.05	0	1355.05	1291.34	1291.34
3	26.9202	56872.7	-5.61441	MSW and CCR	500	33	770.025	1921.12	2188.33	0	2188.33	2112.63	2112.63
4	26.9202	78073.4	-4.66023	MSW and CCR	500	33	976.023	2435.06	2979.73	0	2979.73	2900.17	2900.17
5	28.0191	103365	-3.68792	Protective Cover	500	20	745.611	1860.21	3737.15	0	3737.15	3689.09	3689.09
6	28.0191	125231	-2.69724	Protective Cover	500	20	858.35	2141.48	4509.91	0	4509.91	4469.48	4469.48
7	8.1452	40305.5	-2.05827	Geocomposite	0	20	725.706	1810.55	4974.44	0	4974.44	4948.36	4948.36
8	3.46192	17635	-1.85328	Smooth Liner	0	10	360.846	900.267	5105.67	0	5105.67	5094	5094
9	0.480212	2469.99	-1.78366	Geocomposite	0	20	753.8	1880.64	5167	0	5167	5143.53	5143.53
10	8.52997	44556.3	-1.62457	Protective Cover	500	20	966.451	2411.18	5250.91	0	5250.91	5223.5	5223.5
11	38.9043	223912	-0.787192	MSW and CCR	500	33	1704.63	4252.84	5778.86	0	5778.86	5755.44	5755.44
12	24.8055	161367	0.337401	Protective Cover	500	20	1148.46	2865.28	6498.53	0	6498.53	6505.29	6505.29
13	24.8055	175296	1.21317	Protective Cover	500	20	1227.57	3062.65	7040.82	0	7040.82	7066.81	7066.81
14	24.8055	188189	2.08922	Protective Cover	500	20	1300.27	3244.02	7539.16	0	7539.16	7586.6	7586.6
15	24.8055	200045	2.96575	Protective Cover	500	20	1366.59	3409.49	7993.76	0	7993.76	8064.56	8064.56
16	24.8055	210863	3.84299	Protective Cover	500	20	1426.57	3559.11	8404.84	0	8404.84	8500.67	8500.67
17	24.8055	220639	4.72112	Protective Cover	500	20	1480.21	3692.94	8772.54	0	8772.54	8894.79	8894.79
18	26.2428	243559	5.62589	MSW and CCR	500	33	2550.82	6363.98	9029.75	0	9029.75	9281.02	9281.02
19	26.2428	253617	6.55758	MSW and CCR	500	33	2637.08	6579.2	9361.16	0	9361.16	9664.3	9664.3
20	26.2428	262829	7.49102	MSW and CCR	500	33	2714.45	6772.23	9658.38	0	9658.38	10015.3	10015.3
21	26.2428	271190	8.42646	MSW and CCR	500	33	2782.98	6943.19	9921.67	0	9921.67	10333.9	10333.9
22	26.2428	278693	9.36417	MSW and CCR	500	33	2842.69	7092.18	10151.1	0	10151.1	10619.9	10619.9
23	26.2428	285333	10.3044	MSW and CCR	500	33	2893.63	7219.27	10346.8	0	10346.8	10872.9	10872.9
24	26.2428	291101	11.2475	MSW and CCR	500	33	2935.82	7324.52	10508.8	0	10508.8	11092.7	11092.7
25	26.2428	295990	12.1936	MSW and CCR	500	33	2969.27	7407.98	10637.3	0	10637.3	11279	11279
26	26.2428	299991	13.1432	MSW and CCR	500	33	2994	7469.66	10732.3	0	10732.3	11431.4	11431.4
27	26.2428	303093	14.0964	MSW and CCR	500	33	3009.99	7509.57	10793.8	0	10793.8	11549.6	11549.6
28	26.2428	305285	15.0537	MSW and CCR	500	33	3017.26	7527.69	10821.7	0	10821.7	11633.2	11633.2
29	26.2428	306556	16.0153	MSW and CCR	500	33	3015.78	7524	10816	0	10816	11681.6	11681.6
30	26.2428	306893	16.9815	MSW and CCR	500	33	3005.53	7498.44	10776.7	0	10776.7	11694.5	11694.5
31	26.2428	306281	17.9527	MSW and CCR	500	33	2986.5	7450.95	10703.5	0	10703.5	11671.2	11671.2
32	26.2428	304706	18.9293	MSW and CCR	500	33	2958.64	7381.44	10596.5	0	10596.5	11611.1	11611.1
33	26.2428	302150	19.9116	MSW and CCR	500	33	2921.9	7289.79	10455.4	0	10455.4	11513.8	11513.8
34	26.2428	298595	20.9001	MSW and CCR	500	33	2876.25	7175.89	10280	0	10280	11378.3	11378.3
35	26.2428	294023	21.8951	MSW and CCR	500	33	2821.61	7039.59	10070.1	0	10070.1	11204.1	11204.1
36	26.2428	288412	22.8972	MSW and CCR	500	33	2757.94	6880.72	9825.46	0	9825.46	10990.3	10990.3
37	26.2428	281740	23.9067	MSW and CCR	500	33	2685.14	6699.09	9545.78	0	9545.78	10736	10736
38	26.2428	273981	24.9241	MSW and CCR	500	33	2603.13	6494.5	9230.73	0	9230.73	10440.4	10440.4
39	26.2428	265110	25.95	MSW and CCR	500	33	2511.83	6266.71	8879.95	0	8879.95	10102.3	10102.3
40	26.2428	255097	26.9849	MSW and CCR	500	33	2411.12	6015.46	8493.07	0	8493.07	9720.8	9720.8
41	26.2428	243911	28.0295	MSW and CCR	500	33	2300.9	5740.48	8069.63	0	8069.63	9294.56	9294.56
42	26.2428	231392	29.0843	MSW and CCR	500	33	2179.94	5438.7	7604.92	0	7604.92	8817.48	8817.48
43	26.2428	214830	30.15	MSW and CCR	500	33	2025.12	5052.42	7010.11	0	7010.11	8186.39	8186.39
44	26.2428	195839	31.2273	MSW and CCR	500	33	1850.85	4617.64	6340.61	0	6340.61	7462.73	7462.73
45	26.2428	175521	32.3171	MSW and CCR	500	33	1666.92	4158.76	5634.01	0	5634.01	6688.49	6688.49
46	26.2428	153827	33.4202	MSW and CCR	500	33	1473.18	3675.41	4889.71	0	4889.71	5861.83	5861.83
47	26.2428	130177	34.5375	MSW and CCR	500	33	1265.01	3156.06	4089.96	0	4089.96	4960.6	4960.6
48	26.2428	96886.2	35.6699	MSW and CCR	500	33	978.592	2441.47	2989.6	0	2989.6	3692.01	3692.01
49	26.2428	59268.3	36.8187	MSW and CCR	500	33	659.739	1645.97	1764.64	0	1764.64	2258.52	2258.52
50	26.2428	20032	37.985	MSW and CCR	500	33	331.693	827.534	504.357	0	504.357	763.365	763.365

Global Minimum Query (janbu simplified) - Safety Factor: 2.4036

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	20.3357	7925.79	-11.9556	MSW and CCR	500	33	332.333	798.796	460.106	0	460.106	389.736	389.736
2	20.3357	23476.1	-10.879	MSW and CCR	500	33	548.397	1318.13	1259.81	0	1259.81	1154.41	1154.41
3	20.3357	38427.1	-9.80617	MSW and CCR	500	33	753.757	1811.73	2019.9	0	2019.9	1889.62	1889.62
4	20.3357	52784.8	-8.73684	MSW and CCR	500	33	948.71	2280.32	2741.45	0	2741.45	2595.65	2595.65
5	20.3357	66554.8	-7.67057	MSW and CCR	500	33	1133.51	2724.51	3425.44	0	3425.44	3272.78	3272.78
6	20.3357	79741.6	-6.60696	MSW and CCR	500	33	1308.41	3144.9	4072.78	0	4072.78	3921.23	3921.23
7	20.3357	92349.4	-5.54563	MSW and CCR	500	33	1473.63	3542.02	4684.3	0	4684.3	4541.22	4541.22
8	20.3357	104382	-4.48621	MSW and CCR	500	33	1629.38	3916.37	5260.76	0	5260.76	5132.92	5132.92
9	20.3357	115841	-3.42833	MSW and CCR	500	33	1775.83	4268.38	5802.82	0	5802.82	5696.44	5696.44
10	20.3357	126730	-2.37161	MSW and CCR	500	33	1913.16	4598.48	6311.12	0	6311.12	6231.88	6231.88
11	20.3357	137049	-1.31571	MSW and CCR	500	33	2041.53	4907.03	6786.23	0	6786.23	6739.34	6739.34
12	19.1322	138177	-0.291473	Protective Cover	500	20	1302.67	3131.09	7228.87	0	7228.87	7222.24	7222.24
13	19.1322	146864	0.701431	Protective Cover	500	20	1367.88	3287.84	7659.54	0	7659.54	7676.29	7676.29
14	19.1322	154853	1.69455	Protective Cover	500	20	1427.25	3430.54	8051.58	0	8051.58	8093.81	8093.81
15	12.3698	104065	2.51246	Protective Cover	500	20	1472.17	3538.51	8348.26	0	8348.26	8412.86	8412.86
16	19.3034	168000	3.33546	Protective Cover	500	20	1512.57	3635.61	8615.01	0	8615.01	8703.17	8703.17
17	19.3034	174240	4.33949	Protective Cover	500	20	1556.97	3742.34	8908.27	0	8908.27	9026.42	9026.42
18	19.3034	179757	5.34486	Protective Cover	500	20	1595.54	3835.04	9162.94	0	9162.94	9312.21	9312.21
19	21.2171	203606	6.4019	MSW and CCR	500	33	2718.38	6533.89	9291.37	0	9291.37	9596.38	9596.38
20	21.2171	209668	7.51118	MSW and CCR	500	33	2778.98	6679.55	9515.66	0	9515.66	9882.07	9882.07
21	21.2171	215068	8.6233	MSW and CCR	500	33	2830.76	6804.01	9707.32	0	9707.32	10136.6	10136.6
22	21.2171	219801	9.7387	MSW and CCR	500	33	2873.76	6907.37	9866.48	0	9866.48	10359.7	10359.7
23	21.2171	223861	10.8578	MSW and CCR	500	33	2908.02	6989.71	9993.26	0	9993.26	10551	10551
24	21.2171	227240	11.9812	MSW and CCR	500	33	2933.55	7051.09	10087.8	0	10087.8	10710.3	10710.3
25	21.2171	229930	13.1092	MSW and CCR	500	33	2950.38	7091.53	10150	0	10150	10837.1	10837.1
26	21.2171	231923	14.2425	MSW and CCR	500	33	2958.5	7111.05	10180.1	0	10180.1	10931.1	10931.1
27	21.2171	233208	15.3815	MSW and CCR	500	33	2957.9	7109.62	10177.9	0	10177.9	10991.6	10991.6
28	21.2171	233773	16.5267	MSW and CCR	500	33	2948.57	7087.19	10143.4	0	10143.4	11018.3	11018.3
29	21.2171	233607	17.6788	MSW and CCR	500	33	2930.48	7043.71	10076.4	0	10076.4	11010.5	11010.5
30	21.2171	232695	18.8383	MSW and CCR	500	33	2903.59	6979.06	9976.87	0	9976.87	10967.5	10967.5
31	21.2171	231023	20.0059	MSW and CCR	500	33	2867.84	6893.13	9844.55	0	9844.55	10888.7	10888.7
32	21.2171	228573	21.1822	MSW and CCR	500	33	2823.17	6785.77	9679.24	0	9679.24	10773.3	10773.3
33	21.2171	225329	22.3679	MSW and CCR	500	33	2769.52	6656.81	9480.65	0	9480.65	10620.3	10620.3
34	21.2171	221269	23.5638	MSW and CCR	500	33	2706.79	6506.03	9248.45	0	9248.45	10429	10429
35	21.2171	216372	24.7708	MSW and CCR	500	33	2634.88	6333.2	8982.34	0	8982.34	10198.2	10198.2
36	21.2171	210613	25.9895	MSW and CCR	500	33	2553.69	6138.05	8681.84	0	8681.84	9926.78	9926.78
37	21.2171	203966	27.2211	MSW and CCR	500	33	2463.09	5920.29	8346.53	0	8346.53	9613.54	9613.54
38	21.2171	196403	28.4665	MSW and CCR	500	33	2362.95	5679.58	7975.84	0	7975.84	9257.03	9257.03
39	21.2171	187890	29.7267	MSW and CCR	500	33	2253.1	5415.55	7569.26	0	7569.26	8855.79	8855.79
40	21.2171	178392	31.0029	MSW and CCR	500	33	2133.37	5127.78	7126.15	0	7126.15	8408.16	8408.16
41	21.2171	167870	32.2965	MSW and CCR	500	33	2003.59	4815.83	6645.79	0	6645.79	7912.24	7912.24
42	21.2171	156280	33.6088	MSW and CCR	500	33	1863.54	4479.2	6127.44	0	6127.44	7365.99	7365.99
43	21.2171	143573	34.9415	MSW and CCR	500	33	1712.99	4117.35	5570.23	0	5570.23	6767.07	6767.07
44	21.2171	129695	36.2961	MSW and CCR	500	33	1551.71	3729.69	4973.3	0	4973.3	6112.98	6112.98
45	21.2171	114585	37.6748	MSW and CCR	500	33	1379.42	3315.57	4335.6	0	4335.6	5400.77	5400.77
46	21.2171	98172.6	39.0795	MSW and CCR	500	33	1195.83	2874.3	3656.1	0	3656.1	4627.22	4627.22
47	21.2171	80380.7	40.5129	MSW and CCR	500	33	1000.63	2405.12	2933.63	0	2933.63	3788.64	3788.64
48	21.2171	61016.3	41.9776	MSW and CCR	500	33	792.424	1904.67	2163	0	2163	2875.94	2875.94
49	21.2171	38214.6	43.4768	MSW and CCR	500	33	553.004	1329.2	1276.86	0	1276.86	1801.21	1801.21
50	21.2171	13030.5	45.0142	MSW and CCR	500	33	294.39	707.595	319.669	0	319.669	614.205	614.205

Query 1 (janbu simplified) - Safety Factor: 2.4036

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	20.3357	7925.79	-11.9556	MSW and CCR	500	33	332.333	798.796	460.106	0	460.106	389.736	389.736
2	20.3357	23476.1	-10.879	MSW and CCR	500	33	548.397	1318.13	1259.81	0	1259.81	1154.41	1154.41
3	20.3357	38427.1	-9.80617	MSW and CCR	500	33	753.757	1811.73	2019.9	0	2019.9	1889.62	1889.62
4	20.3357	52784.8	-8.73684	MSW and CCR	500	33	948.71	2280.32	2741.45	0	2741.45	2595.65	2595.65
5	20.3357	66554.8	-7.67057	MSW and CCR	500	33	1133.51	2724.51	3425.44	0	3425.44	3272.78	3272.78
6	20.3357	79741.6	-6.60696	MSW and CCR	500	33	1308.41	3144.9	4072.78	0	4072.78	3921.23	3921.23
7	20.3357	92349.4	-5.54563	MSW and CCR	500	33	1473.63	3542.02	4684.3	0	4684.3	4541.22	4541.22
8	20.3357	104382	-4.48621	MSW and CCR	500	33	1629.38	3916.37	5260.76	0	5260.76	5132.92	5132.92
9	20.3357	115841	-3.42833	MSW and CCR	500	33	1775.83	4268.38	5802.82	0	5802.82	5696.44	5696.44
10	20.3357	126730	-2.37161	MSW and CCR	500	33	1913.16	4598.48	6311.12	0	6311.12	6231.88	6231.88
11	20.3357	137049	-1.31571	MSW and CCR	500	33	2041.53	4907.03	6786.23	0	6786.23	6739.34	6739.34
12	19.1322	138177	-0.291473	Protective Cover	500	20	1302.67	3131.09	7228.87	0	7228.87	7222.24	7222.24
13	19.1322	146864	0.701431	Protective Cover	500	20	1367.88	3287.84	7659.54	0	7659.54	7676.29	7676.29
14	19.1322	154853	1.69455	Protective Cover	500	20	1427.25	3430.54	8051.58	0	8051.58	8093.81	8093.81
15	12.3698	104065	2.51246	Protective Cover	500	20	1472.17	3538.51	8348.26	0	8348.26	8412.86	8412.86
16	19.3034	168000	3.33546	Protective Cover	500	20	1512.57	3635.61	8615.01	0	8615.01	8703.17	8703.17
17	19.3034	174240	4.33949	Protective Cover	500	20	1556.97	3742.34	8908.27	0	8908.27	9026.42	9026.42
18	19.3034	179757	5.34486	Protective Cover	500	20	1595.54	3835.04	9162.94	0	9162.94	9312.21	9312.21
19	21.2171	203606	6.4019	MSW and CCR	500	33	2718.38	6533.89	9291.37	0	9291.37	9596.38	9596.38
20	21.2171	209668	7.51118	MSW and CCR	500	33	2778.98	6679.55	9515.66	0	9515.66	9882.07	9882.07
21	21.2171	215068	8.6233	MSW and CCR	500	33	2830.76	6804.01	9707.32	0	9707.32	10136.6	10136.6
22	21.2171	219801	9.7387	MSW and CCR	500	33	2873.76	6907.37	9866.48	0	9866.48	10359.7	10359.7
23	21.2171	223861	10.8578	MSW and CCR	500	33	2908.02	6989.71	9993.26	0	9993.26	10551	10551
24	21.2171	227240	11.9812	MSW and CCR	500	33	2933.55	7051.09	10087.8	0	10087.8	10710.3	10710.3
25	21.2171	229930	13.1092	MSW and CCR	500	33	2950.38	7091.53	10150	0	10150	10837.1	10837.1
26	21.2171	231923	14.2425	MSW and CCR	500	33	2958.5	7111.05	10180.1	0	10180.1	10931.1	10931.1
27	21.2171	233208	15.3815	MSW and CCR	500	33	2957.9	7109.62	10177.9	0	10177.9	10991.6	10991.6
28	21.2171	233773	16.5267	MSW and CCR	500	33	2948.57	7087.19	10143.4	0	10143.4	11018.3	11018.3
29	21.2171	233607	17.6788	MSW and CCR	500	33	2930.48	7043.71	10076.4	0	10076.4	11010.5	11010.5
30	21.2171	232695	18.8383	MSW and CCR	500	33	2903.59	6979.06	9976.87	0	9976.87	10967.5	10967.5
31	21.2171	231023	20.0059	MSW and CCR	500	33	2867.84	6893.13	9844.55	0	9844.55	10888.7	10888.7
32	21.2171	228573	21.1822	MSW and CCR	500	33	2823.17	6785.77	9679.24	0	9679.24	10773.3	10773.3
33	21.2171	225329	22.3679	MSW and CCR	500	33	2769.52	6656.81	9480.65	0	9480.65	10620.3	10620.3
34	21.2171	221269	23.5638	MSW and CCR	500	33	2706.79	6506.03	9248.45	0	9248.45	10429	10429
35	21.2171	216372	24.7708	MSW and CCR	500	33	2634.88	6333.2	8982.34	0	8982.34	10198.2	10198.2
36	21.2171	210613	25.9895	MSW and CCR	500	33	2553.69	6138.05	8681.84	0	8681.84	9926.78	9926.78
37	21.2171	203966	27.2211	MSW and CCR	500	33	2463.09	5920.29	8346.53	0	8346.53	9613.54	9613.54
38	21.2171	196403	28.4665	MSW and CCR	500	33	2362.95	5679.58	7975.84	0	7975.84	9257.03	9257.03
39	21.2171	187890	29.7267	MSW and CCR	500	33	2253.1	5415.55	7569.26	0	7569.26	8855.79	8855.79
40	21.2171	178392	31.0029	MSW and CCR	500	33	2133.37	5127.78	7126.15	0	7126.15	8408.16	8408.16
41	21.2171	167870	32.2965	MSW and CCR	500	33	2003.59	4815.83	6645.79	0	6645.79	7912.24	7912.24
42	21.2171	156280	33.6088	MSW and CCR	500	33	1863.54	4479.2	6127.44	0	6127.44	7365.99	7365.99
43	21.2171	143573	34.9415	MSW and CCR	500	33	1712.99	4117.35	5570.23	0	5570.23	6767.07	6767.07
44	21.2171	129695	36.2961	MSW and CCR	500	33	1551.71	3729.69	4973.3	0	4973.3	6112.98	6112.98
45	21.2171	114585	37.6748	MSW and CCR	500	33	1379.42	3315.57	4335.6	0	4335.6	5400.77	5400.77
46	21.2171	98172.6	39.0795	MSW and CCR	500	33	1195.83	2874.3	3656.1	0	3656.1	4627.22	4627.22
47	21.2171	80380.7	40.5129	MSW and CCR	500	33	1000.63	2405.12	2933.63	0	2933.63	3788.64	3788.64
48	21.2171	61016.3	41.9776	MSW and CCR	500	33	792.424	1904.67	2163	0	2163	2875.94	2875.94
49	21.2171	38214.6	43.4768	MSW and CCR	500	33	553.004	1329.2	1276.86	0	1276.86	1801.21	1801.21
50	21.2171	13030.5	45.0142	MSW and CCR	500	33	294.39	707.595	319.669	0	319.669	614.205	614.205

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 2.49488

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	259.613	1118.9	0	0	0
2	286.534	1115.34	10455.2	0	0
3	313.454	1112.24	29544.8	0	0
4	340.374	1109.59	56062.5	0	0
5	367.294	1107.4	88872.5	0	0
6	395.313	1105.59	116510	0	0
7	423.332	1104.27	146510	0	0
8	431.478	1103.98	153877	0	0
9	434.94	1103.87	155698	0	0
10	435.42	1103.85	156137	0	0
11	443.95	1103.61	165650	0	0
12	482.854	1103.08	235048	0	0
13	507.66	1103.22	262583	0	0
14	532.465	1103.75	289331	0	0
15	557.27	1104.65	314758	0	0
16	582.076	1105.94	338380	0	0
17	606.881	1107.6	359757	0	0
18	631.687	1109.65	378498	0	0
19	657.93	1112.24	422087	0	0
20	684.173	1115.25	463042	0	0
21	710.415	1118.7	500939	0	0
22	736.658	1122.59	535391	0	0
23	762.901	1126.92	566052	0	0
24	789.144	1131.69	592612	0	0
25	815.387	1136.91	614803	0	0
26	841.63	1142.58	632392	0	0
27	867.872	1148.71	645187	0	0
28	894.115	1155.3	653036	0	0
29	920.358	1162.36	655826	0	0
30	946.601	1169.89	653486	0	0
31	972.844	1177.9	645985	0	0
32	999.087	1186.41	633338	0	0
33	1025.33	1195.41	615604	0	0
34	1051.57	1204.91	592886	0	0
35	1077.82	1214.93	565339	0	0
36	1104.06	1225.48	533168	0	0
37	1130.3	1236.56	496630	0	0
38	1156.54	1248.2	456042	0	0
39	1182.79	1260.39	411778	0	0
40	1209.03	1273.16	364280	0	0
41	1235.27	1286.52	314056	0	0
42	1261.51	1300.5	261690	0	0
43	1287.76	1315.09	207880	0	0
44	1314	1330.34	154163	0	0
45	1340.24	1346.25	101846	0	0
46	1366.49	1362.85	52055.1	0	0
47	1392.73	1380.16	6034.4	0	0
48	1418.97	1398.23	-34643.3	0	0
49	1445.21	1417.06	-65279.3	0	0
50	1471.46	1436.71	-82635.4	0	0
51	1497.7	1457.2	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 2.4036

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	299.234	1130.89	0	0	0
2	319.57	1126.59	8738.26	0	0
3	339.905	1122.68	24812	0	0
4	360.241	1119.16	47237.1	0	0
5	380.577	1116.04	75093.8	0	0
6	400.912	1113.3	107522	0	0
7	421.248	1110.94	143718	0	0
8	441.584	1108.97	182929	0	0
9	461.919	1107.37	224451	0	0
10	482.255	1106.16	267627	0	0
11	502.591	1105.31	311841	0	0
12	522.927	1104.85	356519	0	0
13	542.059	1104.75	382141	0	0
14	561.191	1104.98	406513	0	0
15	580.323	1105.55	429257	0	0
16	592.693	1106.09	442933	0	0
17	611.996	1107.22	462434	0	0
18	631.3	1108.68	479435	0	0
19	650.603	1110.49	493680	0	0
20	671.82	1112.87	529227	0	0
21	693.037	1115.67	561559	0	0
22	714.254	1118.88	590374	0	0
23	735.472	1122.52	615408	0	0
24	756.689	1126.59	636428	0	0
25	777.906	1131.1	653238	0	0
26	799.123	1136.04	665674	0	0
27	820.34	1141.42	673608	0	0
28	841.557	1147.26	676949	0	0
29	862.774	1153.56	675640	0	0
30	883.991	1160.32	669663	0	0
31	905.208	1167.56	659038	0	0
32	926.425	1175.28	643826	0	0
33	947.643	1183.5	624133	0	0
34	968.86	1192.23	600106	0	0
35	990.077	1201.49	571945	0	0
36	1011.29	1211.28	539897	0	0
37	1032.51	1221.62	504269	0	0
38	1053.73	1232.54	465426	0	0
39	1074.95	1244.04	423799	0	0
40	1096.16	1256.16	379892	0	0
41	1117.38	1268.91	334289	0	0
42	1138.6	1282.32	287665	0	0
43	1159.81	1296.42	240792	0	0
44	1181.03	1311.24	194557	0	0
45	1202.25	1326.82	149973	0	0
46	1223.46	1343.21	108203	0	0
47	1244.68	1360.44	70575.8	0	0
48	1265.9	1378.57	38617.7	0	0
49	1287.12	1397.66	14138.4	0	0
50	1308.33	1417.77	181.665	0	0
51	1329.55	1439	0	0	0

Query 1 (janbu simplified) - Safety Factor: 2.4036

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	299.234	1130.89	0	0	0
2	319.57	1126.59	8738.26	0	0
3	339.905	1122.68	24812	0	0
4	360.241	1119.16	47237.1	0	0
5	380.577	1116.04	75093.8	0	0
6	400.912	1113.3	107522	0	0
7	421.248	1110.94	143718	0	0
8	441.584	1108.97	182929	0	0
9	461.919	1107.37	224451	0	0
10	482.255	1106.16	267627	0	0
11	502.591	1105.31	311841	0	0
12	522.927	1104.85	356519	0	0
13	542.059	1104.75	382141	0	0
14	561.191	1104.98	406513	0	0
15	580.323	1105.55	429257	0	0
16	592.693	1106.09	442933	0	0
17	611.996	1107.22	462434	0	0
18	631.3	1108.68	479435	0	0
19	650.603	1110.49	493680	0	0
20	671.82	1112.87	529227	0	0
21	693.037	1115.67	561559	0	0
22	714.254	1118.88	590374	0	0
23	735.472	1122.52	615408	0	0
24	756.689	1126.59	636428	0	0
25	777.906	1131.1	653238	0	0
26	799.123	1136.04	665674	0	0
27	820.34	1141.42	673608	0	0
28	841.557	1147.26	676949	0	0
29	862.774	1153.56	675640	0	0
30	883.991	1160.32	669663	0	0
31	905.208	1167.56	659038	0	0
32	926.425	1175.28	643826	0	0
33	947.643	1183.5	624133	0	0
34	968.86	1192.23	600106	0	0
35	990.077	1201.49	571945	0	0
36	1011.29	1211.28	539897	0	0
37	1032.51	1221.62	504269	0	0
38	1053.73	1232.54	465426	0	0
39	1074.95	1244.04	423799	0	0
40	1096.16	1256.16	379892	0	0
41	1117.38	1268.91	334289	0	0
42	1138.6	1282.32	287665	0	0
43	1159.81	1296.42	240792	0	0
44	1181.03	1311.24	194557	0	0
45	1202.25	1326.82	149973	0	0
46	1223.46	1343.21	108203	0	0
47	1244.68	1360.44	70575.8	0	0
48	1265.9	1378.57	38617.7	0	0
49	1287.12	1397.66	14138.4	0	0
50	1308.33	1417.77	181.665	0	0
51	1329.55	1439	0	0	0

List Of Coordinates

External Boundary

X	Y
1758.6	1413.4
1625	1457.2
1411	1457.2
1281.2	1428.2
240.8	1113.2
240.8	1111.4
240.8	1111.3
240.8	1111.1
240.8	1109.1
240.8	1017.16
1728.8	1017.16
1758.6	1017.16
1758.6	1159.2
1758.6	1161

Material Boundary

X	Y
240.8	1113.2
257.3	1110
434.8	1105.8
460.7	1099.6
472.1	1102.6
1553.9	1150.4
1581.2	1147
1728.8	1151.8
1758.6	1161

Material Boundary

X	Y
240.8	1111.4
257.3	1108.2
434.8	1104
460.7	1097.8
472.1	1100.8
700	1110.8
1553.9	1148.6
1581.2	1145.2
1728.8	1148.9
1758.6	1159.2

Material Boundary

X	Y
240.8	1111.3
257.3	1108.1
434.8	1103.9
460.7	1097.7
472.1	1100.7
700	1110.7
1553.9	1148.5
1581.4	1145.1
1728.8	1148.9

Material Boundary

X	Y
240.8	1111.1
257.3	1107.9
434.8	1103.7
460.7	1097.5
472.1	1100.5
700	1110.5
1553.9	1148.3
1581.4	1144.9
1728.8	1148.7

Material Boundary

X	Y
240.8	1109.1
257.3	1105.9
434.919	1102.02
460.7	1095.7
472.1	1098.5
700	1108.5
1553.9	1146.3
1581.4	1142.9
1728.8	1147.9

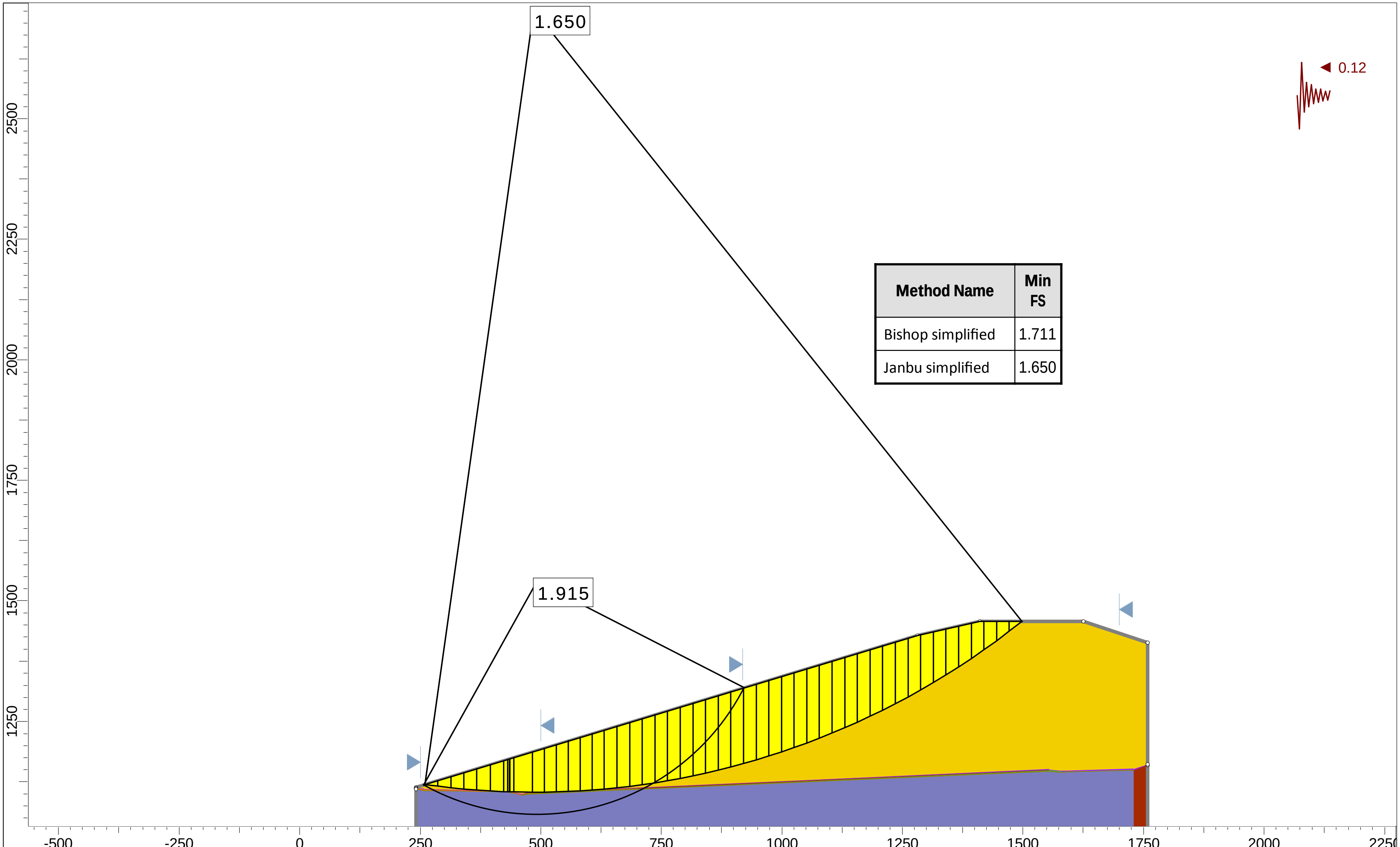
Material Boundary

X	Y
700	1108.5
700	1110.5
700	1110.7

Material Boundary

X	Y
1728.8	1017.16
1728.8	1147.9
1728.8	1148.7
1728.8	1148.9

SIESMIC ANALYSIS



Method Name	Min FS
Bishop simplified	1.711
Janbu simplified	1.650

rocscience

SLIDEINTERPRET 7.022

Project	Pine Bluff MSWLF - CCR Management Plan		
Analysis Description	Circular with Seismic		
Drawn By	Marc Liverman	*Scale* 1:3304	*Company* Atlantic Coast Consulting
Date	3/31/17	*File Name*	PBL 4 CCR Siesmic.slim

Slide Analysis Information

Pine Bluff MSWLF - CCR Management Plan

Project Summary

File Name:	PBL 4 CCR Siesmic.slim
Slide Modeler Version:	7.022
Project Title:	Pine Bluff MSWLF - CCR Management Plan
Analysis:	Circular with Seismic
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	3/31/17
Comments	
	Pine Bluff MSWLF
	Co-Mingled MSW and CCR Ratio 10:1 (by weight)

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
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:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Circular
Search Method:	Slope Search
Number of Surfaces:	5000
Upper Angle:	Not Defined
Lower Angle:	Not Defined
Composite Surfaces:	Disabled
Reverse Curvature:	Invalid Surfaces
Minimum Elevation [ft]:	1025
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis: No
Staged pseudostatic analysis: No

Loading

Seismic Load Coefficient (Horizontal): 0.12

Material Properties

Property	MSW and CCR	Textured Liner	Smooth Liner	Recompacted Liner Base	GCL	Geocomposite	Protective Cover
Color							
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	74.5	100	100	130	100	60	110
Cohesion [psf]	500	0	0	500	0	0	500
Friction Angle [deg]	33	15	10	30	33	20	20
Water Surface	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	1.710620
Center:	485.699, 2726.150
Radius:	1623.078
Left Slip Surface Endpoint:	259.613, 1118.896
Right Slip Surface Endpoint:	1497.700, 1457.200
Resisting Moment:	1.03384e+010 lb-ft
Driving Moment:	6.04366e+009 lb-ft
Total Slice Area:	133991 ft2
Surface Horizontal Width:	1238.09 ft
Surface Average Height:	108.224 ft

Method: janbu simplified

FS	1.650270
Center:	485.699, 2726.150
Radius:	1623.078
Left Slip Surface Endpoint:	259.613, 1118.896
Right Slip Surface Endpoint:	1497.700, 1457.200
Resisting Horizontal Force:	5.9915e+006 lb
Driving Horizontal Force:	3.63062e+006 lb
Total Slice Area:	133991 ft2
Surface Horizontal Width:	1238.09 ft
Surface Average Height:	108.224 ft

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Method: janbu simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.71062

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	26.9202	11740.5	-7.52774	MSW and CCR	500	33	482	824.518	499.716	0	499.716	436.022	436.022
2	26.9202	34763.4	-6.57015	MSW and CCR	500	33	818.251	1399.72	1385.44	0	1385.44	1291.2	1291.2
3	26.9202	56872.7	-5.61441	MSW and CCR	500	33	1136.67	1944.41	2224.2	0	2224.2	2112.46	2112.46
4	26.9202	78073.4	-4.66023	MSW and CCR	500	33	1437.72	2459.39	3017.19	0	3017.19	2899.99	2899.99
5	28.0191	103365	-3.68792	Protective Cover	500	20	1092.18	1868.3	3759.38	0	3759.38	3688.98	3688.98
6	28.0191	125231	-2.69724	Protective Cover	500	20	1255.84	2148.26	4528.56	0	4528.56	4469.4	4469.4
7	8.1452	40305.5	-2.05827	Geocomposite	0	20	1060.97	1814.92	4986.44	0	4986.44	4948.31	4948.31
8	3.46192	17635	-1.85328	Smooth Liner	0	10	526.832	901.21	5111.02	0	5111.02	5093.97	5093.97
9	0.480212	2469.99	-1.78366	Geocomposite	0	20	1101.68	1884.56	5177.79	0	5177.79	5143.48	5143.48
10	8.52997	44556.3	-1.62457	Protective Cover	500	20	1412.21	2415.75	5263.49	0	5263.49	5223.44	5223.44
11	38.9043	223912	-0.787192	MSW and CCR	500	33	2490.22	4259.82	5789.61	0	5789.61	5755.39	5755.39
12	24.8055	161367	0.337401	Protective Cover	500	20	1674.33	2864.15	6495.47	0	6495.47	6505.33	6505.33
13	24.8055	175296	1.21317	Protective Cover	500	20	1787.86	3058.35	7029.01	0	7029.01	7066.87	7066.87
14	24.8055	188189	2.08922	Protective Cover	500	20	1891.83	3236.21	7517.65	0	7517.65	7586.66	7586.66
15	24.8055	200045	2.96575	Protective Cover	500	20	1986.33	3397.86	7961.79	0	7961.79	8064.7	8064.7
16	24.8055	210863	3.84299	Protective Cover	500	20	2071.42	3543.42	8361.72	0	8361.72	8500.87	8500.87
17	24.8055	220639	4.72112	Protective Cover	500	20	2147.17	3672.99	8717.7	0	8717.7	8895.03	8895.03
18	26.2428	243559	5.62589	MSW and CCR	500	33	3678.32	6292.2	8919.2	0	8919.2	9281.54	9281.54
19	26.2428	253617	6.55758	MSW and CCR	500	33	3795.78	6493.13	9228.62	0	9228.62	9664.96	9664.96
20	26.2428	262829	7.49102	MSW and CCR	500	33	3900.04	6671.49	9503.25	0	9503.25	10016.1	10016.1
21	26.2428	271190	8.42646	MSW and CCR	500	33	3991.26	6827.53	9743.52	0	9743.52	10334.8	10334.8
22	26.2428	278693	9.36417	MSW and CCR	500	33	4069.55	6961.45	9949.75	0	9949.75	10620.8	10620.8
23	26.2428	285333	10.3044	MSW and CCR	500	33	4135.01	7073.43	10122.2	0	10122.2	10874	10874
24	26.2428	291101	11.2475	MSW and CCR	500	33	4187.75	7163.65	10261.1	0	10261.1	11093.9	11093.9
25	26.2428	295990	12.1936	MSW and CCR	500	33	4227.85	7232.25	10366.7	0	10366.7	11280.3	11280.3
26	26.2428	299991	13.1432	MSW and CCR	500	33	4255.39	7279.35	10439.3	0	10439.3	11432.9	11432.9
27	26.2428	303093	14.0964	MSW and CCR	500	33	4270.42	7305.06	10478.9	0	10478.9	11551.2	11551.2
28	26.2428	305285	15.0537	MSW and CCR	500	33	4273	7309.48	10485.7	0	10485.7	11634.9	11634.9
29	26.2428	306556	16.0153	MSW and CCR	500	33	4263.17	7292.67	10459.8	0	10459.8	11683.5	11683.5
30	26.2428	306893	16.9815	MSW and CCR	500	33	4240.98	7254.7	10401.3	0	10401.3	11696.4	11696.4
31	26.2428	306281	17.9527	MSW and CCR	500	33	4206.42	7195.59	10310.3	0	10310.3	11673.2	11673.2
32	26.2428	304706	18.9293	MSW and CCR	500	33	4159.53	7115.37	10186.8	0	10186.8	11613.3	11613.3
33	26.2428	302150	19.9116	MSW and CCR	500	33	4100.29	7014.04	10030.7	0	10030.7	11516	11516
34	26.2428	298595	20.9001	MSW and CCR	500	33	4028.71	6891.59	9842.19	0	9842.19	11380.6	11380.6
35	26.2428	294023	21.8951	MSW and CCR	500	33	3944.76	6747.99	9621.07	0	9621.07	11206.5	11206.5
36	26.2428	288412	22.8972	MSW and CCR	500	33	3848.42	6583.19	9367.3	0	9367.3	10992.7	10992.7
37	26.2428	281740	23.9067	MSW and CCR	500	33	3739.66	6397.14	9080.78	0	9080.78	10738.5	10738.5
38	26.2428	273981	24.9241	MSW and CCR	500	33	3618.42	6189.74	8761.42	0	8761.42	10442.9	10442.9
39	26.2428	265110	25.95	MSW and CCR	500	33	3484.65	5960.91	8409.06	0	8409.06	10104.9	10104.9
40	26.2428	255097	26.9849	MSW and CCR	500	33	3338.28	5710.52	8023.51	0	8023.51	9723.34	9723.34
41	26.2428	243911	28.0295	MSW and CCR	500	33	3179.23	5438.46	7604.55	0	7604.55	9297.07	9297.07
42	26.2428	231392	29.0843	MSW and CCR	500	33	3005.91	5141.97	7148	0	7148	8819.99	8819.99
43	26.2428	214830	30.15	MSW and CCR	500	33	2786.57	4766.76	6570.23	0	6570.23	8188.79	8188.79
44	26.2428	195839	31.2273	MSW and CCR	500	33	2541.34	4347.27	5924.27	0	5924.27	7465.02	7465.02
45	26.2428	175521	32.3171	MSW and CCR	500	33	2283.82	3906.74	5245.93	0	5245.93	6690.65	6690.65
46	26.2428	153827	33.4202	MSW and CCR	500	33	2013.88	3444.98	4534.89	0	4534.89	5863.81	5863.81
47	26.2428	130177	34.5375	MSW and CCR	500	33	1725.37	2951.45	3774.9	0	3774.9	4962.37	4962.37
48	26.2428	96886.2	35.6699	MSW and CCR	500	33	1331.59	2277.85	2737.64	0	2737.64	3693.43	3693.43
49	26.2428	59268.3	36.8187	MSW and CCR	500	33	895.564	1531.97	1589.1	0	1589.1	2259.52	2259.52
50	26.2428	20032	37.985	MSW and CCR	500	33	449.144	768.314	413.169	0	413.169	763.889	763.889

Query 1 (bishop simplified) - Safety Factor: 1.71062

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	26.9202	11740.5	-7.52774	MSW and CCR	500	33	482	824.518	499.716	0	499.716	436.022	436.022
2	26.9202	34763.4	-6.57015	MSW and CCR	500	33	818.251	1399.72	1385.44	0	1385.44	1291.2	1291.2
3	26.9202	56872.7	-5.61441	MSW and CCR	500	33	1136.67	1944.41	2224.2	0	2224.2	2112.46	2112.46
4	26.9202	78073.4	-4.66023	MSW and CCR	500	33	1437.72	2459.39	3017.19	0	3017.19	2899.99	2899.99
5	28.0191	103365	-3.68792	Protective Cover	500	20	1092.18	1868.3	3759.38	0	3759.38	3688.98	3688.98
6	28.0191	125231	-2.69724	Protective Cover	500	20	1255.84	2148.26	4528.56	0	4528.56	4469.4	4469.4
7	8.1452	40305.5	-2.05827	Geocomposite	0	20	1060.97	1814.92	4986.44	0	4986.44	4948.31	4948.31
8	3.46192	17635	-1.85328	Smooth Liner	0	10	526.832	901.21	5111.02	0	5111.02	5093.97	5093.97
9	0.480212	2469.99	-1.78366	Geocomposite	0	20	1101.68	1884.56	5177.79	0	5177.79	5143.48	5143.48
10	8.52997	44556.3	-1.62457	Protective Cover	500	20	1412.21	2415.75	5263.49	0	5263.49	5223.44	5223.44
11	38.9043	223912	-0.787192	MSW and CCR	500	33	2490.22	4259.82	5789.61	0	5789.61	5755.39	5755.39
12	24.8055	161367	0.337401	Protective Cover	500	20	1674.33	2864.15	6495.47	0	6495.47	6505.33	6505.33
13	24.8055	175296	1.21317	Protective Cover	500	20	1787.86	3058.35	7029.01	0	7029.01	7066.87	7066.87
14	24.8055	188189	2.08922	Protective Cover	500	20	1891.83	3236.21	7517.65	0	7517.65	7586.66	7586.66
15	24.8055	200045	2.96575	Protective Cover	500	20	1986.33	3397.86	7961.79	0	7961.79	8064.7	8064.7
16	24.8055	210863	3.84299	Protective Cover	500	20	2071.42	3543.42	8361.72	0	8361.72	8500.87	8500.87
17	24.8055	220639	4.72112	Protective Cover	500	20	2147.17	3672.99	8717.7	0	8717.7	8895.03	8895.03
18	26.2428	243559	5.62589	MSW and CCR	500	33	3678.32	6292.2	8919.2	0	8919.2	9281.54	9281.54
19	26.2428	253617	6.55758	MSW and CCR	500	33	3795.78	6493.13	9228.62	0	9228.62	9664.96	9664.96
20	26.2428	262829	7.49102	MSW and CCR	500	33	3900.04	6671.49	9503.25	0	9503.25	10016.1	10016.1
21	26.2428	271190	8.42646	MSW and CCR	500	33	3991.26	6827.53	9743.52	0	9743.52	10334.8	10334.8
22	26.2428	278693	9.36417	MSW and CCR	500	33	4069.55	6961.45	9949.75	0	9949.75	10620.8	10620.8
23	26.2428	285333	10.3044	MSW and CCR	500	33	4135.01	7073.43	10122.2	0	10122.2	10874	10874
24	26.2428	291101	11.2475	MSW and CCR	500	33	4187.75	7163.65	10261.1	0	10261.1	11093.9	11093.9
25	26.2428	295990	12.1936	MSW and CCR	500	33	4227.85	7232.25	10366.7	0	10366.7	11280.3	11280.3
26	26.2428	299991	13.1432	MSW and CCR	500	33	4255.39	7279.35	10439.3	0	10439.3	11432.9	11432.9
27	26.2428	303093	14.0964	MSW and CCR	500	33	4270.42	7305.06	10478.9	0	10478.9	11551.2	11551.2
28	26.2428	305285	15.0537	MSW and CCR	500	33	4273	7309.48	10485.7	0	10485.7	11634.9	11634.9
29	26.2428	306556	16.0153	MSW and CCR	500	33	4263.17	7292.67	10459.8	0	10459.8	11683.5	11683.5
30	26.2428	306893	16.9815	MSW and CCR	500	33	4240.98	7254.7	10401.3	0	10401.3	11696.4	11696.4
31	26.2428	306281	17.9527	MSW and CCR	500	33	4206.42	7195.59	10310.3	0	10310.3	11673.2	11673.2
32	26.2428	304706	18.9293	MSW and CCR	500	33	4159.53	7115.37	10186.8	0	10186.8	11613.3	11613.3
33	26.2428	302150	19.9116	MSW and CCR	500	33	4100.29	7014.04	10030.7	0	10030.7	11516	11516
34	26.2428	298595	20.9001	MSW and CCR	500	33	4028.71	6891.59	9842.19	0	9842.19	11380.6	11380.6
35	26.2428	294023	21.8951	MSW and CCR	500	33	3944.76	6747.99	9621.07	0	9621.07	11206.5	11206.5
36	26.2428	288412	22.8972	MSW and CCR	500	33	3848.42	6583.19	9367.3	0	9367.3	10992.7	10992.7
37	26.2428	281740	23.9067	MSW and CCR	500	33	3739.66	6397.14	9080.78	0	9080.78	10738.5	10738.5
38	26.2428	273981	24.9241	MSW and CCR	500	33	3618.42	6189.74	8761.42	0	8761.42	10442.9	10442.9
39	26.2428	265110	25.95	MSW and CCR	500	33	3484.65	5960.91	8409.06	0	8409.06	10104.9	10104.9
40	26.2428	255097	26.9849	MSW and CCR	500	33	3338.28	5710.52	8023.51	0	8023.51	9723.34	9723.34
41	26.2428	243911	28.0295	MSW and CCR	500	33	3179.23	5438.46	7604.55	0	7604.55	9297.07	9297.07
42	26.2428	231392	29.0843	MSW and CCR	500	33	3005.91	5141.97	7148	0	7148	8819.99	8819.99
43	26.2428	214830	30.15	MSW and CCR	500	33	2786.57	4766.76	6570.23	0	6570.23	8188.79	8188.79
44	26.2428	195839	31.2273	MSW and CCR	500	33	2541.34	4347.27	5924.27	0	5924.27	7465.02	7465.02
45	26.2428	175521	32.3171	MSW and CCR	500	33	2283.82	3906.74	5245.93	0	5245.93	6690.65	6690.65
46	26.2428	153827	33.4202	MSW and CCR	500	33	2013.88	3444.98	4534.89	0	4534.89	5863.81	5863.81
47	26.2428	130177	34.5375	MSW and CCR	500	33	1725.37	2951.45	3774.9	0	3774.9	4962.37	4962.37
48	26.2428	96886.2	35.6699	MSW and CCR	500	33	1331.59	2277.85	2737.64	0	2737.64	3693.43	3693.43
49	26.2428	59268.3	36.8187	MSW and CCR	500	33	895.564	1531.97	1589.1	0	1589.1	2259.52	2259.52
50	26.2428	20032	37.985	MSW and CCR	500	33	449.144	768.314	413.169	0	413.169	763.889	763.889

Global Minimum Query (janbu simplified) - Safety Factor: 1.65027

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	26.9202	11740.5	-7.52774	MSW and CCR	500	33	500.634	826.182	502.275	0	502.275	436.119	436.119
2	26.9202	34763.4	-6.57015	MSW and CCR	500	33	849.656	1402.16	1389.21	0	1389.21	1291.35	1291.35
3	26.9202	56872.7	-5.61441	MSW and CCR	500	33	1179.98	1947.29	2228.64	0	2228.64	2112.64	2112.64
4	26.9202	78073.4	-4.66023	MSW and CCR	500	33	1492.11	2462.39	3021.81	0	3021.81	2900.18	2900.18
5	28.0191	103365	-3.68792	Protective Cover	500	20	1132.72	1869.29	3762.12	0	3762.12	3689.11	3689.11
6	28.0191	125231	-2.69724	Protective Cover	500	20	1302.27	2149.09	4530.84	0	4530.84	4469.49	4469.49
7	8.1452	40305.5	-2.05827	Geocomposite	0	20	1100.09	1815.45	4987.9	0	4987.9	4948.37	4948.37
8	3.46192	17635	-1.85328	Smooth Liner	0	10	546.168	901.325	5111.68	0	5111.68	5094.01	5094.01
9	0.480212	2469.99	-1.78366	Geocomposite	0	20	1142.26	1885.04	5179.12	0	5179.12	5143.55	5143.55
10	8.52997	44556.3	-1.62457	Protective Cover	500	20	1464.19	2416.31	5265.03	0	5265.03	5223.5	5223.5
11	38.9043	223912	-0.787192	MSW and CCR	500	33	2581.8	4260.67	5790.92	0	5790.92	5755.44	5755.44
12	24.8055	161367	0.337401	Protective Cover	500	20	1735.49	2864.02	6495.1	0	6495.1	6505.32	6505.32
13	24.8055	175296	1.21317	Protective Cover	500	20	1852.93	3057.83	7027.56	0	7027.56	7066.8	7066.8
14	24.8055	188189	2.08922	Protective Cover	500	20	1960.44	3235.26	7515.07	0	7515.07	7586.59	7586.59
15	24.8055	200045	2.96575	Protective Cover	500	20	2058.12	3396.45	7957.93	0	7957.93	8064.56	8064.56
16	24.8055	210863	3.84299	Protective Cover	500	20	2146.02	3541.52	8356.49	0	8356.49	8500.65	8500.65
17	24.8055	220639	4.72112	Protective Cover	500	20	2224.22	3670.57	8711.07	0	8711.07	8894.76	8894.76
18	26.2428	243559	5.62589	MSW and CCR	500	33	3807.6	6283.56	8905.89	0	8905.89	9280.97	9280.97
19	26.2428	253617	6.55758	MSW and CCR	500	33	3928.31	6482.78	9212.68	0	9212.68	9664.26	9664.26
20	26.2428	262829	7.49102	MSW and CCR	500	33	4035.35	6659.41	9484.66	0	9484.66	10015.3	10015.3
21	26.2428	271190	8.42646	MSW and CCR	500	33	4128.83	6813.69	9722.22	0	9722.22	10333.9	10333.9
22	26.2428	278693	9.36417	MSW and CCR	500	33	4208.91	6945.84	9925.72	0	9925.72	10619.8	10619.8
23	26.2428	285333	10.3044	MSW and CCR	500	33	4275.69	7056.05	10095.4	0	10095.4	10872.8	10872.8
24	26.2428	291101	11.2475	MSW and CCR	500	33	4329.3	7144.52	10231.7	0	10231.7	11092.6	11092.6
25	26.2428	295990	12.1936	MSW and CCR	500	33	4369.82	7211.39	10334.6	0	10334.6	11278.9	11278.9
26	26.2428	299991	13.1432	MSW and CCR	500	33	4397.34	7256.8	10404.6	0	10404.6	11431.4	11431.4
27	26.2428	303093	14.0964	MSW and CCR	500	33	4411.93	7280.88	10441.6	0	10441.6	11549.6	11549.6
28	26.2428	305285	15.0537	MSW and CCR	500	33	4413.66	7283.73	10446	0	10446	11633.1	11633.1
29	26.2428	306556	16.0153	MSW and CCR	500	33	4402.58	7265.44	10417.8	0	10417.8	11681.5	11681.5
30	26.2428	306893	16.9815	MSW and CCR	500	33	4378.71	7226.06	10357.2	0	10357.2	11694.4	11694.4
31	26.2428	306281	17.9527	MSW and CCR	500	33	4342.1	7165.64	10264.2	0	10264.2	11671	11671
32	26.2428	304706	18.9293	MSW and CCR	500	33	4292.77	7084.23	10138.8	0	10138.8	11611	11611
33	26.2428	302150	19.9116	MSW and CCR	500	33	4230.73	6981.84	9981.16	0	9981.16	11513.6	11513.6
34	26.2428	298595	20.9001	MSW and CCR	500	33	4155.96	6858.46	9791.17	0	9791.17	11378.2	11378.2
35	26.2428	294023	21.8951	MSW and CCR	500	33	4068.47	6714.08	9568.84	0	9568.84	11204	11204
36	26.2428	288412	22.8972	MSW and CCR	500	33	3968.24	6548.67	9314.12	0	9314.12	10990.1	10990.1
37	26.2428	281740	23.9067	MSW and CCR	500	33	3855.23	6362.17	9026.96	0	9026.96	10735.9	10735.9
38	26.2428	273981	24.9241	MSW and CCR	500	33	3729.41	6154.53	8707.2	0	8707.2	10440.2	10440.2
39	26.2428	265110	25.95	MSW and CCR	500	33	3590.72	5925.65	8354.76	0	8354.76	10102.2	10102.2
40	26.2428	255097	26.9849	MSW and CCR	500	33	3439.1	5675.44	7969.49	0	7969.49	9720.66	9720.66
41	26.2428	243911	28.0295	MSW and CCR	500	33	3274.49	5403.79	7551.17	0	7551.17	9294.4	9294.4
42	26.2428	231392	29.0843	MSW and CCR	500	33	3095.25	5107.99	7095.69	0	7095.69	8817.37	8817.37
43	26.2428	214830	30.15	MSW and CCR	500	33	2868.7	4734.13	6519.98	0	6519.98	8186.25	8186.25
44	26.2428	195839	31.2273	MSW and CCR	500	33	2615.61	4316.46	5876.83	0	5876.83	7462.6	7462.6
45	26.2428	175521	32.3171	MSW and CCR	500	33	2349.97	3878.08	5201.78	0	5201.78	6688.35	6688.35
46	26.2428	153827	33.4202	MSW and CCR	500	33	2071.69	3418.85	4494.62	0	4494.62	5861.7	5861.7
47	26.2428	130177	34.5375	MSW and CCR	500	33	1774.44	2928.31	3739.27	0	3739.27	4960.52	4960.52
48	26.2428	96886.2	35.6699	MSW and CCR	500	33	1369.1	2259.39	2709.22	0	2709.22	3691.93	3691.93
49	26.2428	59268.3	36.8187	MSW and CCR	500	33	920.54	1519.14	1569.34	0	1569.34	2258.47	2258.47
50	26.2428	20032	37.985	MSW and CCR	500	33	461.541	761.668	402.933	0	402.933	763.335	763.335

Query 1 (janbu simplified) - Safety Factor: 1.65027

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	26.9202	11740.5	-7.52774	MSW and CCR	500	33	500.634	826.182	502.275	0	502.275	436.119	436.119
2	26.9202	34763.4	-6.57015	MSW and CCR	500	33	849.656	1402.16	1389.21	0	1389.21	1291.35	1291.35
3	26.9202	56872.7	-5.61441	MSW and CCR	500	33	1179.98	1947.29	2228.64	0	2228.64	2112.64	2112.64
4	26.9202	78073.4	-4.66023	MSW and CCR	500	33	1492.11	2462.39	3021.81	0	3021.81	2900.18	2900.18
5	28.0191	103365	-3.68792	Protective Cover	500	20	1132.72	1869.29	3762.12	0	3762.12	3689.11	3689.11
6	28.0191	125231	-2.69724	Protective Cover	500	20	1302.27	2149.09	4530.84	0	4530.84	4469.49	4469.49
7	8.1452	40305.5	-2.05827	Geocomposite	0	20	1100.09	1815.45	4987.9	0	4987.9	4948.37	4948.37
8	3.46192	17635	-1.85328	Smooth Liner	0	10	546.168	901.325	5111.68	0	5111.68	5094.01	5094.01
9	0.480212	2469.99	-1.78366	Geocomposite	0	20	1142.26	1885.04	5179.12	0	5179.12	5143.55	5143.55
10	8.52997	44556.3	-1.62457	Protective Cover	500	20	1464.19	2416.31	5265.03	0	5265.03	5223.5	5223.5
11	38.9043	223912	-0.787192	MSW and CCR	500	33	2581.8	4260.67	5790.92	0	5790.92	5755.44	5755.44
12	24.8055	161367	0.337401	Protective Cover	500	20	1735.49	2864.02	6495.1	0	6495.1	6505.32	6505.32
13	24.8055	175296	1.21317	Protective Cover	500	20	1852.93	3057.83	7027.56	0	7027.56	7066.8	7066.8
14	24.8055	188189	2.08922	Protective Cover	500	20	1960.44	3235.26	7515.07	0	7515.07	7586.59	7586.59
15	24.8055	200045	2.96575	Protective Cover	500	20	2058.12	3396.45	7957.93	0	7957.93	8064.56	8064.56
16	24.8055	210863	3.84299	Protective Cover	500	20	2146.02	3541.52	8356.49	0	8356.49	8500.65	8500.65
17	24.8055	220639	4.72112	Protective Cover	500	20	2224.22	3670.57	8711.07	0	8711.07	8894.76	8894.76
18	26.2428	243559	5.62589	MSW and CCR	500	33	3807.6	6283.56	8905.89	0	8905.89	9280.97	9280.97
19	26.2428	253617	6.55758	MSW and CCR	500	33	3928.31	6482.78	9212.68	0	9212.68	9664.26	9664.26
20	26.2428	262829	7.49102	MSW and CCR	500	33	4035.35	6659.41	9484.66	0	9484.66	10015.3	10015.3
21	26.2428	271190	8.42646	MSW and CCR	500	33	4128.83	6813.69	9722.22	0	9722.22	10333.9	10333.9
22	26.2428	278693	9.36417	MSW and CCR	500	33	4208.91	6945.84	9925.72	0	9925.72	10619.8	10619.8
23	26.2428	285333	10.3044	MSW and CCR	500	33	4275.69	7056.05	10095.4	0	10095.4	10872.8	10872.8
24	26.2428	291101	11.2475	MSW and CCR	500	33	4329.3	7144.52	10231.7	0	10231.7	11092.6	11092.6
25	26.2428	295990	12.1936	MSW and CCR	500	33	4369.82	7211.39	10334.6	0	10334.6	11278.9	11278.9
26	26.2428	299991	13.1432	MSW and CCR	500	33	4397.34	7256.8	10404.6	0	10404.6	11431.4	11431.4
27	26.2428	303093	14.0964	MSW and CCR	500	33	4411.93	7280.88	10441.6	0	10441.6	11549.6	11549.6
28	26.2428	305285	15.0537	MSW and CCR	500	33	4413.66	7283.73	10446	0	10446	11633.1	11633.1
29	26.2428	306556	16.0153	MSW and CCR	500	33	4402.58	7265.44	10417.8	0	10417.8	11681.5	11681.5
30	26.2428	306893	16.9815	MSW and CCR	500	33	4378.71	7226.06	10357.2	0	10357.2	11694.4	11694.4
31	26.2428	306281	17.9527	MSW and CCR	500	33	4342.1	7165.64	10264.2	0	10264.2	11671	11671
32	26.2428	304706	18.9293	MSW and CCR	500	33	4292.77	7084.23	10138.8	0	10138.8	11611	11611
33	26.2428	302150	19.9116	MSW and CCR	500	33	4230.73	6981.84	9981.16	0	9981.16	11513.6	11513.6
34	26.2428	298595	20.9001	MSW and CCR	500	33	4155.96	6858.46	9791.17	0	9791.17	11378.2	11378.2
35	26.2428	294023	21.8951	MSW and CCR	500	33	4068.47	6714.08	9568.84	0	9568.84	11204	11204
36	26.2428	288412	22.8972	MSW and CCR	500	33	3968.24	6548.67	9314.12	0	9314.12	10990.1	10990.1
37	26.2428	281740	23.9067	MSW and CCR	500	33	3855.23	6362.17	9026.96	0	9026.96	10735.9	10735.9
38	26.2428	273981	24.9241	MSW and CCR	500	33	3729.41	6154.53	8707.2	0	8707.2	10440.2	10440.2
39	26.2428	265110	25.95	MSW and CCR	500	33	3590.72	5925.65	8354.76	0	8354.76	10102.2	10102.2
40	26.2428	255097	26.9849	MSW and CCR	500	33	3439.1	5675.44	7969.49	0	7969.49	9720.66	9720.66
41	26.2428	243911	28.0295	MSW and CCR	500	33	3274.49	5403.79	7551.17	0	7551.17	9294.4	9294.4
42	26.2428	231392	29.0843	MSW and CCR	500	33	3095.25	5107.99	7095.69	0	7095.69	8817.37	8817.37
43	26.2428	214830	30.15	MSW and CCR	500	33	2868.7	4734.13	6519.98	0	6519.98	8186.25	8186.25
44	26.2428	195839	31.2273	MSW and CCR	500	33	2615.61	4316.46	5876.83	0	5876.83	7462.6	7462.6
45	26.2428	175521	32.3171	MSW and CCR	500	33	2349.97	3878.08	5201.78	0	5201.78	6688.35	6688.35
46	26.2428	153827	33.4202	MSW and CCR	500	33	2071.69	3418.85	4494.62	0	4494.62	5861.7	5861.7
47	26.2428	130177	34.5375	MSW and CCR	500	33	1774.44	2928.31	3739.27	0	3739.27	4960.52	4960.52
48	26.2428	96886.2	35.6699	MSW and CCR	500	33	1369.1	2259.39	2709.22	0	2709.22	3691.93	3691.93
49	26.2428	59268.3	36.8187	MSW and CCR	500	33	920.54	1519.14	1569.34	0	1569.34	2258.47	2258.47
50	26.2428	20032	37.985	MSW and CCR	500	33	461.541	761.668	402.933	0	402.933	763.335	763.335

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.71062

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	259.613	1118.9	0	0	0
2	286.534	1115.34	13323.7	0	0
3	313.454	1112.24	35440.3	0	0
4	340.374	1109.59	65052.5	0	0
5	367.294	1107.4	100947	0	0
6	395.313	1105.59	125886	0	0
7	423.332	1104.27	151967	0	0
8	431.478	1103.98	157218	0	0
9	434.94	1103.87	157496	0	0
10	435.42	1103.85	157805	0	0
11	443.95	1103.61	165758	0	0
12	482.854	1103.08	238710	0	0
13	507.66	1103.22	259864	0	0
14	532.465	1103.75	279414	0	0
15	557.27	1104.65	296882	0	0
16	582.076	1105.94	311839	0	0
17	606.881	1107.6	323903	0	0
18	631.687	1109.65	332745	0	0
19	657.93	1112.24	376836	0	0
20	684.173	1115.25	418016	0	0
21	710.415	1118.7	455869	0	0
22	736.658	1122.59	490023	0	0
23	762.901	1126.92	520147	0	0
24	789.144	1131.69	545954	0	0
25	815.387	1136.91	567195	0	0
26	841.63	1142.58	583662	0	0
27	867.872	1148.71	595190	0	0
28	894.115	1155.3	601653	0	0
29	920.358	1162.36	602967	0	0
30	946.601	1169.89	599091	0	0
31	972.844	1177.9	590027	0	0
32	999.087	1186.41	575819	0	0
33	1025.33	1195.41	556558	0	0
34	1051.57	1204.91	532383	0	0
35	1077.82	1214.93	503477	0	0
36	1104.06	1225.48	470079	0	0
37	1130.3	1236.56	432477	0	0
38	1156.54	1248.2	391016	0	0
39	1182.79	1260.39	346099	0	0
40	1209.03	1273.16	298195	0	0
41	1235.27	1286.52	247834	0	0
42	1261.51	1300.5	195622	0	0
43	1287.76	1315.09	142273	0	0
44	1314	1330.34	89354.1	0	0
45	1340.24	1346.25	38182.2	0	0
46	1366.49	1362.85	-10129.3	0	0
47	1392.73	1380.16	-54354.1	0	0
48	1418.97	1398.23	-92949.1	0	0
49	1445.21	1417.06	-121254	0	0
50	1471.46	1436.71	-136120	0	0
51	1497.7	1457.2	0	0	0

Query 1 (bishop simplified) - Safety Factor: 1.71062

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	259.613	1118.9	0	0	0
2	286.534	1115.34	13323.7	0	0
3	313.454	1112.24	35440.3	0	0
4	340.374	1109.59	65052.5	0	0
5	367.294	1107.4	100947	0	0
6	395.313	1105.59	125886	0	0
7	423.332	1104.27	151967	0	0
8	431.478	1103.98	157218	0	0
9	434.94	1103.87	157496	0	0
10	435.42	1103.85	157805	0	0
11	443.95	1103.61	165758	0	0
12	482.854	1103.08	238710	0	0
13	507.66	1103.22	259864	0	0
14	532.465	1103.75	279414	0	0
15	557.27	1104.65	296882	0	0
16	582.076	1105.94	311839	0	0
17	606.881	1107.6	323903	0	0
18	631.687	1109.65	332745	0	0
19	657.93	1112.24	376836	0	0
20	684.173	1115.25	418016	0	0
21	710.415	1118.7	455869	0	0
22	736.658	1122.59	490023	0	0
23	762.901	1126.92	520147	0	0
24	789.144	1131.69	545954	0	0
25	815.387	1136.91	567195	0	0
26	841.63	1142.58	583662	0	0
27	867.872	1148.71	595190	0	0
28	894.115	1155.3	601653	0	0
29	920.358	1162.36	602967	0	0
30	946.601	1169.89	599091	0	0
31	972.844	1177.9	590027	0	0
32	999.087	1186.41	575819	0	0
33	1025.33	1195.41	556558	0	0
34	1051.57	1204.91	532383	0	0
35	1077.82	1214.93	503477	0	0
36	1104.06	1225.48	470079	0	0
37	1130.3	1236.56	432477	0	0
38	1156.54	1248.2	391016	0	0
39	1182.79	1260.39	346099	0	0
40	1209.03	1273.16	298195	0	0
41	1235.27	1286.52	247834	0	0
42	1261.51	1300.5	195622	0	0
43	1287.76	1315.09	142273	0	0
44	1314	1330.34	89354.1	0	0
45	1340.24	1346.25	38182.2	0	0
46	1366.49	1362.85	-10129.3	0	0
47	1392.73	1380.16	-54354.1	0	0
48	1418.97	1398.23	-92949.1	0	0
49	1445.21	1417.06	-121254	0	0
50	1471.46	1436.71	-136120	0	0
51	1497.7	1457.2	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.65027

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	259.613	1118.9	0	0	0
2	286.534	1115.34	13854.9	0	0
3	313.454	1112.24	36863.3	0	0
4	340.374	1109.59	67701.4	0	0
5	367.294	1107.4	105131	0	0
6	395.313	1105.59	131259	0	0
7	423.332	1104.27	158700	0	0
8	431.478	1103.98	164284	0	0
9	434.94	1103.87	164631	0	0
10	435.42	1103.85	164960	0	0
11	443.95	1103.61	173377	0	0
12	482.854	1103.08	250045	0	0
13	507.66	1103.22	272781	0	0
14	532.465	1103.75	294016	0	0
15	557.27	1104.65	313262	0	0
16	582.076	1105.94	330082	0	0
17	606.881	1107.6	344086	0	0
18	631.687	1109.65	354936	0	0
19	657.93	1112.24	402608	0	0
20	684.173	1115.25	447470	0	0
21	710.415	1118.7	489099	0	0
22	736.658	1122.59	527111	0	0
23	762.901	1126.92	561166	0	0
24	789.144	1131.69	590963	0	0
25	815.387	1136.91	616245	0	0
26	841.63	1142.58	636795	0	0
27	867.872	1148.71	652437	0	0
28	894.115	1155.3	663036	0	0
29	920.358	1162.36	668498	0	0
30	946.601	1169.89	668772	0	0
31	972.844	1177.9	663851	0	0
32	999.087	1186.41	653770	0	0
33	1025.33	1195.41	638610	0	0
34	1051.57	1204.91	618498	0	0
35	1077.82	1214.93	593610	0	0
36	1104.06	1225.48	564172	0	0
37	1130.3	1236.56	530462	0	0
38	1156.54	1248.2	492815	0	0
39	1182.79	1260.39	451622	0	0
40	1209.03	1273.16	407338	0	0
41	1235.27	1286.52	360483	0	0
42	1261.51	1300.5	311648	0	0
43	1287.76	1315.09	261532	0	0
44	1314	1330.34	211649	0	0
45	1340.24	1346.25	163286	0	0
46	1366.49	1362.85	117538	0	0
47	1392.73	1380.16	75610.4	0	0
48	1418.97	1398.23	39018.3	0	0
49	1445.21	1417.06	12288.4	0	0
50	1471.46	1436.71	-1497.03	0	0
51	1497.7	1457.2	0	0	0

Query 1 (janbu simplified) - Safety Factor: 1.65027

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	259.613	1118.9	0	0	0
2	286.534	1115.34	13854.9	0	0
3	313.454	1112.24	36863.3	0	0
4	340.374	1109.59	67701.4	0	0
5	367.294	1107.4	105131	0	0
6	395.313	1105.59	131259	0	0
7	423.332	1104.27	158700	0	0
8	431.478	1103.98	164284	0	0
9	434.94	1103.87	164631	0	0
10	435.42	1103.85	164960	0	0
11	443.95	1103.61	173377	0	0
12	482.854	1103.08	250045	0	0
13	507.66	1103.22	272781	0	0
14	532.465	1103.75	294016	0	0
15	557.27	1104.65	313262	0	0
16	582.076	1105.94	330082	0	0
17	606.881	1107.6	344086	0	0
18	631.687	1109.65	354936	0	0
19	657.93	1112.24	402608	0	0
20	684.173	1115.25	447470	0	0
21	710.415	1118.7	489099	0	0
22	736.658	1122.59	527111	0	0
23	762.901	1126.92	561166	0	0
24	789.144	1131.69	590963	0	0
25	815.387	1136.91	616245	0	0
26	841.63	1142.58	636795	0	0
27	867.872	1148.71	652437	0	0
28	894.115	1155.3	663036	0	0
29	920.358	1162.36	668498	0	0
30	946.601	1169.89	668772	0	0
31	972.844	1177.9	663851	0	0
32	999.087	1186.41	653770	0	0
33	1025.33	1195.41	638610	0	0
34	1051.57	1204.91	618498	0	0
35	1077.82	1214.93	593610	0	0
36	1104.06	1225.48	564172	0	0
37	1130.3	1236.56	530462	0	0
38	1156.54	1248.2	492815	0	0
39	1182.79	1260.39	451622	0	0
40	1209.03	1273.16	407338	0	0
41	1235.27	1286.52	360483	0	0
42	1261.51	1300.5	311648	0	0
43	1287.76	1315.09	261532	0	0
44	1314	1330.34	211649	0	0
45	1340.24	1346.25	163286	0	0
46	1366.49	1362.85	117538	0	0
47	1392.73	1380.16	75610.4	0	0
48	1418.97	1398.23	39018.3	0	0
49	1445.21	1417.06	12288.4	0	0
50	1471.46	1436.71	-1497.03	0	0
51	1497.7	1457.2	0	0	0

List Of Coordinates

External Boundary

X	Y
1758.6	1413.4
1625	1457.2
1411	1457.2
1281.2	1428.2
240.8	1113.2
240.8	1111.4
240.8	1111.3
240.8	1111.1
240.8	1109.1
240.8	1017.16
1728.8	1017.16
1758.6	1017.16
1758.6	1159.2
1758.6	1161

Material Boundary

X	Y
240.8	1113.2
257.3	1110
434.8	1105.8
460.7	1099.6
472.1	1102.6
1553.9	1150.4
1581.2	1147
1728.8	1151.8
1758.6	1161

Material Boundary

X	Y
240.8	1111.4
257.3	1108.2
434.8	1104
460.7	1097.8
472.1	1100.8
700	1110.8
1553.9	1148.6
1581.2	1145.2
1728.8	1148.9
1758.6	1159.2

Material Boundary

X	Y
240.8	1111.3
257.3	1108.1
434.8	1103.9
460.7	1097.7
472.1	1100.7
700	1110.7
1553.9	1148.5
1581.4	1145.1
1728.8	1148.9

Material Boundary

X	Y
240.8	1111.1
257.3	1107.9
434.8	1103.7
460.7	1097.5
472.1	1100.5
700	1110.5
1553.9	1148.3
1581.4	1144.9
1728.8	1148.7

Material Boundary

X	Y
240.8	1109.1
257.3	1105.9
434.919	1102.02
460.7	1095.7
472.1	1098.5
700	1108.5
1553.9	1146.3
1581.4	1142.9
1728.8	1147.9

Material Boundary

X	Y
700	1108.5
700	1110.5
700	1110.7

Material Boundary

X	Y
1728.8	1017.16
1728.8	1147.9
1728.8	1148.7
1728.8	1148.9

ATLANTIC COAST
CONSULTING, INC.

Section 1
B. Base Liner Stability Analysis

OBJECTIVE: Verify the stability of the waste mass at Pine Bluff Landfill with respect to failure surfaces passing through the base liner with the inclusion of Combustible Coal Residual (CCR) to the waste mass. The original stability calculations, as prepared by Jordan, Jones and Goulding, Inc and dated December 2000, will be analyzed with respect to failure surfaces passing through the weakest interface of liner system. The stability of the waste mass was evaluated under both static and seismic conditions. The objective is to find the minimum interface friction angle required for a stable base liner system within the revised co-mingled (MSW and CCR) waste mass.

METHOD: Evaluate the stability of the waste mass and base liner system and apply seismic loadings. The Simplified Janbu and Bishop Methods for non-circular (block) surfaces was used to evaluate failure at the liner system. The data for these failure planes are summarized below with details provided in the attached SLIDE output files.

The first step in the evaluation is to input the geometry and individual layers' physical properties into SLIDE Version 7.022 and run a static analysis on the landfill mass for the scenario described above. The SLIDE program was then used to evaluate the seismic stability. The potential for permanent deformations under seismic conditions was calculated by applying a horizontal acceleration coefficient to the analysis.

The evaluation as shown was the result of an iterative process that was used to identify the minimum friction angle that would result in meeting the required design factors of safety.

GEOMETRY: The base liner system will have six possible options, as listed below, from top to bottom:

Option 1
- 24" of 1 x 10^{-2} cm/sec protective cover
- textured 60 mil HDPE geomembrane
- 18" of 1x10^{-7} cm/sec compacted soil

Option 2
- 24" of #89 stone
- geotextile for cushion
- textured 60 mil HDPE geomembrane
- 18" of 1x10^{-7} cm/sec compacted soil

Option 3
- 24" of protective cover
- geonet with cushion geotextile bonded to both sides
- textured 60 mil HDPE geomembrane
- 18" of 1x10^{-7} cm/sec compacted soil

Option 4
- 24" of 1 x 10^{-2} cm/sec protective cover
- textured 60 mil HDPE geomembrane
- geosynthetic clay liner (GCL)
  18" of 1x10^{-7} cm/sec compacted soil

Option 5
- 24" of # 89 stone
- geotextile cushion
  textured 60 mil HDPE geomembrane
- geosynthetic clay liner (GCL)
  18" of 1x10^{-7} cm/sec compacted soil

Option 6
- 24" of protective cover
- geonet with cushion geotextile bonded to both sides
  textured 60 mil HDPE geomembrane
- geosynthetic clay liner (GCL)
  18" of 1x10^{-7} cm/sec compacted soil

For liner stability analysis, the liner system was modeled using the most critical interface within the lining system (i.e. the interface with the lowest interface friction angle). According to the original design calculations by JJG, liner options 1-3 exhibited the lowest friction angle at the interface of the HDPE liner/compacted soil. Options 4-6 exhibited the lowest friction angle at the interface of the HDPE liner/GCL. The lowest friction angle for all options is assumed to be 15 degrees in areas with textured HDPE liner. However, a portion of the critical section passes through an area with smooth HDPE liner. The lowest friction angle used for this area is 10 degrees. The critical section from the original design calculations was evaluated with the inclusion of CCR material into the waste. This section is shown on the attached plan view of the landfill (Figure 1)

DATA: The material and interface properties used in the slope stability analysis are summarized in Table 1. The waste properties for the analysis were taken from a May 2000 technical paper "Municipal Solid Waste Slope Failure. I: Waste and Foundation Soil Properties", by Eid, Stark, Evans and Sherry. Soils properties used are from onsite field test as well as specified soil properties for the landfill construction. The geosynthetic properties are artificial values used in the iterative design in order to determine the minimum requirements.

Table1. Material properties used in slope stability analyses

Material	SLIDE Material Unit ID #	Unit Weight (pcf)	Cohesion (psf)	Peak Friction Angle vs material below (deg)
Co-Mingled Municipal Solid Waste and CCR (10:1)	1	74.5	500	33
Textured HDPE Geomembrane	2	100	0	15
Smooth HDPE Geomembrane	3	100	0	10
Recompacted Liner Base	4	130	500	25
Geosynthetic Clay Liner (GCL)	5	100	0	15
Geocomposite	6	60	0	15
Protective Cover Layer	7	110	500	20

The following assumptions were also used in the preparation of the stability analysis:

- The seismic coefficient for the site is 0.22g (Ah-horizontal) and 0.0g (Av-vertical). *Note: the seismic coefficients are used to increase or decrease the weight of each slice in the vertical direction by (Av)W and introduce a horizontal force of magnitude (Ah)W into the calculations. The increased inertial forces are assumed to act through the static center of gravity of each slice. The seismic coefficients are generally not the same as the expected peak ground accelerations at the site. For a preliminary assessment, these coefficients are estimated at 50% of the anticipated peak ground acceleration expected at the site (i.e. 0.11 Ah & 0.0 Av). Ah is then iteratively increased up to evaluate a conservative scenario for stability during an expected seismic event. (Reference: Misc. Paper GL-84-13, US Army Corps of Engineers, WES, Vicksburg, MS).*
- Fully drained conditions within the landfill due to the presence of a leachate collection system

RESULTS: The SLIDE computer results for the analysis are attached. Figure 2 shows the critical cross section evaluated for failure and corresponding factors of safety for the analysis.

The minimum FOS against failure for the landfill expansion is as follows:

Table 2. Results

Scenario	FOS	SLIDE file
Janbu Block	1.782	PBL 4 CCR Block Static.slim
Bishop Block	1.852	PBL 4 CCR Block Static.slim
Janbu Block with Seismic	1.155	PBL 4 CCR Block Siesmic.slim
Bishop Block with Seismic	1.210	PBL 4 CCR Block Siesmic.slim

CONCLUSION:

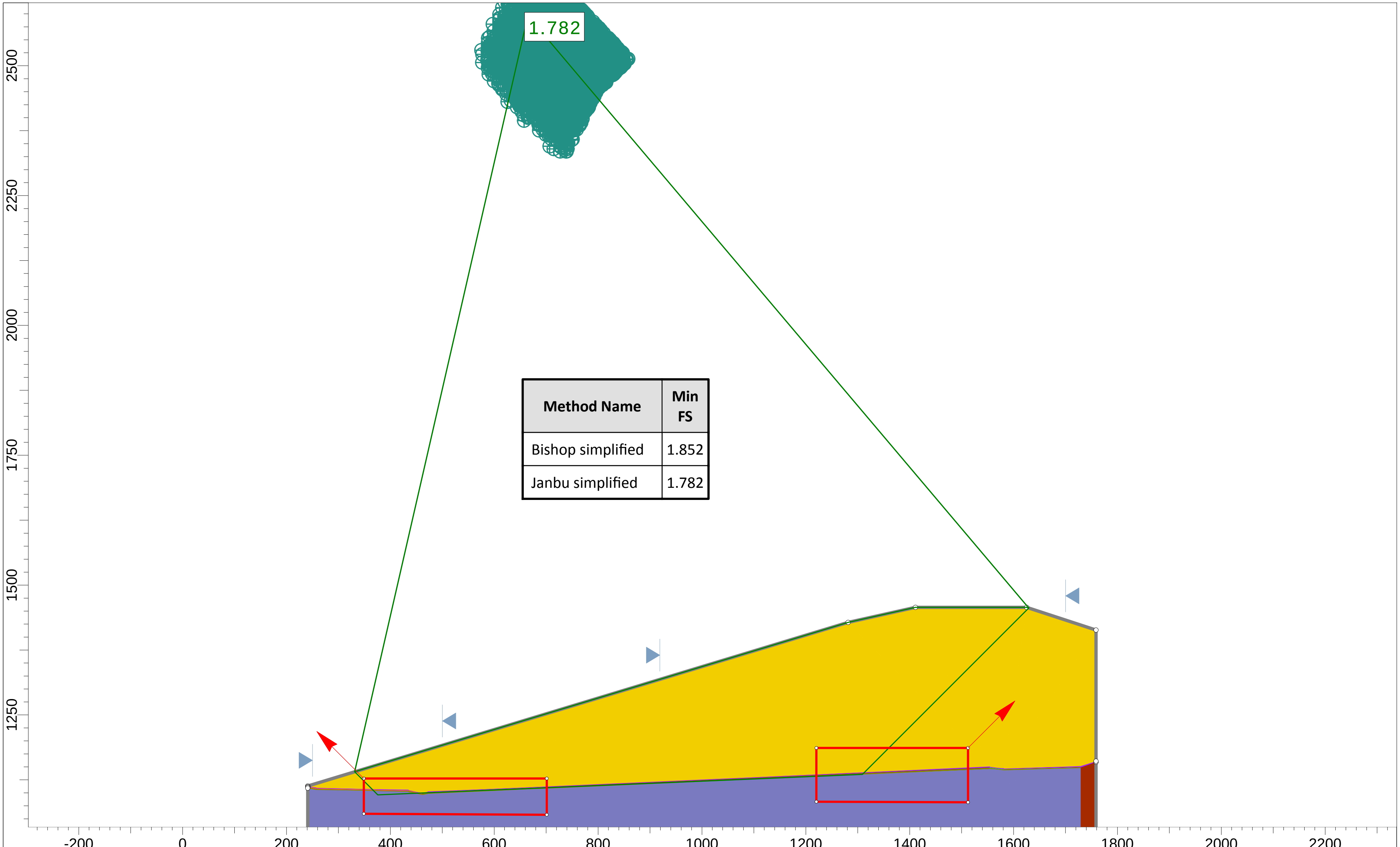
The static stability analysis of the landfill mass failure at the liner interface produced a minimum calculated factor of safety of 1.782. This values is considered adequate (greater than 1.5) and demonstrate the overall stability of the landfill mass under static conditions.

The calculated factors of safety for the seismic conditions are greater than 1.0, therefore no permanent deformations are expected in the landfill liner system during the 250 year seismic event.


PHASE 2
PHASE 4
PHASE 5
PHASE 6
V.E. 1076.9
F1
G1
6/17
LOCATION OF CRITICAL
STABILITY SECTIONS
ON LINER GRADE PLAN
1" = 200'
PINE BLUFF MSWLF
1180-072 EGM

FIGURE 1

STATIC ANALYSIS



Method Name	Min FS
Bishop simplified	1.852
Janbu simplified	1.782

rocscience

SLIDEINTERPRET 7.022

Project	Pine Bluff MSWLF - CCR Management Plan
Analysis Description	Block Sliding - Static
Drawn By	Marc Liverman
Scale	1:3067
Company	Atlantic Coast Consulting
Date	3/31/17
File Name	PBL 4 CCR Block Static.slim

Slide Analysis Information
Pine Bluff MSWLF - CCR Management Plan

Project Summary

File Name:	PBL 4 CCR Block Static.slim
Slide Modeler Version:	7.022
Project Title:	Pine Bluff MSWLF - CCR Management Plan
Analysis:	Block Sliding - Static
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	3/31/17
Comments	
	Pine Bluff MSWLF
	Co-Mingled MSW and CCR Ratio 10:1 (by weight)

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
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:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Non-Circular Block Search
Number of Surfaces:	5000
Multiple Groups:	Disabled
Pseudo-Random Surfaces:	Enabled
Convex Surfaces Only:	Disabled
Left Projection Angle (Start Angle):	135
Left Projection Angle (End Angle):	135
Right Projection Angle (Start Angle):	45
Right Projection Angle (End Angle):	45
Minimum Elevation:	Not Defined
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis: No
Staged pseudostatic analysis: No

Material Properties

Property	MSW and CCR	Textured Liner	Smooth Liner	Recompacted Liner Base	GCL	Geocomposite	Protective Cover
Color							
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	74.5	100	100	130	100	60	110
Cohesion [psf]	500	0	0	500	0	0	500
Friction Angle [deg]	33	15	10	25	15	15	20
Water Surface	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	1.851520
Axis Location:	664.775, 2596.141
Left Slip Surface Endpoint:	331.129, 1140.549
Right Slip Surface Endpoint:	1629.061, 1455.869
Resisting Moment:	9.38667e+009 lb-ft
Driving Moment:	5.06971e+009 lb-ft
Total Slice Area:	219287 ft2
Surface Horizontal Width:	1297.93 ft
Surface Average Height:	168.951 ft

Method: janbu simplified

FS	1.782020
Axis Location:	664.775, 2596.141
Left Slip Surface Endpoint:	331.129, 1140.549
Right Slip Surface Endpoint:	1629.061, 1455.869
Resisting Horizontal Force:	5.47571e+006 lb
Driving Horizontal Force:	3.07276e+006 lb
Total Slice Area:	219287 ft2
Surface Horizontal Width:	1297.93 ft
Surface Average Height:	168.951 ft

Global Minimum Coordinates

Method: bishop simplified

X	Y
331.129	1140.55
375.614	1096.06
1308.74	1135.55
1629.06	1455.87

Method: janbu simplified

X	Y
331.129	1140.55
375.614	1096.06
1308.74	1135.55
1629.06	1455.87

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Method: janbu simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.85152

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	33.0782	53098	-45	MSW and CCR	500	33	1281.76	2373.21	2884.48	0	2884.48	1602.72	1602.72
2	2.15089	7208.53	-45	Protective Cover	500	20	1155.59	2139.59	4504.73	0	4504.73	3349.15	3349.15
3	2.04847	7398.39	-45	GCL	0	15	610.914	1131.12	4221.4	0	4221.4	3610.49	3610.49
4	7.20779	30861.1	-45	Recompacted Liner Base	500	25	1801.11	3334.79	6079.24	0	6079.24	4278.13	4278.13
5	35.3093	180240	2.4231	Recompacted Liner Base	500	25	1539.28	2850.01	5039.6	0	5039.6	5104.74	5104.74
6	35.3093	199099	2.4231	Recompacted Liner Base	500	25	1672.38	3096.44	5568.08	0	5568.08	5638.85	5638.85
7	6.7864	39670.6	2.4231	GCL	0	15	840.828	1556.81	5810.1	0	5810.1	5845.68	5845.68
8	0.709979	4182.78	2.4231	Smooth Liner	0	10	558.811	1034.65	5867.81	0	5867.81	5891.46	5891.46
9	0.354989	2094.41	2.4231	Geocomposite	0	15	848.638	1571.27	5864.08	0	5864.08	5899.99	5899.99
10	6.38981	37918	2.4231	Protective Cover	500	20	1424.75	2637.95	5873.96	0	5873.96	5934.25	5934.25
11	0.515021	3074.25	2.4231	MSW and CCR	500	33	2329.19	4312.54	5870.8	0	5870.8	5969.37	5969.37
12	8.15064	49598.2	2.4231	Protective Cover	500	20	1454.2	2692.48	6023.78	0	6023.78	6085.32	6085.32
13	0.452813	2807.39	2.4231	Geocomposite	0	15	891.786	1651.16	6162.21	0	6162.21	6199.95	6199.95
14	0.905627	5628.37	2.4231	Smooth Liner	0	10	589.494	1091.46	6189.99	0	6189.99	6214.94	6214.94
15	33.5298	219992	2.4231	GCL	0	15	943.744	1747.36	6521.26	0	6521.26	6561.2	6561.2
16	33.5298	241871	2.4231	GCL	0	15	1037.6	1921.14	7169.8	0	7169.8	7213.71	7213.71
17	33.5298	263743	2.4231	GCL	0	15	1131.43	2094.86	7818.14	0	7818.14	7866.02	7866.02
18	33.5298	285614	2.4231	GCL	0	15	1225.26	2268.59	8466.48	0	8466.48	8518.32	8518.32
19	33.5298	307486	2.4231	GCL	0	15	1319.08	2442.31	9114.81	0	9114.81	9170.63	9170.63
20	33.5298	329357	2.4231	GCL	0	15	1412.91	2616.03	9763.15	0	9763.15	9822.94	9822.94
21	33.5298	351229	2.4231	GCL	0	15	1506.74	2789.75	10411.5	0	10411.5	10475.2	10475.2
22	33.5298	373097	2.4231	GCL	0	15	1600.55	2963.45	11059.8	0	11059.8	11127.5	11127.5
23	33.5298	394964	2.4231	GCL	0	15	1694.36	3137.14	11707.9	0	11707.9	11779.6	11779.6
24	33.5298	416832	2.4231	GCL	0	15	1788.16	3310.82	12356.2	0	12356.2	12431.8	12431.8
25	33.5298	438699	2.4231	GCL	0	15	1881.97	3484.51	13004.4	0	13004.4	13084	13084
26	33.5298	460566	2.4231	GCL	0	15	1975.78	3658.2	13652.6	0	13652.6	13736.2	13736.2
27	33.5298	482433	2.4231	GCL	0	15	2069.59	3831.89	14300.8	0	14300.8	14388.4	14388.4
28	33.5298	504300	2.4231	GCL	0	15	2163.4	4005.57	14949	0	14949	15040.5	15040.5
29	33.5298	526167	2.4231	GCL	0	15	2257.2	4179.26	15597.2	0	15597.2	15692.7	15692.7
30	33.5298	548034	2.4231	GCL	0	15	2351.01	4352.95	16245.4	0	16245.4	16344.9	16344.9
31	33.5298	569901	2.4231	GCL	0	15	2444.82	4526.63	16893.6	0	16893.6	16997.1	16997.1
32	33.5298	591769	2.4231	GCL	0	15	2538.63	4700.32	17541.8	0	17541.8	17649.3	17649.3
33	33.5298	613636	2.4231	GCL	0	15	2632.44	4874.01	18190.1	0	18190.1	18301.4	18301.4
34	33.5298	635503	2.4231	GCL	0	15	2726.25	5047.7	18838.3	0	18838.3	18953.6	18953.6
35	33.5298	657370	2.4231	GCL	0	15	2820.05	5221.38	19486.5	0	19486.5	19605.8	19605.8
36	33.5298	679237	2.4231	GCL	0	15	2913.86	5395.07	20134.7	0	20134.7	20258	20258
37	33.5298	701104	2.4231	GCL	0	15	3007.67	5568.76	20782.9	0	20782.9	20910.2	20910.2
38	33.5298	722971	2.4231	GCL	0	15	3101.47	5742.44	21431.1	0	21431.1	21562.3	21562.3
39	33.5298	742597	2.4231	GCL	0	15	3185.66	5898.32	22012.8	0	22012.8	22147.6	22147.6
40	2.29947	51239.3	45	GCL	0	15	2817.78	5217.18	19470.8	0	19470.8	22288.6	22288.6
41	1.90401	42088.3	45	Protective Cover	500	20	3858.44	7143.97	18254.1	0	18254.1	22112.6	22112.6
42	35.1239	737660	45	MSW and CCR	500	33	5656.21	10472.6	15356.4	0	15356.4	21012.7	21012.7
43	35.1239	666284	45	MSW and CCR	500	33	5128.28	9495.11	13851.3	0	13851.3	18979.5	18979.5
44	35.1239	594463	45	MSW and CCR	500	33	4597.04	8511.52	12336.7	0	12336.7	16933.7	16933.7
45	35.1239	508988	45	MSW and CCR	500	33	3964.82	7340.94	10534.1	0	10534.1	14498.9	14498.9
46	35.1239	417079	45	MSW and CCR	500	33	3285	6082.24	8595.88	0	8595.88	11880.9	11880.9
47	35.1239	325169	45	MSW and CCR	500	33	2605.17	4823.53	6657.66	0	6657.66	9262.83	9262.83
48	35.1239	233259	45	MSW and CCR	500	33	1925.35	3564.83	4719.41	0	4719.41	6644.76	6644.76
49	35.1239	141349	45	MSW and CCR	500	33	1245.53	2306.12	2781.18	0	2781.18	4026.71	4026.71
50	35.1239	49237.3	45	MSW and CCR	500	33	564.216	1044.66	838.699	0	838.699	1402.92	1402.92

Global Minimum Query (janbu simplified) - Safety Factor: 1.78202

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	33.0782	53098	-45	MSW and CCR	500	33	1363.08	2429.03	2970.43	0	2970.43	1607.36	1607.36
2	2.15089	7208.53	-45	Protective Cover	500	20	1213.29	2162.11	4566.6	0	4566.6	3353.31	3353.31
3	2.04847	7398.39	-45	GCL	0	15	639.342	1139.32	4252.02	0	4252.02	3612.68	3612.68
4	7.20779	30861.1	-45	Recompacted Liner Base	500	25	1898.55	3383.26	6183.18	0	6183.18	4284.63	4284.63
5	35.3093	180240	2.4231	Recompacted Liner Base	500	25	1598.6	2848.73	5036.86	0	5036.86	5104.5	5104.5
6	35.3093	199099	2.4231	Recompacted Liner Base	500	25	1736.82	3095.05	5565.11	0	5565.11	5638.61	5638.61
7	6.7864	39670.6	2.4231	GCL	0	15	873.396	1556.41	5808.59	0	5808.59	5845.55	5845.55
8	0.709979	4182.78	2.4231	Smooth Liner	0	10	580.51	1034.48	5866.81	0	5866.81	5891.38	5891.38
9	0.354989	2094.41	2.4231	Geocomposite	0	15	881.511	1570.87	5862.56	0	5862.56	5899.87	5899.87
10	6.38981	37918	2.4231	Protective Cover	500	20	1479.79	2637.02	5871.42	0	5871.42	5934.04	5934.04
11	0.515021	3074.25	2.4231	MSW and CCR	500	33	2418.53	4309.86	5866.67	0	5866.67	5969.01	5969.01
12	8.15064	49598.2	2.4231	Protective Cover	500	20	1510.38	2691.53	6021.18	0	6021.18	6085.09	6085.09
13	0.452813	2807.39	2.4231	Geocomposite	0	15	926.325	1650.73	6160.63	0	6160.63	6199.82	6199.82
14	0.905627	5628.37	2.4231	Smooth Liner	0	10	612.384	1091.28	6188.93	0	6188.93	6214.85	6214.85
15	33.5298	219992	2.4231	GCL	0	15	980.298	1746.91	6519.56	0	6519.56	6561.04	6561.04
16	33.5298	241871	2.4231	GCL	0	15	1077.79	1920.64	7167.93	0	7167.93	7213.53	7213.53
17	33.5298	263743	2.4231	GCL	0	15	1175.25	2094.32	7816.11	0	7816.11	7865.85	7865.85
18	33.5298	285614	2.4231	GCL	0	15	1272.71	2268	8464.27	0	8464.27	8518.13	8518.13
19	33.5298	307486	2.4231	GCL	0	15	1370.17	2441.67	9112.46	0	9112.46	9170.44	9170.44
20	33.5298	329357	2.4231	GCL	0	15	1467.63	2615.35	9760.61	0	9760.61	9822.72	9822.72
21	33.5298	351229	2.4231	GCL	0	15	1565.09	2789.03	10408.8	0	10408.8	10475	10475
22	33.5298	373097	2.4231	GCL	0	15	1662.54	2962.68	11056.9	0	11056.9	11127.2	11127.2
23	33.5298	394964	2.4231	GCL	0	15	1759.98	3136.32	11704.9	0	11704.9	11779.4	11779.4
24	33.5298	416832	2.4231	GCL	0	15	1857.43	3309.97	12353	0	12353	12431.6	12431.6
25	33.5298	438699	2.4231	GCL	0	15	1954.87	3483.61	13001	0	13001	13083.7	13083.7
26	33.5298	460566	2.4231	GCL	0	15	2052.31	3657.25	13649	0	13649	13735.9	13735.9
27	33.5298	482433	2.4231	GCL	0	15	2149.75	3830.89	14297.1	0	14297.1	14388.1	14388.1
28	33.5298	504300	2.4231	GCL	0	15	2247.19	4004.53	14945.1	0	14945.1	15040.2	15040.2
29	33.5298	526167	2.4231	GCL	0	15	2344.63	4178.18	15593.2	0	15593.2	15692.4	15692.4
30	33.5298	548034	2.4231	GCL	0	15	2442.07	4351.82	16241.2	0	16241.2	16344.5	16344.5
31	33.5298	569901	2.4231	GCL	0	15	2539.51	4525.46	16889.2	0	16889.2	16996.7	16996.7
32	33.5298	591769	2.4231	GCL	0	15	2636.95	4699.1	17537.3	0	17537.3	17648.9	17648.9
33	33.5298	613636	2.4231	GCL	0	15	2734.4	4872.75	18185.3	0	18185.3	18301.1	18301.1
34	33.5298	635503	2.4231	GCL	0	15	2831.84	5046.39	18833.4	0	18833.4	18953.2	18953.2
35	33.5298	657370	2.4231	GCL	0	15	2929.28	5220.03	19481.4	0	19481.4	19605.4	19605.4
36	33.5298	679237	2.4231	GCL	0	15	3026.72	5393.67	20129.5	0	20129.5	20257.5	20257.5
37	33.5298	701104	2.4231	GCL	0	15	3124.16	5567.31	20777.5	0	20777.5	20909.7	20909.7
38	33.5298	722971	2.4231	GCL	0	15	3221.6	5740.96	21425.5	0	21425.5	21561.9	21561.9
39	33.5298	742597	2.4231	GCL	0	15	3309.05	5896.79	22007.1	0	22007.1	22147.1	22147.1
40	2.29947	51239.3	45	GCL	0	15	2912	5189.24	19366.5	0	19366.5	22278.5	22278.5
41	1.90401	42088.3	45	Protective Cover	500	20	3981.06	7094.32	18117.7	0	18117.7	22098.8	22098.8
42	35.1239	737660	45	MSW and CCR	500	33	5812.5	10358	15180	0	15180	20992.5	20992.5
43	35.1239	666284	45	MSW and CCR	500	33	5269.98	9391.21	13691.3	0	13691.3	18961.2	18961.2
44	35.1239	594463	45	MSW and CCR	500	33	4724.07	8418.38	12193.2	0	12193.2	16917.3	16917.3
45	35.1239	508988	45	MSW and CCR	500	33	4074.37	7260.61	10410.4	0	10410.4	14484.8	14484.8
46	35.1239	417079	45	MSW and CCR	500	33	3375.76	6015.68	8493.41	0	8493.41	11869.2	11869.2
47	35.1239	325169	45	MSW and CCR	500	33	2677.16	4770.75	6576.38	0	6576.38	9253.54	9253.54
48	35.1239	233259	45	MSW and CCR	500	33	1978.55	3525.82	4659.36	0	4659.36	6637.91	6637.91
49	35.1239	141349	45	MSW and CCR	500	33	1279.95	2280.89	2742.33	0	2742.33	4022.28	4022.28
50	35.1239	49237.3	45	MSW and CCR	500	33	579.807	1033.23	821.098	0	821.098	1400.9	1400.9

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.85152

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	331.129	1140.55	0	0	0
2	364.207	1107.47	137730	0	0
3	366.358	1105.32	149899	0	0
4	368.406	1103.27	159796	0	0
5	375.614	1096.06	216570	0	0
6	410.923	1097.56	263285	0	0
7	446.233	1099.05	313901	0	0
8	453.019	1099.34	317928	0	0
9	453.729	1099.37	318147	0	0
10	454.084	1099.38	318360	0	0
11	460.474	1099.65	325858	0	0
12	460.989	1099.68	326927	0	0
13	469.139	1100.02	336679	0	0
14	469.592	1100.04	336964	0	0
15	470.498	1100.08	337259	0	0
16	504.028	1101.5	359589	0	0
17	537.557	1102.92	384138	0	0
18	571.087	1104.33	410908	0	0
19	604.617	1105.75	439898	0	0
20	638.147	1107.17	471108	0	0
21	671.676	1108.59	504537	0	0
22	705.206	1110.01	540187	0	0
23	738.736	1111.43	578056	0	0
24	772.266	1112.85	618145	0	0
25	805.795	1114.27	660453	0	0
26	839.325	1115.69	704981	0	0
27	872.855	1117.1	751728	0	0
28	906.385	1118.52	800695	0	0
29	939.915	1119.94	851881	0	0
30	973.444	1121.36	905287	0	0
31	1006.97	1122.78	960912	0	0
32	1040.5	1124.2	1.01876e+006	0	0
33	1074.03	1125.62	1.07882e+006	0	0
34	1107.56	1127.04	1.14111e+006	0	0
35	1141.09	1128.46	1.20561e+006	0	0
36	1174.62	1129.87	1.27233e+006	0	0
37	1208.15	1131.29	1.34127e+006	0	0
38	1241.68	1132.71	1.41244e+006	0	0
39	1275.21	1134.13	1.48582e+006	0	0
40	1308.74	1135.55	1.56119e+006	0	0
41	1311.04	1137.85	1.52288e+006	0	0
42	1312.95	1139.75	1.49546e+006	0	0
43	1348.07	1174.88	1.15436e+006	0	0
44	1383.19	1210	847627	0	0
45	1418.32	1245.13	575466	0	0
46	1453.44	1280.25	344455	0	0
47	1488.57	1315.37	157690	0	0
48	1523.69	1350.5	15172.8	0	0
49	1558.81	1385.62	-83097.7	0	0
50	1593.94	1420.74	-137121	0	0
51	1629.06	1455.87	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.78202

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	331.129	1140.55	0	0	0
2	364.207	1107.47	143416	0	0
3	366.358	1105.32	155852	0	0
4	368.406	1103.27	165874	0	0
5	375.614	1096.06	224147	0	0
6	410.923	1097.56	273155	0	0
7	446.233	1099.05	326262	0	0
8	453.019	1099.34	330531	0	0
9	453.729	1099.37	330767	0	0
10	454.084	1099.38	330993	0	0
11	460.474	1099.65	338876	0	0
12	460.989	1099.68	339995	0	0
13	469.139	1100.02	350248	0	0
14	469.592	1100.04	350551	0	0
15	470.498	1100.08	350869	0	0
16	504.028	1101.5	374539	0	0
17	537.557	1102.92	400564	0	0
18	571.087	1104.33	428942	0	0
19	604.617	1105.75	459673	0	0
20	638.147	1107.17	492758	0	0
21	671.676	1108.59	528195	0	0
22	705.206	1110.01	565987	0	0
23	738.736	1111.43	606131	0	0
24	772.266	1112.85	648628	0	0
25	805.795	1114.27	693478	0	0
26	839.325	1115.69	740680	0	0
27	872.855	1117.1	790236	0	0
28	906.385	1118.52	842144	0	0
29	939.915	1119.94	896405	0	0
30	973.444	1121.36	953019	0	0
31	1006.97	1122.78	1.01199e+006	0	0
32	1040.5	1124.2	1.07331e+006	0	0
33	1074.03	1125.62	1.13698e+006	0	0
34	1107.56	1127.04	1.203e+006	0	0
35	1141.09	1128.46	1.27138e+006	0	0
36	1174.62	1129.87	1.34211e+006	0	0
37	1208.15	1131.29	1.4152e+006	0	0
38	1241.68	1132.71	1.49063e+006	0	0
39	1275.21	1134.13	1.56842e+006	0	0
40	1308.74	1135.55	1.64832e+006	0	0
41	1311.04	1137.85	1.6105e+006	0	0
42	1312.95	1139.75	1.58359e+006	0	0
43	1348.07	1174.88	1.25489e+006	0	0
44	1383.19	1210	959395	0	0
45	1418.32	1245.13	697309	0	0
46	1453.44	1280.25	474987	0	0
47	1488.57	1315.37	295422	0	0
48	1523.69	1350.5	158614	0	0
49	1558.81	1385.62	64562.8	0	0
50	1593.94	1420.74	13268.9	0	0
51	1629.06	1455.87	0	0	0

List Of Coordinates

Block Search Window

X	Y
348.839	1127.73
348.839	1059.62
701.182	1057.87
701.182	1127.73

Block Search Window

X	Y
1220.26	1186.49
1220.26	1082.99
1512.21	1081.92
1512.21	1186.49

External Boundary

X	Y
1758.6	1413.4
1625	1457.2
1411	1457.2
1281.2	1428.2
240.8	1113.2
240.8	1111.4
240.8	1111.3
240.8	1111.1
240.8	1109.1
240.8	1017.16
1728.8	1017.16
1758.6	1017.16
1758.6	1159.2
1758.6	1161

Material Boundary

X	Y
240.8	1113.2
257.3	1110
434.8	1105.8
460.7	1099.6
472.1	1102.6
1553.9	1150.4
1581.2	1147
1728.8	1151.8
1758.6	1161

Material Boundary

X	Y
240.8	1111.4
257.3	1108.2
434.8	1104
460.7	1097.8
472.1	1100.8
700	1110.8
1553.9	1148.6
1581.4	1145.2
1728.79	1149.12
1758.6	1159.2

Material Boundary

X	Y
240.8	1111.3
257.3	1108.1
434.8	1103.9
460.7	1097.7
472.1	1100.7
700	1110.7
1553.9	1148.5
1581.4	1145.1
1728.8	1148.9

Material Boundary

X	Y
240.8	1111.1
257.3	1107.9
434.8	1103.7
460.7	1097.5
472.1	1100.5
700	1110.5
1553.9	1148.3
1581.4	1144.9
1728.8	1148.7

Material Boundary

X	Y
240.8	1109.1
257.3	1105.9
434.8	1101.7
460.7	1095.7
472.1	1098.5
700	1108.5
1553.9	1146.3
1581.4	1142.9
1728.8	1147.9

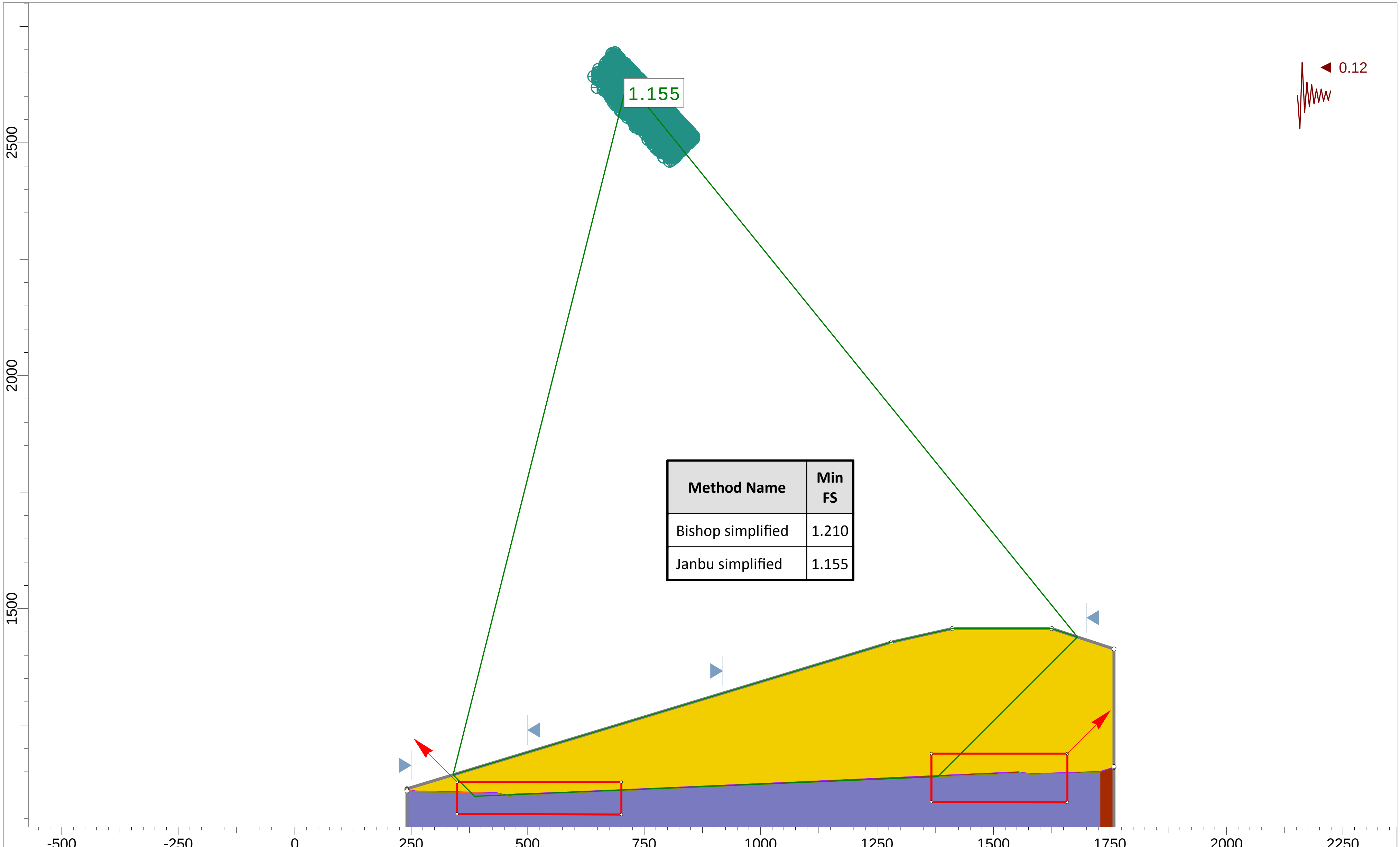
Material Boundary

X	Y
700	1108.5
700	1110.5
700	1110.7

Material Boundary

X	Y
1728.8	1017.16
1728.8	1147.9
1728.8	1148.7
1728.8	1148.9

SIESMIC ANALYSIS



Method Name	Min FS
Bishop simplified	1.210
Janbu simplified	1.155

Project	Pine Bluff MSWLF - CCR Management Plan		
Analysis Description	Block with Seismic		
Drawn By Marc Liverman	*Scale* 1:3420	*Company*	Atlantic Coast Consulting
Date	3/31/17	*File Name*	PBL 4 CCR Block Siesmic.slim

SLIDEINTERPRET 7.022

Slide Analysis Information
CCR Management Plan

Project Summary

File Name:	PBL 4 CCR Block Siesmic.slim
Slide Modeler Version:	7.022
Project Title:	CCR Management Plan
Analysis:	Block with Seismic
Author:	Marc Liverman
Company:	Atlantic Coast Consulting
Date Created:	3/39/17

Comments

Pine Bluff MSWLF
Co-Mingled MSW and CCR Ratio 10:1 (by weight)

General Settings

Units of Measurement:	Imperial Units
Time Units:	seconds
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:	50
Check malpha < 0.2:	Yes
Initial trial value of FS:	3
Steffensen Iteration:	Yes

Groundwater Analysis

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	9.81
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

Random Numbers

Pseudo-random Seed:	10116
Random Number Generation Method:	rand

Surface Options

Surface Type:	Non-Circular Block Search
Number of Surfaces:	5000
Multiple Groups:	Disabled
Pseudo-Random Surfaces:	Enabled
Convex Surfaces Only:	Disabled
Left Projection Angle (Start Angle):	135
Left Projection Angle (End Angle):	135
Right Projection Angle (Start Angle):	45
Right Projection Angle (End Angle):	45
Minimum Elevation:	Not Defined
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

Seismic

Advanced seismic analysis: No
Staged pseudostatic analysis: No

Loading

Seismic Load Coefficient (Horizontal): 0.12

Material Properties

Property	MSW and CCR	Textured Liner	Smooth Liner	Recompacted Liner Base	GCL	Geocomposite	Protective Cover
Color							
Strength Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Unit Weight [lbs/ft3]	74.5	100	100	130	100	60	110
Cohesion [psf]	500	0	0	500	0	0	500
Friction Angle [deg]	33	15	10	25	15	15	20
Water Surface	None	None	None	None	None	None	None
Ru Value	0	0	0	0	0	0	0

Global Minimums

Method: bishop simplified

FS	1.210230
Axis Location:	713.975, 2631.346
Left Slip Surface Endpoint:	339.858, 1143.192
Right Slip Surface Endpoint:	1680.028, 1439.159
Resisting Moment:	9.54488e+009 lb-ft
Driving Moment:	7.88684e+009 lb-ft
Total Slice Area:	239073 ft2
Surface Horizontal Width:	1340.17 ft
Surface Average Height:	178.39 ft

Method: janbu simplified

FS	1.154550
Axis Location:	713.975, 2631.346
Left Slip Surface Endpoint:	339.858, 1143.192
Right Slip Surface Endpoint:	1680.028, 1439.159
Resisting Horizontal Force:	5.52896e+006 lb
Driving Horizontal Force:	4.78884e+006 lb
Total Slice Area:	239073 ft2
Surface Horizontal Width:	1340.17 ft
Surface Average Height:	178.39 ft

Global Minimum Coordinates

Method: bishop simplified

X	Y
339.858	1143.19
385.991	1097.06
1380.31	1139.45
1680.03	1439.16

Method: janbu simplified

X	Y
339.858	1143.19
385.991	1097.06
1380.31	1139.45
1680.03	1439.16

Valid / Invalid Surfaces

Method: bishop simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Method: janbu simplified

Number of Valid Surfaces: 5000
Number of Invalid Surfaces: 0

Slice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.21023

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	35.9967	62881	-45	MSW and CCR	500	33	2915.61	3528.56	4663.58	0	4663.58	1747.96	1747.96
2	2.15089	7817.79	-45	Protective Cover	500	20	2154.43	2607.36	5789.91	0	5789.91	3635.48	3635.48
3	2.04847	7978.64	-45	GCL	0	15	1107.69	1340.56	5003.05	0	5003.05	3895.36	3895.36
4	5.93679	26530.2	-45	Recompacted Liner Base	500	25	3474.08	4204.43	7944.19	0	7944.19	4470.11	4470.11
5	29.0726	149607	2.44098	Recompacted Liner Base	500	25	2357.18	2852.73	5045.43	0	5045.43	5145.92	5145.92
6	29.0726	162366	2.44098	Recompacted Liner Base	500	25	2523.55	3054.07	5477.23	0	5477.23	5584.81	5584.81
7	6.83629	39395.7	2.44098	GCL	0	15	1263.96	1529.68	5708.84	0	5708.84	5762.72	5762.72
8	0.709192	4119.5	2.44098	Smooth Liner	0	10	841.088	1017.91	5772.86	0	5772.86	5808.71	5808.71
9	0.354596	2062.76	2.44098	Geocomposite	0	15	1275.91	1544.14	5762.8	0	5762.8	5817.19	5817.19
10	6.38273	37347	2.44098	Protective Cover	500	20	2145.37	2596.39	5759.78	0	5759.78	5851.24	5851.24
11	5.19899	30838	2.44098	MSW and CCR	500	33	3515.55	4254.63	5781.63	0	5781.63	5931.49	5931.49
12	8.16219	49732	2.44098	Protective Cover	500	20	2217.14	2683.25	5998.42	0	5998.42	6092.93	6092.93
13	23.8158	153223	2.44098	Geocomposite	0	15	1411.12	1707.78	6373.52	0	6373.52	6433.67	6433.67
14	32.0013	223214	2.44098	Smooth Liner	0	10	1009.98	1222.31	6932.09	0	6932.09	6975.14	6975.14
15	32.0013	243105	2.44098	Smooth Liner	0	10	1099.99	1331.24	7549.82	0	7549.82	7596.71	7596.71
16	32.0013	262995	2.44098	Smooth Liner	0	10	1189.99	1440.16	8167.54	0	8167.54	8218.27	8218.27
17	32.0013	282886	2.44098	Smooth Liner	0	10	1279.99	1549.08	8785.27	0	8785.27	8839.84	8839.84
18	32.0013	302777	2.44098	Smooth Liner	0	10	1369.99	1658	9403	0	9403	9461.4	9461.4
19	34.5101	348806	2.44098	GCL	0	15	2216.87	2682.92	10012.8	0	10012.8	10107.3	10107.3
20	34.5101	371937	2.44098	GCL	0	15	2363.88	2860.84	10676.8	0	10676.8	10777.6	10777.6
21	34.5101	395064	2.44098	GCL	0	15	2510.87	3038.73	11340.7	0	11340.7	11447.7	11447.7
22	34.5101	418192	2.44098	GCL	0	15	2657.86	3216.62	12004.6	0	12004.6	12117.9	12117.9
23	34.5101	441319	2.44098	GCL	0	15	2804.85	3394.51	12668.5	0	12668.5	12788	12788
24	34.5101	464446	2.44098	GCL	0	15	2951.84	3572.4	13332.4	0	13332.4	13458.2	13458.2
25	34.5101	487574	2.44098	GCL	0	15	3098.82	3750.29	13996.3	0	13996.3	14128.4	14128.4
26	34.5101	510701	2.44098	GCL	0	15	3245.81	3928.18	14660.2	0	14660.2	14798.5	14798.5
27	34.5101	533828	2.44098	GCL	0	15	3392.8	4106.07	15324.1	0	15324.1	15468.7	15468.7
28	34.5101	556956	2.44098	GCL	0	15	3539.79	4283.96	15987.9	0	15987.9	16138.8	16138.8
29	34.5101	580083	2.44098	GCL	0	15	3686.78	4461.85	16651.8	0	16651.8	16809	16809
30	34.5101	603211	2.44098	GCL	0	15	3833.77	4639.74	17315.7	0	17315.7	17479.2	17479.2
31	34.5101	626338	2.44098	GCL	0	15	3980.76	4817.63	17979.6	0	17979.6	18149.3	18149.3
32	34.5101	649465	2.44098	GCL	0	15	4127.74	4995.52	18643.5	0	18643.5	18819.5	18819.5
33	34.5101	672593	2.44098	GCL	0	15	4274.72	5173.4	19307.4	0	19307.4	19489.6	19489.6
34	34.5101	695720	2.44098	GCL	0	15	4421.71	5351.29	19971.3	0	19971.3	20159.8	20159.8
35	34.5101	718847	2.44098	GCL	0	15	4568.7	5529.18	20635.2	0	20635.2	20829.9	20829.9
36	34.5101	741975	2.44098	GCL	0	15	4715.69	5707.07	21299.1	0	21299.1	21500.1	21500.1
37	34.5101	762425	2.44098	GCL	0	15	4845.67	5864.37	21886.1	0	21886.1	22092.7	22092.7
38	34.5101	778570	2.44098	GCL	0	15	4948.27	5988.55	22349.6	0	22349.6	22560.5	22560.5
39	34.5101	794657	2.44098	GCL	0	15	5050.52	6112.29	22811.4	0	22811.4	23026.7	23026.7
40	1.53831	35683.8	45	GCL	0	15	4204.57	5088.5	18990.6	0	18990.6	23195.1	23195.1
41	1.89795	43748.1	45	Protective Cover	500	20	5646.56	6833.64	17401.5	0	17401.5	23048.1	23048.1
42	32.9197	724323	45	MSW and CCR	500	33	7951.43	9623.06	14048.3	0	14048.3	21999.7	21999.7
43	32.9197	649767	45	MSW and CCR	500	33	7160.64	8666.02	12574.6	0	12574.6	19735.2	19735.2
44	32.9197	569031	45	MSW and CCR	500	33	6304.3	7629.65	10978.7	0	10978.7	17283	17283
45	32.9197	488294	45	MSW and CCR	500	33	5447.96	6593.29	9382.84	0	9382.84	14830.8	14830.8
46	32.9197	407558	45	MSW and CCR	500	33	4591.63	5556.93	7786.99	0	7786.99	12378.6	12378.6
47	32.9197	326822	45	MSW and CCR	500	33	3735.3	4520.57	6191.13	0	6191.13	9926.43	9926.43
48	32.9197	246086	45	MSW and CCR	500	33	2878.97	3484.21	4595.27	0	4595.27	7474.23	7474.23
49	32.9197	159380	45	MSW and CCR	500	33	1959.31	2371.22	2881.42	0	2881.42	4840.73	4840.73
50	32.9197	53602.5	45	MSW and CCR	500	33	837.373	1013.41	790.59	0	790.59	1627.96	1627.96

Global Minimum Query (janbu simplified) - Safety Factor: 1.15455

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]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	35.9967	62881	-45	MSW and CCR	500	33	3245.75	3747.38	5000.52	0	5000.52	1754.77	1754.77
2	2.15089	7817.79	-45	Protective Cover	500	20	2308.39	2665.15	5948.7	0	5948.7	3640.31	3640.31
3	2.04847	7978.64	-45	GCL	0	15	1178	1360.06	5075.81	0	5075.81	3897.81	3897.81
4	5.93679	26530.2	-45	Recompacted Liner Base	500	25	3760.46	4341.64	8238.41	0	8238.41	4477.95	4477.95
5	29.0726	149607	2.44098	Recompacted Liner Base	500	25	2468.85	2850.41	5040.48	0	5040.48	5145.73	5145.73
6	29.0726	162366	2.44098	Recompacted Liner Base	500	25	2643.1	3051.59	5471.91	0	5471.91	5584.58	5584.58
7	6.83629	39395.7	2.44098	GCL	0	15	1324.29	1528.96	5706.15	0	5706.15	5762.6	5762.6
8	0.709192	4119.5	2.44098	Smooth Liner	0	10	881.374	1017.59	5771.05	0	5771.05	5808.62	5808.62
9	0.354596	2062.76	2.44098	Geocomposite	0	15	1336.81	1543.41	5760.09	0	5760.09	5817.08	5817.08
10	6.38273	37347	2.44098	Protective Cover	500	20	2247.4	2594.73	5755.23	0	5755.23	5851.03	5851.03
11	5.19899	30838	2.44098	MSW and CCR	500	33	3680.95	4249.84	5774.25	0	5774.25	5931.16	5931.16
12	8.16219	49732	2.44098	Protective Cover	500	20	2322.58	2681.53	5993.72	0	5993.72	6092.72	6092.72
13	23.8158	153223	2.44098	Geocomposite	0	15	1478.47	1706.97	6370.5	0	6370.5	6433.52	6433.52
14	32.0013	223214	2.44098	Smooth Liner	0	10	1058.36	1221.93	6929.94	0	6929.94	6975.05	6975.05
15	32.0013	243105	2.44098	Smooth Liner	0	10	1152.67	1330.82	7547.48	0	7547.48	7596.61	7596.61
16	32.0013	262995	2.44098	Smooth Liner	0	10	1246.99	1439.71	8164.98	0	8164.98	8218.14	8218.14
17	32.0013	282886	2.44098	Smooth Liner	0	10	1341.3	1548.6	8782.52	0	8782.52	8839.7	8839.7
18	32.0013	302777	2.44098	Smooth Liner	0	10	1435.62	1657.49	9400.06	0	9400.06	9461.26	9461.26
19	34.5101	348806	2.44098	GCL	0	15	2322.69	2681.66	10008.1	0	10008.1	10107.1	10107.1
20	34.5101	371937	2.44098	GCL	0	15	2476.71	2859.49	10671.8	0	10671.8	10777.4	10777.4
21	34.5101	395064	2.44098	GCL	0	15	2630.72	3037.3	11335.4	0	11335.4	11447.5	11447.5
22	34.5101	418192	2.44098	GCL	0	15	2784.72	3215.1	11998.9	0	11998.9	12117.6	12117.6
23	34.5101	441319	2.44098	GCL	0	15	2938.73	3392.91	12662.5	0	12662.5	12787.8	12787.8
24	34.5101	464446	2.44098	GCL	0	15	3092.74	3570.72	13326.1	0	13326.1	13457.9	13457.9
25	34.5101	487574	2.44098	GCL	0	15	3246.74	3748.52	13989.7	0	13989.7	14128.1	14128.1
26	34.5101	510701	2.44098	GCL	0	15	3400.74	3926.33	14653.2	0	14653.2	14798.2	14798.2
27	34.5101	533828	2.44098	GCL	0	15	3554.74	4104.13	15316.8	0	15316.8	15468.4	15468.4
28	34.5101	556956	2.44098	GCL	0	15	3708.75	4281.94	15980.4	0	15980.4	16138.5	16138.5
29	34.5101	580083	2.44098	GCL	0	15	3862.75	4459.74	16644	0	16644	16808.6	16808.6
30	34.5101	603211	2.44098	GCL	0	15	4016.76	4637.55	17307.6	0	17307.6	17478.8	17478.8
31	34.5101	626338	2.44098	GCL	0	15	4170.77	4815.36	17971.1	0	17971.1	18148.9	18148.9
32	34.5101	649465	2.44098	GCL	0	15	4324.77	4993.16	18634.7	0	18634.7	18819.1	18819.1
33	34.5101	672593	2.44098	GCL	0	15	4478.78	5170.97	19298.3	0	19298.3	19489.3	19489.3
34	34.5101	695720	2.44098	GCL	0	15	4632.77	5348.77	19961.9	0	19961.9	20159.4	20159.4
35	34.5101	718847	2.44098	GCL	0	15	4786.78	5526.58	20625.5	0	20625.5	20829.5	20829.5
36	34.5101	741975	2.44098	GCL	0	15	4940.79	5704.39	21289.1	0	21289.1	21499.7	21499.7
37	34.5101	762425	2.44098	GCL	0	15	5076.97	5861.61	21875.8	0	21875.8	22092.3	22092.3
38	34.5101	778570	2.44098	GCL	0	15	5184.47	5985.73	22339	0	22339	22560.1	22560.1
39	34.5101	794657	2.44098	GCL	0	15	5291.59	6109.41	22800.6	0	22800.6	23026.2	23026.2
40	1.53831	35683.8	45	GCL	0	15	4367.45	5042.44	18818.6	0	18818.6	23186.1	23186.1
41	1.89795	43748.1	45	Protective Cover	500	20	5850.7	6754.93	17185.3	0	17185.3	23036	23036
42	32.9197	724323	45	MSW and CCR	500	33	8190.75	9456.63	13792	0	13792	21982.7	21982.7
43	32.9197	649767	45	MSW and CCR	500	33	7376.16	8516.14	12343.8	0	12343.8	19719.9	19719.9
44	32.9197	569031	45	MSW and CCR	500	33	6494.05	7497.7	10775.5	0	10775.5	17269.6	17269.6
45	32.9197	488294	45	MSW and CCR	500	33	5611.94	6479.26	9207.25	0	9207.25	14819.2	14819.2
46	32.9197	407558	45	MSW and CCR	500	33	4729.83	5460.82	7638.99	0	7638.99	12368.8	12368.8
47	32.9197	326822	45	MSW and CCR	500	33	3847.72	4442.38	6070.73	0	6070.73	9918.45	9918.45
48	32.9197	246086	45	MSW and CCR	500	33	2965.61	3423.95	4502.48	0	4502.48	7468.09	7468.09
49	32.9197	159380	45	MSW and CCR	500	33	2018.28	2330.21	2818.27	0	2818.27	4836.55	4836.55
50	32.9197	53602.5	45	MSW and CCR	500	33	862.576	995.887	763.6	0	763.6	1626.18	1626.18

Interslice Data

Global Minimum Query (bishop simplified) - Safety Factor: 1.21023

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	339.858	1143.19	0	0	0
2	375.854	1107.19	265320	0	0
3	378.005	1105.04	281472	0	0
4	380.054	1103	293033	0	0
5	385.991	1097.06	357645	0	0
6	415.063	1098.3	401994	0	0
7	444.136	1099.54	449116	0	0
8	450.972	1099.83	451369	0	0
9	451.681	1099.86	451297	0	0
10	452.036	1099.87	451415	0	0
11	458.419	1100.15	459065	0	0
12	463.618	1100.37	472367	0	0
13	471.78	1100.72	482416	0	0
14	495.595	1101.73	491178	0	0
15	527.597	1103.1	487269	0	0
16	559.598	1104.46	483011	0	0
17	591.599	1105.82	478405	0	0
18	623.6	1107.19	473451	0	0
19	655.602	1108.55	468148	0	0
20	690.112	1110.02	488095	0	0
21	724.622	1111.49	509365	0	0
22	759.132	1112.97	531957	0	0
23	793.642	1114.44	555872	0	0
24	828.152	1115.91	581109	0	0
25	862.663	1117.38	607669	0	0
26	897.173	1118.85	635551	0	0
27	931.683	1120.32	664756	0	0
28	966.193	1121.79	695284	0	0
29	1000.7	1123.26	727134	0	0
30	1035.21	1124.73	760306	0	0
31	1069.72	1126.21	794801	0	0
32	1104.23	1127.68	830619	0	0
33	1138.74	1129.15	867760	0	0
34	1173.25	1130.62	906222	0	0
35	1207.76	1132.09	946008	0	0
36	1242.27	1133.56	987116	0	0
37	1276.78	1135.03	1.02955e+006	0	0
38	1311.29	1136.5	1.07315e+006	0	0
39	1345.8	1137.97	1.11767e+006	0	0
40	1380.31	1139.45	1.16311e+006	0	0
41	1381.85	1140.98	1.13609e+006	0	0
42	1383.75	1142.88	1.10853e+006	0	0
43	1416.67	1175.8	821006	0	0
44	1449.59	1208.72	564899	0	0
45	1482.51	1241.64	342815	0	0
46	1515.43	1274.56	154753	0	0
47	1548.35	1307.48	712.865	0	0
48	1581.27	1340.4	-119304	0	0
49	1614.19	1373.32	-205299	0	0
50	1647.11	1406.24	-254756	0	0
51	1680.03	1439.16	0	0	0

Global Minimum Query (janbu simplified) - Safety Factor: 1.15455

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [degrees]
1	339.858	1143.19	0	0	0
2	375.854	1107.19	289578	0	0
3	378.005	1105.04	306412	0	0
4	380.054	1103	318271	0	0
5	385.991	1097.06	386377	0	0
6	415.063	1098.3	434128	0	0
7	444.136	1099.54	484892	0	0
8	450.972	1099.83	487577	0	0
9	451.681	1099.86	487535	0	0
10	452.036	1099.87	487676	0	0
11	458.419	1100.15	496008	0	0
12	463.618	1100.37	510211	0	0
13	471.78	1100.72	521161	0	0
14	495.595	1101.73	531604	0	0
15	527.597	1103.1	529316	0	0
16	559.598	1104.46	526825	0	0
17	591.599	1105.82	524129	0	0
18	623.6	1107.19	521230	0	0
19	655.602	1108.55	518127	0	0
20	690.112	1110.02	541899	0	0
21	724.622	1111.49	567247	0	0
22	759.132	1112.97	594172	0	0
23	793.642	1114.44	622673	0	0
24	828.152	1115.91	652750	0	0
25	862.663	1117.38	684403	0	0
26	897.173	1118.85	717632	0	0
27	931.683	1120.32	752438	0	0
28	966.193	1121.79	788820	0	0
29	1000.7	1123.26	826778	0	0
30	1035.21	1124.73	866312	0	0
31	1069.72	1126.21	907422	0	0
32	1104.23	1127.68	950109	0	0
33	1138.74	1129.15	994371	0	0
34	1173.25	1130.62	1.04021e+006	0	0
35	1207.76	1132.09	1.08763e+006	0	0
36	1242.27	1133.56	1.13662e+006	0	0
37	1276.78	1135.03	1.18718e+006	0	0
38	1311.29	1136.5	1.23915e+006	0	0
39	1345.8	1137.97	1.29221e+006	0	0
40	1380.31	1139.45	1.34636e+006	0	0
41	1381.85	1140.98	1.31987e+006	0	0
42	1383.75	1142.88	1.29313e+006	0	0
43	1416.67	1175.8	1.02248e+006	0	0
44	1449.59	1208.72	781569	0	0
45	1482.51	1241.64	572863	0	0
46	1515.43	1274.56	396362	0	0
47	1548.35	1307.48	252066	0	0
48	1581.27	1340.4	139975	0	0
49	1614.19	1373.32	60089.5	0	0
50	1647.11	1406.24	14790.5	0	0
51	1680.03	1439.16	0	0	0

List Of Coordinates

Block Search Window

X	Y
348.839	1127.73
348.839	1059.62
701.182	1057.87
701.182	1127.73

Block Search Window

X	Y
1366.67	1188.69
1366.67	1085.19
1658.61	1084.11
1658.61	1188.69

External Boundary

X	Y
1758.6	1413.4
1625	1457.2
1411	1457.2
1281.2	1428.2
240.8	1113.2
240.8	1111.4
240.8	1111.3
240.8	1111.1
240.8	1109.1
240.8	1017.16
1728.8	1017.16
1758.6	1017.16
1758.6	1159.2
1758.6	1161

Material Boundary

X	Y
240.8	1113.2
257.3	1110
434.8	1105.8
460.7	1099.6
472.1	1102.6
1553.9	1150.4
1581.2	1147
1728.8	1151.8
1758.6	1161

Material Boundary

X	Y
240.8	1111.4
257.3	1108.2
434.8	1104
460.7	1097.8
472.1	1100.8
700	1110.8
1553.9	1148.6
1581.4	1145.2
1728.79	1149.12
1758.6	1159.2

Material Boundary

X	Y
240.8	1111.3
257.3	1108.1
434.8	1103.9
460.7	1097.7
472.1	1100.7
700	1110.7
1553.9	1148.5
1581.4	1145.1
1728.8	1148.9

Material Boundary

X	Y
240.8	1111.1
257.3	1107.9
434.8	1103.7
460.7	1097.5
472.1	1100.5
700	1110.5
1553.9	1148.3
1581.4	1144.9
1728.8	1148.7

Material Boundary

X	Y
240.8	1109.1
257.3	1105.9
434.8	1101.7
460.7	1095.7
472.1	1098.5
700	1108.5
1553.9	1146.3
1581.4	1142.9
1728.8	1147.9

Material Boundary

X	Y
700	1108.5
700	1110.5
700	1110.7

Material Boundary

X	Y
1728.8	1017.16
1728.8	1147.9
1728.8	1148.7
1728.8	1148.9

Liner System Analysis

Atlantic Coast Consulting, Inc.

Design Calculations Notebook

1

2

3

4

IN THIS SECTION:

A. HELP Model Analysis

B. Liner Filter Fabric Analysis

C. Base Liner Geocomposite Analysis

ATLANTIC COAST
CONSULTING, INC.

Section 2
A. Help Model Analysis

OBJECTIVE:
Verify the performance of the leachate collection layer as shown on the Pine Bluff Solid Waste Management Facility D&O Plans. The original design calculations, as prepared by Jordan, Jones and Goulding, Inc and dated December 2000, will be analyzed with the addition of Coal Combustion Residuals (CCR) to the waste mass using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3.07.

METHODOLOGY:
Using the HELP Model, evaluate the leachate collection/protective cover and liner systems with different fill heights to verify that they meet the design guidelines. Each of the scenarios described below cannot result in more than 30 centimeters (12 inches) of head on top of the HDPE liner.

INPUT DATA:

- The daily precipitation, temperature, and solar radiation data was synthetically generated in HELP using the coefficients for Atlanta, Georgia, and the mean monthly precipitation and temperature for Atlanta, Georgia. The peak daily rainfall from the synthetically generated record was adjusted to match the 25-year 24-hour storm event precipitation for Cherokee County, Georgia (i.e., 6.90 inches) for simulation terms longer than one year.

- The initial waste placement (12 feet) and the 4 lifts of waste (48 feet) scenarios were modeled using simulation terms of 1 year and 10 years, respectively. The 6 lifts of waste (72 feet) and final waste height scenarios (339 feet) were modeled with a simulation term of 50 years.

- All calculations were performed for a unit acre area.

- The base liner slope was set at 2% with a drainage length of 600 feet (Phase 1).

- The material properties of each layer used in the analysis was based on the anticipated and/or the required material. Tables 1, 2, 4, and 6 of the HELP User's manual provide default values used. Default values were utilized for all layers except for the following conditions:

    - Parameters for the drainage geocomposite used in the leachate collection system are based on design calculations as performed in Section 2C of this report.

- Saturated hydraulic conductivity of MSW waste materials was assumed to vary with height. This is based on research as presented in "Estimating the Hydraulic Conductivity of Landfilled Municipal Solid Waste Using Borehole Permeameter Test" by J. Pradeep, J. Powell, T. G. Townsend, and D. Reinhart dated 2006. For the MSW waste, the model results presented in these calculations assume default hydraulic conductivity for waste heights less than 50' and 10^{-4} cm/sec hydraulic conductivity for waste heights of 50' and more.
- The saturated hydraulic conductivity of the CCR was assumed to be $5x10^{-5}$ cm/sec based on the default saturated hydraulic conductivity of High-Density Electric Plant Coal Bottom Ash shown in Table 4 of the HELP user manual. Assuming an estimated maximum MSW to CCR ratio by weight of 10:1, and unit weights of 70 lb/ft^3 and 115 lb/ft^3 of MSW and CCR, respectively, the estimated MSW to CCR ratio by height is 15:1. Therefore, the hydraulic conductivity of the CCR is negligible.

- Bare ground conditions were assumed in each scenario.

- The soil modeled for use as intermediate cover and site soils was HELP soil material #12. The hydraulic conductivity of the soil was adjusted to 10^{-4} cm/sec based on Geotechnical Soil Boring Investigation performed by ACC for the Pine Bluff MSW Landfill.

- The 12' waste height scenario assumed no runoff with 3% top slopes. The 48' and 72' waste height scenarios were modeled with 25% runoff with 3% top slopes. The final waste height scenario was modeled with 99% runoff with 33% top slopes.

- Default SCS curve numbers were utilized based on the ground conditions.

- Recirculation was modeled for scenarios with waste depths greater than 15 feet. Based on the original design calculations, the 48' and 72' scenarios were modeled with 50% recirculation and the final waste height, was modeled with 80% recirculation.

- Based on the original design calculations, base liner option 3 and leachate collection/protective cover system option 3 were utilized for all scenarios.

- Geomembrane in the base liner was assumed to be installed with good placement, a pinhole density of 1 hole per acre and installation defect density of 1 holes per acre. These assumptions will result in modeling that assumes the worst case for the peak daily head on the base liner.

The leachate collection/protective cover and base liner systems modeled are described as follows from top to bottom:

Leachate Collection/Protective Cover System Option 3:

24 inches of site soils
Double Sided Drainage Geocomposite

Base Liner System Option 3:

60-Mil HDPE Textured Liner
Geosynthetic Clay Liner
24 inches of 1x10^{-4} cm/sec compacted soil

RESULTS:
A summary of the scenarios modeled are presented in Table 2A-1. The maximum annual average leachate generation rate occurs in the 48 feet of waste scenario modeled with 25% runoff and 50% recirculation. The maximum peak head on the base liner occur in the 339 feet of waste scenario modeled with 99% runoff and 80% recirculation.

CONCLUSION:

Each of the scenarios modeled meet the design guidelines. Therefore, the leachate collection/protective cover system and liner system will provide for sufficient leachate collection.

Table 2A – 1

Results Summary

Pine Bluff CCR Management
HELP Model Analysis - Summary
Table 2A-1

File Name	Scenario	Description: Base Liner Option	Description: Waste Depth (ft)	Description: Runoff (%)	Description: Recirculation (%)	Description: Simulation Term (yrs)	Maximum Base Liner Head per Peak Daily Value (inches)	Annual Average Leachate Generation Rate (CF/Ac/Yr)	Annual Average Leachate Generation Rate (Gal/Ac/Day)	Recirculated Leachate (CF/Ac/Yr)	Recirculated Leachate (Gal/Ac/Day)	Peak Daily Leachate Generation Rate (CF/Ac/Day)
PBCCR_1.out	1	1	12	0	0	1	0.087	37,057	759	-	-	672
PBCCR_2.out	2	1	48	25	50	10	0.125	-	-	38,832	796	-
PBCCR_3.out	3	1	72	25	50	50	0.084	-	-	29,854	612	-
PBCCR_4.out	4	1	339	99	80	50	0.353	-	-	6,892	141	-

LCS Option 3/Liner System Option 3

with 12' Lift of Waste

```
♀
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:       C:\HELP3\TEMP.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\EVAP.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\PBCCR_1.D10
OUTPUT DATA FILE:            C:\HELP3\PBCCR_1.OUT


TIME:  11:18     DATE:   4/ 4/2017


******************************************************************************

     TITLE:  PINE BLUFF CCR - 1 LIFT OF WASTE

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.4710 VOL/VOL
           FIELD CAPACITY             =      0.3420 VOL/VOL
           WILTING POINT              =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.3189 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC


                                   LAYER  2
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
```

```
              MATERIAL TEXTURE NUMBER  18
THICKNESS                    =    144.00   INCHES
POROSITY                     =      0.6710 VOL/VOL
FIELD CAPACITY               =      0.2920 VOL/VOL
WILTING POINT                =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.3166 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC


                        LAYER  3
                        --------

           TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     24.00   INCHES
POROSITY                     =      0.4710 VOL/VOL
FIELD CAPACITY               =      0.3420 VOL/VOL
WILTING POINT                =      0.2100 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.3800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-04 CM/SEC


                        LAYER  4
                        --------

             TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      0.25   INCHES
POROSITY                     =      0.8500 VOL/VOL
FIELD CAPACITY               =      0.0100 VOL/VOL
WILTING POINT                =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1383 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =   22.7000008000     CM/SEC
SLOPE                        =      2.00   PERCENT
DRAINAGE LENGTH              =    600.0    FEET


                        LAYER  5
                        --------

             TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER  35
THICKNESS                    =      0.06   INCHES
POROSITY                     =      0.0000 VOL/VOL
FIELD CAPACITY               =      0.0000 VOL/VOL
WILTING POINT                =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
FML PLACEMENT QUALITY        =  3 - GOOD


                        LAYER  6
                        --------
```

```
                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER  17
   THICKNESS                   =      0.25   INCHES
   POROSITY                    =      0.7500 VOL/VOL
   FIELD CAPACITY              =      0.7470 VOL/VOL
   WILTING POINT               =      0.4000 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.7500 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.300000003000E-08 CM/SEC
```

```
          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

  NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
           SOIL DATA BASE USING SOIL TEXTURE #12 WITH BARE
           GROUND CONDITIONS, A SURFACE SLOPE OF  3.% AND
           A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER              =     95.20
FRACTION OF AREA ALLOWING RUNOFF     =      0.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      1.000  ACRES
EVAPORATIVE ZONE DEPTH               =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE    =      6.772  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE   =     12.362  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE   =      3.290  INCHES
INITIAL SNOW WATER                   =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS     =     58.762  INCHES
TOTAL INITIAL WATER                  =     58.762  INCHES
TOTAL SUBSURFACE INFLOW              =      0.00   INCHES/YEAR
```

```
           EVAPOTRANSPIRATION AND WEATHER DATA
           -----------------------------------

  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
           ATLANTA               GEORGIA

       STATION LATITUDE                        =  33.65 DEGREES
       MAXIMUM LEAF AREA INDEX                 =   1.00
       START OF GROWING SEASON (JULIAN DATE)   =     77
       END OF GROWING SEASON (JULIAN DATE)     =    316
       EVAPORATIVE ZONE DEPTH                  =  22.0  INCHES
       AVERAGE ANNUAL WIND SPEED               =   9.10 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  65.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY   =  76.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY   =  69.00 %
```

```
  NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ATLANTA             GEORGIA

           NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
```

4.91	4.43	5.91	4.43	4.02	3.41
4.73	3.41	3.17	2.53	3.43	4.23

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
41.90	44.90	52.50	61.80	69.30	75.80
78.60	78.20	73.00	62.20	52.00	44.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA
AND STATION LATITUDE = 33.65 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 1

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	1.79	4.77	4.50	2.44	3.27	4.87
	6.08	3.78	4.69	1.39	5.75	6.14
STD. DEVIATIONS	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00
RUNOFF						
TOTALS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOTRANSPIRATION						
TOTALS	1.864	2.500	3.647	2.931	2.997	6.473
	5.553	5.390	1.954	2.303	1.901	1.718
STD. DEVIATIONS	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	3.4482	1.2514	0.7555	2.5918	0.0083	0.0018
	0.0109	0.0000	0.0000	0.0300	0.0969	2.0138
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

```
                       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  PERCOLATION/LEAKAGE THROUGH LAYER  6
  ------------------------------------
    TOTALS             0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

    STD. DEVIATIONS    0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000


-------------------------------------------------------------------------------
              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  5
  -------------------------------------
    AVERAGES           0.0259   0.0104   0.0057   0.0201   0.0001   0.0000
                       0.0001   0.0000   0.0000   0.0002   0.0008   0.0151

    STD. DEVIATIONS    0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH    1
-------------------------------------------------------------------------------
                                     INCHES           CU. FEET        PERCENT
                                -------------------  -------------   ---------
 PRECIPITATION                   49.47     (   0.000)     179576.1     100.00

 RUNOFF                           0.000    (  0.0000)         0.00      0.000

 EVAPOTRANSPIRATION              39.231    (  0.0000)    142408.73     79.303

 LATERAL DRAINAGE COLLECTED      10.20857 (  0.00000)    37057.109   20.63588
   FROM LAYER  4

 PERCOLATION/LEAKAGE THROUGH      0.00000 (  0.00000)        0.005    0.00000
   LAYER  6

 AVERAGE HEAD ON TOP              0.007 (    0.000)
   OF LAYER  5

 CHANGE IN WATER STORAGE          0.030    (  0.0000)       110.25      0.061
*******************************************************************************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******************************************************************************

              PEAK DAILY VALUES FOR YEARS    1 THROUGH    1
   ------------------------------------------------------------------------
                                                 (INCHES)     (CU. FT.)
                                                ----------   -------------
      PRECIPITATION                                2.17         7877.100
```

RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 4	0.18502	671.62500
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00004
AVERAGE HEAD ON TOP OF LAYER 5	0.043	
MAXIMUM HEAD ON TOP OF LAYER 5	0.087	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	0.89	3231.8435

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3979

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1495

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 1

LAYER	(INCHES)	(VOL/VOL)
1	3.8269	0.3189
2	45.6377	0.3169
3	9.1069	0.3795
4	0.0337	0.1346
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

****
****

LCS Option 3/Liner System Option 3

with 48' of Waste and 50 % Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:    C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:      C:\HELP3\TEMP.D7
SOLAR RADIATION DATA FILE:  C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:    C:\HELP3\EVAP.D11
SOIL AND DESIGN DATA FILE:  C:\HELP3\PBCCR_2.D10
OUTPUT DATA FILE:           C:\HELP3\PBCCR_2.OUT


TIME:  11:20     DATE:   4/ 4/2017


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     TITLE:  PINE BLUFF CCR - 4 LIFT W/ 50% RECIRC

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.4710 VOL/VOL
           FIELD CAPACITY             =      0.3420 VOL/VOL
           WILTING POINT              =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.3129 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC


                                   LAYER  2
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
```

```
            MATERIAL TEXTURE NUMBER  18
THICKNESS                    =    576.00   INCHES
POROSITY                     =      0.6710 VOL/VOL
FIELD CAPACITY               =      0.2920 VOL/VOL
WILTING POINT                =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.2992 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC
NOTE:   50.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
        IS RECIRCULATED INTO THIS LAYER.


                      LAYER  3
                      --------

        TYPE 1 - VERTICAL PERCOLATION LAYER
            MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     24.00   INCHES
POROSITY                     =      0.4710 VOL/VOL
FIELD CAPACITY               =      0.3420 VOL/VOL
WILTING POINT                =      0.2100 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.3721 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-04 CM/SEC


                      LAYER  4
                      --------

          TYPE 2 - LATERAL DRAINAGE LAYER
            MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      0.25   INCHES
POROSITY                     =      0.8500 VOL/VOL
FIELD CAPACITY               =      0.0100 VOL/VOL
WILTING POINT                =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1427 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =   15.1999998000     CM/SEC
SLOPE                        =      2.00   PERCENT
DRAINAGE LENGTH              =    600.0    FEET
NOTE:   50.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
        LAYER IS RECIRCULATED INTO LAYER #  2.


                      LAYER  5
                      --------

          TYPE 4 - FLEXIBLE MEMBRANE LINER
            MATERIAL TEXTURE NUMBER  35
THICKNESS                    =      0.06   INCHES
POROSITY                     =      0.0000 VOL/VOL
FIELD CAPACITY               =      0.0000 VOL/VOL
WILTING POINT                =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
FML PLACEMENT QUALITY        =  3 - GOOD
```

```
                         LAYER  6
                         --------

               TYPE 3 - BARRIER SOIL LINER
               MATERIAL TEXTURE NUMBER  17
   THICKNESS                    =      0.25   INCHES
   POROSITY                     =      0.7500 VOL/VOL
   FIELD CAPACITY               =      0.7470 VOL/VOL
   WILTING POINT                =      0.4000 VOL/VOL
   INITIAL SOIL WATER CONTENT   =      0.7500 VOL/VOL
   EFFECTIVE SAT. HYD. COND.    =  0.300000003000E-08 CM/SEC




            GENERAL DESIGN AND EVAPORATIVE ZONE DATA
            ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #12 WITH BARE
          GROUND CONDITIONS, A SURFACE SLOPE OF  3.% AND
          A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER             =     95.20
FRACTION OF AREA ALLOWING RUNOFF    =     25.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =      1.000  ACRES
EVAPORATIVE ZONE DEPTH              =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      6.653  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =     12.362  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      3.290  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =    185.239  INCHES
TOTAL INITIAL WATER                 =    185.239  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR




             EVAPOTRANSPIRATION AND WEATHER DATA
             -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          ATLANTA              GEORGIA

     STATION LATITUDE                           =  33.65 DEGREES
     MAXIMUM LEAF AREA INDEX                    =   1.00
     START OF GROWING SEASON (JULIAN DATE)      =     77
     END OF GROWING SEASON (JULIAN DATE)        =    316
     EVAPORATIVE ZONE DEPTH                     =  22.0  INCHES
     AVERAGE ANNUAL WIND SPEED                  =   9.10 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY      =  65.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY      =  67.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY      =  76.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY      =  69.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    ATLANTA             GEORGIA
```

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
4.91	4.43	5.91	4.43	4.02	3.41
4.73	3.41	3.17	2.53	3.43	4.23

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
41.90	44.90	52.50	61.80	69.30	75.80
78.60	78.20	73.00	62.20	52.00	44.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA
AND STATION LATITUDE = 33.65 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.22	4.25	6.02	4.64	4.21	3.78
	5.26	3.50	4.05	2.56	3.00	4.47
STD. DEVIATIONS	2.37	1.82	2.13	2.93	1.91	1.87
	2.77	1.44	2.41	1.86	1.72	2.49
RUNOFF						
TOTALS	0.378	0.340	0.672	0.374	0.322	0.168
	0.361	0.222	0.337	0.165	0.186	0.332
STD. DEVIATIONS	0.326	0.287	0.543	0.393	0.263	0.142
	0.396	0.159	0.286	0.208	0.211	0.341
EVAPOTRANSPIRATION						
TOTALS	1.887	2.305	3.423	3.844	3.776	4.585
	4.586	3.623	2.661	2.036	1.631	1.443
STD. DEVIATIONS	0.308	0.241	0.364	0.906	0.677	1.506
	1.733	0.863	1.255	0.254	0.170	0.225

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	0.5232	0.8438	0.8716	1.1321	1.2224	1.1830
	1.1670	1.1124	0.8059	0.7077	0.5815	0.5467
STD. DEVIATIONS	0.3390	0.3758	0.2987	0.2263	0.1976	0.1235
	0.1744	0.2668	0.4107	0.5684	0.4922	0.4525

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.5232	0.8438	0.8716	1.1321	1.2224	1.1830
	1.1670	1.1124	0.8059	0.7077	0.5815	0.5467
STD. DEVIATIONS	0.3390	0.3758	0.2987	0.2263	0.1976	0.1235
	0.1744	0.2668	0.4107	0.5684	0.4922	0.4525

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	0.5232	0.8438	0.8716	1.1321	1.2224	1.1830
	1.1670	1.1124	0.8059	0.7077	0.5815	0.5467
STD. DEVIATIONS	0.3390	0.3758	0.2987	0.2263	0.1976	0.1235
	0.1744	0.2668	0.4107	0.5684	0.4922	0.4525

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0118	0.0208	0.0196	0.0263	0.0275	0.0275
	0.0262	0.0250	0.0187	0.0159	0.0135	0.0123
STD. DEVIATIONS	0.0076	0.0093	0.0067	0.0053	0.0044	0.0029
	0.0039	0.0060	0.0095	0.0128	0.0114	0.0102

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 10

	INCHES	CU. FEET	PERCENT
PRECIPITATION	49.97 (6.061)	181402.0	100.00
RUNOFF	3.857 (0.9022)	13999.72	7.718
EVAPOTRANSPIRATION	35.801 (2.6930)	129956.37	71.640
DRAINAGE RECIRCULATED INTO LAYER 2	10.69756 (2.73280)	38832.133	21.40668

LATERAL DRAINAGE COLLECTED FROM LAYER 4	10.69756 (	2.73280)	38832.133	21.40668
DRAINAGE RECIRCULATED FROM LAYER 4	10.69756 (	2.73280)	38832.133	21.40668
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (	0.00000)	0.012	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.020 (	0.005)		
CHANGE IN WATER STORAGE	-0.380 (	3.5491)	-1380.14	-0.761

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	6.90	25047.000
RUNOFF	1.892	6868.9590
DRAINAGE RECIRCULATED INTO LAYER 2	0.09080	329.58936
DRAINAGE COLLECTED FROM LAYER 4	0.09080	329.58936
DRAINAGE RECIRCULATED FROM LAYER 4	0.09080	329.58936
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00005
AVERAGE HEAD ON TOP OF LAYER 5	0.063	
MAXIMUM HEAD ON TOP OF LAYER 5	0.125	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	5.7 FEET	
SNOW WATER	3.04	11027.9346
MAXIMUM VEG. SOIL WATER (VOL/VOL)		0.4449
MINIMUM VEG. SOIL WATER (VOL/VOL)		0.1495

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 10

LAYER	(INCHES)	(VOL/VOL)
1	4.1832	0.3486
2	168.0441	0.2917
3	9.0002	0.3750
4	0.0219	0.0876
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 3/Liner System Option 3

with 72' of Waste and 50% Recirculation

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:     C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:       C:\HELP3\TEMP.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\EVAP.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\PBCCR_3.D10
OUTPUT DATA FILE:            C:\HELP3\PBCCR_3.OUT


TIME:  11:21     DATE:   4/ 4/2017


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     TITLE:  PINE BLUFF CCR - 6 LIFT W/ 50% RECIRC

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER   0
           THICKNESS                    =     12.00   INCHES
           POROSITY                     =      0.4710 VOL/VOL
           FIELD CAPACITY               =      0.3420 VOL/VOL
           WILTING POINT                =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT   =      0.3183 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-04 CM/SEC


                                   LAYER  2
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
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```
              MATERIAL TEXTURE NUMBER   0
THICKNESS                   =    864.00   INCHES
POROSITY                    =      0.6710 VOL/VOL
FIELD CAPACITY              =      0.2920 VOL/VOL
WILTING POINT               =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.3004 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC
NOTE:   50.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
          IS RECIRCULATED INTO THIS LAYER.


                         LAYER  3
                         --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                   =     24.00   INCHES
POROSITY                    =      0.4710 VOL/VOL
FIELD CAPACITY              =      0.3420 VOL/VOL
WILTING POINT               =      0.2100 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.3420 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC


                         LAYER  4
                         --------

              TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                   =      0.25   INCHES
POROSITY                    =      0.8500 VOL/VOL
FIELD CAPACITY              =      0.0100 VOL/VOL
WILTING POINT               =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0101 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =   14.5000000000     CM/SEC
SLOPE                       =      2.00   PERCENT
DRAINAGE LENGTH             =    600.0    FEET
NOTE:   50.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
          LAYER IS RECIRCULATED INTO LAYER #  2.


                         LAYER  5
                         --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER  35
THICKNESS                   =      0.06   INCHES
POROSITY                    =      0.0000 VOL/VOL
FIELD CAPACITY              =      0.0000 VOL/VOL
WILTING POINT               =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY         =      1.00   HOLES/ACRE
FML INSTALLATION DEFECTS    =      1.00   HOLES/ACRE
FML PLACEMENT QUALITY       =  3 - GOOD
```

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 17

THICKNESS	=	0.25 INCHES
POROSITY	=	0.7500 VOL/VOL
FIELD CAPACITY	=	0.7470 VOL/VOL
WILTING POINT	=	0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.300000003000E-08 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #12 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 200. FEET.

SCS RUNOFF CURVE NUMBER	=	95.20	
FRACTION OF AREA ALLOWING RUNOFF	=	25.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	7.648	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	12.362	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	3.290	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	271.741	INCHES
TOTAL INITIAL WATER	=	271.741	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
ATLANTA GEORGIA

STATION LATITUDE	=	33.65 DEGREES
MAXIMUM LEAF AREA INDEX	=	1.00
START OF GROWING SEASON (JULIAN DATE)	=	77
END OF GROWING SEASON (JULIAN DATE)	=	316
EVAPORATIVE ZONE DEPTH	=	22.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	9.10 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	65.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	76.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	69.00 %

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
4.91	4.43	5.91	4.43	4.02	3.41
4.73	3.41	3.17	2.53	3.43	4.23

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
41.90	44.90	52.50	61.80	69.30	75.80
78.60	78.20	73.00	62.20	52.00	44.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA
AND STATION LATITUDE = 33.65 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 50

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.38	4.40	5.69	4.55	4.21	3.57
	4.95	3.32	3.57	2.47	3.31	3.85
STD. DEVIATIONS	2.22	1.97	2.48	2.29	2.20	1.65
	2.34	1.79	2.19	1.39	1.75	2.14
RUNOFF						
TOTALS	0.376	0.378	0.557	0.378	0.343	0.171
	0.336	0.202	0.281	0.158	0.270	0.287
STD. DEVIATIONS	0.326	0.315	0.431	0.295	0.283	0.126
	0.331	0.188	0.281	0.161	0.244	0.301
EVAPOTRANSPIRATION						
TOTALS	1.787	2.173	3.457	3.739	3.828	4.423
	4.804	3.397	2.442	1.801	1.487	1.491
STD. DEVIATIONS	0.258	0.335	0.400	0.853	1.057	1.176
	1.374	1.482	1.245	0.537	0.273	0.229

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	0.6354	0.4713	0.4544	0.4506	0.6003	0.6945
	0.8210	0.8628	0.8345	0.8547	0.7717	0.7731
STD. DEVIATIONS	0.2542	0.2514	0.3013	0.2970	0.3317	0.3527
	0.3090	0.2865	0.2708	0.2623	0.2785	0.2541

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.6354	0.4713	0.4544	0.4506	0.6003	0.6945
	0.8210	0.8628	0.8345	0.8547	0.7717	0.7731
STD. DEVIATIONS	0.2542	0.2514	0.3013	0.2970	0.3317	0.3527
	0.3090	0.2865	0.2708	0.2623	0.2785	0.2541

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	0.6354	0.4713	0.4544	0.4506	0.6003	0.6945
	0.8210	0.8628	0.8345	0.8547	0.7717	0.7731
STD. DEVIATIONS	0.2542	0.2514	0.3013	0.2970	0.3317	0.3527
	0.3090	0.2865	0.2708	0.2623	0.2785	0.2541

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0150	0.0122	0.0107	0.0110	0.0141	0.0169
	0.0193	0.0203	0.0203	0.0201	0.0188	0.0182
STD. DEVIATIONS	0.0060	0.0065	0.0071	0.0072	0.0078	0.0086
	0.0073	0.0067	0.0066	0.0062	0.0068	0.0060

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 50

	INCHES	CU. FEET	PERCENT
PRECIPITATION	48.30 (6.672)	175321.7	100.00
RUNOFF	3.737 (0.9639)	13564.78	7.737
EVAPOTRANSPIRATION	34.829 (3.6726)	126429.84	72.113
DRAINAGE RECIRCULATED INTO LAYER 2	8.22429 (2.73967)	29854.172	17.02822

LATERAL DRAINAGE COLLECTED FROM LAYER 4	8.22429 (	2.73967)	29854.172	17.02822
DRAINAGE RECIRCULATED FROM LAYER 4	8.22429 (	2.73967)	29854.172	17.02822
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (	0.00000)	0.011	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.016 (	0.005)		
CHANGE IN WATER STORAGE	1.507 (	4.9745)	5471.64	3.121

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	6.90	25047.000
RUNOFF	1.903	6908.5410
DRAINAGE RECIRCULATED INTO LAYER 2	0.05877	213.32841
DRAINAGE COLLECTED FROM LAYER 4	0.05877	213.32841
DRAINAGE RECIRCULATED FROM LAYER 4	0.05877	213.32841
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00004
AVERAGE HEAD ON TOP OF LAYER 5	0.043	
MAXIMUM HEAD ON TOP OF LAYER 5	0.084	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	9.7 FEET	
SNOW WATER	5.40	19602.5937
MAXIMUM VEG. SOIL WATER (VOL/VOL)		0.4942
MINIMUM VEG. SOIL WATER (VOL/VOL)		0.1495

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 50

LAYER	(INCHES)	(VOL/VOL)
1	4.5262	0.3772
2	333.8882	0.3864
3	8.4935	0.3539
4	0.0127	0.0510
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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LCS Option 3/Liner System Option 3

with 339' of Waste and 80% Recirculation

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**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
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PRECIPITATION DATA FILE:     C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:       C:\HELP3\TEMP.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\EVAP.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\PBCCR_4.D10
OUTPUT DATA FILE:            C:\HELP3\PBCCR_4.OUT


TIME:  15:35     DATE:   4/ 4/2017


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     TITLE:  PINE BLUFF CCR - INTERMEDIATE COVER W/ 80% RECIRCULATION

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     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =     12.00   INCHES
           POROSITY                   =      0.4710 VOL/VOL
           FIELD CAPACITY             =      0.3420 VOL/VOL
           WILTING POINT              =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.3235 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC


                                   LAYER  2
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
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              MATERIAL TEXTURE NUMBER   0
  THICKNESS                    =   4068.00   INCHES
  POROSITY                     =      0.6710 VOL/VOL
  FIELD CAPACITY               =      0.2920 VOL/VOL
  WILTING POINT                =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.2924 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-04 CM/SEC
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM LAYER # 4
         IS RECIRCULATED INTO THIS LAYER.


                        LAYER  3
                        --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
  THICKNESS                    =     24.00   INCHES
  POROSITY                     =      0.4710 VOL/VOL
  FIELD CAPACITY               =      0.3420 VOL/VOL
  WILTING POINT                =      0.2100 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.3420 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.999999975000E-04 CM/SEC


                        LAYER  4
                        --------

              TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
  THICKNESS                    =      0.25   INCHES
  POROSITY                     =      0.8500 VOL/VOL
  FIELD CAPACITY               =      0.0100 VOL/VOL
  WILTING POINT                =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.2429 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.444700003000     CM/SEC
  SLOPE                        =      2.00   PERCENT
  DRAINAGE LENGTH              =    600.0    FEET
NOTE:   80.00 PERCENT OF THE DRAINAGE COLLECTED FROM THIS
         LAYER IS RECIRCULATED INTO LAYER #  2.


                        LAYER  5
                        --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER  35
  THICKNESS                    =      0.06   INCHES
  POROSITY                     =      0.0000 VOL/VOL
  FIELD CAPACITY               =      0.0000 VOL/VOL
  WILTING POINT                =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS     =      1.00   HOLES/ACRE
  FML PLACEMENT QUALITY        =  3 - GOOD
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                         LAYER  6
                         --------

               TYPE 3 - BARRIER SOIL LINER
               MATERIAL TEXTURE NUMBER  17
   THICKNESS                    =      0.25   INCHES
   POROSITY                     =      0.7500 VOL/VOL
   FIELD CAPACITY               =      0.7470 VOL/VOL
   WILTING POINT                =      0.4000 VOL/VOL
   INITIAL SOIL WATER CONTENT   =      0.7500 VOL/VOL
   EFFECTIVE SAT. HYD. COND.    =  0.300000003000E-08 CM/SEC



          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #12 WITH BARE
          GROUND CONDITIONS, A SURFACE SLOPE OF 33.% AND
          A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER              =     95.50
FRACTION OF AREA ALLOWING RUNOFF     =     99.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      1.000  ACRES
EVAPORATIVE ZONE DEPTH               =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE    =      7.660  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE   =     12.362  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE   =      3.290  INCHES
INITIAL SNOW WATER                   =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS     =   1201.647  INCHES
TOTAL INITIAL WATER                  =   1201.647  INCHES
TOTAL SUBSURFACE INFLOW              =      0.00   INCHES/YEAR



           EVAPOTRANSPIRATION AND WEATHER DATA
           -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          ATLANTA              GEORGIA

     STATION LATITUDE                          =  33.65 DEGREES
     MAXIMUM LEAF AREA INDEX                   =   1.00
     START OF GROWING SEASON (JULIAN DATE)     =     77
     END OF GROWING SEASON (JULIAN DATE)       =    316
     EVAPORATIVE ZONE DEPTH                    =  22.0  INCHES
     AVERAGE ANNUAL WIND SPEED                 =   9.10 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  65.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  76.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  69.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    ATLANTA             GEORGIA
```

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
4.91	4.43	5.91	4.43	4.02	3.41
4.73	3.41	3.17	2.53	3.43	4.23

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
41.90	44.90	52.50	61.80	69.30	75.80
78.60	78.20	73.00	62.20	52.00	44.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR ATLANTA GEORGIA
AND STATION LATITUDE = 33.65 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 50

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	4.38	4.40	5.69	4.55	4.21	3.57
	4.95	3.32	3.57	2.47	3.31	3.85
STD. DEVIATIONS	2.22	1.97	2.48	2.29	2.20	1.65
	2.34	1.79	2.19	1.39	1.75	2.14
RUNOFF						
TOTALS	1.578	1.586	2.254	1.548	1.402	0.717
	1.358	0.843	1.139	0.644	1.100	1.189
STD. DEVIATIONS	1.336	1.283	1.601	1.174	1.129	0.510
	1.241	0.748	1.118	0.642	0.981	1.210
EVAPOTRANSPIRATION						
TOTALS	1.568	1.991	3.257	3.336	3.374	4.039
	4.044	2.566	2.039	1.578	1.339	1.291
STD. DEVIATIONS	0.216	0.316	0.399	0.894	0.944	1.024
	1.255	1.138	1.072	0.586	0.272	0.179

LATERAL DRAINAGE RECIRCULATED INTO LAYER 2

TOTALS	0.1899	0.1564	0.1301	0.0732	0.0705	0.1292
	0.2006	0.1778	0.1891	0.1984	0.1867	0.1966
STD. DEVIATIONS	0.0435	0.0676	0.0745	0.0633	0.0570	0.0808
	0.0619	0.0502	0.0392	0.0370	0.0356	0.0381

LATERAL DRAINAGE COLLECTED FROM LAYER 4

TOTALS	0.0475	0.0391	0.0325	0.0183	0.0176	0.0323
	0.0502	0.0445	0.0473	0.0496	0.0467	0.0492
STD. DEVIATIONS	0.0109	0.0169	0.0186	0.0158	0.0143	0.0202
	0.0155	0.0126	0.0098	0.0092	0.0089	0.0095

LATERAL DRAINAGE RECIRCULATED FROM LAYER 4

TOTALS	0.1899	0.1564	0.1301	0.0732	0.0705	0.1292
	0.2006	0.1778	0.1891	0.1984	0.1867	0.1966
STD. DEVIATIONS	0.0435	0.0676	0.0745	0.0633	0.0570	0.0808
	0.0619	0.0502	0.0392	0.0370	0.0356	0.0381

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 5

AVERAGES	0.0912	0.0824	0.0624	0.0363	0.0338	0.0641
	0.0963	0.0854	0.0938	0.0953	0.0926	0.0944
STD. DEVIATIONS	0.0209	0.0355	0.0358	0.0314	0.0274	0.0401
	0.0297	0.0241	0.0194	0.0178	0.0177	0.0183

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 50

	INCHES	CU. FEET	PERCENT
PRECIPITATION	48.30 (6.672)	175321.7	100.00
RUNOFF	15.357 (3.7562)	55745.89	31.796
EVAPOTRANSPIRATION	30.422 (3.0223)	110430.81	62.988
DRAINAGE RECIRCULATED INTO LAYER 2	1.89861 (0.42632)	6891.958	3.93103

LATERAL DRAINAGE COLLECTED FROM LAYER 4	0.47465 (	0.10658)	1722.989	0.98276
DRAINAGE RECIRCULATED FROM LAYER 4	1.89861 (	0.42632)	6891.958	3.93103
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001 (	0.00000)	0.022	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.077 (	0.017)		
CHANGE IN WATER STORAGE	2.045 (	1.8282)	7421.73	4.233

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	6.90	25047.000
RUNOFF	5.890	21380.9766
DRAINAGE RECIRCULATED INTO LAYER 2	0.01200	43.55485
DRAINAGE COLLECTED FROM LAYER 4	0.00300	10.88871
DRAINAGE RECIRCULATED FROM LAYER 4	0.01200	43.55485
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00013
AVERAGE HEAD ON TOP OF LAYER 5	0.179	
MAXIMUM HEAD ON TOP OF LAYER 5	0.353	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	7.3 FEET	
SNOW WATER	5.40	19602.5937

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4411

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1495

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

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FINAL WATER STORAGE AT END OF YEAR 50

LAYER	(INCHES)	(VOL/VOL)
1	4.4926	0.3744
2	1290.8691	0.3173
3	8.2173	0.3424
4	0.1083	0.4333
5	0.0000	0.0000
6	0.1875	0.7500
SNOW WATER	0.000	

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Section 2
B. Liner Filter Fabric Analysis

OBJECTIVE:

Evaluate the performance of the geotextile filter component of the geocomposite within the option 3 leachate collection system used in the Pine Bluff MSW Landfill. The analysis applies to the condition when borrowed soil from on-site will be placed over the geotextile filter used in seperation from the geocomposite drainage system. For application purposes the geotextile filter is designed to provide permeability for water while also preventing clogging of the underlying geocomposite drainage system by soil particles.

METHODOLOGY:

This geotextile filter design is based upon the publication "Geotextile Filter Design, Application and Product Selection Guide," by Mirafi, See Attachment 1. The design is a seven step process used to select the appropriate geotextile filter.

Step 1: Define Application Filter Requirements

(i) Drainage material adjacent to the geotextile will consist of an HDPE geonet. This corresponds to a relatively low void volume condition and will not result in sharp contact points as can be expected with a regular gravel or rock.

(ii) Since the void volume is relatively small a high degree of retention from the filter will be necessary.

Step 2: Boundary Conditions

(i) Since the geotextile is being used in base liner leachate collection system construction, confining pressures will be high.
(ii) Since the flow will only be in a downward direction into the drainage net, a steady flow condition is applicable.

Step 3: Soil Retention Requirements

The soil to be retained (i.e., site soils) was presumed to be derived from on-site materials. The particle size distribution tests for on-site soils were performed by Timely Engineering Soil Tests, LLC during Soils Analyis for Pine Bluff Landfill Expansion permit number 028-039D(SL). The results of the testing are attached in Attachment 2, and summarized in Table 1. The average particle size distribution of anticipated site soils is shown in Table 1.

Step 4: Geotextile Permeability Requirements

Minimum allowable geotextile permeability = $k_g \geq i_s k_s$

Soil d_{20} is predominantly greater than 0.002mm and d_{10} is less than 0.07mm. A permeability of 1.0E-04 cm/s is estimated for the soil based on soil testing performed.

k_s= 1.0E-04 cm/s

Hydraulic Gradient, i_s = 1.5 for landfill leachate collection systems based on Giroud 1988

Therefore, required geotextile permeability:

1.5E-04 cm/s

From Attachment 3, the Permeability for a 8 oz/sy fabric is 0.3 cm/s

Step 5: Anti-Clogging Requirements

The largest opening size that satisfies the AOS criteria will be selected to satisfy this requirement.

From Chart 1, since d_{20}>0.002 mm, and d_{10}<0.07 mm ; soil is less than 20% clay and more than 10% silt. Since the application favors retention and $C_c = (d_{30})^2/d_{60}xd_{10}$ = 1.5, the soil is stable. Thus, $C'_u = d_{60}/d_{30}$ = 2.09.

Therefore, the soil is classified as uniformely graded loose soil and $O_{95} < C'_u d'_{50}$ = 0.27mm

Step 6: Survivability Requirements

Since the application is for subsurface drainage with rounded drainage media, high confining stress and heavy compaction, the following criteria are selected for survivability.

Grab strength ≥ 157 lb, Elongation ≥ 50%

Puncture strength ≥ 56 lb, Burst strength ≥ 189 psi, Trapezoidal Tear ≥ 56 lb

Step 7: Durability Requirements

Since the geotextile will not be left exposed to sunlight, nor exposed to adverse chemicals, special durability requirements do not apply.

Results:

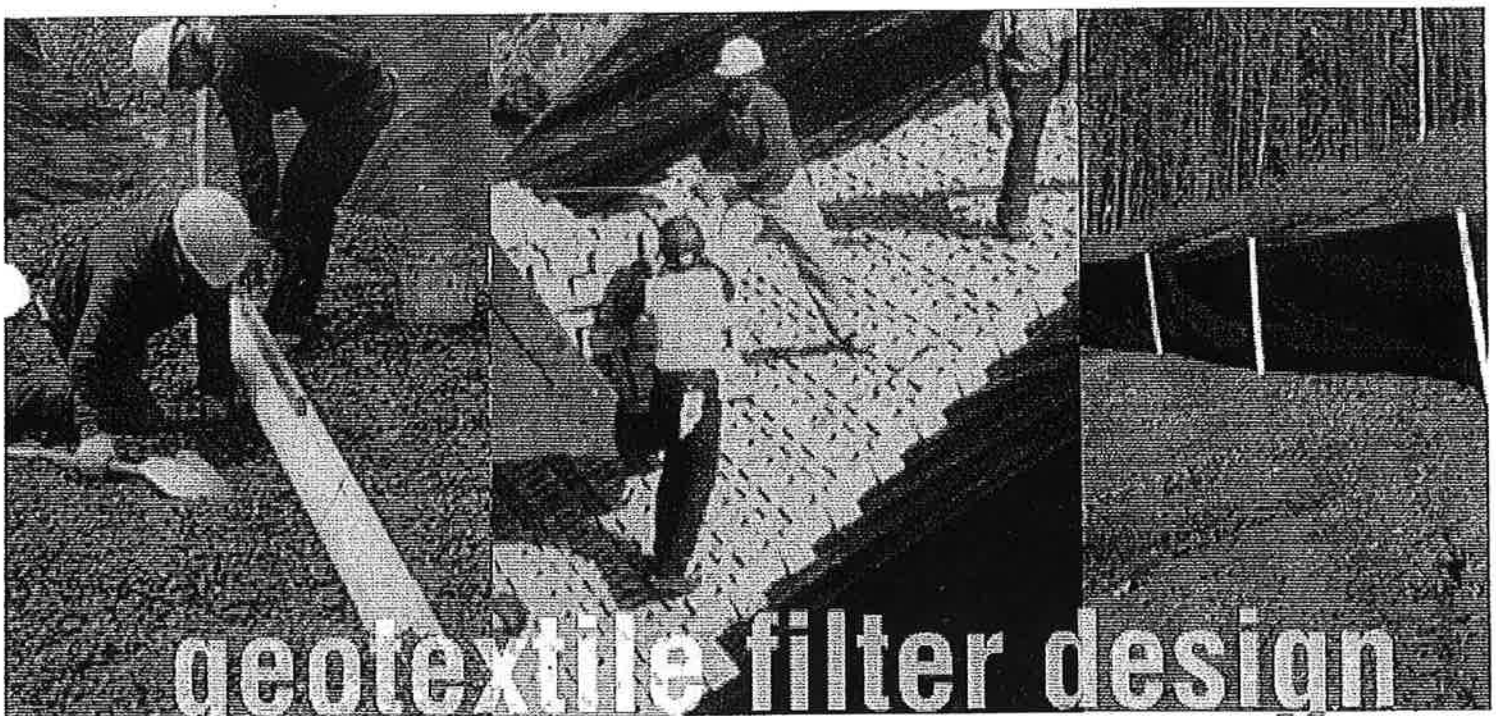
Based on opening size, permeability, and survivablility requirements, the Skaps GE-160 geotextile fabric was considered as a typical product meeting the selection criteria. Conservatively, the Skaps GE-180 was chosen for the leachate collection system. The property sheet from the manufacturer is attached in Attachment 3.

Product Selection-8.0 oz/yd^2 nonwoven

Maximum AOS per ASTM D-4751 = 0.21; OK

MIRAFI®

geotextile filter design, application, and product selection guide



Marine & Transportation Engineering

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Attachment 1

MIRAFI®

GEOTEXTILE FILTER DESIGN, APPLICATION, AND PRODUCT SELECTION GUIDE

Drainage and Erosion Control Applications

TABLE OF CONTENTS

INTRODUCTION
AND EXPLANATION OF THE PROBLEM

Drainage

Aggregate trench and blanket drains are commonly used to drain water from surrounding soils or waste materials. These drains are typically installed less than three feet deep. They may be at greater depths in situations where there is a need to significantly lower the groundwater table or to drain leachate.

In loose or gap graded soils, the groundwater flow can carry soil particles toward the drain. These migrating particles can clog drainage systems.

Erosion Control

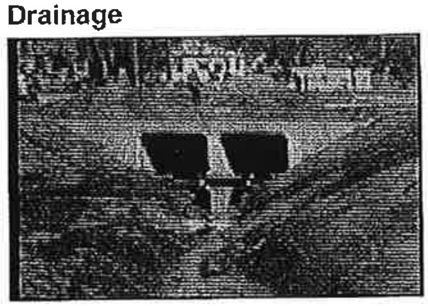
Stone and concrete revetments are often used on waterway slopes to resist soil erosion. These armored systems, when placed directly on the soil, have not sufficiently prevented erosion. Fluctuating water levels cause seepage in and out of embankment slopes resulting in the displacement of fine soil particles.

As with trench drains, these fine soil particles are carried away with receding flows. This action eventually leads to undermining of the armor system.

Typical Solutions

Specially graded fill material which is intended to act as a soil filter is frequently placed between the drain or revetment and the soil to be protected. This graded filter is often difficult to obtain, expensive to purchase, time consuming to install and segregates during placement, thus compromising its filtration ability.

Drainage



Geotextile filters retain soil particles while allowing seeping water to drain freely. Fine soil particles are prevented from clogging drainage systems.

Erosion Control

Geotextile filters retain soil particles while allowing water to pass freely. Buildup of hydrostatic pressures in protected slopes is prevented, thus enhancing slope stability.

THE MIRAFI®
SOLUTION

Filtration geotextiles provide alternatives to graded filters.

Designing with Geotextile Filters

Geotextiles are frequently used in armored erosion control and drainage applications. Some of the most common applications include slopes, dam embankments/spillways, shorelines armored with riprap, flexible block mats and concrete filled fabric formed systems. Drainage applications include pavement edge drains, french drains, prefabricated drainage panels and leachate collection/leak detection systems.

In all of the above applications, geotextiles are used to retain soil particles while allowing liquid to pass freely. But the fact that geotextiles are widely used where their primary function is filtration, there remains much confusion about proper filtration design procedures.

For this reason, Mirafi® commissioned Geosyntec Consultants, Inc. to develop a generic *Geotextile Filter Design Manual.* The manual offers a systematic approach to solving most common filtration design problems. It is available to practicing designers exclusively through Mirafi®. This *Geotextile Filter Design, Application, and Product Selection Guide* is excerpted from the manual.

Mechanisms of Filtration

A filter should prevent excessive migration of soil particles, while at the same time allowing liquid to flow freely through the filter layer. Filtration is therefore summarized by two seemingly conflicting requirements.

- The filter must retain soil, implying that the size of filter pore spaces or openings should be smaller than a specified maximum value; and
- The filter must be permeable enough to allow a relatively free flow through it, implying that the size of filter pore spaces and number of openings should be larger than a specified minimum value.

Geotextile Filter Requirements

Before the introduction of geotextiles, granular materials were widely used as filters for geotechnical engineering applications. Drainage criteria for geotextile filters is largely derived from those for granular filters. The criteria for both are, therefore, similar.

In addition to retention and permeability criteria, several other considerations are required for geotextile filter design. Some considerations are noted below:

- **Retention:** Ensures that the geotextile openings are small enough to prevent excessive migration of soil particles.
- **Permeability:** Ensures that the geotextile is permeable enough to allow liquids to pass through without causing significant upstream pressure buildup.
- **Anti-clogging:** Ensures that the geotextile has adequate openings, preventing trapped soil from clogging openings and affecting permeability.
- **Survivability:** Ensures that the geotextile is strong enough to resist damage during installation.
- **Durability:** Ensures that the geotextile is resilient to adverse chemical, biological and ultraviolet (UV) light exposure for the design life of the project.

The specified numerical criteria for geotextile filter requirements depends on the application of the filter, filter boundary conditions, properties of the soil being filtered, and construction methods used to install the filter. These factors are discussed in the following step-by-step geotextile design methodology

SYSTEMATIC DESIGN APPROACH

Design Methodology

The proposed design methodology represents years of research and experience in geotextile filtration design. The approach presents a logical progression through seven steps.

Step 1: Define the Application Filter Requirements

Step 2: Define Boundary Conditions

Step 3: Determine Soil Retention Requirements

Step 4: Determine Permeability Requirements

Step 5: Determine Anti-Clogging Requirements

Step 6: Determine Survivability Requirements

Step 7: Determine Durability Requirements

STEP ONE:

DEFINE APPLICATION FILTER REQUIREMENTS

Geotextile filters are used between the soil and drainage or armoring medium. Typical drainage media include natural materials such as gravel and sand, as well as geosynthetic materials such as geonets and cuspated drainage cores. Armoring material is often riprap or concrete blocks. Often, an armoring system includes a sand bedding layer beneath the surface armor. The armoring system can be considered to act as a "drain" for water seeping from the protected slope.

Identifying the Drainage Material

The drainage medium adjacent to the geotextile must be identified. The primary reasons for this include:

- Large voids or high pore volume can influence the selection of the retention criterion
- Sharp contact points such as highly angular gravel or rock will influence the geosynthetic survivability requirements.

Retention vs. Permeability Trade-Off

The drainage medium adjacent to the geotextile often affects the selection of the retention criterion. Due to the conflicting nature of filter requirements, it is necessary to decide whether retention or permeability is the favored filter characteristic.

For example, a drainage material that has relatively little void volume (i.e., a geonet or a wick drain) requires a high degree of retention from the filter. Conversely, where the drainage material void volume is large (i.e., a gravel trench or riprap layer), the permeability and anti-clogging criteria are favored.

STEP TWO:

DEFINE BOUNDARY CONDITIONS

Evaluate Confining Stress

The confining pressure is important for several reasons:

- High confining pressures tend to increase the relative density of coarse grained soil, increasing the soil's resistance to particle movement. This affects the selection of retention criteria.
- High confining pressures decrease the hydraulic conductivity of fine grained soils, increasing the potential for soil to intrude into, or through, the geotextile filter.
- For all soil conditions, high confining pressures increase the potential for the geotextile and soil mass to intrude into the flow paths. This can reduce flow capacity within the drainage media, especially when geosynthetic drainage cores are used.

Define Flow Conditions

Flow conditions can be either steady-state or dynamic. Defining these conditions is important because the retention criteria for each is different. Examples of applications with steady-state flow conditions include standard dewatering drains, wall drains and leachate collection drains. Inland waterways and shoreline protection are typical examples of applications where waves or water currents cause dynamic flow conditions.

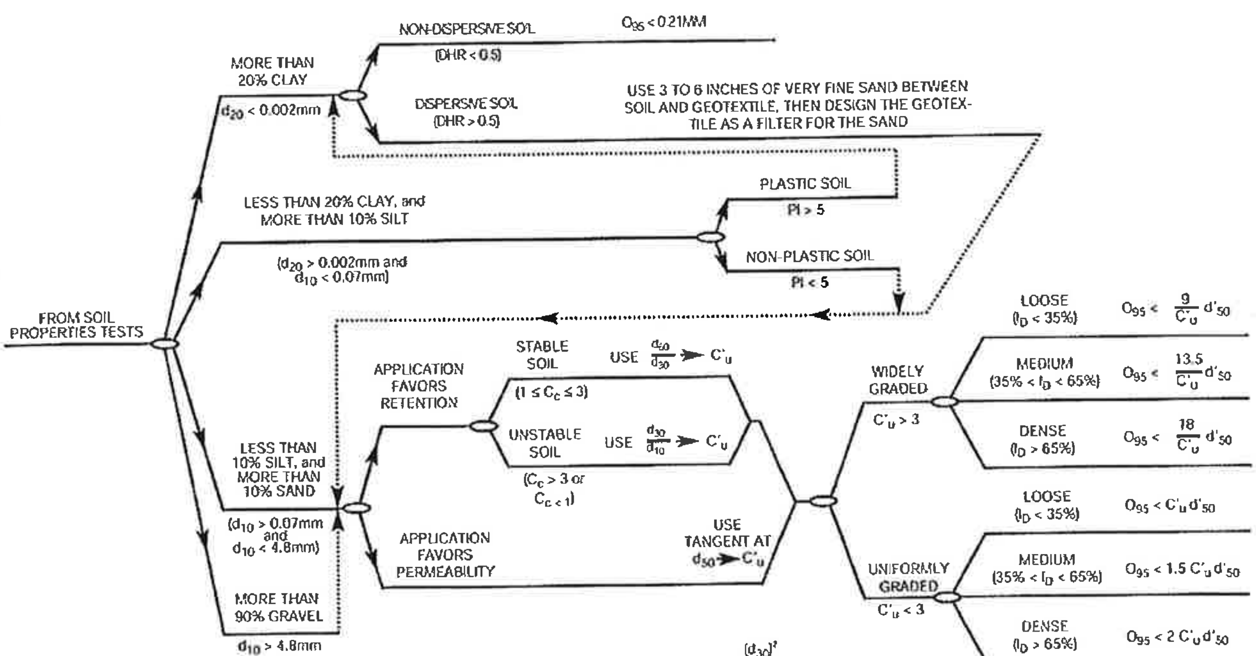
STEP THREE:

DETERMINE SOIL RETENTION REQUIREMENTS

Charts 1 and 2 indicate the use of particle-size parameters for determing retention criteria. These charts show that the amount of gravel, sand, silt and clay affects the retention criteria selection process. Chart 1 shows the numerical retention criteria for steady-state flow conditions; Chart 2 is for dynamic flow conditions.

For predominantly coarse grained soils, the grain-size distribution curve is used to calculate specific parameters such as C_u, C'_u, C_c, that govern the retention criteria.

Chart 1. Soil Retention Criteria of Steady-State Flow Conditions



NOTES:

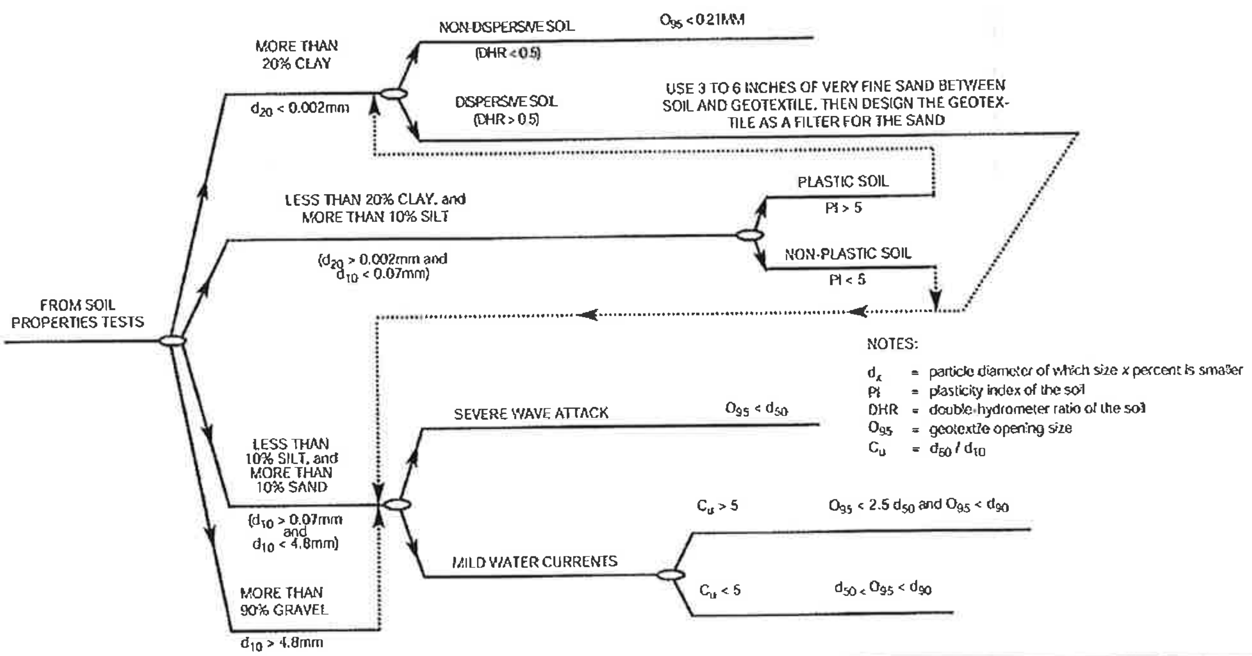
d_x = particle diameter of which size x percent is smaller

$C'_u = \sqrt{\frac{d'_{100}}{d'_0}}$ where: d'_{100} and d'_0 are the extremeties of a straight line drawn through the particle-size distribution, as directed above and d'_{50} is the midpoint of this line

$C_c = \frac{(d_{30})^2}{d_{60} \times d_{10}}$

I_D = relative density of the soil
PI = plasticity index of the soil
DHR = double-hydrometer ratio of the soil
O_{95} = geotextile opening size

Chart 2. Soil Retention Criteria of Dynamic Flow Conditions



Analysis of the soil to be protected is critical to proper filtration design.

Define Soil Particle-Size Distribution

The particle-size distribution of the soil to be protected should be determined using test method ASTM D 422. The grain size distribution curve is used to determine parameters necessary for the selection of numerical retention criteria.

Define Soil Atterberg Limits

For fine-grained soils, the plasticity index (PI) should be determined using the Atterberg Limits test procedure (ASTM D 4318). Charts 1 and 2 show how to use the PI value for selecting appropriate numerical retention criteria.

Determine the Maximum Allowable Geotextile Opening Size (O_{95})

The last step in determining soil retention requirements is evaluating the maximum allowable opening size (O_{95}) of the geotextile which will provide adequate soil retention. The O_{95} is also known as the geotextile's Apparent Opening Size (AOS) and is determined from test procedure ASTM D 4751. AOS can often be obtained from manufacturer's literature.

STEP FOUR:

DETERMINE GEOTEXTILE PERMEABILITY REQUIREMENTS

Define the Soil Hydraulic Conductivity (k_s)

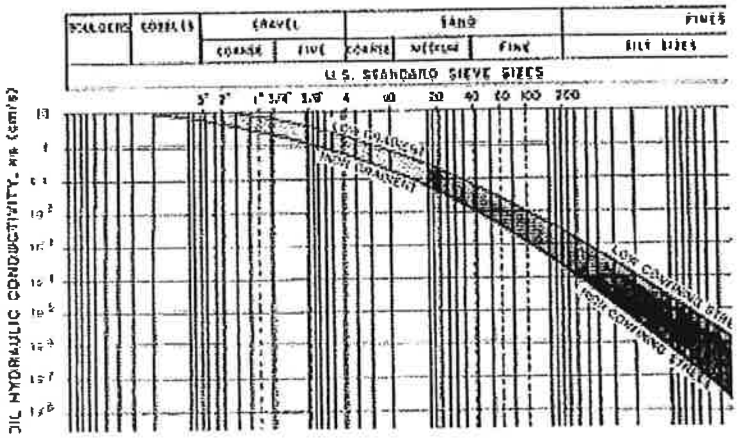
Determine the soil hydraulic conductivity, often referred to as permeability, using one of the following methods:

- For critical applications, such as earth dams, soil permeability should be lab measured using representative field conditions in accordance with test procedure ASTM D 5084.
- For non-critical applications, estimate the soil-hydraulic conductivity using the characteristic grain diameter d_{15}, of the soil (see Figure 2 on the following page).

STEP FOUR:

DETERMINE GEOTEXTILE PERMEABILITY REQUIREMENTS
(continued)

Figure 2. Typical Hydraulic Conductivity Values



Define the Hydraulic Gradient for the Application (i_s)

The hydraulic gradient will vary depending on the filtration application. Anticipated hydraulic gradients for various applications may be estimated using Table 1 below.

Table 1. Typical Hydraulic Gradients[a]

Drainage Applications	Typical Hydraulic Gradient
Channel Lining	1.0
Standard Dewatering Trench	1.0
Vertical Wall Drain	1.5
Pavement Edge Drain	1.0
Landfill LCDRS	1.5
Landfill LCRS	1.5
Landfill SWCRS	1.5
Shoreline Protection	
Current Exposure	1.0[b]
Wave Exposure	10[b]
Dams	10[b]
Liquid Impoundments	10[b]

[a] *Table developed after Giroud, 1988.*
[b] *Critical applications may require designing with higher gradients than those given.*

Determine the Minimum Allowable Geotextile Permeability (k_g)

The requirement of geotextile permeability can be affected by the filter application, flow conditions and soil type. The following equation can be used for all flow conditions to determine the minimum allowable geotextile permeability (Giroud, 1988):

$$k_g \geq i_s k_s$$

Permeability of the geotextile can be calculated from the permittivity test procedure (ASTM D 4491). This value is often available from manufacturer's literature. Geotextile permeability is defined as the product of the permittivity, Ψ, and the geotextile thickness, t_g:

$$k_g = \Psi t_g$$

STEP FIVE:

DETERMINE ANTI-CLOGGING REQUIREMENTS

To minimize the risk of clogging, follow this criteria:

- Use the largest opening size (O_{95}) that satisfies the retention criteria.
- For nonwoven geotextiles, use the largest porosity available, never less than 30%.
- For woven geotextiles, use the largest percentage of open area available, never less than 4%.

NOTE: For critical soils and applications, laboratory testing is recommended to determine geotextile clogging resistance.

STEP SIX:

DETERMINE SURVIVABILITY REQUIREMENTS

Both the type of drainage or armor material placed adjacent to the geotextile and the construction techniques used in placing these materials can result in damage to the geotextile. To ensure construction survivability, specify the minimum strength properties that fit with the severity of the installation. Use Table 2 as a guide in selecting required geotextile strength properties to ensure survivability for various degrees of installation conditions. Some engineering judgement must be used in defining this severity.

Table 2. Survivability Strength Requirements (after AASHTO, 1996)

		GRAB STRENGTH (LBS)	ELONGATION (%)	SEWN SEAM STRENGTH (LBS)	PUNCTURE STRENTH (LBS)	BURST STRENTH (LBS)	TRAPEZOID TEAR (LBS)
SUBSURFACE DRAINAGE	HIGH CONTACT STRESSES	247	< 50% *	222	90	392	56
	(ANGULAR DRAINAGE MEDIA) (HEAVY COMPACTION) or (HEAVY CONFINING STRESSES)	157	≥ 50%	142	56	189	56
	LOW CONTACT STRESSES	180	< 50% *	162	67	305	56
	(ROUNDED DRAINAGE MEDIA) (LIGHT COMPACTION) or (LIGHT CONFINING STRESSES)	112	≥ 50%	101	40	138	40
ARMORED EROSION CONTROL	HIGH CONTACT STRESSES	247	< 50% *	222	90	392	56
	(DIRECT STONE PLACEMENT) (DROP HEIGHT > 3 FT)	202	≥ 50%	182	79	247	79
	LOW CONTACT STRESSES	247	< 50% *	222	90	292	56
	(SAND OR GEOTEXTILE CUSHION) and (DROP HEIGHT < 3 FT)	157	≥ 50%	142	56	189	56

* Only woven monofilament geotextiles are acceptable as < 50% elongation filtration geotextiles. No woven slit film geotextiles are permitted.

STEP SEVEN:

DETERMINE DURABILITY REQUIREMENTS

During installation, if the geotextile filter is exposed to sunlight for extended periods, a high carbon black content and UV stabilizers are recommended for added resistance to UV degradation. Polypropylene is one of the most durable geotextiles today. It is inert to most naturally occurring chemicals in civil engineering applications.

However, if it is known that the geotextile may exposed to adverse chemicals (such as in waste containment landfill applications), use test method ASTM D5322 to determine its compatibility.

References

Giroud, J.P., "Review of Geotextile Filter Design Criteria." Proceedings of First Indian Conference on Reinforced Soil and Geotextiles, Calcutta, India, 1988.

Heerten, G., "Dimensioning the Filtration Properties of Geotextiles Considering Long-Term Conditions." Proceedings of Second International Conference on Geotextiles, Las Vegas, Nevada, 1982.

AASHTO, "Standard Specification for Geotextile Specification for Highway Applications", M288-96

GEOTEXTILE FILTER FABRIC SELECTION GUIDE

		Silty Gravel w/Sand (GM)	Well-Graded Sand (SW) #1	Well-Graded Silty Sand (SW) #2	Silty Sand (SM)
SOIL PROPERTIES		k_s = .005cm/s PI = 0 C_c = 2.8 C'_u = 34 d'_{50} = 3.5mm C_u = 211 d_{50} = 5.0mm d_{90} = 22mm	k_s = .005cm/s PI = 0 C_c = 1.0 C'_u = 9.1 d'_{50} = .52mm C_u = 8.4 d_{50} = .60mm d_{90} = 2.7mm	k_s = .001cm/s PI = 0 C_c = 2.1 C'_u = 5.3 d'_{50} = .28mm C_u = 6.6 d_{50} = .28mm d_{90} = 1.6mm	k_s = .00005cm/s PI = 0 C_c = 3.0 C'_u = 16.2 d'_{50} = .21 C_u = 67 d_{50} = .22mm d_{90} = .95mm (Note: Moderate to Heavy Compaction Required)
SUBSURFACE DRAINAGE[2]	Soil Retention[1]	1.85 mm	1.03 mm	.95 mm	.18 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	n > 30%
	Survivability Req't	LOW	LOW	LOW	LOW
	Gradation	Widely Graded	Widely Graded	Widely Graded	Widely Graded
	Relative Soil Density	Dense	Dense	Dense	Medium
	RECOMMENDED FABRIC	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**MIRAFI 180N**
	Soil Retention[1]	.93 mm	.51 mm	.48 mm	.18 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	n > 30%
	Survivability Req't	HIGH	HIGH	HIGH	HIGH
	Gradation	Widely Graded	Widely Graded	Widely Graded	Widely Graded
	Relative Soil Density	Loose	Loose	Loose	Medium
	RECOMMENDED FABRIC	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**MIRAFI 180N**
ARMORED EROSION CONTROL[3] — Mild Current Exposure, Minimal Drawdown Potential, Non-Vegetated	Soil Retention[1]	12.5 mm	1.5 mm	0.7 mm	0.55 mm
	Permeability	5×10^{-3}	5×10^{-3}	1×10^{-3}	5×10^{-5}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%
	Flow Conditions	Mild Currents	Mild Currents	Mild Currents	Mild Currents
	RECOMMENDED FABRIC	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**	**FILTERWEAVE 400**
ARMORED EROSION CONTROL[3] — Wave Exposure, High Velocity Channel Lining, Spillway Overtopping	Soil Retention[1]	5.0 mm	0.60 mm	0.28 mm	0.22 mm
	Permeability	$.5 \times 10^{-2}$	$.5 \times 10^{-2}$	1×10^{-2}	5×10^{-4}
	Clogging Resistance	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%	P.O.A. > 6%
	Flow Conditions	Severe Wave Attack	Severe Wave Attack	Severe Wave Attack	Severe Wave Attack
	RECOMMENDED FABRIC	**FILTERWEAVE 404**	**FILTERWEAVE 404**	**FILTERWEAVE 500**	**FILTERWEAVE 700**

[1] Maximum opening size of geotextile (O_{95}) to retain soil. [2] Steady state flow condition. [3] Dynamic Flow Conditions

	Clayey Sand (SC)	Sandy Silt (ML)	Lean Clay (CL)
	k_s = .00001cm/s PI = 16.0 C_c = 20 C'_u = n/a d'_{50} = n/a C_u = 345 d_{50} = .55mm d_{90} = 5.8mm > 10% silt < 20% clay	k_s = .00005cm/s PI = 0 C_c = 2.9 C'_u = 1.7 d'_{50} = .07 C_u = 10.8 d_{50} = .072mm d_{90} = .13mm	k_s = .0000001cm/s PI = 16.7 C_c = 3.3 C'_u = n/a d'_{50} = n/a C_u = 36 d_{50} = .014mm d_{90} = .05mm > 16% silt < 20% clay
	.21 mm 1 x 10^{-5} n > 30% LOW Non-dispersive	.24 mm 5 x 10^{-5} n > 30% LOW Uniformly Graded Dense	.21 mm 1 x 10^{-7} n > 30% LOW Non-dispersive
	MIRAFI 140N Series	**MIRAFI 140N Series**	**MIRAFI 140N Series**
	.21 mm 1 x 10^{-5} n > 30% HIGH Non-dispersive	.18 mm 5 x 10^{-5} n > 30% HIGH Uniformly Graded Medium	.21 mm 1 x 10^{-7} n > 30% HIGH Non-dispersive
	MIRAFI 160N	**MIRAFI 180N**	**MIRAFI 160N**
	1.4 mm 1 x 10^{-5} P.O.A. > 6% Mild Currents	0.13 mm 5 x 10^{-5} n > 30% Mild Currents	0.035 mm 1 x 10^{-7} n > 30% Mild Currents
	FILTERWEAVE 400	**MIRAFI 1100N**	**MIRAFI 1160N**
	0.55 mm 1 x 10^{-4} P.O.A. > 6% Severe Wave Attack	0.07 mm 5 x 10^{-4} P.O.A. > 6% Severe Wave Attack	0.014 mm 1 x 10^{-6} n > 30% Severe Wave Attack
	FILTERWEAVE 404	**MIRAFI 1160N**	**MIRAFI 1160N**

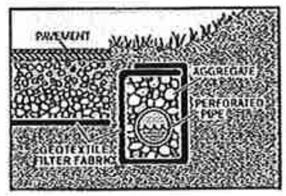
Ten Cate Ni

DISCLAIMER

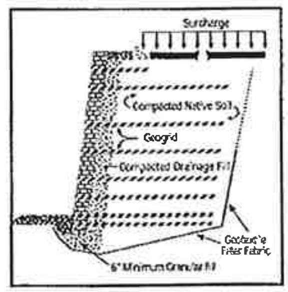
The information presented herein will not apply to every installation. Applicability of products will vary as a result of site conditions and installation procedures. Final determination of the suitability of any information or material for the use contemplated, of its manner of use, and whether the use infringes any patents, is the sole responsibility of the user.

TYPICAL SECTIONS AND APPLICATIONS:

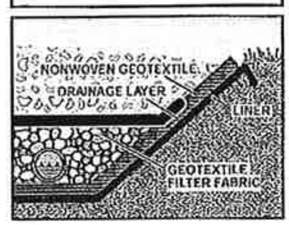
DRAINAGE



- Seepage Cut-off
- Pavement Edge Drains
- Slope Seepage Cut-off
- Surface Water Recharge
- Trench or "French" Drains

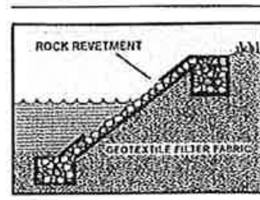


- Structure Pressure Relief
- Foundation Wall Drains
- Retaining Wall Drains
- Bridge Abutment Drains
- Planter Drains



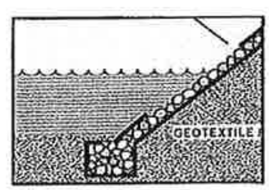
- Leachate Collection and Removal
- Blanket Drains
- Subsurface Gas Collection

ARMORED EROSION CONTROL



- River and Streambed Lining
- Culvert Inlet and Discharge Aprons
- Abutment Scour Protection
- Access Ramps

Proper installation of filtration geotextiles includes anchoring the geotextile in key trenches at the top and bottom of



- Coastal Slope Protection
- Shoreline Slope Protection
- Pier Scour Protection
- Sand Dune Protection

Underwater geotextile placement is common and must include anchorage of the toe to resist scour.

Ten Cate Nicolon

For more information on Mirafi® Geotextiles Filters in drainge and armored erosion control applications, contact one of the following offices:

In North America contact:
Ten Cate Nicolon
365 South Holland Drive
Pendergrass, Ga. 30567
706-693-2226
Toll free: 888-795-0808
Fax: 706-695-4400

In Europe contact:
Ten Cate Nicolon Europe
Sluiskade NZ 14
Postbus 236
7600 AE Almelo
The Netherlands
Tel: +31-546-544487
Fax: +31-546-544490

In Asia contact:
Royal Ten Cate Regional Office
11th Floor, Menara Glomac
Kelana Business Centre
97, Jalan SS 7/2
47301 Petaling Jaya
Selangor Darul Ehsan
Malaysia
Tel: +60-3-582-8283
Fax: +60-3-582-8285

In Latin America & Caribbean contact:
Ten Cate Nicolon
5800 Monroe Road
Charlotte
North Carolina 28212
USA
Tel: 704-531-5801
Fax: 704-531-5801

log on to our website:
www.tcnicolon.com

Attachment 2

TIMELY ENGINEERING SOIL TESTS, LLC

1874 Forge Street Tucker, GA 30084
Phone: 770-938-8233
Fax: 770-923-8973
Web: www.test-llc.com

Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15495/ST-3	Depth/Elev.	20.0-20.5'
Location	SB-3	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	1070.80
Mass of Dry Sample & Tare, g	905.46
Mass of Tare, g	0.00
Moisture Content, %	18.3

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	494.15
Mass of Dry Sample & Tare, g	492.10
Mass of Tare, g	182.24
Moisture Content, %	0.7

Mass of Total Sample before separation on #4 sieve & Tare, g	1070.80
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	1063.76

Mass of Sample used for hydrometer analysis, g	90.20
Dry Mass, g	89.61
% of Total Sample passing #4 sieve	98.9

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"		0.00	0.0	100.0
#4	COARSE SAND	11.97	1.1	98.9

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	1.18	97.6
#20		2.21	96.4
#40	FINE SAND	4.19	94.3
#60		10.04	87.8
#100		28.31	67.6
#200	FINES	52.51	40.9

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:30

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	3.3
% COARSE GRAVEL	0.0	% FINE SAND	53.3
% FINE GRAVEL	1.1	% FINES	40.9
% COARSE SAND	1.3	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	14.7	% CLAY(<0.002mm)	10.8

Date	Time	Testing time (min)	Reading	Temp (^{o}C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:32	2	31.0	28.7	0.01212	5.0	26.0	12.1	0.99	0.0298	28.4
06/12/13	13:35	5	26.5	28.7	0.01212	5.0	21.5	12.8	0.99	0.0194	23.5
06/12/13	13:45	15	24.0	28.7	0.01212	5.0	19.0	13.2	0.99	0.0114	20.8
06/12/13	14:00	30	21.5	28.7	0.01212	5.0	16.5	13.6	0.99	0.0082	18.0
06/12/13	14:30	60	19.5	28.7	0.01212	5.0	14.5	14.0	0.99	0.0058	15.8
06/12/13	17:40	250	16.0	28.7	0.01212	5.0	11.0	14.6	0.99	0.0029	12.0
06/13/13	13:30	1440	14.0	28.7	0.01212	5.0	9.0	14.9	0.99	0.0012	9.8

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

TIMELY ENGINEERING SOIL TESTS, LLC

1874 Forge Street Tucker, GA 30084
Phone: 770-938-8233
Fax: 770-923-8973
Web: www.test-llc.com

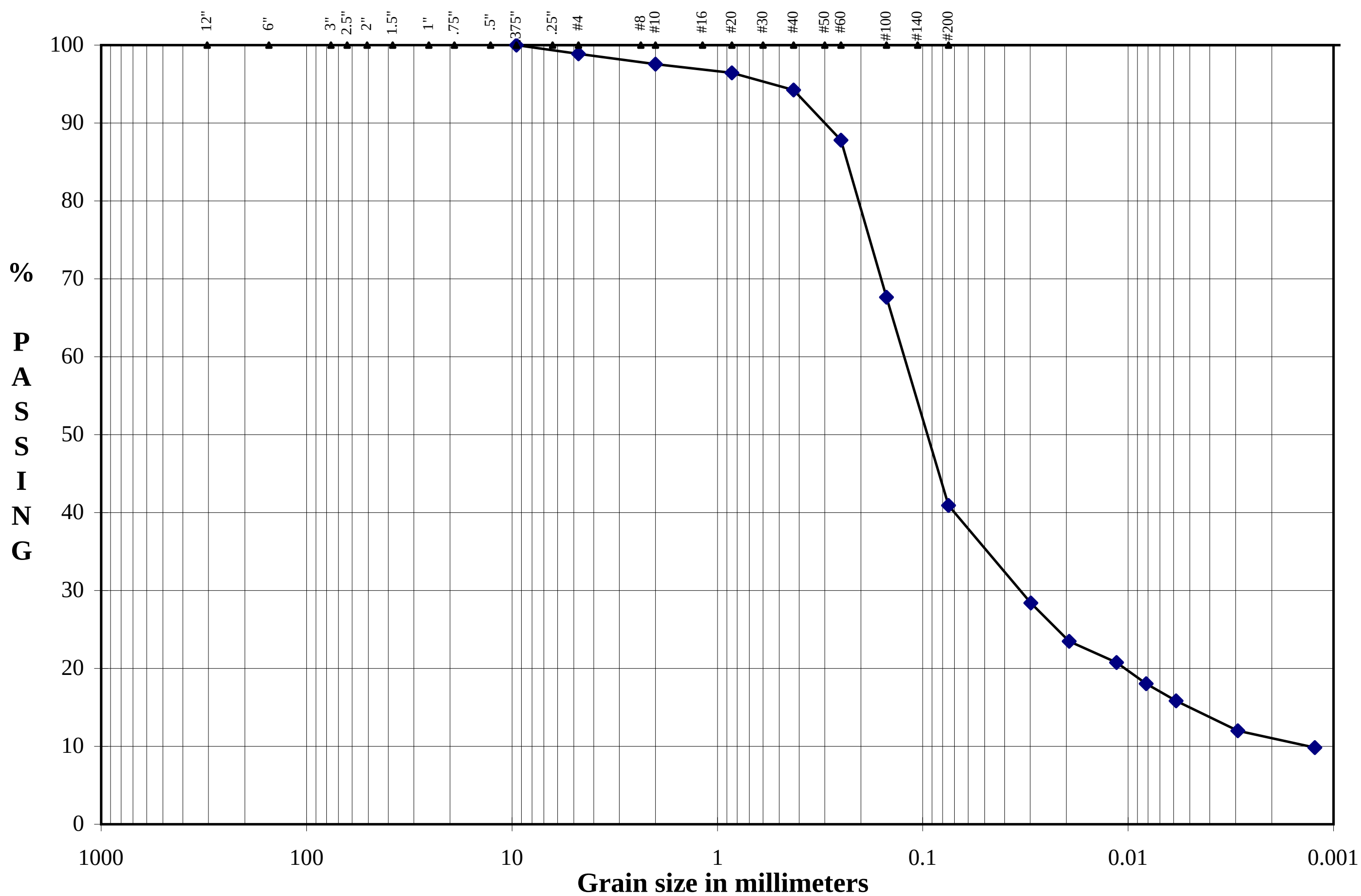
Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15495/ST-3	Depth/Elev.	20.0-20.5'
Location	SB-3	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel		Sand			Fines
		Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

DESCRIPTION: NA

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

USCS (ASTM D2487; D2488): NA

T.E.ST.	TIMELY ENGINEERING SOIL TESTS, LLC	1874 Forge Street Tucker, GA 30084 Phone: 770-938-8233 Fax: 770-923-8973 Web: www.test-llc.com	Tested By: RI Date: 06/11/13 Checked By: [signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15496/ST-4	Depth/Elev.	33.5-34.5'
Location	SB-4	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	1053.00
Mass of Dry Sample & Tare, g	962.36
Mass of Tare, g	0.00
Moisture Content, %	9.4

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	400.89
Mass of Dry Sample & Tare, g	400.00
Mass of Tare, g	125.60
Moisture Content, %	0.3

Mass of Total Sample before separation on #4 sieve & Tare, g	1053.00
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	1049.60

Mass of Sample used for hydrometer analysis, g	104.90
Dry Mass, g	104.56
% of Total Sample passing #4 sieve	100.0

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g: 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"			0.0	100.0
#4	COARSE SAND	0.00	0.0	100.0

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.05	100.0
#20		0.26	99.8
#40	FINE SAND	0.85	99.2
#60		5.02	95.2
#100		36.99	64.6
#200	FINES	77.66	25.7

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:32

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	0.8
% COARSE GRAVEL	0.0	% FINE SAND	73.5
% FINE GRAVEL	0.0	% FINES	25.7
% COARSE SAND	0.0	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	1.8	% CLAY(<0.002mm)	0.4

Date	Time	Testing time (min)	Reading	Temp (°C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:34	2	17.5	28.7	0.01212	5.0	12.5	14.3	0.99	0.0324	11.8
06/12/13	13:37	5	14.5	28.7	0.01212	5.0	9.5	14.8	0.99	0.0209	9.0
06/12/13	13:47	15	11.0	28.7	0.01212	5.0	6.0	15.4	0.99	0.0123	5.7
06/12/13	14:02	30	8.5	28.7	0.01212	5.0	3.5	15.8	0.99	0.0088	3.3
06/12/13	14:32	60	7.5	28.7	0.01212	5.0	2.5	16.0	0.99	0.0063	2.4
06/12/13	17:42	250	6.0	28.7	0.01212	5.0	1.0	16.2	0.99	0.0031	0.9
06/13/13	13:32	1440	5.0	28.7	0.01212	5.0	0.0	16.4	0.99	0.0013	0.0

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

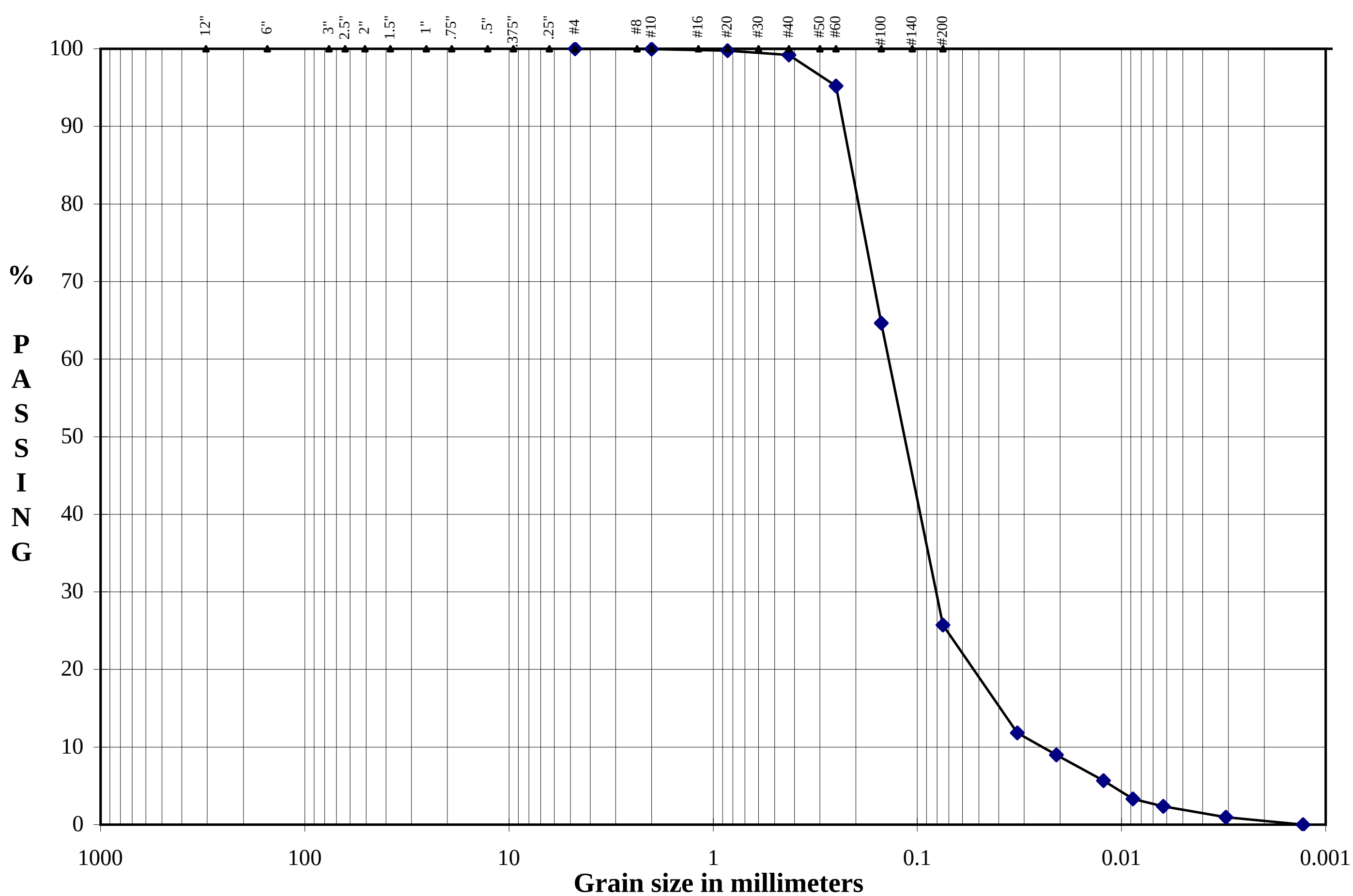
T.E.S.T.	TIMELY ENGINEERING SOIL TESTS, LLC	1874 Forge Street Tucker, GA 30084 Phone: 770-938-8233 Fax: 770-923-8973 Web: www.test-llc.com	Tested By	RI
			Date	06/11/13
			Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15496/ST-4	Depth/Elev.	33.5-34.5'
Location	SB-4	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel		Sand			Fines
		Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

DESCRIPTION: NA

USCS (ASTM D2487; D2488): NA

TIMELY ENGINEERING SOIL TESTS, LLC

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Phone: 770-938-8233
Fax: 770-923-8973
Web: www.test-llc.com

Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15497/ST-5	Depth/Elev.	10.5-11.5'
Location	SB-5	Add. Info	-

ASTM D 422/AASHTO T 88
Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	1041.00
Mass of Dry Sample & Tare, g	712.70
Mass of Tare, g	0.00
Moisture Content, %	46.1

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	348.85
Mass of Dry Sample & Tare, g	344.00
Mass of Tare, g	125.75
Moisture Content, %	2.2

Mass of Total Sample before separation on #4 sieve & Tare, g	1041.00
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	1018.37

Mass of Sample used for hydrometer analysis, g	90.28
Dry Mass, g	88.32
% of Total Sample passing #4 sieve	100.0

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g: 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"			0.0	100.0
#4	COARSE SAND	0.00	0.0	100.0

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.98	98.9
#20		2.73	96.9
#40	FINE SAND	4.69	94.7
#60		8.25	90.7
#100		14.63	83.4
#200	FINES	25.04	71.6

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:34

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	4.2
% COARSE GRAVEL	0.0	% FINE SAND	23.0
% FINE GRAVEL	0.0	% FINES	71.6
% COARSE SAND	1.1	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	21.6	% CLAY(<0.002mm)	18.5

Date	Time	Testing time (min)	Reading	Temp (^{o}C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:36	2	35.5	28.7	0.01212	5.0	30.5	11.3	0.99	0.0288	34.2
06/12/13	13:39	5	32.0	28.7	0.01212	5.0	27.0	11.9	0.99	0.0187	30.3
06/12/13	13:49	15	29.0	28.7	0.01212	5.0	24.0	12.4	0.99	0.0110	26.9
06/12/13	14:04	30	26.5	28.7	0.01212	5.0	21.5	12.8	0.99	0.0079	24.1
06/12/13	14:34	60	25.0	28.7	0.01212	5.0	20.0	13.1	0.99	0.0057	22.4
06/12/13	17:44	250	22.0	28.7	0.01212	5.0	17.0	13.6	0.99	0.0028	19.1
06/13/13	13:34	1440	21.0	28.7	0.01212	5.0	16.0	13.7	0.99	0.0012	17.9

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

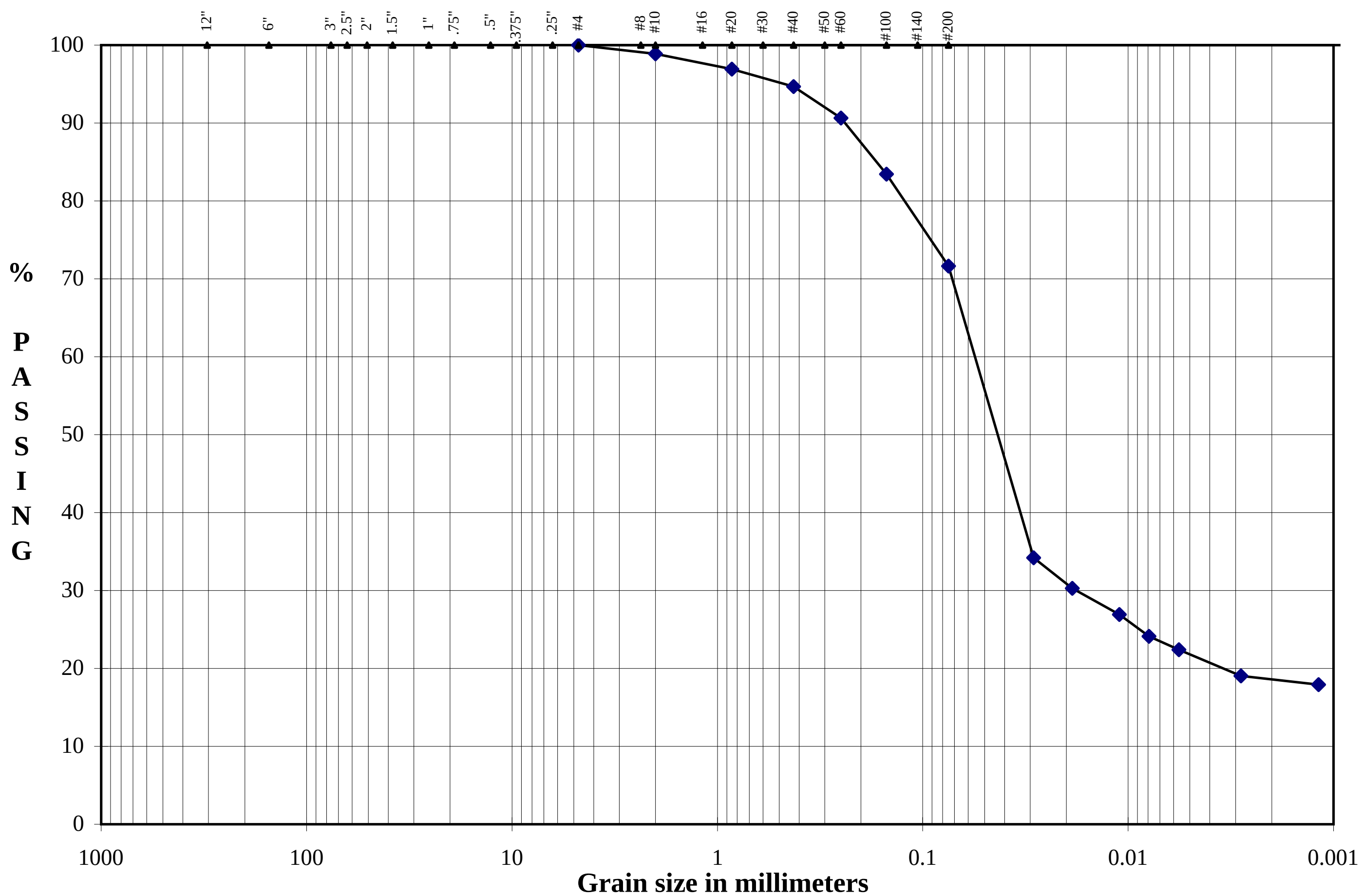
TIMELY ENGINEERING SOIL TESTS, LLC	1874 Forge Street Tucker, GA 30084 Phone: 770-938-8233 Fax: 770-923-8973 Web: www.test-llc.com	Tested By	RI
		Date	06/11/13
		Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15497/ST-5	Depth/Elev.	10.5-11.5'
Location	SB-5	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel (Coarse)	Gravel (Fine)	Sand (Coarse)	Sand (Medium)	Sand (Fine)	Fines (Silt or Clay)

DESCRIPTION: NA

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

USCS (ASTM D2487; D2488): NA

TIMELY ENGINEERING SOIL TESTS, LLC
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Fax: 770-923-8973
Web: www.test-llc.com

Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15498/ST-6	Depth/Elev.	18.5-20.0'
Location	SB-6	Add. Info	-

ASTM D 422/AASHTO T 88
Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	994.20
Mass of Dry Sample & Tare, g	801.20
Mass of Tare, g	0.00
Moisture Content, %	24.1

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	418.08
Mass of Dry Sample & Tare, g	415.30
Mass of Tare, g	125.90
Moisture Content, %	1.0

Mass of Total Sample before separation on #4 sieve & Tare, g	994.20
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	984.74

Mass of Sample used for hydrometer analysis, g	100.44
Dry Mass, g	99.48
% of Total Sample passing #4 sieve	100.0

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g: 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"			0.0	100.0
#4	COARSE SAND	0.00	0.0	100.0

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.00	100.0
#20		0.02	100.0
#40	FINE SAND	0.17	99.8
#60		2.29	97.7
#100		12.87	87.1
#200	FINES	51.03	48.7

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:36

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	0.2
% COARSE GRAVEL	0.0	% FINE SAND	51.1
% FINE GRAVEL	0.0	% FINES	48.7
% COARSE SAND	0.0	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	5.3	% CLAY(<0.002mm)	1.6

Date	Time	Testing time (min)	Reading	Temp (°C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:38	2	31.0	28.7	0.01212	5.0	26.0	12.1	0.99	0.0298	25.9
06/12/13	13:41	5	25.0	28.7	0.01212	5.0	20.0	13.1	0.99	0.0196	19.9
06/12/13	13:51	15	18.0	28.7	0.01212	5.0	13.0	14.2	0.99	0.0118	12.9
06/12/13	14:06	30	15.0	28.7	0.01212	5.0	10.0	14.7	0.99	0.0085	10.0
06/12/13	14:36	60	12.0	28.7	0.01212	5.0	7.0	15.2	0.99	0.0061	7.0
06/12/13	17:46	250	7.5	28.7	0.01212	5.0	2.5	16.0	0.99	0.0031	2.5
06/13/13	13:36	1440	6.0	28.7	0.01212	5.0	1.0	16.2	0.99	0.0013	1.0

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

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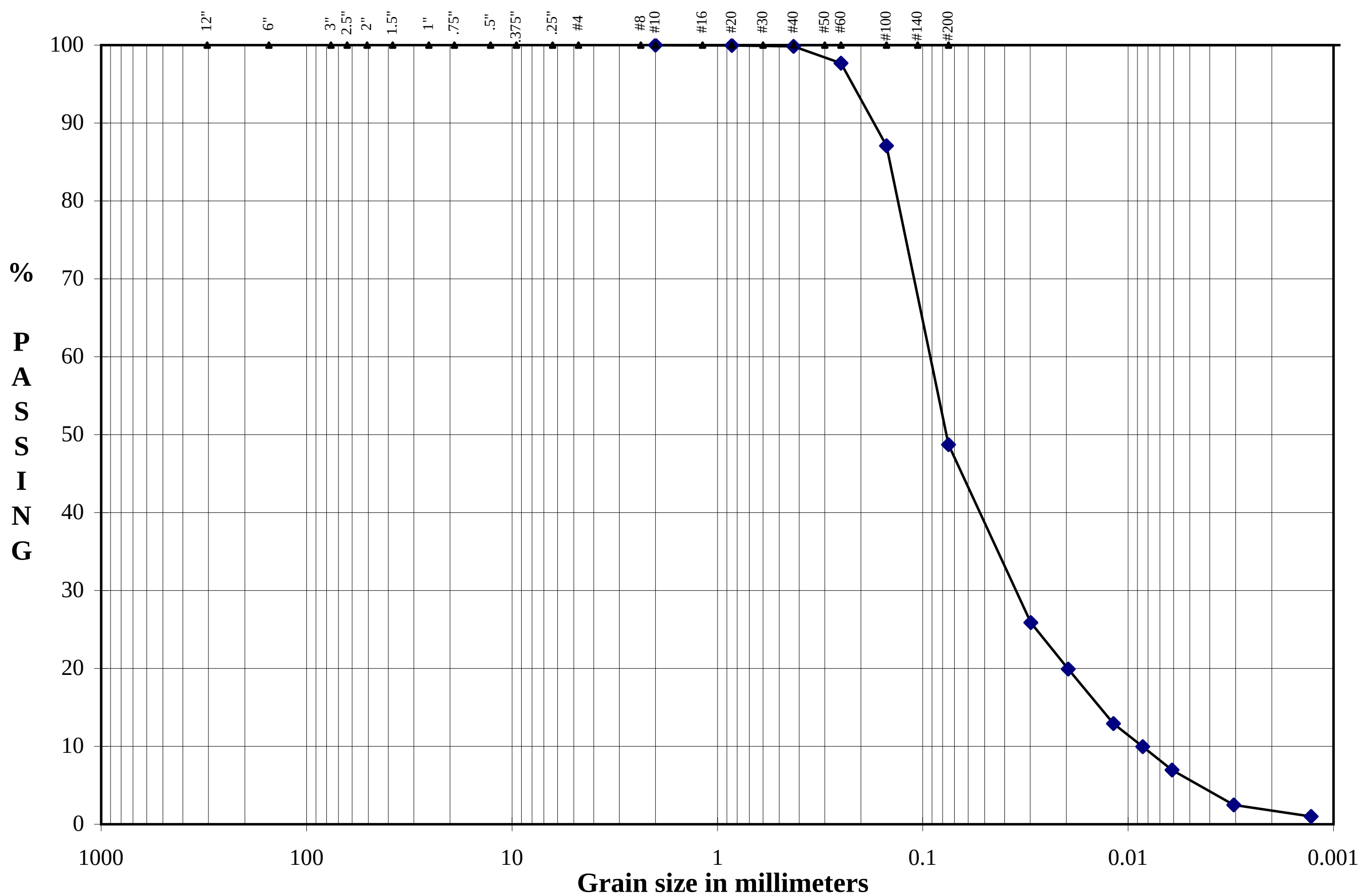
		Date	06/11/13
		Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15498/ST-6	Depth/Elev.	18.5-20.0'
Location	SB-6	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel		Sand			Fines
		Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

DESCRIPTION: NA

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

USCS (ASTM D2487; D2488): NA

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Tested By	RI		
Date	06/11/13		
Checked By	[signature]		
Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15499/ST-7	Depth/Elev.	28.5-30.0'
Location	SB-7	Add. Info	-

ASTM D 422/AASHTO T 88
Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	1106.00
Mass of Dry Sample & Tare, g	970.52
Mass of Tare, g	0.00
Moisture Content, %	14.0

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	546.45
Mass of Dry Sample & Tare, g	545.00
Mass of Tare, g	178.44
Moisture Content, %	0.4

Mass of Total Sample before separation on #4 sieve & Tare, g	1106.00
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	1101.64

Mass of Sample used for hydrometer analysis, g	104.23
Dry Mass, g	103.82
% of Total Sample passing #4 sieve	99.9

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g: 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"		0.00	0.0	100.0
#4	COARSE SAND	1.02	0.1	99.9

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.67	99.3
#20		0.99	99.0
#40	FINE SAND	1.75	98.2
#60		14.38	86.1
#100		53.24	48.7
#200	FINES	85.64	17.5

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:38

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	1.0
% COARSE GRAVEL	0.0	% FINE SAND	80.7
% FINE GRAVEL	0.1	% FINES	17.5
% COARSE SAND	0.6	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	0.9	% CLAY(<0.002mm)	0.0

Date	Time	Testing time (min)	Reading	Temp (°C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:40	2	12.0	28.7	0.01212	5.0	7.0	15.2	0.99	0.0334	6.7
06/12/13	13:43	5	10.0	28.7	0.01212	5.0	5.0	15.6	0.99	0.0214	4.8
06/12/13	13:53	15	8.5	28.7	0.01212	5.0	3.5	15.8	0.99	0.0124	3.3
06/12/13	14:08	30	7.5	28.7	0.01212	5.0	2.5	16.0	0.99	0.0088	2.4
06/12/13	14:38	60	6.5	28.7	0.01212	5.0	1.5	16.1	0.99	0.0063	1.4
06/12/13	17:48	250	5.0	28.7	0.01212	5.0	0.0	16.4	0.99	0.0031	0.0
06/13/13	13:38	1440	5.0	28.7	0.01212	5.0	0.0	16.4	0.99	0.0013	0.0

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

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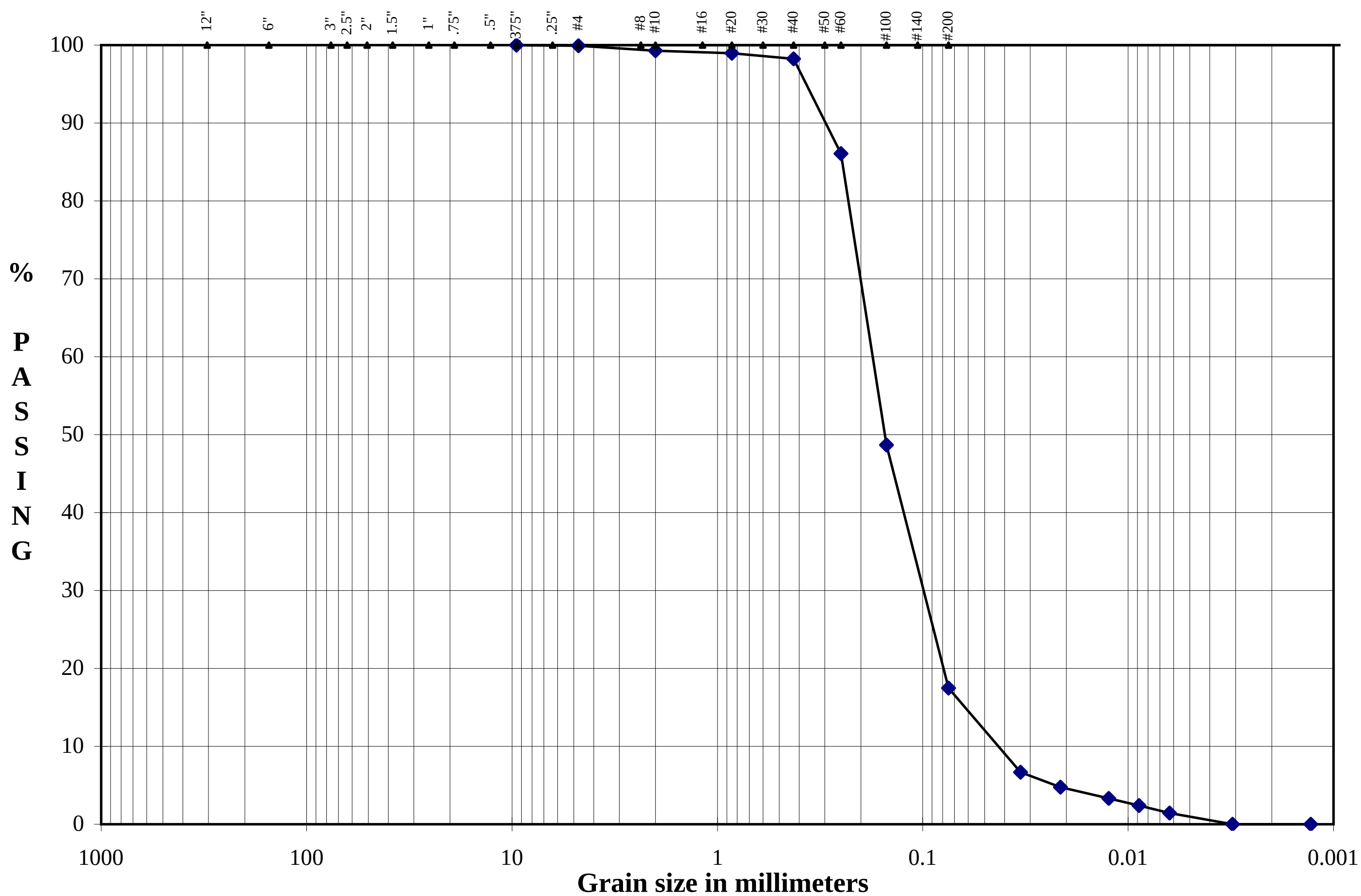
Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15499/ST-7	Depth/Elev.	28.5-30.0'
Location	SB-7	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel		Sand			Fines
		Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

DESCRIPTION: NA

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

USCS (ASTM D2487; D2488): NA

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Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15500/ST-8	Depth/Elev.	11.0-12.0'
Location	SB-8	Add. Info	-

ASTM D 422/AASHTO T 88
Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	1156.10
Mass of Dry Sample & Tare, g	996.22
Mass of Tare, g	0.00
Moisture Content, %	16.0

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	439.86
Mass of Dry Sample & Tare, g	437.80
Mass of Tare, g	127.86
Moisture Content, %	0.7

Mass of Total Sample before separation on #4 sieve & Tare, g	1156.10
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	1148.47

Mass of Sample used for hydrometer analysis, g	101.17
Dry Mass, g	100.50
% of Total Sample passing #4 sieve	100.0

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"			0.0	100.0
#4	COARSE SAND	0.00	0.0	100.0

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.33	99.7
#20		5.24	94.8
#40	FINE SAND	11.13	88.9
#60		22.38	77.7
#100		50.55	49.7
#200	FINES	72.67	27.7

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:40

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	10.7
% COARSE GRAVEL	0.0	% FINE SAND	61.2
% FINE GRAVEL	0.0	% FINES	27.7
% COARSE SAND	0.3	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	7.2	% CLAY(<0.002mm)	3.8

Date	Time	Testing time (min)	Reading	Temp (°C)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:42	2	23.0	28.7	0.01212	5.0	18.0	13.4	0.99	0.0314	17.7
06/12/13	13:45	5	20.0	28.7	0.01212	5.0	15.0	13.9	0.99	0.0202	14.8
06/12/13	13:55	15	17.5	28.7	0.01212	5.0	12.5	14.3	0.99	0.0118	12.3
06/12/13	14:10	30	15.0	28.7	0.01212	5.0	10.0	14.7	0.99	0.0085	9.9
06/12/13	14:40	60	13.5	28.7	0.01212	5.0	8.5	15.0	0.99	0.0061	8.4
06/12/13	17:50	250	10.0	28.7	0.01212	5.0	5.0	15.6	0.99	0.0030	4.9
06/13/13	13:40	1440	8.0	28.7	0.01212	5.0	3.0	15.9	0.99	0.0013	3.0

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

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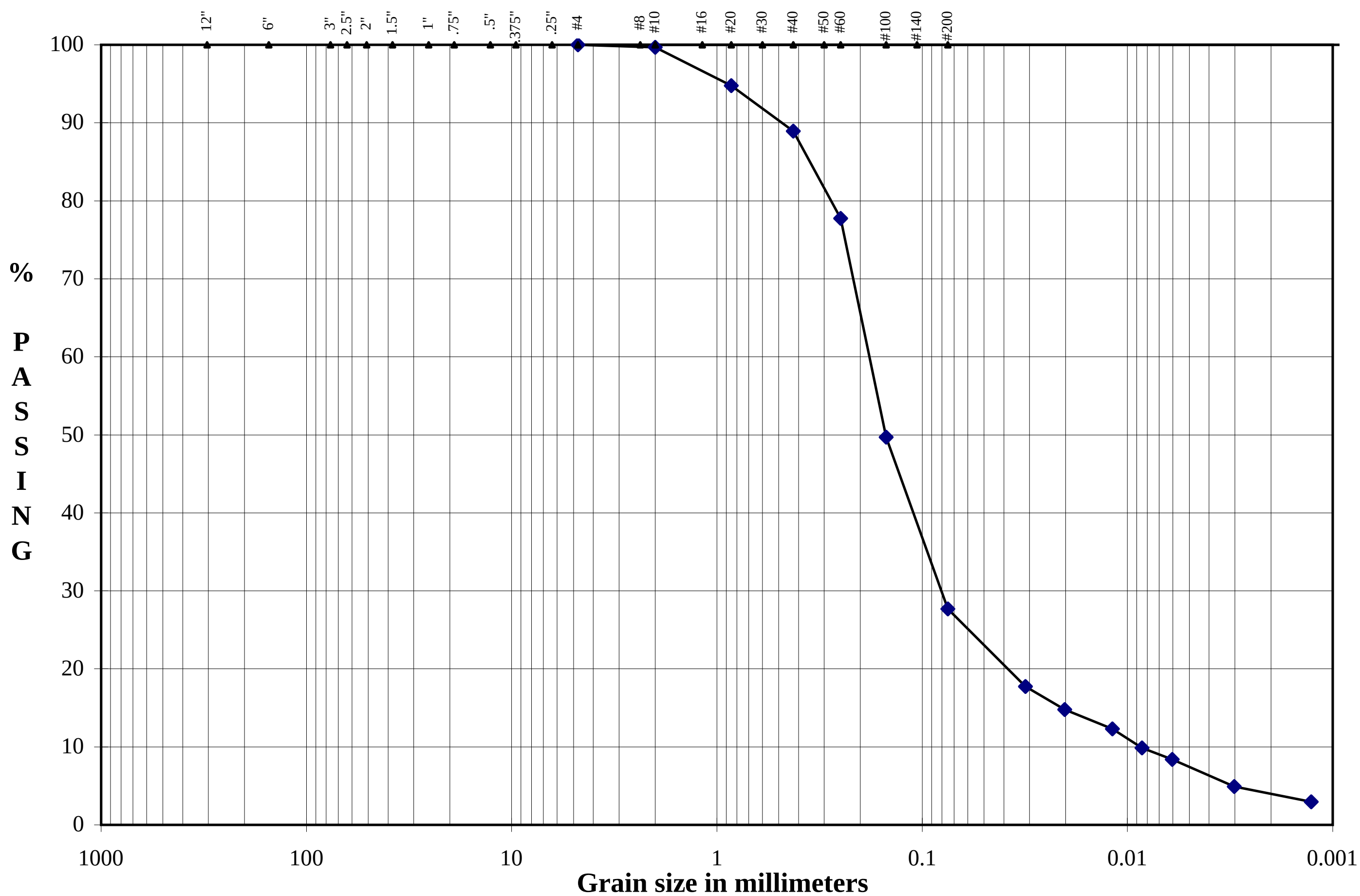
		Tested By	RI
		Date	06/11/13
		Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15500/ST-8	Depth/Elev.	11.0-12.0'
Location	SB-8	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel: Coarse	Gravel: Fine	Sand: Coarse	Sand: Medium	Sand: Fine	Fines: Silt or Clay

DESCRIPTION: NA

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

USCS (ASTM D2487; D2488): NA

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Tested By	RI
Date	06/11/13
Checked By	[signature]

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15501/ST-9	Depth/Elev.	28.5-30.0'
Location	SB-9	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

As-Received Moisture Content

Mass of Wet Sample & Tare, g	951.30
Mass of Dry Sample & Tare, g	794.95
Mass of Tare, g	0.00
Moisture Content, %	19.7

Moisture Content of Material Used for Hydrometer Analysis

Mass of Wet Sample & Tare, g	391.82
Mass of Dry Sample & Tare, g	390.40
Mass of Tare, g	127.68
Moisture Content, %	0.5

Mass of Total Sample before separation on #4 sieve & Tare, g	951.30
Mass of Tare, g	0.00
Total Mass of Dry Sample, g	946.19

Mass of Sample used for hydrometer analysis, g	100.15
Dry Mass, g	99.61
% of Total Sample passing #4 sieve	100.0

SIEVE ANALYSIS

PORTION OF SAMPLE RETAINED ON #4 SIEVE

Mass of Tare, g: 0.00

Sieve Size		Sample & Tare, g	% RETAINED	%PASSING
12"	COBBLES		0.0	100.0
3"	COARSE GRAVEL		0.0	100.0
2.5"			0.0	100.0
2"			0.0	100.0
1.5"			0.0	100.0
1"			0.0	100.0
.75"	FINE GRAVEL		0.0	100.0
.5"			0.0	100.0
.375"			0.0	100.0
#4	COARSE SAND	0.00	0.0	100.0

PORTION OF SAMPLE PASSING #4 SIEVE (Hydrometer Backsieve)

Sieve Size		Cumulative Mass retained, g	% PASSING
#10	MEDIUM SAND	0.76	99.2
#20		1.29	98.7
#40	FINE SAND	1.73	98.3
#60		3.06	96.9
#100		11.74	88.2
#200	FINES	48.93	50.9

Remarks

HYDROMETER ANALYSIS

Length of Dispersion Period	1 Minute
Mechanical Dispersion Device ID #	61
Amount of Dispersing Agent (ml)	125.0
Specific Gravity (assumed)	2.700
Specific Gravity (tested)	
Starting time	13:42

PARTICLE-SIZE ANALYSIS

% COBBLES	0.0	% MEDIUM SAND	1.0
% COARSE GRAVEL	0.0	% FINE SAND	47.4
% FINE GRAVEL	0.0	% FINES	50.9
% COARSE SAND	0.8	% TOTAL SAMPLE	100.0
% CLAY(<0.005mm)	1.5	% CLAY(<0.002mm)	0.0

Date	Time	Testing time (min)	Reading	Temp (^oC)	K	Composite Correction	Actual Reading	Effective Depth (cm)	a	Particle Diam. (mm)	Percent Passing
06/12/13	13:44	2	29.0	28.7	0.01212	5.0	24.0	12.4	0.99	0.0302	23.9
06/12/13	13:47	5	19.0	28.7	0.01212	5.0	14.0	14.1	0.99	0.0203	13.9
06/12/13	13:57	15	12.0	28.7	0.01212	5.0	7.0	15.2	0.99	0.0122	7.0
06/12/13	14:12	30	9.5	28.7	0.01212	5.0	4.5	15.6	0.99	0.0087	4.5
06/12/13	14:42	60	7.5	28.7	0.01212	5.0	2.5	16.0	0.99	0.0063	2.5
06/12/13	17:52	250	5.0	28.7	0.01212	5.0	0.0	16.4	0.99	0.0031	0.0
06/13/13	13:42	1440	5.0	28.7	0.01212	5.0	0.0	16.4	0.99	0.0013	0.0

Hydrometer 152H ID #	451190	Oven ID #	12/13/14/15
Sieve Shaker ID #	54/130	Balance ID#	1/6/7

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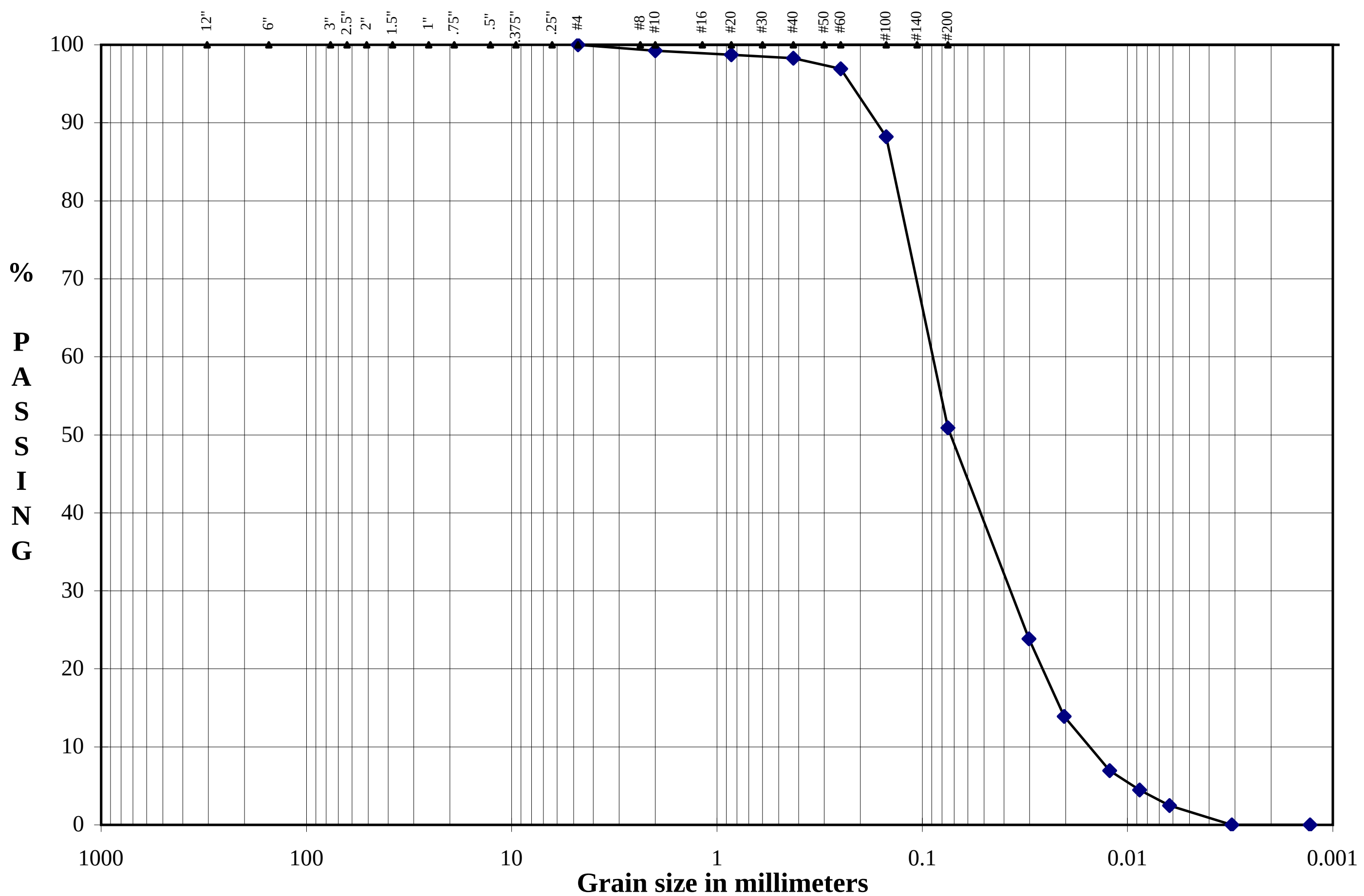
Fax: 770-923-8973
Web: www.test-llc.com

Tested By	RI		
Date	06/11/13		
Checked By	[signature]		
Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15501/ST-9	Depth/Elev.	28.5-30.0'
Location	SB-9	Add. Info	-

ASTM D 422/AASHTO T 88

Standard Test Method for Particle-Size Analysis of Soils (with Hydrometer Analysis)

Particle-Size Analysis



Boulders	Cobbles	Gravel (Coarse)	Gravel (Fine)	Sand (Coarse)	Sand (Medium)	Sand (Fine)	Fines (Silt or Clay)

D_{10}	NA	mm
D_{30}	NA	mm
D_{60}	NA	mm
Cu	NA	
Cc	NA	

DESCRIPTION: NA

USCS (ASTM D2487; D2488): NA

NON-WOVEN GEOTEXTILES
FOR ENVIRONMENTAL APPLICATION

COMPARATIVE PRODUCT SPECIFICATION CHART

SKAPS

SKAPS INDUSTRIES
335 Athena Drive,
Athens, GA 30601
Ph: (706)-354-3700
Fax: (706)-354-3737
Email: contact@skaps.com

PROPERTY	TEST METHOD	UNIT	M.A.R.V. (Minimum Average Roll Value)							
			GE140	GE160	GE170	GE180	GE110	GE112	GE114	GE116
Weight	ASTM D 5261	oz/yd^2 g/m^2	4 135	6 203	7 237	8 271	10 339	12 407	14 475	16 542
Thickness*	ASTM D 5199	mils mm	70 1.77	85 2.16	90 2.29	100 2.5	110 2.79	120 3.05	135 3.43	175 4.45
Grab Tensile	ASTM D 4632	lbs kN	105 0.467	160 0.711	200 0.889	225 1	270 1.2	330 1.47	390 1.73	425 1.89
Grab Elongation	ASTM D 4632	%	50	50	50	50	50	50	50	50
Trapezoid Tear Strength	ASTM D 4533	lbs kN	45 0.2	65 0.29	75 0.33	90 0.4	100 0.44	125 0.556	135 0.6	150 0.667
CBR Puncture Resistance	ASTM D 6241	lbs kN	305 1.36	450 2	540 2.4	600 2.67	725 3.22	900 4	1045 4.65	1200 5.34
Permittivity*	ASTM D 4491	sec^{-1}	2	1.63	1.41	1.26	0.94	0.9	0.64	0.57
Permeability*	ASTM D 4491	cm/sec	0.55	0.48	0.46	0.3	0.3	0.3	0.25	0.25
Water Flow*	ASTM D 4491	gpm/ft^2 $l/min/m^2$	160 6518	125 5080	110 4470	100 4074	75 3055	70 2544	50 2037	45 1833
AOS*	ASTM D 4751	US Sieve mm	70 0.212	70 0.212	70 0.212	80 0.18	100 0.15	100 0.15	100 0.15	100 0.15
UV Resistance at 500 hrs	ASTM D 4355	%	70	70	70	70	70	70	70	70

** At the time of manufacturing. Handling may change these properties.*

PACKAGING DETAILS

Roll Dimension (ft)	15 x 1350	15 x 900	15 x 780	15 x 690	15 x 570	15 x 480	15 x 390	15 x 360
Square Yards/Roll	2250	1500	1300	1150	950	800	650	600
Estimated Roll Weight (lbs)	620	620	620	620	620	620	620	620

Attachment 3

Section 2
C. Base Liner Geocomposite Analysis

Project #	I002-415			
Project Name:	Pine Bluff CCR Management	By: JLY	Date:	3/23/2017
Subject:	Base Liner Geocomposite Analysis	Chk'd: RB	Date:	4/3/2017

OBJECTIVE: Evaluate the transmissivity of the geocomposite specified in the leachate collection system.

METHODOLOGY: The leachate collection system is evaluated per the HELP model analysis of the site geometry as well as the attached April 2005 GFR article by Thiel, Narejo and Richardson. The evaluation for the geocomposite takes into account several reduction factors as recommended in the article.

$$\theta_{design} = \frac{q_i * L}{\sin \beta}$$

Input Parameters

L=	600	(ft)	Max horizontal drainage length of slope
β=	2	% slope, or	
	0.02	radians, or	
	1.15	degrees	
λMSW=	70	lb/ft^3	
λCCR=	115	lb/ft^3	
λMSW/CCR=	74.5	lb/ft^3	(When MSW to CCR ratio by weight is at maximum 10:1)

HELP Model Analysis Results

Stage	Total Thickness of solid waste, t_{WASTE} (ft)	Peak imprringement rate into the LCRS drainage layer, q_i (ft/sec)
I - Initial Operation	12	1.95E-07
II - Active Operation	48	8.71E-08
II - Active Operation	72	5.74E-08
III - Intermediate Cover	339	4.60E-09

Reduction Factors & Factor of Safety

Stage	Chemical Clogging Reduction Factor RF_{cc} (GRI-GC8)	Biological Clogging Reduction Factor RF_{bc} (GRE-GC8)	Creep Reduction Factor RF_{cr} (GSE)
I - Initial Operation	1.2	1.1	1.12
II - Active Operation	1.5	1.2	1.12
II - Active Operation	1.5	1.2	1.12
III - Intermediate Cover	2	1.3	1.16

Overall Factor of Safety (Narejo and Richardson 2003)

Stage	FS_D
I - Initial Operation	2
II - Active Operation	3
III - Intermediate Cover	4

Solution

Stage	Normal Stess $\sigma=\lambda_{MSW/CCR}*t_{WASTE}$ (lb/ft^2)	Design required transmissivity of LCRS $\theta_{req}=(q_i*L)/\sin\beta$ (ft^2/sec)	(m^2/sec)
I - Initial Operation	858	5.85E-03	5.44E-04
II - Active Operation	3540	2.61E-03	2.43E-04
II - Active Operation	5328	1.72E-03	1.60E-04
III - Intermediate Cover	25220	1.38E-04	1.28E-05

*Note: The initial 8 ft of waste is MSW only.

Stage	Allowable transmissivity of LCRS $\theta_{allow}=\theta_{req}*FS_D$ (ft^2/sec)	Specified *minimum* 100-hour transmissivity of LCRS $\theta_{100}=\theta_{allow}*RF_{cr}*RF_{cc}*RF_{bc}$ (ft^2/sec)	(m^2/sec)
I - Initial Operation	1.17E-02	1.73E-02	1.61E-03
II - Active Operation	7.84E-03	1.58E-02	1.47E-03
II - Active Operation	5.16E-03	1.04E-02	9.67E-04
III - Intermediate Cover	5.52E-04	1.66E-03	1.55E-04

Project #	I002-415				
Project Name:	Pine Bluff CCR Management	By:	JLY	Date:	3/23/2017
Subject:	Base Liner Geocomposite Analysis	Chk'd:	RB	Date:	4/3/2017

***Use GSE 270 mil PermaNet HL Geocomposite double sided with 8oz. Geotextile (or approved equal).**

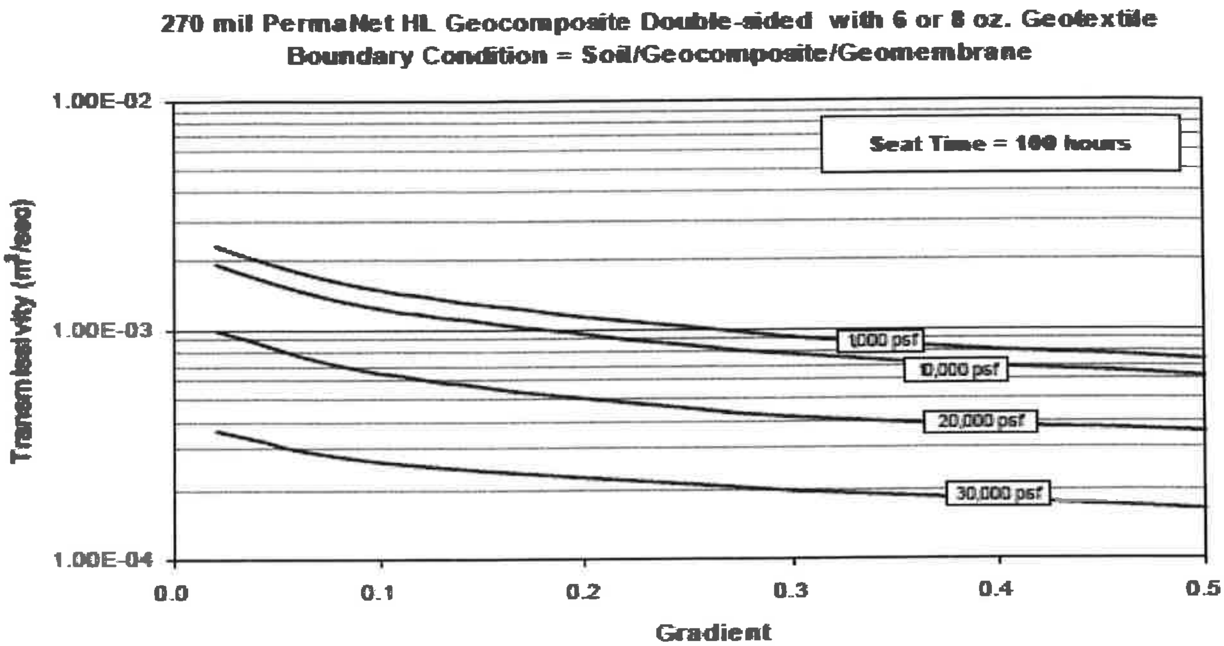
Stage	Normal Stess $\sigma=(\lambda_{msw}*t_{msw})+(\lambda_{ccr}*t_{ccr})$ (lb/ft2)	Published 100-hour transmissivity of GSE 270 Mil PermiNet HL (Figure A-14) θ_{100} (ft^2/sec)	(m^2/sec)
I - Initial Operation	858	2.48E-02	2.30E-03
II - Active Operation	3,540	2.26E-02	2.10E-03
II - Active Operation	5,328	2.15E-02	2.00E-03

***Based on the current D&O Plans, the minimum specified transmissivity of the geocomposite under the total load of the landfill is 3.05×10^{-5}.**

III - Intermediate Cover	25,220	3.28E-04	3.05E-05

CONCLUSION:

Stage	Published 100-hour θ_{100} (ft^2/sec)	Specified 100-hour transmissivity of LCRS for HELP model use $\theta_{HELP}=\theta_{100}/(RF_{cr}*RF_{cc}*RF_{bc})$ (ft^2/sec)	(m^2/sec)
I - Initial Operation	2.48E-02	1.67E-02	1.56E-03
II - Active Operation	2.26E-02	1.12E-02	1.04E-03
II - Active Operation	2.15E-02	1.07E-02	9.92E-04
III - Intermediate Cover	-	3.28E-04	3.05E-05



A-14 Performance Transmissivity of PermaNet HL Geocomposite under Soil

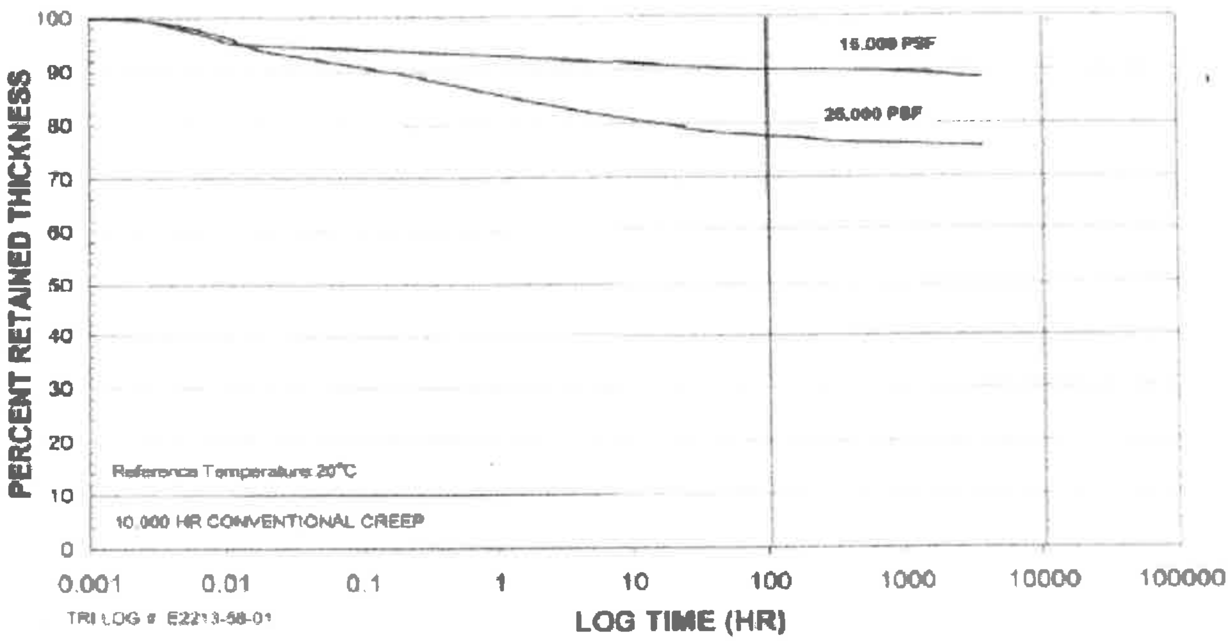


Figure B-5. Creep Curves for GSE PermaNet HL geonet at 15,000 psf and 25,000 psf.

Table B-5. Creep Reduction Factors for GSE PermaNet HL geonet from 100 hours to 50 Years.

Stress (psf)	Creep Reduction Factor
15,000	1.12
25,000	1.16

Range of Clogging Reduction Factors (modified from Koerner, 1998)

Application	Chemical Clogging (RF_{CC})	Biological Clogging (RF_{BC})
Sport fields	1.0 to 1.2	1.1 to 1.3
Capillary breaks	1.0 to 1.2	1.1 to 1.3
Roof and plaza decks	1.0 to 1.2	1.1 to 1.3
Retaining walls, seeping rock and soil slopes	1.1 to 1.5	1.0 to 1.2
Drainage blankets	1.0 to 1.2	1.0 to 1.2
Landfill caps	1.0 to 1.2	1.2 to 3.5
Landfill leak detection	1.1 to 1.5	1.1 to 1.3
Landfill leachate collection	1.5 to 2.0	1.1 to 1.3

From GRI Standard - GC8

By Richard Thiel, Dhani Narejo, and Gregory N. Richardson

Landfill drainage layers: Part 3 of 4

Previous *GFR* articles have described the methodology for designing a geocomposite for use in a landfill leachate collection system (LCS). (See Part 1 of this series—January/February 2005 for a complete *GFR* bibliography of geocomposite-related articles since 1998.) This article updates the magazine's series regarding this aspect of designing with geocomposites by expanding the documented design methodology to account for the different stages of a landfill life during operations and post-closure.

Also, the article will review the basic design equation for head buildup, which for geocomposites is often referred to as the "Giroud Equation." It will be seen that a key input parameter to this equation, which is the leachate impingement rate, typically decreases over the landfill life. At the same time, the reduction factors typically increase over the landfill life due to aging, creep, chemical precipitation and the like. These two considerations tend to offset each other. A logical design can take these factors into account so that an overly conservative design does not result. The proposed design concept is illustrated through the use of a design example.

Background on "design" transmissivity

The calculation procedure for the design of geocomposites used in leachate collection systems can be performed using Giroud's method (Giroud et. al. 2000). The "design" transmissivity (θ_{design})—also referred to in the literature as "required" transmissivity ($\theta_{required}$)—of relatively low-thickness layers such as with geonets and geocomposites can be calculated as:

Equation 1

$$\theta_{design} = \frac{q_i \bullet L}{\sin\beta}$$

where θ_{design} = calculated design transmissivity for geocomposites (m^3/s per m width); q_i = liquid impingement rate (m/s); L = horizontal length of slope (m); and β = slope angle (degrees). Leachate impingement into the leachate collection layer is buffered to lesser and greater degrees due to the thickness of overlying waste and soil material. A commonly used computer model that is available for performing water balance analyses is the HELP Model (Schroeder, et al. 1994). Landfill leachate collection system (LCS) impingement rates depend on the operational stage of a landfill, which can be conveniently broken down as follows: (i) initial operation stage; (ii) active operation stage; and (iii) post-closure stage. Early in the landfill operation, surface water control may not be well established, and relatively thin layers of soil and waste may allow for a relatively large portion of the surface water to infiltrate into the LCS. As filling progresses, the use of protective soil and surface grading can reduce the amount of infiltration into the waste; thus, decreasing the LCS flow rate. In the post-closure period, the application of the final cover system greatly reduces the amount of infiltration into the waste, and thus greatly reduces the amount of leachate entering the LCS.

Photo 1. Author Richard Thiel holding 35 mm rounded gravel cemented by leachate chemical precipitation.

Pressure kPa (psf)	Creep Reduction Factor (RF_{CR})
48 (1000)	1.1
240 (5000)	1.2
478 (10,000)	1.3
718 (15,000)	1.6

Table 1. Creep reduction factors (RF_{CR}) for one manufacturer's biplanar geonet product line (Narejo and Allen 2004).

It is possible to model the landfill leachate generation in several operational stages (as few as three and as many as six) with varying geometry, waste thickness, cover slopes and cover materials. Separate HELP analyses can be performed for each operational stage modeled. An example of what a designer might consider when modeling a landfill broken into four stages is presented below (Bachus, et. al 2004):

- *Initial operation stage*—Model leachate flow into the LCS based on a "fluff" layer of waste being placed in the landfill cell. A typical waste thickness might be on the order of 10 ft. The slope might be fairly flat (~2%) with a 6 inch daily cover layer.
- *Active operation stage I*—Model leachate flow into the LCS based on the landfill at a representative point in time in the landfill's developmental phasing plan. The waste thickness might be on the order of half of the final thickness of the waste. The slope might be fairly flat, with an intermediate cover.
- *Active operation stage II*—Model leachate flow into the LCS based on the landfill at final grades with an intermediate cover in place and fair vegetation.
- *Post-closure stage*—Model leachate flow into the LCS based on the final closure conditions. The landfill will be at final grades with a permanent cover in place. Often this condition is modeled in HELP as simply the amount of infiltration through the final cover system.

Allowable and specified transmissivity

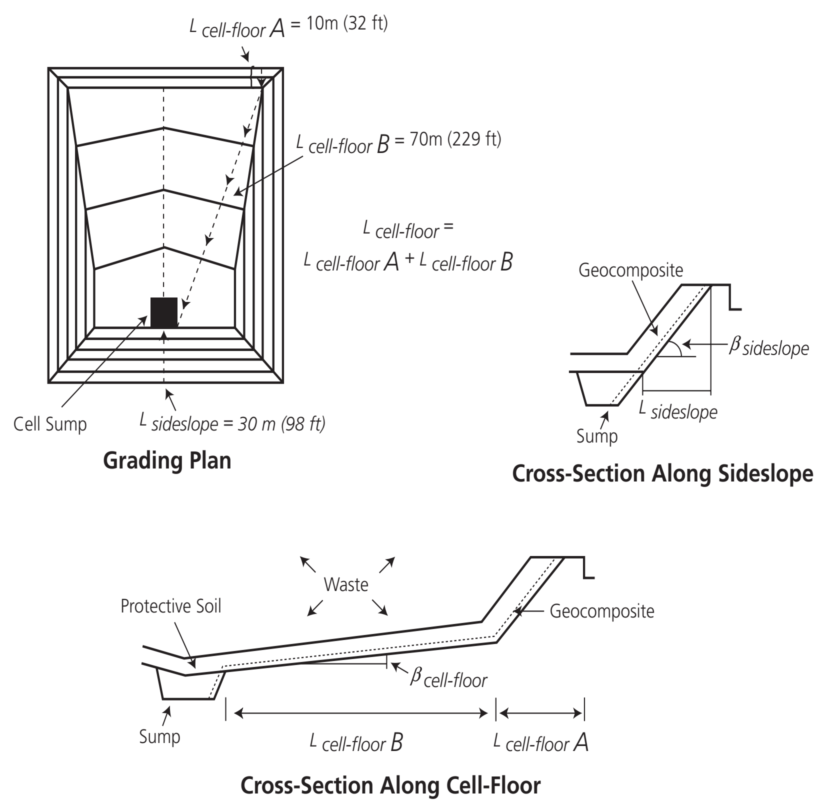


Figure 1. Simplified schematic of design geometry for example problem.

The next step in the design process is to define an allowable transmissivity (θ_{allow}), which is related to the design transmissivity (θ_{design}), by multiplying the design transmissivity by an overall factor of safety, FS_D.

Equation 2

$$\theta_{allow} = \theta_{design} \bullet FS_D$$

The overall drainage factor of safety should be applied to take into account possible uncertainties in the selection and determination of the design parameters. Recommended values of FS_D are typically between 2.0 and 3.0 or greater (Giroud, et al. 2000). For bottom liner LCS systems, a lower FS would be acceptable in the early stages of the project, but a higher FS may be desirable for long-term conditions. The authors will demonstrate that taking into account the various stages of landfill development and leachate generation can work to the advantage of many designs accounting for appropriate factors of safety.

Finally, the *specified* (also referred to as *maximum* or *ultimate* in the literature) transmissivity (θ_{spec}), which is the value that appears in the specifications, is obtained by multiplying the allowable transmissivity by appropriate *reduction factors*. These reduction factors take into account environmental factors such as biological clogging, chemical clogging and long-term creep of the geocomposite drainage layer that will decrease the in-place capacity of the geocomposite over time. The magnitude of each reduction factor (which should be equal to or greater than 1) should reflect a correction that provides a best estimate of the anticipated reduction. The reduction factors should not be inflated to a larger value to account for uncertainty, since this is accounted for in the overall factor of safety, FS. The *specified* transmissivity is shown in **Equation 3** (see also, test standard GRI-GC8 [2001]):

Equation 3

$$\theta_{spec} = \theta_{allow} \bullet RF_{CR} \bullet RF_{CC} \bullet RF_{BC}$$

where:

θ_{spec} = specified value of transmissivity for geocomposites or geonet (m^2/s), as tested in accordance with GRI-GC8 and ASTM D4716;

θ_{allow} = minimum allowable transmissivity of geocomposites or geonet (m^2/s);

RF_{CR} = partial reduction factor for long-term creep (dimensionless);

RF_{CC} = partial reduction factor for chemical clogging (dimensionless); and

RF_{BC} = partial reduction factor for biological clogging (dimensionless).

Additional reduction factors, such as for particulate clogging, can be incorporated by the designer if deemed applicable to a given situation. The specified transmissivity (θ_{spec}) in **Equation 3** should be compared with the

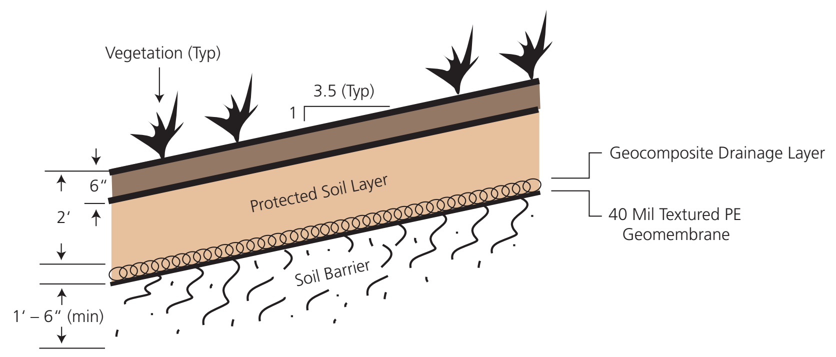


Figure 2. Design of final cover system.

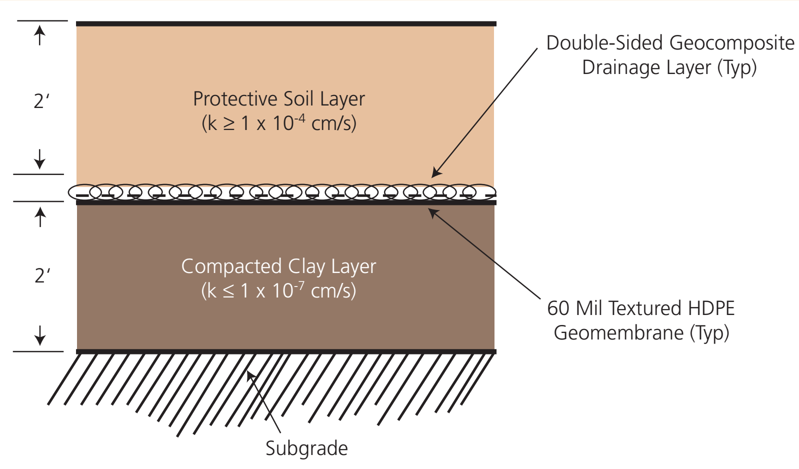


Figure 3. Design of bottom liner system.

100-hour transmissivity value obtained from a laboratory test. The 100-hour transmissivity test value should be equal to or higher than the specified value of θ_{spec}. A description of typical values of reduction factors for bottom liner LCSs is given in the following paragraphs.

Chemical clogging reduction factor, RF_{CC}

The designer should evaluate the soils she anticipates using in the protective layer of the liner system and the materials anticipated in the overlying waste, in order to judge the risk of chemical clogging. GRI-GC8 recommends using values in the range of 1.5 to 2.0 for chemical clogging in the leachate collection system. A greater reduction factor might be appropriate for "bioreactor" landfills based on observations of significant leachate collection gravel clogging (**Figure 1**). The design example presented in this paper illustrates how a properly designed system can accommodate such a large reduction.

Biological clogging reduction factor, RF_{BC}

The biological clogging reduction factor accounts for the reduction of flow in the geonet due to the growth of biological organisms such as fungi or algae, or root penetration through the overlying soil. GRI-GC8 recommends using values in the range of 1.1 to 1.3 for biological clogging in the leachate collection system. In the authors' experience, and as suggested in other field literature (e.g., Rowe et al. 1997), the reduction factor for biological clogging in leachate collection systems can either be maintained fairly low or be lumped in with the reduction factor for chemical precipitation.

Creep reduction factors, RF_{CR}

Performance transmissivity tests are typically conducted for up to 100 hours, as required by GRI test procedure GC8. The decrease in transmissivity with time asymptotically approaches a stable value within 100 hours, and usually much sooner than that, indicating that much of the initial compression (and geotextile intrusion) has already taken place. The reduction factor for creep, RF_{CR}, accounts for the decrease in transmissivity beyond the first 100 hours experienced in the transmissivity test. The quality of the geonet core, including its structure, thickness, mass and density can have a significant influence on creep reduction factors. **Table 1** presents creep reduction factors for one manufacturer's biplanar geonet. Products from other manufacturers can have creep factors different from those given here.

Creep reduction factors should be selected on the basis of the expected normal stress in the LCS if one is to follow the staged design concept presented in this paper. A much lower creep reduction factor should be used at the initial stage of landfill operation as overlying waste thickness is small. A conservative value of creep reduction factors may be 2 for the final (closure) stage of landfill liner systems with overburden stresses up to 15,000 pounds per square foot (psf).

LCS geocomposite design example

The purpose of this design example is to demonstrate how the different stages of a landfill life can be taken into account when designing a geocomposite for a leachate collection system. The particular case of a "bioreactor" landfill, which is especially aggressive on drainage systems, is used. The design process involves the following steps:

Step 1. Choose appropriate values for site specific design parameters (geometry and soil properties).

Step 2. Establish design input flow rate (i.e., impingement rate, q_i) for each stage of landfill life.

Step 3. Solve for the needed design transmissivity, θ_{design}, at different stages of the

Stage	Description	Peak LCS in-flow—q_i
I	Initial operation—10 ft. (3 m) waste	0.571 in./day = 1.68×10^{-5} cm/s
II	Active operation—80 ft. (24 m) waste	0.064 in./day = 1.88×10^{-6} cm/s
III	Intermediate cover—140 ft. (43 m) waste	0.030 in./day = 8.80×10^{-7} cm/s
IV	Post closure—140 ft. (43 m) waste	1.09×10^{-5} in./day = 3.20×10^{-10} cm/s

Table 2. HELP analysis results for LCS design example.

landfill life.

Step 4. Establish a specified transmissivity, θ_{spec}, for each of the stages by selecting an appropriate global factor of safety and appropriate reduction factors. For this design example, several specified transmissivities would be calculated, one for each stage of the landfill life. The maximum required transmissivity would be specified in the contract documents.

Step 5. Develop specifications describing laboratory testing conditions and acceptance criteria.

Step 1—Establish input parameters

Several of the input parameters are derived from the geometry of the design. For this example, **Figure 1** shows a simplified design that will be used in selecting these geometric input parameters. **Figure 2** shows the schematic cross section of the liner and leachate collection system.

The inputs used in this example are presented below:

- Slope of cell floor = 4.5% = 2.57 degrees
- Drainage length on cell floor = 262 ft. (229 ft. + 33 ft. [70 m + 10 m])
- Side slope angle = 18.43 degrees (ΔS side-slope = 0.333)
- Drainage length on sideslope = 98 ft. (30 m)
- Unit weight of waste = 75 pcf (11.8 kN/m^3) (typically ranges from 60 to 90 pcf)
- Thickness of waste = varies depending on operating stage

Cover soil properties (daily cover, interim cover, final cover):

Daily cover

- Permeability of daily cover = 5 x 10^{-3} cm/s (based on type of soil used for interim cover)
- Thickness of daily cover = 0.5 ft. (15 cm) (based on anticipated/required operating procedures)

Interim cover

- Permeability of interim cover = 1 x 10^{-4} cm/s (based on type of soil used for interim cover)
- Thickness of interim cover = 1 ft. (30 cm) (based on anticipated/required operating procedures)

Step 2—Establish design impingement rates

Select the impingement rates, q_i, to include in the various stages of operational life and for the final cover design. It is recommended that the designer model the impingement rate for key stages in the operating life of the landfill. The number of key stages will vary depending on site-specific landfill conditions such as: (i) interim staging and sequencing; (ii) runoff/run-on control practices; (iii) use of daily, interim and final cover materials; and (iv) thickness of waste and other overlying materials. For most sites it will likely take 3–6 stages to adequately define the operation stages.

For the leachate collector design example, it will be assumed that four stages will provide an adequate modeling of the landfill life. The results for the impingement rate for various operational stages for the design example have been obtained using HELP and are shown for each stage in **Table 2**. A more reliable indicator of stage impingement rates can generally be obtained from past operational records of the landfill itself or neighboring facilities. With over a decade of national lined landfill experience on file with most state regulators, good regional data on leachate generation rates is readily available.

Step 3—Solve for design transmissivity

Solve for θ_{design} for cell floor and side slope for each Stage (I–IV). For this example, the results of the θ_{design} solution are:

Stage IA (cell-floor)

$$\theta_{design} = \frac{1.68 \times 10^{-7} \text{ m/sec} \times 30 \text{ m}}{\sin 18.435°} = 1.59 \times 10^{-5} \text{ m}^2\text{/sec}$$

Stage IB (side slope)

$$\theta_{design} = \frac{1.68 \times 10^{-7} \text{ m/sec} \times 80 \text{ m}}{\sin 2.577°} = 2.99 \times 10^{-4} \text{ m}^2\text{/sec}$$

Results of similar calculations for other cases are summarized in **Table 3**.

Step 4—Establish specified transmissivity values

The specified transmissivity, θ_{spec}, is increased above the design transmissivity to account for uncertainties (in the form of an overall factor of safety) and the long-term reduction of the transmissivity of the geocomposite due to anticipated environmental factors (in the form of reduction factors).

- FS_D = The global factor of safety is a somewhat arbitrary value selected by the designer based on the level of uncertainty and relative risk associated with failure. Typical values suggested for design with geocomposites range from 2.0 to 3.0 (Narejo and Richardson 2003). Given the higher levels of uncertainty associated with long-term performance of bioreactor systems, and the relative importance of having leachate collection systems that operate well into the future, somewhat higher factors of safety may be warranted for the different life stages. For this design example we have chosen values of FS_D = 2.0, 3.0, 4.0 and 5.0 for Stages I–IV, respectively, as shown in **Table 3**. These values reflect advancing degrees of uncertainty as time goes forward.
- RF_{CC} = The suggested range for the reduction factor for chemical clogging from GRI-GC8 is from 1.5 to 2.0 for most leachate collection systems based on the chemical makeup of leachate and the length of time exposure. While these values might be typical for "standard average" landfill conditions, a more rigorous and expansive interpretation might be appropriate over the lifetime of a "bioreactor" landfill. For a very short exposure time, as in Stage I, a low value would be appropriate. As exposure time increases, the recommended reduction factor would be increased. We have chosen values of 1.2, 1.5, 2.0, and 4.0 for Stages I-IV, respectively, as shown on **Table 3**. This suggests that up to half of the flow capacity could be lost due to biological clogging during the active life of the cell, and 75% of the flow capacity could be lost to chemical precipitation during the long-term post-closure period.
- RF_{BC} = The suggested range for the reduction factor for biological clogging from GRI-GC8 is from 1.1 to 1.3 for leachate collection systems. We believe this range is appropriate even for bioreactor landfills because the most serious clogging condition is probably from chemical precipitation rather than a biological mechanism.
- RF_{CR} = The creep reduction factor varies with stress and is product-specific. For this design example, **Table 1** provides data for a particular bi-planar product from one manufacturer.

Based on the selected reduction factors and global factors of safety, the specified transmissivities, θ_{spec}, can be calculated as follows:

Case	Description	q_i (cm/sec)	θ_{design} (m²/sec)	σ_{100} (psf)	RF_{cc}	RF_{bc}	FS_d	RF_{cr}	θ_{spec} (m²/sec)	θ_{100} (m²/sec)	Ratio $\theta_{100}/\theta_{req}$	Acceptable
IA	Initial Operation	1.68E-05	2.99E-04	750 psf	1.2	1.1	2.0	1.10	8.7E-04	9.0E-04	1.0	Yes
IB	Initial Operation	1.68E-05	1.59E-05	750 psf	1.2	1.1	2.0	1.10	4.6E-05	5.0E-04	11	Yes
IIA	Active Operation	1.88E-06	3.34E-05	6,000 psf	1.5	1.2	3.0	1.25	2.2E-04	4.0E-04	1.8	Yes
IIB	Active Operation	1.88E-06	1.78E-06	6,000 psf	1.5	1.2	3.0	1.25	1.2E-05	3.0E-04	25	Yes
IIIA	Intermediate Cover	8.80E-07	1.56E-05	10,000 psf	2.0	1.3	4.0	1.30	2.1E-04	2.0E-04	0.95	No
IIIB	Intermediate Cover	8.80E-07	8.35E-07	10,000 psf	2.0	1.3	4.0	1.30	1.1E-05	1.5E-04	13	Yes
IVA	Post-Closure	3.20E-10	5.69E-09	10,500 psf	4.0	1.3	5.0	1.40	2.1E-07	2.0E-04	966	Yes
IVB	Post-Closure	3.20E-10	3.04E-10	10,500 psf	4.0	1.3	5.0	1.40	1.1E-08	1.5E-04	13,565	Yes

Table 3. Results of calculations for the design example.

Stage IA (floor)

θ_{spec} =
2.99×10^{-4} m²/s • 2 • 1.2 • 1.1 • 1.1
= 8.6×10^{-4} m²/s

Stage IB (side slope)

θ_{spec} =
1.59×10^{-5} m²/s • 2 • 1.2 • 1.1 • 1.1
= 4.6×10^{-5} m²/s

Results of similar computations for all stages of the design case are shown in **Table 3**.

Step 5—Specification development

The specifications should clearly define the conditions of the laboratory testing and the criteria that define the product's acceptability.

The required laboratory testing conditions include: (i) applied stress; (ii) hydraulic gradient; (iii) boundary conditions; and (iv) seating time.

(i) Applied stress—The applied stress used in testing should be equal to the maximum applied stress anticipated in field conditions.

For the design example:

$$\sigma_{100} = t_{waste} \bullet \gamma_{waste}$$

Stage I: σ_{100} = 10 ft. • 75 pcf
= 750 psf (36 kPa)

Stage II: σ_{100} = 80 ft. • 75 pcf
= 6000 psf (287 kPa)

Stages III and IV: σ_{100} = 140 ft. • 75 pcf
= 10,500 psf (503 kPa)

(ii) Hydraulic gradient—The hydraulic gradient is equal to the sine of the slope angle in units of length/length.

For the design example:

Stages A (cell floor)
Slope angle = 2.57 deg.
—> Gradient = 0.045

Stages B (cell side slope)
Slope angle = 18.43 deg. _
—> Gradient = 0.32

(iii) Boundary conditions—The term "boundary conditions" refers to the makeup of the overlying and underlying materials during testing of the geocomposite. The testing procedure should follow the guidelines of GRI-GC8, which requires that the boundary conditions mimic field conditions. This means that site-specific materials shall be used wherever possible. This example assumes that the on-site soil anticipated to be used as protective soil between the waste and the geocomposite will be used above the geocomposite, and that a textured geomembrane will be used below the geocomposite. Both materials to be used in testing should be provided to the laboratory by the engineer or contractor.

(iv) Seating time—Seating time affects the amount of creep and intrusion that the geocomposite undergoes prior to transmissivity testing, which in turn affects the measured transmissivity of the product. The laboratory testing should follow the guidelines of GRI-GC8, which requires a seating time of at least 100 hours for testing the transmissivity of the geocomposite. A greater seating time is acceptable; however, this may incur greater testing expense and is usually not necessary. As required by GRI-GC8, a seating time of 100 hours is used in this design example.

An acceptable product should possess a creep reduction factor lower than that used in the design, and a 100-hour transmissivity value higher than the specified value (θ_{spec}) for each of the design stages as presented in **Table 3**.

Discussion of results, conclusions

This third part to the Designer's Forum series demonstrates how the different stages of a landfill life can be taken into account when designing for a leachate collection system with geocomposites. **Table 3** summarizes the results for the design example. The following observations can be drawn from this exercise:

- For this design example, the critical stages in the design of the geocomposite appear to occur right at the beginning of cell operations, and towards the end of the active cell life. This is probably a typical situation for many landfills.
- If the most conservative parameters had been used for the reduction factors for all stages, even with a modest factor of safety of only 2.0, the selected geocomposite would have failed the criteria by a very large margin.
- The condition on the floor is typically more critical than on the side slope. This is because the smaller gradient on the floor requires more head build-up to pass a certain amount of flow.
- **Table 3** indicates that the sample product that was tested for this design passes all the criteria, except for the condition of Stage III of the landfill life on the floor. It only fails that stage just barely, however, and the designer could either re-visit the arbitrary factor of safety for that design stage (a FS_D value of 4.0 is fairly high, whereas a value of 3.8 would result in a passing criteria), or could require a thicker or more robust geocomposite product that has a higher transmissivity.

The most significant conclusion demonstrated by this exercise is that the use of unique reduction factors, and a unique factor of safety, for each stage of a landfill's life can reduce the conservatism inherent in a single calculation. This design approach allows the critical points in a landfill's life to be identified with regard to performance of the geocomposite, and focused laboratory testing can be performed to address those critical conditions.

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Base Grade Settlement Analysis

Atlantic Coast Consulting, Inc.

1

Design Calculations Notebook

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Base Grade Settlement Analysis

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Section 3
Base Grade Settlement Analysis

OBJECTIVE: Evaluate the base grade settlement as a result of the change in stress in the subgrade soils due to placement of waste in the landfill. Determine effects of the estimated settlement (overall and differential) on the proposed waste containment systems.

METHOD: The compression of the subgrade soils as a result of placement of waste in the landfill and the resulting impact on the landfill liner system was evaluated. The overall settlement is a sum of the primary and secondary settlements of the subgrade. The first step in the evaluation was to review the geometry and soils and waste mass and the physical properties of the soils and waste at discreet points along a selected cross section and perform a one-dimensional settlement analysis at critical analysis locations. This allows for an estimation of post settlement base grades and the resulting tensile stresses in the liner system.

Primary Settlement (Sc)

The following equation is used to estimate the *primary settlement* in normally consolidated clays or loose granular materials:

$$S_c = \left(\frac{C_c}{1+e_0}\right) \cdot H \cdot \log\left(\frac{\sigma_0' + \Delta\sigma_0'}{\sigma_0'}\right) \qquad (6.1)$$

where H = thickness of the layer after excavation to be evaluated,
C_c = primary compression index,
e_o = initial void ratio,
σ_o' = effective vertical stress at the middle of the layer after excavation, but before loading, and
$\Delta\sigma_o$' = increase or change in effective vertical stress due to loading.

The following equation is used to estimate the consolidation settlement in overconsolidated clays. Dense cohesionless materials do not settle significantly and thus, do not have to be evaluated using this equation.

$$S_c = \left(\frac{C_r}{1+e_0}\right) \cdot H \cdot \log\left(\frac{\sigma_0' + \Delta\sigma_0'}{\sigma_0'}\right) \qquad (6.2)$$

where C_r = recompressive index.

Secondary Settlement (S_s)

Secondary settlement can be calculated using the following equation:

$$S_s = \frac{C_\alpha}{1+e_p} \cdot H \cdot \log\left(\frac{t_s}{t_{pf}}\right) \qquad (6.4)$$

where C_a = *secondary compression* index of the *compressible layer*,
H = thickness of the layer to be evaluated after excavation, but before loading
t_s = time over which *secondary compression* is to be calculated (use 100 years plus the maximum time it will take to complete *primary consolidation* under the facility unless some other time frame is acceptable to Ohio EPA for a specific facility), and
t_{pf} = time to complete *primary consolidation* in the consolidating layer in the field, and
e_p = the void ratio at the time of complete *primary consolidation* in the test specimen of the *compressible layer*.

Both t_s and t_{pf} must be expressed in the same units (e.g., days, months, years).

DATA: Design drawings of the liner system and final cover grades of the landfill were used to identify a representative cross section for settlement analysis. The critical section was chosen to coincide with Phase 1 that includes the designed highest waste fill grades and the cells sump area. The selected cross section location is shown in Figure 3-1. The results of a previous subsurface exploration outlined in the report "Rock Coring and Geotechnical Soil Boring Investigation" by Atlantic Coast Consulting, Inc., dated May 17, 2013 were used to characterize the subsurface stratigraphy used in this analysis. The geometry of the landfill and subsurface soils along the analyzed cross section is shown in Figure 3-2.

Soil Layer Data:
The subgrade soil at the site consists of several layers as discussed in the cited report. Below the proposed landfill base grades, the compressible layer is the Clayey Sand. These calculations assume that the layers beneath it are not affected by the landfill loading. The following subgrade soil material properties were used based on experience and the references cited.

Layer 1 – Clayey Sand

This layer was modeled as an normally consolidated soil due to the lab reported liquidity index (between 0 and 0.02). The void ratio was calculated on the undisturbed samples. The Re-Compression Index was calculated based on the equation from Nagaraj and Murthy(1985) as shown on the attached. The layer was assumed to have a total unit weight of 110 pcf as computed from the undisturbed samples.

The placement of liner soil (unit weight 120 pcf), municipal solid waste (unit weight 74.5 pcf), and the final cover soil (unit weight 120 psf) were assumed to result in an increase in stress in the underlying layers. The change in stress was estimated at the midpoint of each layer, and the resulting change in layer thickness was estimated using either elastic or consolidation properties. The total change in stress for all underlying layers was computed at the settlement at the landfill subgrade level. The difference in settlement between two adjacent points was used to compute the change in slope and, any induced tensile stresses.

RESULTS: The output for the spreadsheet computation of the base grade settlement analysis is attached. As indicated, the estimated settlement ranges from 1.58 to 0.07 ft under the landfill liner. Based on this computed settlement, the maximum tensile stress in the liner system is anticipated to be 0.00% (which is less than the typically acceptable value of 5%), while the overall landfill Leachate Collection System slope towards the sump is maintained.

CONCLUSION: The analysis indicates that the proposed landfill geometry is adequately designed to accommodate the anticipated base grade settlements.

Point No.	A	B
Horizontal Distance	0.00	1050
Top of Final Cover Elevation (ft MSL)	1410.00	1100.00
Top of Waste Elevation (ft MSL)	1407.00	1096.00
Top of Liner Elevation (ft MSL)	1118.00	1092.00
Subgrade Elevation (ft MSL)	1116.00	1090.00
Existing Ground Elevation (ft MSL)	1120.00	1100.00
Groundwater Elevation (ft MSL)	1045.00	1030.00
Cut (ft)	4.00	10.00
Fill (ft)	0.00	0.00
Soil Density (pcf)	110.0	110.0
Liner Soil Thickness (ft)	2.00	2.00
Liner Soil Density (pcf)	120	120
Cover Soil Thickness (ft)	3.00	4.00
Cover Soil Density (pcf)	120	120
Waste Thickness (ft)	339.00	4.00
Waste Density (pcf)	74.5	74.5
Change in Stress (psf)	25415.50	-82.00
Primary Settlement		
Layer 1 (Clayey Sand)		
Top Elevation (ft MSL)	1115.00	1098.00
Bottom Elevation (ft MSL)	1075.00	1085.00
Mid Point Elevation (ft MSL)	1095.00	1091.50
Soil Density (pcf)	110.0	110.0
Layer Thickness (ft)	40.00	13.00
Effective Initial Stress before loading(psf)	2200.00	715.00
Initial Void Ratio	0.67	0.67
Re-compression Index	0.05	0.05
Primary Layer Settlement (ft)	1.316	-0.021
Secondary Settlement		
Layer 1 (Clayey Sand)		
Top Elevation (ft MSL)	1115.00	1098.00
Bottom Elevation (ft MSL)	1075.00	1085.00
Mid Point Elevation (ft MSL)	1095.00	1091.50
Soil Density (pcf)	110.0	110.0
Layer Thickness (ft)	40.00	13.00
Time for secondary compression (years)	200.00	200.00
Time for primary compression (years)	100.00	100.00
Void Ratio after primary consolidation	0.134	0.134
Secondary compression Index	0.03	0.03
Secondary Settlement (ft)	0.265	0.086
Total Settlement (ft)	1.58	0.07
Initial Length of Liner Segment (ft)		1050.32
Final Length of Liner Segment (ft)		1050.28
Strain (%, Tensile Negative)		0.00
Initial Liner Slope (ft/f)		2.48%
Final Liner Slope (ft/ft)		2.35%

T.E. S.T.	TIMELY ENGINEERING SOIL TESTS, LLC	1874 Forge Street Tucker, GA 30084 Phone: 770-938-8233 Fax: 770-923-8973 Web: www.test-llc.com	Tested By: EB Date: 05/01/13 Checked By: [signature]

ASTM D 4767M / AASHTO T 297M

Standard Test Method for Multistage Consolidated Undrained Triaxial Compression Test for Cohesive Soils

Client Pr. #	I002-264	Lab. PR. #	1308-06-2
Pr. Name	Pine Bluff Soil Analysis	S. Type	UD
Sample ID	15496/ST-4	Depth/Elev.	33.5-34.5'
Location	SB-4	Add. Info	-

SPECIMEN PROPERTIES

	(initial)	(after consol.)
Height, in	5.700	5.695
Diameter, in	2.850	2.850
Height-to-Diameter Ratio	2.0	2.0
Area, in^2	6.38	6.38
Volume, cm^3	595.88	595.37
Mass of Wet Sample, g	1053.00	1201.30
Mass of Dry Sample, g	962.36	962.36
Wet Density, pcf	110.3	126.0
Dry Density, pcf	100.8	100.9
Specific Gravity (assumed)	2.700	2.700
Volume of Solids, cm^3	356.43	356.43
Volume of Voids, cm^3	239.44	238.94
Void Ratio	0.67	0.67
% Saturation	37.9	100.0

WATER CONTENT DETERMINATION

	(initial)	(final)
Mass of Wet Sample and Tare, g	1053.00	1201.30
Mass of Dry Sample and Tare, g	962.36	962.36
Mass of Tare, g	0.00	0.00
Moisture, %	9.42	24.83

TEST DATA PRIOR TO LOADING

Volume change (Consolidation), ml	148.3
Machine Speed, in / min	0.0100
Strain Rate, % / min	0.18
Chamber Pressure, psi	80.0
Back Pressure, psi	70.0
Eff. Consol. Stress,(Minor pr. stress, σ_3),psi	10.0
Change in Height, in	0.005
"B" Value	0.95
t_{50}, min	-

SHEAR DATA

Elapsed Time (min)	Deformation Stage 1 (inch)	Axial Load (lb)	Pore-Water Pressure, psi		Total Strain Stage 1 (%)	Corrected Area (in^2)	Dev.Stress ($\Delta\sigma=\sigma_1-\sigma_3$)	Major Principal Stress, psi		Eff.Stress Ratio	P' $(\sigma'_1+\sigma'_3)/2$ (psi)	Q $(\sigma_1-\sigma_3)/2$ (psi)	Eff. Minor Pr. Stress
			Total, U	Change, ΔU			(psi)	Total σ_1	Eff. σ'_1	σ'_1/σ'_3			σ'_3 (psi)
0.0	0.000	23.9	70.0	0.0	0.00	6.38	0.0	10.0	10.0	1.00	10.0	0.0	10.0
0.5	0.005	28.3	70.7	0.7	0.09	6.39	0.7	10.7	10.0	1.07	9.7	0.3	9.3
1.0	0.010	32.1	70.8	0.8	0.18	6.39	1.3	11.3	10.4	1.14	9.8	0.6	9.2
1.5	0.015	34.6	71.0	1.0	0.26	6.40	1.7	11.7	10.7	1.18	9.9	0.8	9.1
2.0	0.020	35.4	71.0	1.0	0.35	6.40	1.8	11.8	10.8	1.20	9.9	0.9	9.0
2.5	0.025	38.8	71.2	1.2	0.44	6.41	2.3	12.3	11.1	1.26	10.0	1.2	8.8
3.0	0.030	47.7	71.9	1.9	0.53	6.41	3.7	13.7	11.9	1.46	10.0	1.9	8.1
3.5	0.035	55.5	72.3	2.3	0.61	6.42	4.9	14.9	12.6	1.64	10.2	2.5	7.7
4.0	0.040	60.3	72.6	2.6	0.70	6.42	5.7	15.7	13.1	1.76	10.3	2.8	7.4
5.0	0.050	69.3	73.2	3.2	0.88	6.44	7.1	17.1	13.9	2.03	10.4	3.5	6.8
6.0	0.060	79.1	73.6	3.6	1.05	6.45	8.6	18.6	15.0	2.33	10.7	4.3	6.5
7.0	0.070	86.7	73.8	3.8	1.23	6.46	9.7	19.7	16.0	2.56	11.1	4.9	6.2
8.0	0.080	94.8	74.0	4.0	1.40	6.47	11.0	21.0	17.0	2.81	11.5	5.5	6.1
9.0	0.090	102.3	74.0	4.0	1.58	6.48	12.1	22.1	18.1	3.03	12.0	6.0	6.0
10.0	0.100	109.8	74.1	4.1	1.76	6.49	13.2	23.2	19.1	3.23	12.5	6.6	5.9
12.0	0.120	124.8	74.0	4.0	2.11	6.52	15.5	25.5	21.5	3.58	13.7	7.7	6.0
14.0	0.140	137.8	73.8	3.8	2.46	6.54	17.4	27.4	23.6	3.81	14.9	8.7	6.2
16.0	0.160	151.1	73.5	3.5	2.81	6.56	19.4	29.4	25.9	3.98	16.2	9.7	6.5
18.0	0.180	163	73.1	3.1	3.16	6.59	21.1	31.1	28.0	4.08	17.4	10.6	6.9
19.0	0.190	168.3	72.9	2.9	3.34	6.60	21.9	31.9	29.0	4.09	18.0	10.9	7.1
20.0	0.200	174.2	72.7	2.7	3.51	6.61	22.7	32.7	30.0	4.11	18.7	11.4	7.3
21.0	0.210	179.5	72.5	2.5	3.69	6.62	23.5	33.5	31.0	4.13	19.2	11.7	7.5
22.0	0.220	184.3	72.2	2.2	3.86	6.64	24.2	34.2	31.9	4.11	19.8	12.1	7.8
Values @ Failure				**2.5**	**3.69**	**6.62**	**23.5**	**33.5**	**31.0**	**4.13**	**19.2**	**11.7**	**7.5**
Failure criteria used*			3										

*Note: "1" = Max Deviator Stress; "2" = Deviator Stress @ 15% Strain; "3" = Max Eff.Stress Ratio(σ'_1/σ'_3)

Multistage Triaxial CU.xls [Stage 1], REV. 1, 10-21-05

Equation No. 1 $C_r = 0.0007LLe_o + 0.01$

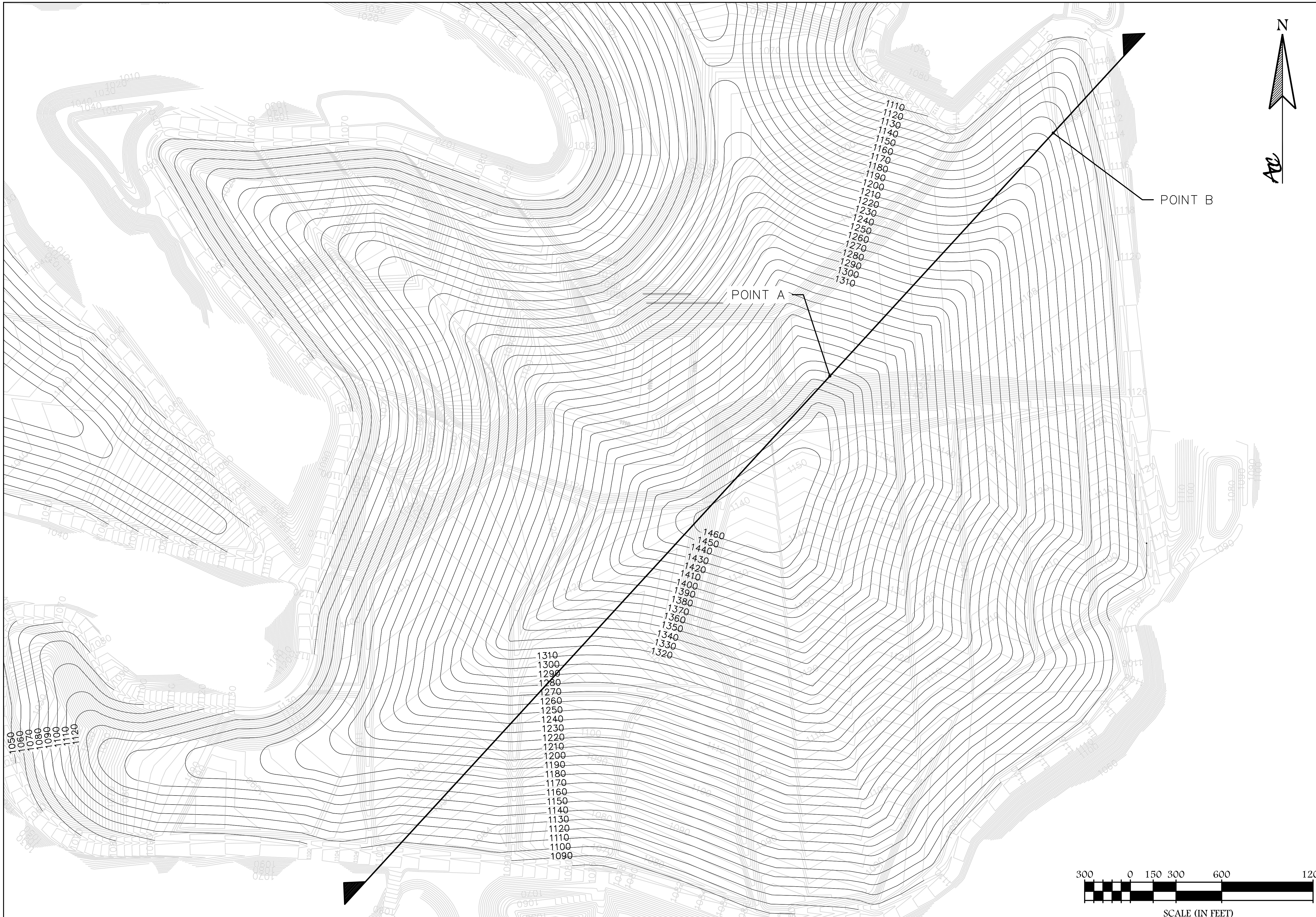
TABLE 2 Previous Published Equations for Recompression Index

Equation No.	Recompression Index	Source
3	$C_r = 0.126 (e_o + 0.003LL - 0.06)$	Azzouz, Krizek & Corotis (1976)
4	$C_r = 0.142 (e_o - 0.0009 w_n^1 + 0.006)$	Azzouz, Krizek & Corotis (1976)
5	$C_r = 0.003w_n + 0.0006LL + 0.004$	Azzouz, Krizek & Corotis (1976)
6	$C_r = 0.135(e_o + 0.01LL - 0.002w_n - 0.06)$	Azzouz, Krizek & Corotis (1976)
7	$C_r = 0.000463LLGs^2$	Nagaraj and Murthy (1985)

[1] w_n denotes natural moisture content [2] Gs denotes specific gravity of solids

TABLE 3 Comparison Between Computed and Actual C_r Values

Equation No.	Computed C_r						
	Figure 9	Figure 10	Figure 11	Figure 12	Figure 13	Figure 14	Figure 15
1	0.045	0.020	0.035	0.032	0.016	0.016	0.025
3	0.110	0.061	0.092	0.083	0.042	0.048	0.087
4	0.101	0.063	0.086	0.075	0.044	0.052	0.089
5	0.126	0.071	0.107	0.093	0.053	0.051	0.093
6	0.175	0.090	0.145	0.139	0.068	0.071	0.119
7	0.085	0.039	0.071	0.074	0.034	0.030	0.043
Actual C_r	*0.059*	*0.020*	*0.043*	*0.031*	*0.014*	*0.010*	*0.028*



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PROJECT:

PINE BLUFF MSW LANDFILL CCR MANAGEMENT

PERMIT # 028-039D(SL)

WASTE MANAGEMENT

13089 E CHEROKEE DR
BALLGROUND, GA 30107
770-479-2936

REVISIONS

Drawn by:	Checked by:
JLY	

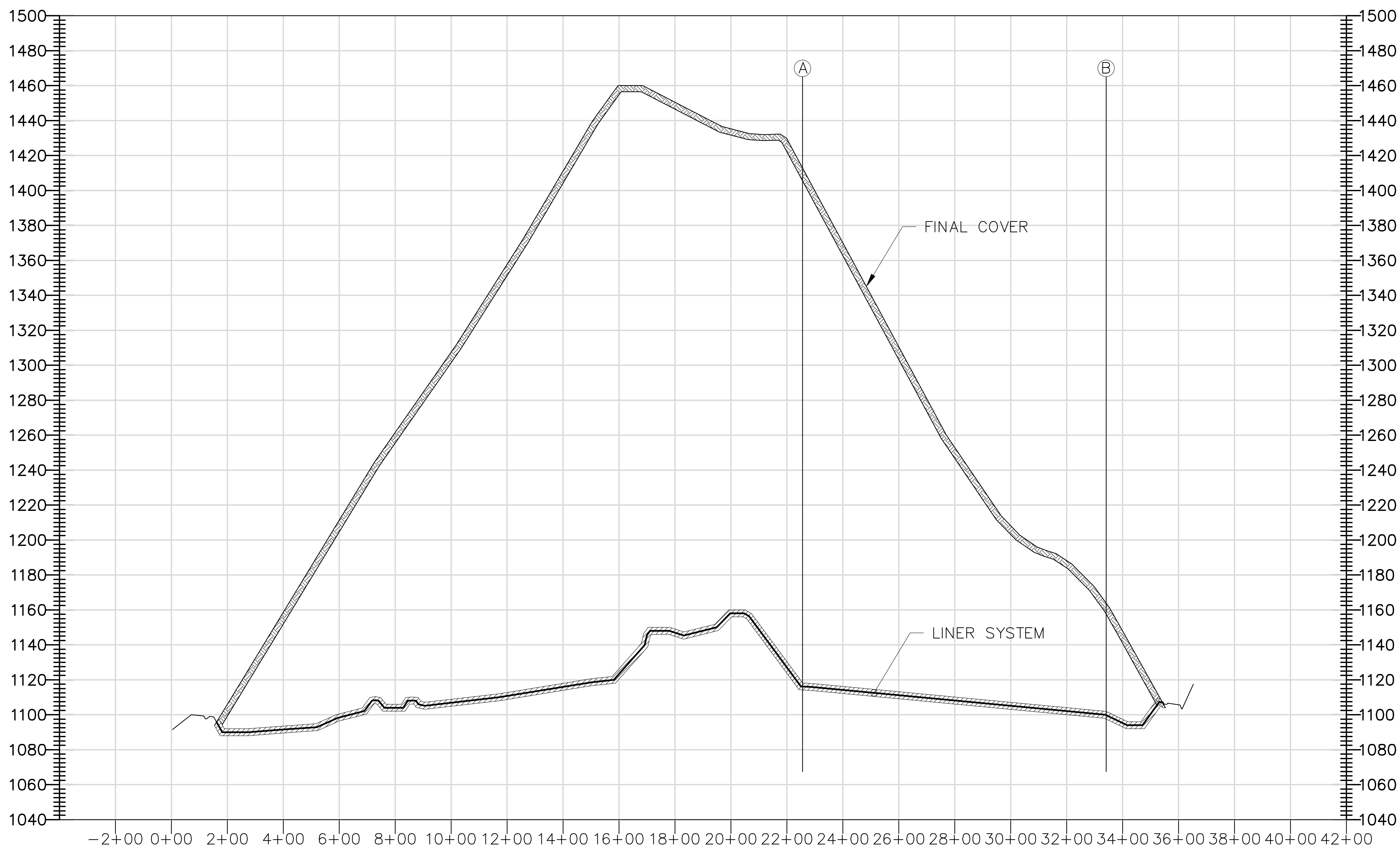
PROJECT NUMBER:

I002-415

APRIL 2017

SETTLEMENT ANALYSIS PLAN VIEW

Figure 3-1



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Drawn by: JLY

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SETTLEMENT ANALYSIS PROFILE VIEW

Figure 3-2

Leachate Collection Pipe Design

ATLANTIC COAST CONSULTING, INC.

Design Calculations Notebook

IN THIS SECTION:

Leachate Collection Pipe Design

1

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3

4

Section 4
Leachate Collection Pipe Design

Project #:	I002-415			
Project Name:	Pine Bluff CCR	By: JLY	Date	03/23/17
Subject:	Leachate Pipe Design	Checked: RB	Date	04/03/17

Leachate Collection Pipe Design SDR 17

Determine the required thickness of the HDPE leachate collection pipes

Pipes are to be placed in the center of the low point of each lined cell. The 6" perforated pipe will be covered in 2-1/2 feet of gravel (see detail).

SDR=	17		
PE Pipe Material Code=	PE 4710		
compressive yield, σ_y =	1150	psi	(See Appendix C, Table C.1, 2nd Ed. Handbook of PE Pipe by PPI)
Normal outer Diameter, B_c=	6.625	inches	(IPS)
minimum wall thickness, t=	0.39	inches	
Average Inner Diameter, B_i=	5.8	inches	
mean radius, r= $(B_i+2t)/2$ =	3.29	inches	
Unit Weights			
Liner System (gravel)	120	lb/ft^3	
Final Cover System	120	lb/ft^3	
MSW Waste	70	lb/ft^3	
CCR	115	lb/ft^3	
Combined MSW and CCR	74.5	lb/ft^3	(When MSW to CCR ratio by weight is at maximum 10:1)

Total External Pressure

$P_T = P_S + P_L + P_I$

P_T = total pressure

P_S = total Static Pressure

P_L = total Dynamic pressure

P_I= total Internal Pressure

Static Load, Post Closure: $P_S = P_{LS} + P_{FC} + P_{MSW} + P_{MSW/CCR} = \rho_{LS}*D_{LS} + \rho_{FC}*D_{FC} + \rho_{MSW}*D_{MSW} + \rho_{MSW/CCR}*D_{MSW/CCR}$

P_{LS} = Pressure from Liner System =	Liner System unit weight,	120	(lb/ft^3) * Depth of Liner System,	2.5	ft =	300	lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	4	ft =	480	lb/ft^2
P_{MSW} = Pressure from $_{MSW}$ =	MSW unit weight,	70.0	(lb/ft^3) * Depth of Stacked MSW,	8	ft =	560	lb/ft^1
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	74.5	(lb/ft^3) * Depth of Stacked MSW/CCR,	186	ft =	13857	lb/ft^2

P_s = 15,197 psf   For Full Cell, P_T= 15197 psf (PL and PI = 0)

Dynamic Load, Active Operation $P_L = 3I_fW_wH^3/(2\pi r^5)$ psf   (Boussinesq Equation - page 203, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_L = vertical soil pressure due to live load, psf

W_w = Wheel load, Single truck Load (lbs) (split load between two wheels assume two axles)

H = Vertical depth to pipe crown, ft

I_f = impact factor = 2.0 since load is traveling

r = distance from point of load application to pipe crown, ft   (See Figure 3-4 on page 203 referenced above)

$r = (X_2 + H_2)^{1/2}$

For empty cell max stess: (Assume directly beneath one wheel)

W =	24,000	lbs	
x_1 =	0	ft	For Wheel load directly above pipe
x_2 =	6	ft (width of axle)	For Wheel load at the other side of axle
H =	2.5	ft	
r_1 =	2.5	ft	
r_2 =	6.50	ft	
P_{L1} =	3,667	psf	Due to wheel load directly above point on pipe
P_{L2} =	31	psf	Due to wheel at the other end of the axle
P_L=	3,698	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 3,998 psf, or

27.8 psi

Compressive Ring Thrust Stress

For burial depth greater than 50', the use of Spangler's modified Iowa formula is impractical since it ignores arching effect. Due to full landfill development depth, CRT should include vertical arching factor per McGrath's modification of the Burns and Richard's equations (see pages 226 and 227, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI).

$$\text{VAF} = 0.88 - 0.71\,\frac{S_A - 1}{S_A + 2.5}$$

VAF = Vertical Arching Factor
S_A = Hoop Thrust Stiffness Ratio

$$S_A = \frac{1.43\ \text{Ms rcent}}{\text{EA}}$$

r_{cent} = radius of centroidal axis of pipe, in	r_{cent} =	3.29	in
M_s = one-dimensional modulus of soil, psi	M_s =	3,234	(Table 3-12, 90%, extrapolated to static load)
E = apparent modulus of elasticity of pipe material, psi	E =	22,960	(Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
A = profile wall average cross sectional area, in^2/in	A =	0.39	in

S_A = 1.70
VAF = 0.76

P_{rd} = (VAF)wH

P_{rd} = radial directed earth pressure, psf
w = unit weight of cover, pcf
H = depth of cover, ft
wH = P_s for post closure condition

P_{rd} = 11,577 psf

S = (P_{rd} * D_o)/(288 * A)

S = pipe wall compressive stress (psi)
D_o = pipe outside diameter (in.)
A = pipe wall thickness (in.)

S = 682.8 psi
Allowable Compressive Stress, psi = 1150

Since 682.8 psi is < 1150 psi; design OK

Design for Wall Crushing (see page 219, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

$$S = \frac{P_t * Bc}{288 * t}$$ (Equation 3-14)

S= pipe wall compressive stress (psi)
P_t= vertical load applied to the pipe (psf)
B_c= pipe outside diameter (in.)
t= pipe wall thickness (in.)

S= 896.4 psi Since 896.4 psi is < 1150 psi so OK ; FS= 1.3

Design for Ring Deflection

Use Watkins-Gaube Method per pages 229-231 of Chapter 6, 2nd Edition Handbook of PE Pipe by PPI

R_F= Relative stiffness between pipe and soil

$$R_F=\frac{12*Es(SDR-1)^3}{E}$$

E= Modulus of elasticity of the pipe material, (psi) E= 22,960 (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio SDR= 17

$E_s = M_s * (1+\mu)(1-2\mu)/(1-\mu)$

μ = Poisson's Ratio μ = 0.2 (Table 3-13)

M_s = one-dimensional modulus of soil, psi M_s = 3,234 (Table 3-12, 90%, extrapolated to static load)

E_s = 2,910.7 psi

$$\varepsilon_s=\frac{w*H}{144*E_s}$$

ε_s= soil strain, %

w = unit weight of cover, pcf

H = depth of cover, ft

wH = Ps for post closure condition wH = 15,197 psf

ε_s= 3.63 %

R_F= 6231.0

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 1.7

$$\frac{\Delta X}{D_i}(100)=Df*\varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_i= inside pipe Diameter, (in)

ε_s= soil strain, %

%ΔX/D_i= 6.16 % Since 6.16 is < 7.5 OK; FS= 1.22

Wall Buckling

$$P_{wc}=\frac{5.65}{SF}\sqrt{R*B'*E'*\frac{E}{12(SDR-1)^3}}$$

(Equation 3-15, page 221, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_{wc}= Allowable wall buckling pressure (psf)

SF= Safety Factor; 2

R= Buoyancy reduction factor; R=1-(0.33*Hw/H)

H_w= groundwater height above pipe (ft); 1 ft

H= Cover above pipe (ft), 200.5

B'= elastic support factor; $B'=1/(1+4e^{-0.065H})$

E'= modulus of soil reaction for pipe bedding (psf);

E= long-term modulus of elasticity of the pipe material (psf);

SDR= standard dimension ratio of the pipe

R= 1

B'= 1

E'= 3000 psi (Table 3-7, slightly compacted crushed rock)

E= 22,960 psi (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

SDR= 17

P_{wc}= 105.8 psi ≥ 105.5 psi so OK ; FS= 1.0

Conclusion

In cells using 6" SDR 17 leachate collection pipes, maximum waste depth (with MSW to CCR ratio by weight of 10:1) is equal to 194 ft. In future Phase 9 cell 23 and Phase 10 cells 24 through 26, the waste depth exceeds 194 ft, therefore, in these cells, the CCR ratio must be decreased or 6" SDR 11 leachate collection pipes must be used (See Figure 4-1). The final waste depths in Phase 1, Phase 2 cell 3, and Phase 3 cells 6 and 9 also exceeds 194 ft (See Figure 4-2). Future disposal of CCR waste will not be allowed in these cells.

Project #:	I002-415				
Project Name:	Pine Bluff CCR	By:	JLY	Date	03/23/17
Subject:	Leachate Pipe Design	Checked:	RB	Date	04/03/17

Leachate Collection Pipe Design SDR 11

Determine the required thickness of the HDPE leachate collection pipes

Pipes are to be placed in the center of the low point of each lined cell. The 6" perforated pipe will be covered in 2-1/2 feet of gravel (see detail).

SDR=	11		
PE Pipe Material Code=	PE 4710		
compressive yield, σ_y =	1150	psi	(See Appendix C, Table C.1, 2nd Ed. Handbook of PE Pipe by PPI)
Normal outer Diameter, B_c=	6.625	inches	(IPS)
minimum wall thickness, t=	0.602	inches	
Average Inner Diameter, B_i=	5.35	inches	
mean radius, r= $(B_i+2t)/2$ =	3.28	inches	
Unit Weights			
Liner System (gravel)	120	lb/ft^3	
Final Cover System	120	lb/ft^3	
MSW Waste	70	lb/ft^3	
CCR	115	lb/ft^3	
Combined MSW and CCR	74.5	lb/ft^3	(When MSW to CCR ratio by weight is at maximum 10:1)

Total External Pressure

$P_T = P_S + P_L + P_I$

P_T = total pressure

P_S = total Static Pressure

P_L = total Dynamic pressure

P_I= total Internal Pressure

Static Load, Post Closure: $P_S = P_{LS} + P_{FC} + P_{MSW} + P_{MSW/CCR} = \rho_{LS}*D_{LS} + \rho_{FC}*D_{FC} + \rho_{MSW}*D_{MSW} + \rho_{MSW/CCR}*D_{MSW/CCR}$

P_{LS} = Pressure from Liner System =	Liner System unit weight,	120	(lb/ft^3) * Depth of Liner System,	2.5	ft =	300	lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	4	ft =	480	lb/ft^2
P_{MSW} = Pressure from $_{MSW}$ =	MSW unit weight,	70.0	(lb/ft^3) * Depth of MSW,	8	ft =	560	lb/ft^3
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	74.5	(lb/ft^3) * Depth of MSW/CCR,	331	ft =	24660	lb/ft^2

*Note: The initial 8 ft of waste is MSW only.

P_s = 26,000 psf For Full Cell, P_T= 25999.5 psf (PL and PI = 0)

Dynamic Load, Active Operation $P_L = 3I_fW_wH^3/(2\pi r^5)$ psf (Boussinesq Equation - page 203, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_L = vertical soil pressure due to live load, psf

W_w = Wheel load, Single truck Load (lbs) (split load between two wheels assume two axles)

H = Vertical depth to pipe crown, ft

I_f = impact factor = 2.0 since load is traveling

r = distance from point of load application to pipe crown, ft (See Figure 3-4 on page 203 referenced above)

$r = (X_2 + H_2)^{1/2}$

For empty cell max stess: (Assume directly beneath one wheel)

W =	24,000	lbs	
x_1 =	0	ft	For Wheel load directly above pipe
x_2 =	6	ft (width of axle)	For Wheel load at the other side of axle
H =	2.5	ft	
r_1 =	2.5	ft	
r_2 =	6.50	ft	
P_{L1} =	3,667	psf	Due to wheel load directly above point on pipe
P_{L2} =	31	psf	Due to wheel at the other end of the axle
P_L=	3,698	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 3,998 psf, or

27.8 psi

Compressive Ring Thrust Stress

For burial depth greater than 50', the use of Spangler's modified Iowa formula is impractical since it ignores arching effect. Due to full landfill development depth, CRT should include vertical arching factor per McGrath's modification of the Burns and Richard's equations (see pages 226 and 227, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI).

$$VAF = 0.88 - 0.71 \frac{S_A - 1}{S_A + 2.5}$$

VAF = Vertical Arching Factor
S_A = Hoop Thrust Stiffness Ratio

$$S_A = \frac{1.43 \text{ Ms rcent}}{\text{EA}}$$

r_{cent} = radius of centroidal axis of pipe, in	r_{cent} =	3.28	in
M_s = one-dimensional modulus of soil, psi	M_s =	4,009	(Table 3-12, 90%, extrapolated to static load)
E = apparent modulus of elasticity of pipe material, psi	E =	22,960	(Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
A = profile wall average cross sectional area, in^2/in	A =	0.602	in

S_A = 1.36
VAF = 0.81

P_{rd} = (VAF)wH

P_{rd} = radial directed earth pressure, psf
w = unit weight of cover, pcf
H = depth of cover, ft
wH = P_s for post closure condition

P_{rd} = 21,162 psf

S = (P_{rd} * D_o)/(288 * A)

S = pipe wall compressive stress (psi)
D_o = pipe outside diameter (in.)
A = pipe wall thickness (in.)

S = 808.6 psi
Allowable Compressive Stress, psi = 1150

Since 808.6 psi is < 1150 psi; design OK

Design for Wall Crushing (see page 219, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

$$S = \frac{P_t * Bc}{288 * t}$$ (Equation 3-14)

S= pipe wall compressive stress (psi)
P_t= vertical load applied to the pipe (psf)
B_c= pipe outside diameter (in.)
t= pipe wall thickness (in.)

S= 993.5 psi Since 993.5 psi is < 1150 psi so OK ; FS= 1.2

Project #:	I002-415		
Project Name:	Pine Bluff CCR	By: JLY	Date 03/23/17
Subject:	Leachate Pipe Design	Checked: RB	Date 04/03/17

Design for Ring Deflection

Use Watkins-Gaube Method per pages 229-231 of Chapter 6, 2nd Edition Handbook of PE Pipe by PPI

R_F= Relative stiffness between pipe and soil

$$R_F = \frac{12 * Es(SDR-1)^3}{E}$$

E= Modulus of elasticity of the pipe material, (psi) E= 22,960 (Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio SDR= 11

$E_s = M_s * (1+\mu)(1-2\mu)/(1-\mu)$

μ = Poisson's Ratio μ = 0.2 (Table 3-13)

M_s = one-dimensional modulus of soil, psi M_s = 4,009 (Table 3-12, 90%, extrapolated to static load)

E_s = 3,608.1 psi

$$\varepsilon_s = \frac{w * H}{144 * E_s}$$

ε_s= soil strain, %

w = unit weight of cover, pcf

H = depth of cover, ft

wH = Ps for post closure condition wH = 26,000 psf

ε_s= 5.00 %

R_F= 1885.7

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 1.4

$$\frac{\Delta X}{D_i}(100) = Df * \varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_i= inside pipe Diameter, (in)

ε_s= soil strain, %

$\%\Delta X/D_i$= 7.01 % Since 7.01 is < 7.5 OK; FS= 1.1

Wall Buckling

$$P_{wc} = \frac{5.65}{SF}\sqrt{R * B' * E' * \frac{E}{12(SDR-1)^3}}$$

(Equation 3-15, page 221, Chapter 6, 2nd Edition Handbook of PE Pipe by PPI)

P_{wc}= Allowable wall buckling pressure (psf)

SF= Safety Factor; 2

R= Buoyancy reduction factor; R=1-(0.33*Hw/H)

H_w= groundwater height above pipe (ft); 1 ft

H= Cover above pipe (ft), 332.5

B'= elastic support factor; $B'=1/(1+4e^{-0.065H})$

E'= modulus of soil reaction for pipe bedding (psf);

E= long-term modulus of elasticity of the pipe material (psf);

SDR= standard dimension ratio of the pipe

R=	1		
B'=	1		
E'=	3000	psi	(Table 3-7, slightly compacted crushed rock)
E=	22,960	psi	(Table B1.1 & B1.2, 100 yrs, PE4710, 90°F)
SDR=	11		

P_{wc}= 214.0 psi ≥ 180.6 psi so OK ; FS= 1.2

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PROJECT:

PINE BLUFF MSW LANDFILL CCR MANAGEMENT

PERMIT # 028-039D(SL)

WASTE MANAGEMENT

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Drawn by:	Checked by:
JLY	

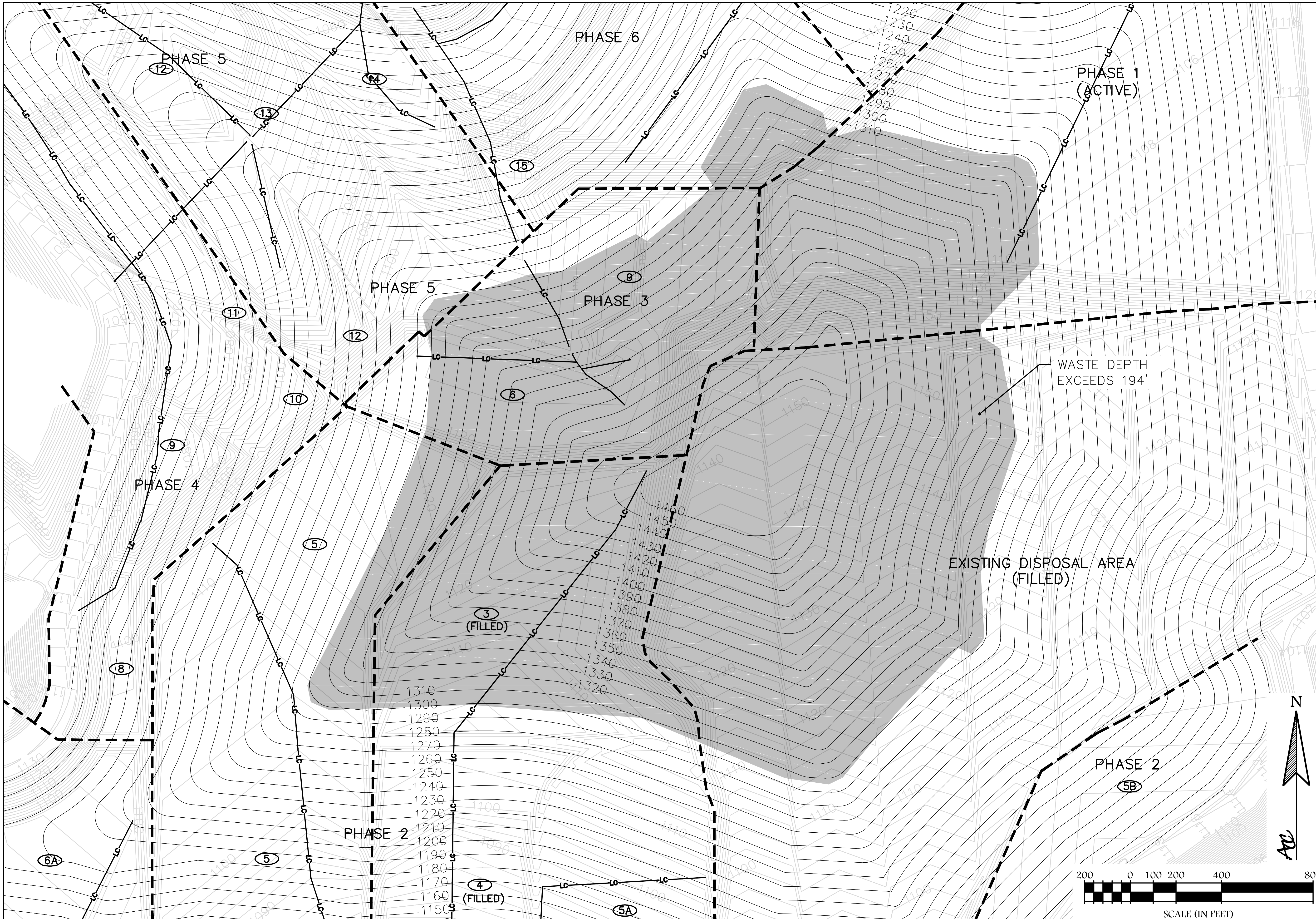
PROJECT NUMBER:

I002-415

APRIL 2017

LEACHATE COLLECTION PIPE MAXIMUM WASTE DEPTH

Figure 4-1



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LEACHATE COLLECTION PIPE MAXIMUM WASTE DEPTH

Figure 4-2

Appendix B
Apparent Elastic Modulus

B.1 – Apparent Elastic Modulus for the Condition of Either a Sustained Constant Load or a Sustained Constant Deformation

B.1.1 – Design Values for the Base Temperature of 73°F (23°C)

TABLE B.1.1
Apparent Elastic Modulus for 73°F (23°C)

Duration of Sustained Loading	Design Values For 73°F (23°C) [1,2,3]					
	PE 2XXX		PE3XXX		PE4XXX	
	psi	MPa	psi	MPa	psi	MPa
0.5hr	62,000	428	78,000	538	82,000	565
1hr	59,000	407	74,000	510	78,000	538
2hr	57,000	393	71,000	490	74,000	510
10hr	50,000	345	62,000	428	65,000	448
12hr	48,000	331	60,000	414	63,000	434
24hr	46,000	317	57,000	393	60,000	414
100hr	42,000	290	52,000	359	55,000	379
1,000hr	35,000	241	44,000	303	46,000	317
1 year	30,000	207	38,000	262	40,000	276
10 years	26,000	179	32,000	221	34,000	234
50 years	22,000	152	28,000	193	29,000	200
100 years	21,000	145	27,000	186	28,000	193

(1) Although there are various factors that determine the exact apparent modulus response of a PE, a major factor is its ratio of crystalline to amorphous content – a parameter that is reflected by a PE's density. Hence, the major headings PE2XXX, PE3XXX and, PE4XXX, which are based on PE's Standard Designation Code. The first numeral of this code denotes the PE's density category in accordance with ASTM D3350 (An explanation of this code is presented in Chapter 5).

(2) The values in this table are applicable to both the condition of sustained and constant loading (under which the resultant strain increases with increased duration of loading) and that of constant strain (under which an initially generated stress gradually relaxes with increased time).

(3) The design values in this table are based on results obtained under uni-axial loading, such as occurs in a test bar that is being subjected to a pulling load. When a PE is subjected to multi-axial stressing its strain response is inhibited, which results in a somewhat higher apparent modulus. For example, the apparent modulus of a PE pipe that is subjected to internal hydrostatic pressure – a condition that induces bi-axial stressing – is about 25% greater than that reported by this table. Thus, the Uni-axial condition represents a conservative estimate of the value that is achieved in most applications.

It should also be kept in mind that these values are for the condition of continually sustained loading. If there is an interruption or a decrease in the loading this, effectively, results in a somewhat larger modulus.

In addition, the values in this table apply to a stress intensity ranging up to about 400psi, a value that is seldom exceeded under normal service conditions.

B.1.2 – Values for Other Temperatures

The multipliers listed in Table B.1.2 when applied to the base temperature value (Table B.1.1) yield the value for another temperature.

TABLE B.1.2
Temperature Compensating Multipliers for Determination of the Apparent Modulus of Elasticity at Temperatures Other than at 73°F (23°C)
Equally Applicable to All Stress-Rated PE's (e.g., All PE2xxx's, All PE3xxx's and All PE4xxx's)

Maximum Sustained Temperature of the Pipe °F (°C)	Compensating Multiplier
-20 (-29)	2.54
-10 (-23)	2.36
0 (-18)	2.18
10 (-12)	2.00
20 (-7)	1.81
30 (-1)	1.65
40 (4)	1.49
50 (10)	1.32
60 (16)	1.18
73.4 (23)	1.00
80 (27)	0.93
90 (32)	0.82
100 (38)	0.73
110 (43)	0.64
120 (49)	0.58
130 (54)	0.50
140 (60)	0.43

B.2 – Approximate Values for the Condition of a Rapidly Increasing Stress OR Strain

B.2.1 – Values for the Base Temperature of 73°F (23°C)

TABLE B.2.1

Rate of Increasing Stress	Approximate Values of Apparent Modulus for 73°F (23°C)					
	For Materials Coded PE2XXX [1]		For Materials Coded PE3XXX [1]		For Materials Coded PE4XXX [1]	
	psi	MPa	psi	MPa	psi	MPa
"Short term" (Results Obtained Under Tensile Testing) [2]	100,000	690	125,000	862	130,000	896
"Dynamic" [3]	150,000psi (1,034MPa), For All Designation Codes					

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code. The X's designate any numeral that is recognized under this code.

(2) Under ASTM D638, "Standard Test Method for Tensile Properties of Plastics", a dog-bone shaped specimen is subjected to a constant rate of pull. The "apparent modulus" under this method is the ratio of stress to strain that is achieved at a certain defined strain. This apparent modulus is of limited value for engineering design.

(3) The dynamic modulus is the ratio of stress to strain that occurs under instantaneous rate of increasing stress, such as can occur in a water-hammer reaction in a pipeline. This modulus is used as a parameter for the computing of a localized surge pressure that results from a water hammer event.

B.2.2 – Values for Other Temperatures

The values for other temperatures may be determined by applying a multiplier, as follows, to the base temperature value:

- For Short-Term Apparent Modulus – Apply the multipliers in Table B.1.2
- For Dynamic Apparent Modulus – Apply the multipliers in Table B.2.2

TABLE B.2.2
Dynamic Modulus, Temperature Compensating Multipliers

Temperature , °F (°C)	Multiplier
40 (4)	1.78
50 (10)	1.52
60 (16)	1.28
73.4 (23)	1.00
80 (27)	0.86
90 (32)	0.69
100 (38)	0.53
110 (43)	0.40
120 (49)	0.29

Appendix C
Allowable Compressive Stress

Table C.1 lists allowable compressive stress values for 73°F (23°C). Values for allowable compressive stress for other temperatures may be determined by application of the same multipliers that are used for pipe pressure rating (See Table A.2).

TABLE C.1
Allowable Compressive Stress for 73°F (23°C)

	Pe Pipe Material Designation Code [1]					
	PE 2406 PE 2708		PE3408 PE 3608 PE 3708 PE 3710 PE 4708		PE 4710	
	psi	MPa	psi	MPa	psi	MPa
Allowable Compressive Stress	800	5.52	1000	6.90	1150	7.93

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code.

Appendix D
Poisson's Ratio

Poisson's Ratio for ambient temperature for all PE pipe materials is approximately 0.45.

This 0.45 value applies both to the condition of tension and compression. While this value increases with temperature, and vice versa, the effect is relatively small over the range of typical working temperatures.

Boussinesq Equation

The Boussinesq Equation gives the pressure at any point in a soil mass under a concentrated surface load. The Boussinesq Equation may be used to find the pressure transmitted from a wheel load to a point that is not along the line of action of the load. Pavement effects are neglected.

(3-4)

$$P'_L = \frac{3 I_f W_w H^3}{2\pi r^5}$$

WHERE

P_L = vertical soil pressure due to live load lb/ft²

W_W = wheel load, lb

H = vertical depth to pipe crown, ft

I_f = impact factor

r = distance from the point of load application to pipe crown, ft

(3-5)

$$r = \sqrt{X^2 + H^2}$$

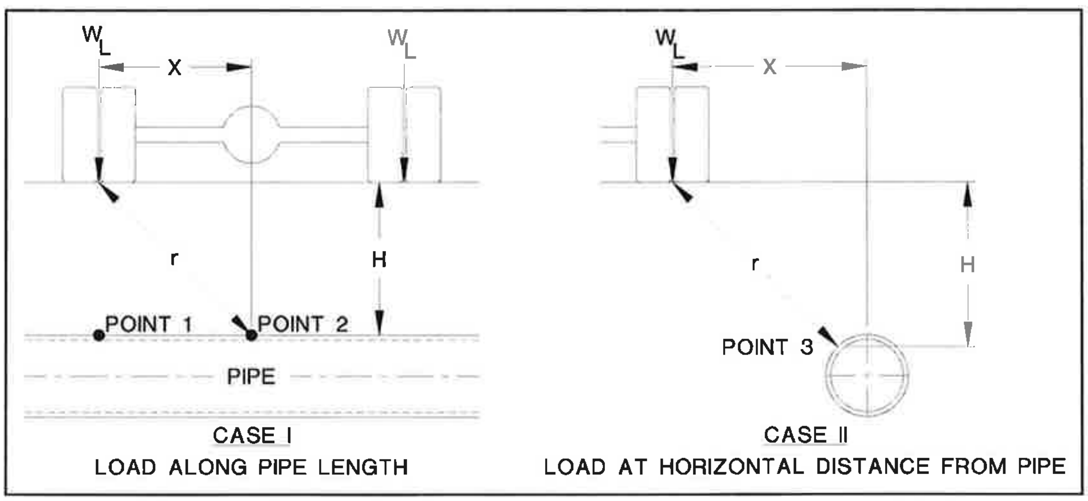

Figure 3-4 Illustration of Boussinesq Point Loading

Example Using Boussinesq Point Loading Technique

Determine the vertical soil pressure applied to a 12" pipe located 4 ft deep under a dirt road when two vehicles traveling over the pipe and in opposite lanes pass each other. Assume center lines of wheel loads are at a distance of 4 feet. Assume a wheel load of 16,000 lb.

TABLE 3-7

Values of E' for Pipe Embedment (See Howard [8])

Soil Type-pipe Embedment Material (Unified Classification System)[1]	E' for Degree of Embedment Compaction, lb/in²			
	Dumped	Slight, <85% Proctor, <40% Relative Density	Moderate, 85%-95% Proctor, 40%-70% Relative Density	High, >95% Proctor, >70% Relative Density
Fine-grained Soils (LL > 50)[2] Soils with medium to high plasticity; CH, MH, CH-MH	No data available: consult a competent soils engineer, otherwise, use E' = 0.			
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse grained particles.	50	200	400	1000
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with more than 25% coarse grained particles; Coarse-grained Soils with Fines, GM, GC, SM, SC[3] containing more than 12% fines.	100	400	1000	2000
Coarse-grained soils with Little or No Fines GW, GP, SW, SP[3] containing less than 12% fines	200	1000	2000	3000
Crushed Rock	1000	3000	3000	3000
Accuracy in Terms of Percentage Deflection[4]	±2%	±2%	±1%	±0.5%

[1] ASTM D-2487, USBR Designation E-3
[2] LL = Liquid Limit
[3] Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).
[4] For ±1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note: Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only; appropriate Deflection Lag Factor must be applied for long-term deflections. If embedment falls on the borderline between two compaction categories, select lower E' value, or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using 12,500 ft-lb/cu ft (598,000 J/m^2) (ASTM D-698, AASHTO T-99, USBR Designation E-11). 1 psi = 6.9 KPa.

Compressive Ring Thrust

Earth pressure exerts a radial-directed force around the circumference of a pipe that results in a compressive ring thrust in the pipe wall. (This thrust is exactly opposite to the tensile hoop thrust induced when a pipe is pressurized.) See Figure 3-1B. Excessive ring compressive thrust may lead to two different performance limits: crushing of the material or buckling (loss of stability) of the pipe wall. See Figure 3-1C. This section will discuss crushing, and the next section will discuss buckling.

As is often the case, the radial soil pressure causing the stress is not uniform around the pipe's circumference. However, for calculation purposes it is assumed uniform and equal to the vertical soil pressure at the pipe crown.

Pressure pipes often have internal pressure higher than the radial pressure applied by the soil. As long as there is pressure in the pipe that exceeds the external pressure, the net thrust in the pipe wall is tensile rather than compressive, and wall crush or buckling checks are not necessary. Whether one needs to check this or not can be quickly determined by simply comparing the internal pressure with the vertical soil pressure.

Crushing occurs when the compressive stress in the wall exceeds the compressive yield stress of the pipe material. Equations 3-13 and 3-14 give the compressive stress resulting from earth and live load pressure for conventional extruded DR pipe and for ASTM F894 profile wall PE Pipe:

(3-13)

$$S = \frac{(P_E + P_L)\,DR}{288}$$

(3-14)

$$S = \frac{(P_E + P_L)\,D_O}{288A}$$

WHERE

P_E = **vertical soil pressure due to earth load, psf**

P_L = **vertical soil pressure due to live-load, psf**

S = **pipe wall compressive stress, lb/in^2**

DR = **Dimension Ratio, D_O/t**

D_O = **pipe outside diameter (for profile pipe $D_O = D_I + 2H_P$), in**

D_I = **pipe inside diameter, in**

H_P = **profile wall height, in**

A = **profile wall average cross-sectional area, in^2/in**
(Obtain the profile wall area from the manufacturer of the profile pipe.)

(Note: These equations contain a factor of 144 in the denominator for correct units conversions.)

raised to a power. Therefore the lower the DR, the higher the resistance. Buried pipe has an added resistance due to support (or constraint) from the surrounding soil.

Non-pressurized pipes or gravity flow pipes are most likely to have a net compressive stress in the pipe wall and, therefore, the allowable buckling pressure should be calculated and compared to the total (soil and ground water) pressure. For most pressure pipe applications, the fluid pressure in the pipe exceeds the external pressure, and the net stress in the pipe wall is tensile. Buckling needs only be considered for that time the pipe is not under pressure, such as during and immediately after construction and during system shut-downs and, in cases in which a surge pressure event can produce a temporary negative internal pressure. Under these circumstances the pipe will react much stiffer to buckling as its modulus is higher under short term loading. When designing, select a modulus appropriate for the duration of the negative external pressure. For pipe that are subjected to negative pressure due to surge, consideration should be given to selecting a DR that gives the pipe sufficient unconstrained collapse strength to resist the full applied negative pressure without support for the soil. This is to insure against construction affects that result in the embedment material not developing its full design strength.

This chapter gives two equations for calculating buckling. The modified Luscher Equation is for buried pipes that are beneath the ground water level, subject to vacuum pressure, or under live load with a shallow cover. These forces act to increase even the slightest eccentricity in the pipe wall by following deformation inward. While soil pressure alone can create instability, soil is less likely to follow deformation inward, particularly if it is granular. So, dry ground buckling is only considered for deep applications and is given by the Moore-Selig Equation found in the section, "Buckling of Pipes in Deep, Dry Fills".

Luscher Equation for Constrained Buckling Below Ground Water Level

For pipes below the ground water level, operating under a full or partial vacuum, or subject to live load, Luscher's equation may be used to determine the allowable constrained buckling pressure. Equation 3-15 and 3-16 are for DR and profile pipe respectively.

(3-15)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{E}{12(DR-1)^3}}$$

(3-16)

$$P_{WC} = \frac{5.65}{N}\sqrt{RB'E'\frac{EI}{D_M^{\,3}}}$$

WHERE
P_{WC} = allowable constrained buckling pressure, lb/in²
N = safety factor

(3-17)
$$R = 1 - 0.33\frac{H_{GW}}{H}$$

WHERE
R = buoyancy reduction factor
H_{GW} = height of ground water above pipe, ft
H = depth of cover, ft

(3-18)
$$B' = \frac{1}{1 + 4e^{(-0.065H)}}$$

WHERE
e = natural log base number, 2.71828
E' = soil reaction modulus, psi
E = apparent modulus of elasticity, psi
DR = Dimension Ratio
I = pipe wall moment of inertia, in^4/in ($t^3/12$, if solid wall construction)
D_M = Mean diameter ($D_I + 2z$ or $D_O - t$), in

Although buckling occurs rapidly, long-term external pressure can gradually deform the pipe to the point of instability. This behavior is considered viscoelastic and can be accounted for in Equations 3-15 and 3-16 by using the apparent modulus of elasticity value for the appropriate time and temperature of the loading. For instance, a vacuum event is resisted by the short-term value of the modulus whereas continuous ground water pressure would be resisted by the 50 year value. For modulus values see Appendix, Chapter 3.

For pipes buried with less than 4 ft or a full diameter of cover, Equations 3-15 and 3-16 may have limited applicability. In this case the designer may want to use Equations 3-39 and 3-40.

The designer should apply a safety factor commensurate with the application. A safety factor of 2.0 has been used for thermoplastic pipe.

The allowable constrained buckling pressure should be compared to the total vertical stress acting on the pipe crown from the combined load of soil, and ground water or floodwater. It is prudent to check buckling resistance against a ground water level for a 100-year-flood. In this calculation the total vertical stress is typically taken as the prism load pressure for saturated soil, plus the fluid pressure of any floodwater above the ground surface.

Determine the earth pressure coefficient:

$$K = \frac{1+\sin(30)}{1-\sin(30)} = \frac{1+0.5}{1-0.5} = 3.0$$

The live load pressure incipient to failure equals:

$$P_{WAT} = \frac{(12)120(3.0*3.0)^2}{40.04} + \frac{7387*0.171}{40.04^2(1.44)}(3000 - \frac{120(40.04)3.0}{288*0.470})$$

$$P_{WAT} = 2904 + 1584 = 4498\ psf$$

The resulting safety factor equals:

$$N = \frac{P_{WAT}}{p_L} = \frac{4498}{1697} = 2.65$$

Installation Category #3: Deep Fill Installation

The performance limits for pipes in a deep fill are the same as for any buried pipe. They include:

1. Compressive ring thrust stress
2. Ring deflection
3. Constrained pipe wall buckling

The suggested calculation method for pipe in deep fill applications involves the introduction of design routines for each performance limit that are different than those previously given.

Compressive ring thrust is calculated using soil arching. The arching calculation may also be used for profile pipe designs in standard trench applications. Profile pipes are relatively low stiffness pipes where significant arching may occur at relatively shallow depths of cover.

At a depth of around 50 feet or so it becomes impractical to use Spangler's equation as published in this chapter because it neglects the significant load reduction due to arching and the inherent stiffening of the embedment and consequential increase in E' due to the increased lateral earth pressure applied to the embedment. This section gives an alternate deflection equation for use with PE pipes. It was first introduced by Watkins et al. (1) for metal pipes, but later Gaube extended its use to include PE pipes. (15)

Where deep fill applications are in dry soil, Luscher's equation (Eq. 3-15 or 3-16) may often be too conservative for design as it considers a radial driving force from ground water or vacuum. Moore and Selig[17] developed a constrained pipe wall buckling equation suitable for pipes in dry soils, which is given in a following section.

Considerable care should be taken in the design of deeply buried pipes whose failure may cause slope failure in earthen structures, or refuse piles or whose failure may have severe environmental or economical impact. These cases normally justify the use of methods beyond those given in this Chapter, including finite element analysis and field testing, along with considerable professional design review.

Compressive Ring Thrust and the Vertical Arching Factor

The combined horizontal and vertical earth load acting on a buried pipe creates a radially-directed compressive load acting around the pipe's circumference. When a PE pipe is subjected to ring compression, thrust stress develops around the pipe hoop, and the pipe's circumference will ever so slightly shorten. The shortening permits "thrust arching," that is, the pipe hoop thrust stiffness is less than the soil hoop thrust stiffness and, as the pipe deforms, less load follows the pipe. This occurs much like the vertical arching described by Marston.[18] Viscoelasticity enhances this effect. McGrath[19] has shown thrust arching to be the predominant form of arching with PE pipes.

Burns and Richard[6] have published equations that give the resulting stress occurring in a pipe due to arching. As discussed above, the arching is usually considered when calculating the ring compressive stress in profile pipes. For deeply buried pipes McGrath [19] has simplified the Burns and Richard's equations to derive a vertical arching factor as given by Equation 3-21.

(3-21)

$$VAF = 0.88 - 0.71\frac{S_A - 1}{S_A + 2.5}$$

WHERE

VAF = **Vertical Arching Factor**

S_A = **Hoop Thrust Stiffness Ratio**

(3-22)

$$S_A = \frac{1.43\, M_S\, r_{CENT}}{EA}$$

WHERE

r_{CENT} = **radius to centroidal axis of pipe, in**

M_S = **one-dimensional modulus of soil, psi**

E = **apparent modulus of elasticity of pipe material, psi (See Appendix, Chapter 3)**

A = **profile wall average cross-sectional area, in^2/in, or wall thickness (in) for DR pipe**

One-dimensional modulus values for soil can be obtained from soil testing, geotechnical texts, or Table 3-12 which gives typical values. The typical values in Table 3-12 were obtained by converting values from McGrath [20].

TABLE 3-12
Typical Values of M_S, One-Dimensional Modulus of Soil

Vertical Soil Stress[1] (psi)	Gravelly Sand/Gravels 95% Std. Proctor (psi)	Gravelly Sand/Gravels 90% Std. Proctor (psi)	Gravelly Sand/Gravels 85% Std. Proctor (psi)
10	3000	1600	550
20	3500	1800	650
40	4200	2100	800
60	5000	2500	1000
80	6000	2900	1300
100	6500	3200	1450

* Adapted and extended from values given by McGrath[20]. For depths not shown in McGrath[20], the MS values were approximated using the hyperbolic soil model with appropriate values for K and n where n=0.4 and K=200, K=100, and K=45 for 95% Proctor, 90% Proctor, and 85% Proctor, respectively.

[1] Vertical Soil Stress (psi) = [soil depth (ft) x soil density (pcf)]/144

The radial directed earth pressure can be found by multiplying the prism load (pressure) by the vertical arching factor as shown in Eq. 3-23.

$$P_{RD} = (VAF)wH \quad (3\text{-}23)$$

WHERE

P_{RD} = **radial directed earth pressure, lb/ft²**

W = **unit weight of soil, pcf**

H = **depth of cover, ft**

The ring compressive stress in the pipe wall can be found by substituting P_{RD} from Equation 3-23 for P_E in Equation 3-13 for DR pipe and Equation 3-14 for profile wall pipe.

Earth Pressure Example

Determine the earth pressure acting on a 36" profile wall pipe buried 30 feet deep. The following properties are for one unique 36" profile pipe made from PE3608 material. Other 36" profile pipe may have different properties. The pipe's cross-sectional area, A, equals 0.470 inches²/inch, its radius to the centroidal axis is 18.00 inches plus 0.58 inches, and its apparent modulus is 27,000 psi. Its wall height is 2.02 in and its D_O equals 36 in +2 (2.02 in) or 40.04 in. Assume the pipe is installed in a clean granular soil compacted to 90% Standard Proctor (Ms = 1875 psi), the insitu soil is as stiff as the embedment, and the backfill weighs 120 pcf. (Where the excavation is in a stable trench, the stiffness of the insitu soil can generally be ignored in this calculation.) The following series of equations calculates the hoop compressive stress, S, in the pipe wall due to the earth pressure applied by the soil above the pipe. The earth pressure is reduced from the prism load by the vertical arching factor.

(From Equation 3-22)

$$S_A = \frac{1.43(1875\frac{lbs}{inch^2})(18.58\,inch)}{(28250\frac{lbs}{inch^2})(0.470\frac{inch^2}{inch})} = 3.93$$

(From Equation 3-21)

$$VAF = 0.88 - 0.71\frac{3.75 - 1}{3.75 + 2.5} = 0.56$$

(From Equation 3-23)

$$P_{RD} = 0.57(120\,pcf)(30\,ft) = 2016\frac{lb}{ft^2}$$

(From Equation 3-14)

$$S = \frac{P_{RD}D_O}{288A} = \frac{2052\,psf(40.04\,in)}{288\,(0.470\,in^2\,/\,in)} = 596\;psi \leq 1000\,psi$$

(Allowable compressive stress per Table C.1, Appendix to Chapter 3)

Ring Deflection of Pipes Using Watkins-Gaube Graph

R. Watkins(1) developed an extremely straight-forward approach to calculating pipe deflection in a fill that does not rely on E'. It is based on the concept that the deflection of a pipe embedded in a layer of soil is proportional to the compression or settlement of the soil layer and that the constant of proportionality is a function of the relative stiffness between the pipe and soil. Watkins used laboratory testing to establish and graph proportionality constants, called Deformation Factors, D_F , for the stiffness ranges of metal pipes. Gaube (15, 16) extended Watkins' work by testing to include PE pipes. In order to predict deflection, the designer first determines the amount of compression in the layer of soil in which the pipe is installed using conventional geotechnical equations. Then, deflection equals the soil compression multiplied by the D_F factor. This bypasses some of the inherent problems associated with using the soil reaction modulus, E', values. The designer using the Watkins-Gaube Graph (Figure 3-6) should select conservative soil modulus values to accommodate variance due to installation. Two other factors to consider when using this method is that it assumes a constant Deformation Factor independent of depth of cover and it does not address the effect of the presence of ground water on the Deformation Factor.

To use the Watkins-Gaube Graph, the designer first determines the relative stiffness between pipe and soil, which is given by the Rigidity Factor, R_F. Equation 3-24 and 3-25 are for DR pipe and for profile pipe respectively:

(3-24)

$$R_F = \frac{12\, E_S\, (DR-1)^3}{E}$$

(3-25)

$$R_F = \frac{E_S D_m^{\;3}}{EI}$$

WHERE

DR = **Dimension Ratio**

E_S = **Secant modulus of the soil, psi**

E = **Apparent modulus of elasticity of pipe material, psi**

I = **Pipe wall moment of inertia of pipe, in^4/in**

D_m = **Mean diameter (D_I + 2z or D_O – t), in**

The secant modulus of the soil may be obtained from testing or from a geotechnical engineer's evaluation. In lieu of a precise determination, the soil modulus may be related to the one-dimensional modulus, M_S, from Table 3-12 by the following equation where μ is the soil's Poisson ratio.

(3-26)

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

TABLE 3-13
Typical range of Poisson's Ratio for Soil (Bowles [21])

Soil Type	Poisson's Ratio, μ
Saturated Clay	0.4-0.5
Unsaturated Clay	0.1-0.3
Sandy Clay	0.2-0.3
Silt	0.3-0.35
Sand (Dense)	0.2-0.4
Coarse Sand (Void Ratio 0.4-0.7)	0.15
Fine-grained Sand (Void Ratio 0.4-0.7)	0.25

Next, the designer determines the Deformation Factor, D_F, by entering the Watkins-Gaube Graph with the Rigidity Factor. See Fig. 3-6. The Deformation Factor is the proportionality constant between vertical deflection (compression) of the soil layer containing the pipe and the deflection of the pipe. Thus, pipe deflection can be obtained by multiplying the proportionality constant D_F times the soil settlement. If D_F is less than 1.0 in Fig. 3-6, use 1.0.

The soil layer surrounding the pipe bears the entire load of the overburden above it without arching. Therefore, settlement (compression) of the soil layer is proportional to the prism load and not the radial directed earth pressure. Soil strain, ε_S, may be determined from geotechnical analysis or from the following equation:

(3-27)

$$\varepsilon_S = \frac{wH}{144 E_S}$$

WHERE

w = unit weight of soil, pcf

H = depth of cover (height of fill above pipe crown), ft

E_S = secant modulus of the soil, psi

The designer can find the pipe deflection as a percent of the diameter by multiplying the soil strain, in percent, by the deformation factor:

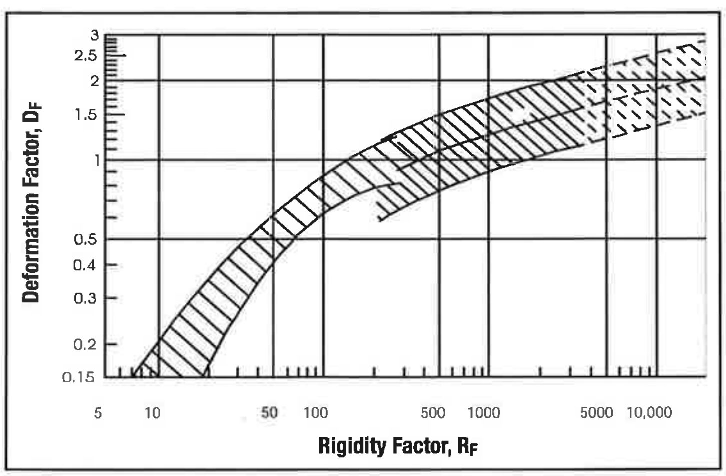

Figure 3-6 Watkins-Gaube Graph

(3-28)

$$\frac{\Delta X}{D_M}(100) = D_F \varepsilon_S$$

WHERE

$\Delta X/D_M$ multiplied by 100 gives percent deflection.

OD			Pipe inside diameter (d)	Minimum Wall Thickness (t)	Weight (w)
Nominal in.	Actual in.	DR	in.	in.	lb. per foot
		7	3.14	0.643	3.384
		7.3	3.19	0.616	3.269
		9	3.44	0.500	2.737
		9.3	3.47	0.484	2.660
		11	3.63	0.409	2.294
4	4.500	11.5	3.67	0.391	2.204
		13.5	3.79	0.333	1.906
		15.5	3.88	0.290	1.678
		17	3.94	0.265	1.540
		21	4.05	0.214	1.262
		26	4.13	0.173	1.030
		32.5	4.21	0.138	0.831
		7	3.88	0.795	5.172
		7.3	3.95	0.762	4.996
		9	4.25	0.618	4.182
		9.3	4.29	0.598	4.065
		11	4.49	0.506	3.505
5	5.563	11.5	4.54	0.484	3.368
		13.5	4.69	0.412	2.912
		15.5	4.80	0.359	2.564
		17	4.87	0.327	2.353
		21	5.00	0.265	1.929
		26	5.11	0.214	1.574
		32.5	5.20	0.171	1.270
		7	4.62	0.946	7.336
		7.3	4.70	0.908	7.086
		9	5.06	0.736	5.932
		9.3	5.11	0.712	5.765
		11	5.35	0.602	4.971
6	6.625	11.5	5.40	0.576	4.777
		13.5	5.58	0.491	4.130
		15.5	5.72	0.427	3.637
		17	5.80	0.390	3.338
		21	5.96	0.315	2.736
		26	6.08	0.255	2.233
		32.5	6.19	0.204	1.801

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