ATLANTIC COAST CONSULTING, INC.

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

RECEIVED

APR 21 2017

SOLID WASTE
MANAGEMENT PROGRAM

April 19, 2017

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

RE: Waste Management of Georgia, Inc.
Superior Landfill & Recycling Center
Minor Modification – Coal Combustible Residuals (CCR) Management Plans
Permit Number: 025-070D (MSWL)

Dear Mr. Cook,

Please find the enclosed copies, as well as documentation of deliveries to each entity, of the notification of the initial submittal of a proposed Coal Combustion Residuals (CCR) Management Plan for the Waste Management of Georgia, Inc. Superior Landfill & Recycling Center facility sent to the local governing authorities within Chatham County, Georgia.

Please let me know if you have any questions.

Sincerely,

ATLANTIC COAST CONSULTING, INC.

Jeff Thomas, P.E.
Project Engineer

cc: Shawn Carroll, WM
Terry Darragh, WM

ATLANTIC COAST
CONSULTING, INC.

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

April 13, 2017

Mr. Lee Smith
County Manager
Chatham County
P. O. Box 8161
Savannah, Georgia 31412

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mr. Smith,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, 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, INC.

Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

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

April 13, 2017

The Honorable Ben Rozier
Mayor
City of Bloomingdale
PO Box 216
Bloomingdale, Georgia 31302

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Rozier,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

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Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

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

April 13, 2017

The Honorable Don Bethune
Mayor
City of Garden City
100 Central Avenue
Garden City, Georgia 31405

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Bethune,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
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Shawn Carroll, WM
File

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

April 13, 2017

The Honorable James Hungerpiller
Mayor
Town of Vernonburg
PO Box 61512
Savannah, Georgia 31420-1512

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Hungerpiller,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

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Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

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

April 13, 2017

The Honorable Mike Lamb
Mayor
City of Pooler
100 SW U.S. HWY 80
Pooler, Georgia 31322

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Lamb,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
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Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

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

April 13, 2017

The Honorable Beth Goette
Mayor
Town of Thunderbolt
2821 River Drive
Thunderbolt, Georgia 31404-3200

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Goette,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
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Shawn Carroll, WM
File

ATLANTIC COAST CONSULTING, INC.

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

April 13, 2017

The Honorable Jason Buelterman
Mayor
City of Tybee Island
PO Box 2749
Tybee Island, Georgia 31328-2749

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Buelterman,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, 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, INC.

Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

ATLANTIC COAST
CONSULTING, INC.

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

April 13, 2017

The Honorable Eddie DeLoach
Mayor
City of Savannah
PO Box 1027
Savannah, Georgia 31401-1027

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor DeLoach,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, Inc., this letter is to provide such notice. You will also be notified if an amended CCR Management Plan is submitted to EPD.

Sincerely,
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Jeff Thomas, PE

Cc: Terry Darragh, WM
Shawn Carroll, WM
File

ATLANTIC COAST
CONSULTING, INC.

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

April 13, 2017

The Honorable Glenn Jones
Mayor
City of Port Wentworth
305 S Coastal Highway
Port Wentworth, Georgia 31407-2001

RE: Notification of Submittal of a Coal Combustion Residuals (CCR) Management Plan
Waste Management of Georgia, Inc.- Superior Landfill & Recycling Center
Chatham County, Georgia

Dear Mayor Jones,

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 10, 2017, a Minor Modification Permit Application for Superior Landfill & Recycling Center was submitted to EPD. On behalf of Waste Management of Georgia, 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, INC.

Jeff Thomas, PE

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Shawn Carroll, WM
File

ATLANTIC COAST
CONSULTING, INC.

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

RECEIVED

APR 10 2017

SOLID WASTE
MANAGEMENT PROGRAM

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

RE: Waste Management of Georgia, Inc.
Superior Landfill & Recycling Center
Minor Modification – Coal Combustible Residuals (CCR) Management Plans
Permit Number: 025-070D (MSWL)

Dear William,

Please find enclosed an executed minor modification form and four copies of the revised Plan Sheets 1, 22, 22A, 23, 25C and 36 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.

CCR Guidance General Requirements

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.*

Response: Superior Landfill & Recycling Center 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 Procedures on Sheet 22A to define the annual reporting requirements related to CCR management and fugitive dust control. *

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, Item R of the Operational Narrative on Sheet 22 has been modified to define the estimated annual and maximum daily tonnages of CCR to be accepted at the facility. Additionally, Section 1, Item R defines the estimated maximum ratio of MSW to CCR. Amount of MSW received ?

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 Procedures on Sheet 22 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 3 of the Operational Procedures on Sheet 22 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 3 of the Operational Procedures on Sheet 22 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 4 of the Operational Procedures on Sheet 22 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.*

Revision: Section 2 of the Operational Procedures on Sheet 43 has been revised to describe co-mingling of CCR and MSW at the working face. Additionally, Section 19 on Sheet 22 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.*

Revision: Section 2 of the Operational Procedures on Sheet 22 has been revised to specify operator training related to CCR waste streams.

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

Revision: Sheet 36 (Solidification Plan), as currently approved, addressed the use of ash as a bulking agent. Additionally, it has been modified to include the use of CCR waste streams as an acceptable bulking agent.

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*

Response: The D&O plan does not mention the permission to recover 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.*

Revision: Section 19 of the Operational Procedures on Sheet 22 has 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 19 of the Operational Procedures on Sheet 22 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: Section 14 of the Operational Procedures on Sheet 22 has been revised to include a water truck in the list of Site Equipment. The use of a water truck to provide dust control was selected as it will be equipment available at the facility.

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

Revision: Section 19 of the Operational Procedures on Sheet 22 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 19 of the Operational Procedures on Sheet 22 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 19 of the Operational Procedures on Sheet 22 has been modified to require preparation and submission of an annual dust control report. Additionally, Section 38 on Sheet 22A was added to allow for the annual fugitive dust report to be included with the annual CCR management plan renewal requirements.

ATLANTIC COAST CONSULTING, INC.

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).*

      Response: 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.*

      Response: 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.*

      Response: Revised base grade settlement analysis and pipe crushing calculations to include CCR loading are attached and demonstrate the integrity of the facility's base grades and leachate collection piping. These calculations require no revisions to the D&O plans.

   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.*

      Repsonse: Revisions to the geocomposite design calculations are not required because the current D&O plans already require a product that is capable of handling the proposed MSW/CCR loading. The attached Leachate Collection Pipe Design Calculations demonstrate the expected pressures on the existing system that are less than the required compressive strength of the geocomposite (per Sheet 26D)

ATLANTIC COAST CONSULTING, INC.

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

Response: 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.*

Response: The estimated maximum ratio of MSW to CCR of 5:1 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 8 of the Operational Procedures on Sheet 22 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 bc 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.*

Response: 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. Additionally, the site specific SWPPP addresses the potential stormwater impacts with waste materials as required by the NPDES Stormwater Industrial Activity permit.

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.*

Response: 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.*

Response: Since no changes in design are required as a condition of the MSW/CCR loading, then there are no previously constructed cells excluded.

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 2 of the Operational Procedures on Sheet 22 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 2 of the Operational Procedures on Sheet 22.

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

   Revision: Per Sheet 36 (Solidification Plan) the CCR material will be subject to the requirements of the Waste Acceptance Plan.

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 2 of the Operational Procedures on Sheet 22. 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 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.

   Revision: The Closure/Post Closure Care Plan on Sheet 23 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).

   Revision: Sheet 25C of the Groundwater Monitoring Plan has been modified 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.

   Revision: Section 38 of the Operational Procedures on Sheet 22A 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.

   Revision: Section 38 of the Operational Procedures on Sheet 22A 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.

ATLANTIC COAST CONSULTING, INC.

Please let me know if you have any questions.

Sincerely,

ATLANTIC COAST CONSULTING, INC.

Jeff Thomas, P.E.
Project Engineer

cc: Shawn Carroll, WM
Robert Brown, ACC

DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION

REQUEST FOR MINOR MODIFICATION TO SOLID WASTE HANDLING PERMIT

Instructions This form must accompany all requests by the Permittee requiring a minor modification for the subject facility. Attached modifications of the Design and Operation (D&O) Plan must be factual and complete. This form and supporting documents must be submitted directly to the EPD Regional office to which the facility is assigned. For modifying a D&O Plan, please include three (3) copies of all pertinent sheets. **Follow-up submittals require the Permittee to submit a new request form.**

APPLICANT TO COMPLETE THE REVERSE SIDE

FOR EPD USE ONLY

Official Facility Name ______________________________

Permit No. ____________ Modification Type ____________________

Review Deadline Date ______________________________

Received By ____________ Date ________ Comments* ____________

Reviewed By ____________ Date ________ Comments* ____________

Action By ____________ Date ________ Comments* ____________

*Disposition: Approved/Denied/Incomplete

Reply to Appropriate EPD District Office

1 Georgia EPD Mountain District
P.O. Box 3250
Cartersville, Georgia 30120
(770) 387-4900
ATTN: Mr. James Cooley, Mgr.

2 Georgia EPD West Central District
2640 Shurling Drive
Macon, Georgia 31202
(478) 751-6612
ATTN: Mr. Todd Bethune, Mgr.

3 Georgia EPD Northeast District
745 Gaines School Road
Athens, Georgia 30605
(706) 369-6376
ATTN: Mr. Derrick Williams, Mgr.

4 Georgia EPD East Central District
3524 Walton Way Ext.
Augusta, GA 30909
(706) 667-4343
ATTN: Mr. Jeff Darley, Mgr.

5 Georgia EPD Coastal District
400 Commerce Center Drive
Brunswick, Georgia 31523-8251
(912) 264-7284
ATTN: Mr. Bruce Foisy, Mgr.

6 Georgia EPD Southwest District
2024 Newton Road
Albany, Georgia 31708
(229) 430-4144
ATTN: Ms. Lisa Myler, Mgr.

NOTE: All minor modifications for private industrial facilities except for those facilities located in the Coastal District should be directed to:
Georgia Environmental Protection Division
Solid Waste Management Program
4244 International Parkway, Suite 104
Atlanta, Georgia 30354
(404) 362-2692
ATTN: Solid Waste Management Program

FACILITY Superior Landfill & Recycling Center Site 2 PERMIT NO. 025-070D(MSWL)

Pursuant to the requirements of the Georgia Comprehensive Solid Waste Management Act, O.C.G.A 12-8-20, et seq. and the Rules of the Georgia Department of Natural Resources, Chapter 391-3-4-.02(4), Solid Waste Management, both as amended, the undersigned hereby:

1 Requests a minor modification as represented in the attached modified D&O Plan, and/or supporting documents;

2 Certifies that the Permittee is the rightful owner of the facility and can verify that this proposed modification shall conform to all local zoning/land use ordinances; and

3 Certifies that the information provided in or submitted by the facility Permittee as part of this request form and modified D&O Plan is true and correct, and if approved, the facility Permittee agrees to comply with provisions of this minor modification to the D&O Plan, provisions of the Act Rules, and conditions of the Permit.

I PERMITTEE Waste Management of Georgia, Inc.

ADDRESS 3001 Little Neck Road PHONE (912) 927-6113

CITY Savannah STATE Georgia ZIP 31419

AUTHORIZED OFFICIAL Tim Bassett

SIGNATURE [signature] DATE 3-24-17

TITLE Environmental Protection Manager

MAILING ADDRESS 3001 Little Neck Road

CITY Savannah STATE Georgia ZIP 31419

II Briefly describe the exact changes to be made to the permit conditions and explain why the change is needed.

Revision of the Facilities Design & Operations Plan to incorporate Coal Combustion Residual Management Plan and Procedures.

III Attached documents include:

Revised Design & Operations Plan Sheets

WASTE MANAGEMENT

WASTE MANAGEMENT OF GEORGIA, INC.

3001 LITTLE NECK ROAD | SAVANNAH, GEORGIA 31419

SUPERIOR LANDFILL & RECYLING CENTER
CCR MANAGEMENT & GROUNDWATER PLANS

PERMIT #: 025-070D(MSWL)

GEORGIA REGISTERED NO. 22184 PROFESSIONAL ENGINEER JEFFERY S. THOMAS
5/22/17

DESIGN CALCULATIONS

ATLANTIC COAST CONSULTING, INC.

MAY 2017

Design Calculations Notebook

Table of Contents

ATLANTIC COAST CONSULTING, INC.

Sections:

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ATLANTIC COAST CONSULTING, INC.

1

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Design Calculations Notebook

IN THIS SECTION:

Stability Analysis

OBJECTIVE: Re-evaluate the global stability of the final configuration of the waste mass co-mingled with CCR at Superior Landfill with respect to failure surfaces passing through the underlying subgrade. This analysis is an amendment to the currently approved global stability calculations by ACC dated March 25, 2015 and approved June 17, 2015. This amended analysis is intended to evaluate the global stability of the landfill mass and perimeter berm for the most critical cross-section as affected by the proposed minor modification grading revisions to the current Design and Operation Plan (D&O) dated June 1, 2011.

BACKGROUND: The global stability analysis contained in the original design calculation submittal (dated 1/7/2010 and approved 6/1/2011) were derived for a cross-section near Section 'C' shown on minor modification Sheet 3 dated 02/05/2014. This section is not affected by the proposed buffer grading revisions. Therefore, a section near Section 'A' shown on Sheet 3 of the proposed minor modification was selected as the valid critical section for this analysis.

METHOD: The waste mass global stability was evaluated for both circular and non circular failure surfaces under static and seismic conditions. For the purpose of this analysis, a critical slope was selected from the disposal areas, which is represented by its longest length and steepest grade. The section selected was considered to be representative of the worst case scenario for the disposal area and the one most affected by the proposed minor modification grading revisions. The location of the critical slope section utilized in the stability analyses is presented in the attached Figure 1. The results of a previously completed subsurface exploration outlined in the report "Report of the Phase I and Phase II Hydrogeologic/Geotechnical Investigation for Superior Landfill and Recycling Center" by SEC Donohue, Inc., dated April, 1992 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 2.

To identify critical failure planes, the computer program XSTABL Version 5.202 was used to perform stability calculations utilizing the Bishop method of slices for circular surfaces and the Simplified Janbu Method for non-circular surfaces. XSTABL was utilized to search through the anticipated zone of failures for each described scenario to identify the critical failure planes with the lowest factor of safety.

The first step in the evaluation was to input the geometry and soil/waste mass into XSTABL and run static analyses on the landfill mass for both circular and non-circular failure surfaces. This allows for the identification of the critical failure planes with the lowest factor of safety for static conditions.

Once the static stability analysis is complete, the input files are amended to include a horizontal acceleration thereby simulating a seismic event. It is worth noting that the point at which the waste mass becomes marginally stable is also known as the yield acceleration (i.e. the horizontal acceleration at which the factor of safety against failure approaches or is equal to one). This yield acceleration can then be compared to the Maximum Horizontal Acceleration (MHA) in lithified earth material expected for the site to determine if the mass remains stable during a predicted seismic event. The Maximum Horizontal Acceleration (MHA) in lithified earth material is derived in accordance with Federal Subtitle D regulations that state the "Maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration depicted on a seismic hazard map, with a 90 percent or greater probability that the acceleration will not be exceeded in 250 years..." Seismic hazard maps prepared by the United States Geological Survey (Algermissen et al., 1990) provide an MHA of 0.160 g for Chatham County, Georgia.

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, from a compilation of strength parameters from laboratory tests, and from other technical publications. The soil properties used for the slope stability analyses were based on the laboratory testing data from the 1992 SEC Donohue report, and based on anticipated strength gain in the clay layer after consolidation of the clay layer.

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

- The seasonal high groundwater surface will be consistent with the April 1992 SEC Donohue Potentiometric Surface for the surficial aquifer.
- The seismic coefficient will be 0.16 (horizontal) and 0.0 (vertical).

Soil Layer	Unit Weight (pcf)	Cohesion (psf)	Friction Angle (degrees)
Engineered Fill/Cypresshead Formation (Sand Layer)	120	0	30
Cypresshead Formation (Clay Layer)	120	0.25 x Vertical Effective Stress	0
Municipal Solid Waste (5:1 Ration MSW/CCR)	79	500	35

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

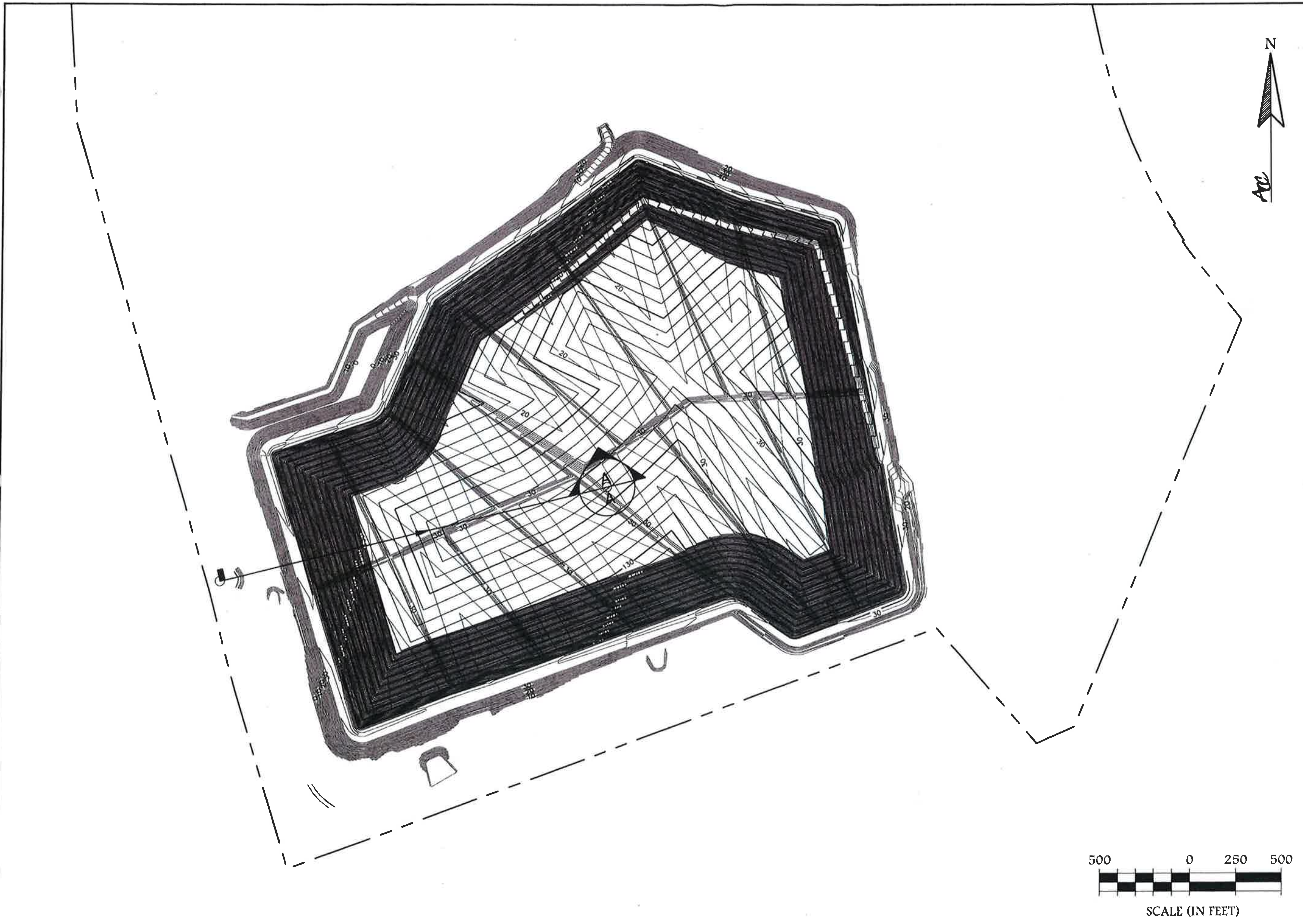
The results of the stability analyses are summarized below and detailed in the attached XSTABL outputs.

RESULTS: The XSTABL program outputs for the critical analyses show the geometry of the critical cross section evaluated for failure, the location of the critical failure surfaces and the associated factors of safety. The minimum factor of safety against failure for the evaluation scenarios are as follows:

Factor of Safety (Circular, w/o seismic) = 2.646
Factor of Safety (Block, w/o seismic) = 3.978
Factor of Safety (Circular, w seismic) = 1.371
Factor of Safety (Block, w seismic) = 1.578

The calculated factors of safety for static conditions are greater than 1.5, and are therefore considered adequate in terms of long term stability. Since the calculated factors of safety for the seismic conditions are greater than 1.0, no permanent deformations are expected in the landfill subgrade when subjected to the MHA.

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



ATLANTIC COAST CONSULTING, INC.
7 East Congress Street
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Savannah, GA 31401
p.912-236-3471
f.912-236-3472
www.atlcc.net

PROJECT:

SUPERIOR LANDFILL
BUFFER GRADING
MINOR MODIFICATION

WASTE MANAGEMENT

WASTE MANAGEMENT
OF GEORGIA, INC.
3001 LITTLE NECK ROAD
SAVANNAH, GA 31419

REVISIONS

Drawn by:	Checked by:

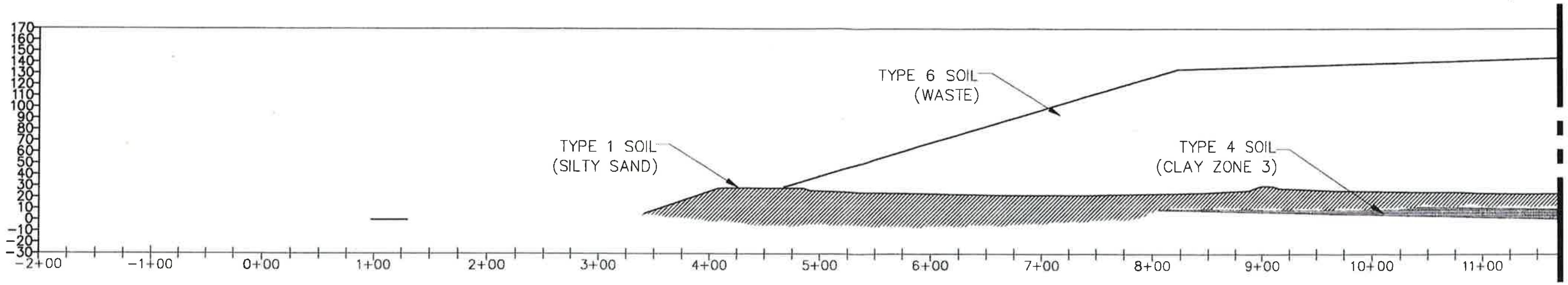
PROJECT NUMBER:

I010-215

MARCH 2015

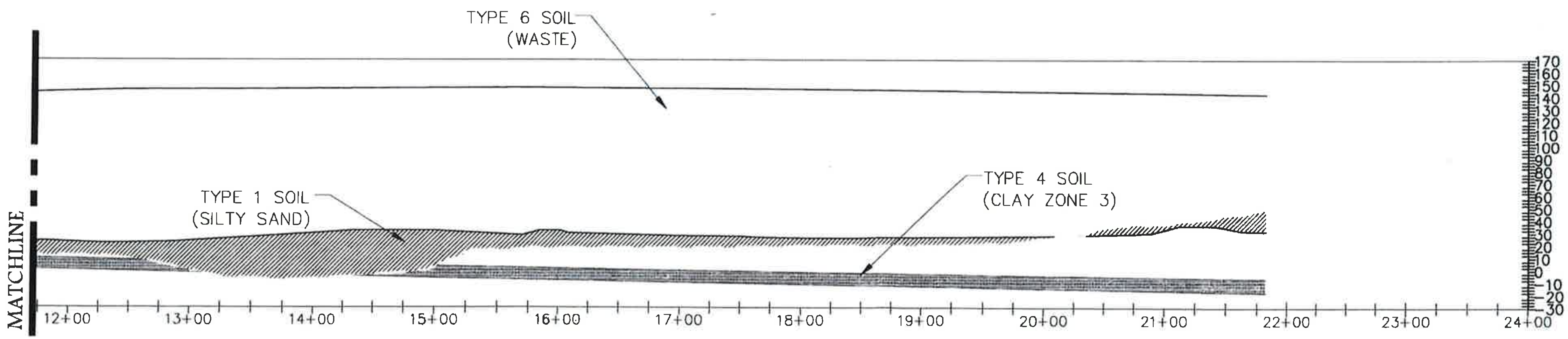
CROSS SECTION
LOCATION PLAN

Figure 2



LANDFILL CROSS SECTION A' (STA: 0+00~11+75)

SCALE H: 1"=100'
SCALE V: 1"=100'



LANDFILL CROSS SECTION A' (STA: 11+75~21+82)

SCALE H: 1"=100'
SCALE V: 1"=100'

NOTE:
SUB-SURFACE DATA DERIVED FROM "REPORT OF PHASE I AND PHASE II HYDROGEOLOGICAY GEOTECHNICAL INVESTIGATION FOR SUPERIOR LANDFILL AND RECYCLING CENTER" BY SEC DONOHUE, INC. DATED APRIL 1992.

ATLANTIC COAST CONSULTING, INC.
7 East Congress Street
Suite 801
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f.912-236-3472
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PROJECT:

SUPERIOR LANDFILL
BUFFER GRADING
MINOR MODIFICATION

WASTE MANAGEMENT

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OF GEORGIA, INC.
3001 LITTLE NECK ROAD
SAVANNAH, GA 31419

REVISIONS

Drawn by:	Checked by:

PROJECT NUMBER:

IO10-215

MARCH 2015

CROSS SECTION

Figure 1

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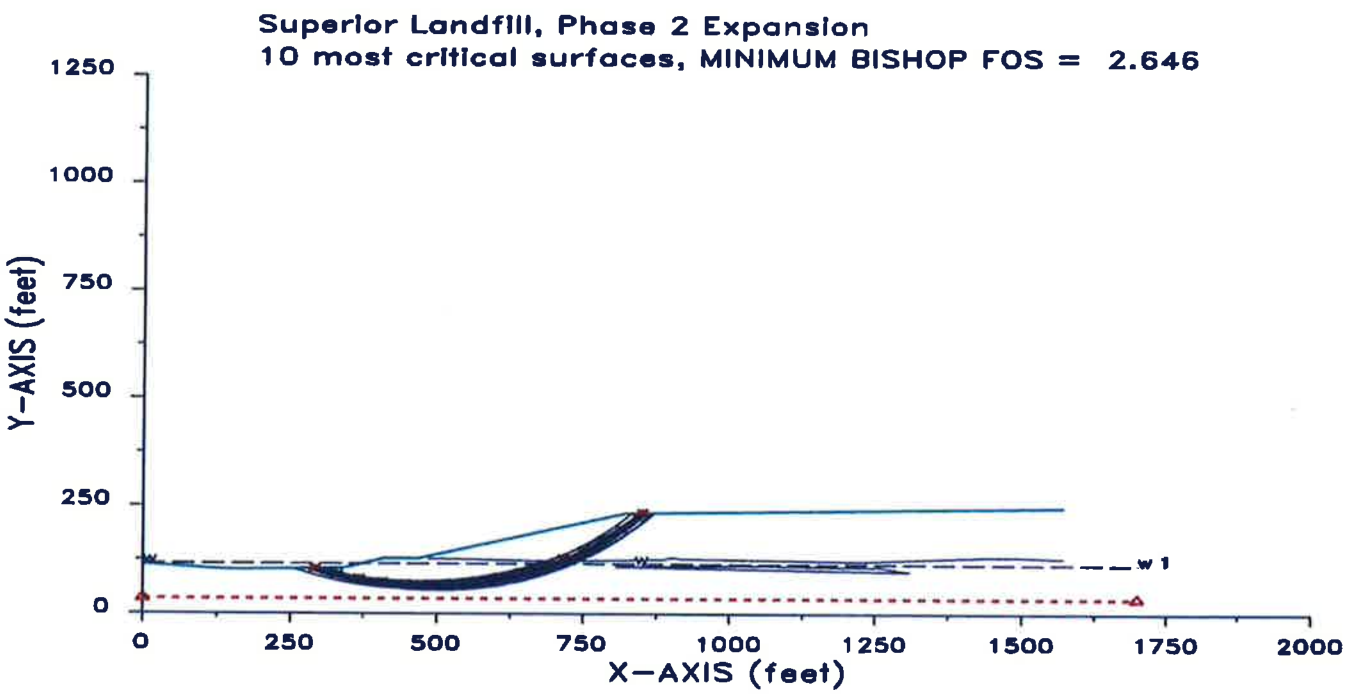

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*        Slope Stability Analysis        *
*               using the                *
*            Method of Slices            *
*                                        *
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*                                        *
*  Ver. 5.202                96 Ä 1599   *
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```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	114.1	146.9	102.0	1
2	146.9	102.0	341.3	105.6	1
3	341.3	105.6	408.6	128.0	1
4	408.6	128.0	466.7	128.0	1
5	466.7	128.0	822.3	233.4	6
6	822.3	233.4	1571.9	247.5	6

13 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	484.7	128.0	709.8	121.9	1
2	709.8	121.9	886.8	126.0	1
3	886.8	126.0	899.1	130.0	1
4	899.1	130.0	908.9	130.0	1
5	908.9	130.0	915.1	128.0	1
6	915.1	128.0	1228.6	122.0	1
7	1228.6	122.0	1433.7	132.0	1
8	1433.7	132.0	1500.0	132.0	1
9	1500.0	132.0	1571.9	128.3	1
10	804.6	109.0	1040.0	111.9	4
11	1040.0	111.9	1261.2	108.4	4
12	1261.2	108.4	1310.6	97.9	4
13	804.6	109.0	1310.6	97.9	1

ISOTROPIC Soil Parameters

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	30.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

2000 trial surfaces will be generated and analyzed.

100 Surfaces initiate from each of 20 points equally spaced along the ground surface between x = 200.0 ft and x = 550.0 ft

Each surface terminates between x = 800.0 ft and x = 1300.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

40.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED BISHOP METHOD * * * * *

The most critical circular failure surface is specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	292.11	104.69
2	329.75	91.17
3	368.35	80.69
4	407.67	73.33
5	447.45	69.14
6	487.44	68.13
7	527.38	70.32
8	567.02	75.69
9	606.10	84.21
10	644.38	95.82
11	681.60	110.45
12	717.54	128.01
13	751.97	148.38
14	784.66	171.44
15	815.40	197.03
16	844.00	224.99
17	851.82	233.96

**** Simplified BISHOP FOS = 2.646 ****

The following is a summary of the TEN most critical surfaces

SU_ACIR.OPT
Problem Description : Superior Landfill, Phase 2 Expansion

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	2.646	480.03	568.67	500.59	292.11	851.82	7.681E+08
2.	2.650	497.77	543.36	484.49	292.11	870.79	8.725E+08
3.	2.652	472.42	548.60	479.14	292.11	833.16	6.722E+08
4.	2.655	502.45	513.16	459.45	292.11	867.54	8.599E+08
5.	2.656	465.27	559.81	501.86	255.26	846.48	8.340E+08
6.	2.657	472.62	600.21	534.28	273.68	861.77	8.636E+08
7.	2.658	486.35	568.60	510.65	273.68	871.89	9.283E+08
8.	2.660	499.24	516.05	452.27	310.53	852.76	7.336E+08
9.	2.661	502.67	521.73	458.87	310.53	859.85	7.707E+08
10.	2.663	467.77	610.46	535.41	292.11	848.26	7.451E+08

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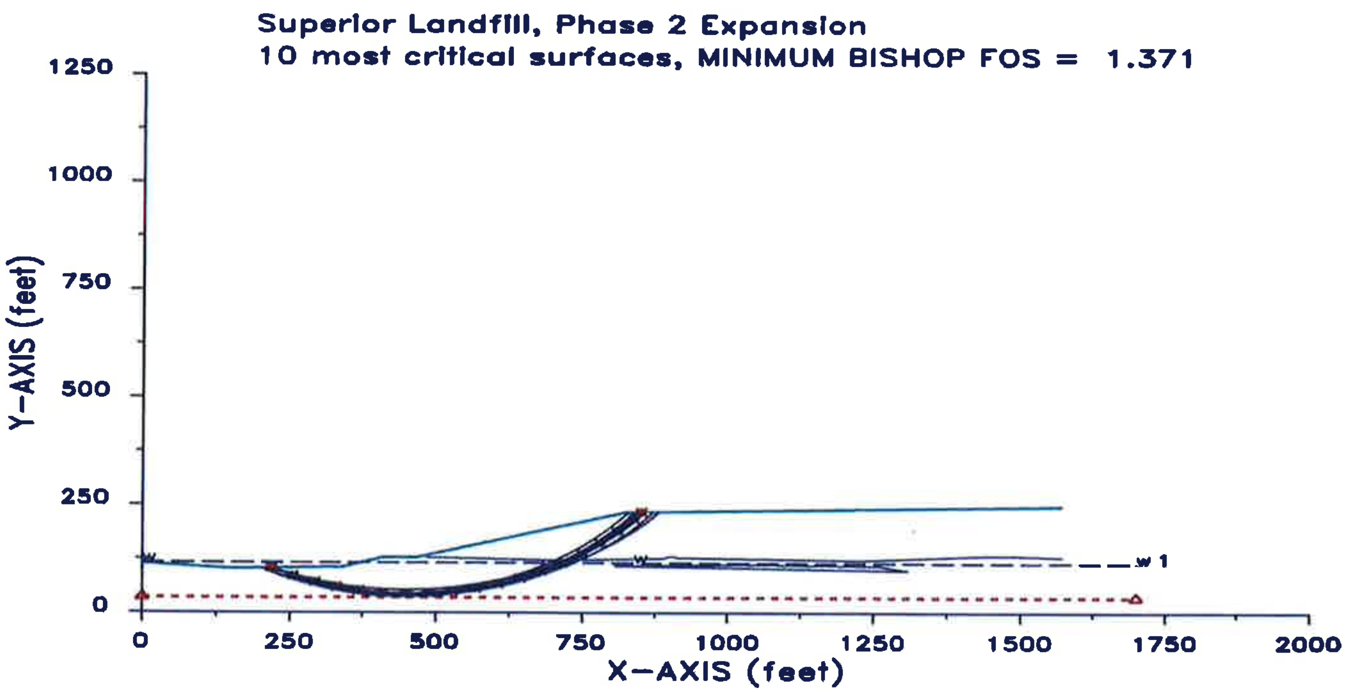

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*      Slope Stability Analysis          *
*           using the                    *
*        Method of Slices                *
*                                        *
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*      Moscow, ID 83843, U.S.A.          *
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*                                        *
*  Ver. 5.202                96 Ä 1599   *
******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	114.1	146.9	102.0	1
2	146.9	102.0	341.3	105.6	1
3	341.3	105.6	408.6	128.0	1
4	408.6	128.0	466.7	128.0	1
5	466.7	128.0	822.3	233.4	6
6	822.3	233.4	1571.9	247.5	6

13 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	484.7	128.0	709.8	121.9	1
2	709.8	121.9	886.8	126.0	1
3	886.8	126.0	899.1	130.0	1
4	899.1	130.0	908.9	130.0	1
5	908.9	130.0	915.1	128.0	1
6	915.1	128.0	1228.6	122.0	1
7	1228.6	122.0	1433.7	132.0	1
8	1433.7	132.0	1500.0	132.0	1
9	1500.0	132.0	1571.9	128.3	1
10	804.6	109.0	1040.0	111.9	4
11	1040.0	111.9	1261.2	108.4	4
12	1261.2	108.4	1310.6	97.9	4
13	804.6	109.0	1310.6	97.9	1

ISOTROPIC Soil Parameters

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	30.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

A horizontal earthquake loading coefficient
of .160 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

2000 trial surfaces will be generated and analyzed.

```
 100 Surfaces initiate from each of  20 points equally spaced
along the ground surface between  x =    200.0 ft
                              and  x =    550.0 ft


Each surface terminates between   x =    800.0 ft
                             and   x =   1300.0 ft


Unless further limitations were imposed, the minimum elevation
at which a surface extends is  y =       .0 ft


   40.0 ft line segments define each trial failure surface.
```

ANGULAR RESTRICTIONS

```
  The first segment of each failure surface will be inclined
  within the angular range defined by :

          Lower angular limit :=   -45.0 degrees
          Upper angular limit :=  (slope angle - 5.0) degrees
```

```
************************************************************************
    --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
************************************************************************
```

USER SELECTED option to maintain strength greater than zero

Factors of safety have been calculated by the :

```
* * * * *   SIMPLIFIED BISHOP METHOD   * * * * *
```

The most critical circular failure surface
is specified by 19 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	218.42	103.32
2	254.47	85.99
3	291.77	71.55
4	330.09	60.09
5	369.20	51.68

6	408.85	46.38
7	448.79	44.21
8	488.78	45.20
9	528.56	49.34
10	567.90	56.59
11	606.54	66.92
12	644.25	80.26
13	680.79	96.53
14	715.94	115.62
15	749.48	137.43
16	781.19	161.81
17	810.89	188.60
18	838.38	217.66
19	851.53	233.95

**** Simplified BISHOP FOS = 1.371 ****

The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Resisting Moment (ft-lb)
1.	1.371	456.25	551.74	507.58	218.42	851.53	9.307E+08
2.	1.371	459.04	555.67	512.36	218.42	857.45	9.650E+08
3.	1.372	456.03	582.61	543.68	200.00	873.06	1.119E+09
4.	1.372	459.82	545.30	503.60	218.42	855.25	9.568E+08
5.	1.372	442.72	548.67	507.50	200.00	840.31	9.244E+08
6.	1.372	454.09	623.08	578.85	200.00	882.73	1.167E+09
7.	1.373	435.56	549.43	504.78	200.00	828.78	8.534E+08
8.	1.373	449.40	603.68	551.10	218.42	857.69	9.466E+08
9.	1.373	447.36	543.05	504.82	200.00	846.33	9.641E+08
10.	1.374	449.15	538.69	501.91	200.00	847.84	9.765E+08

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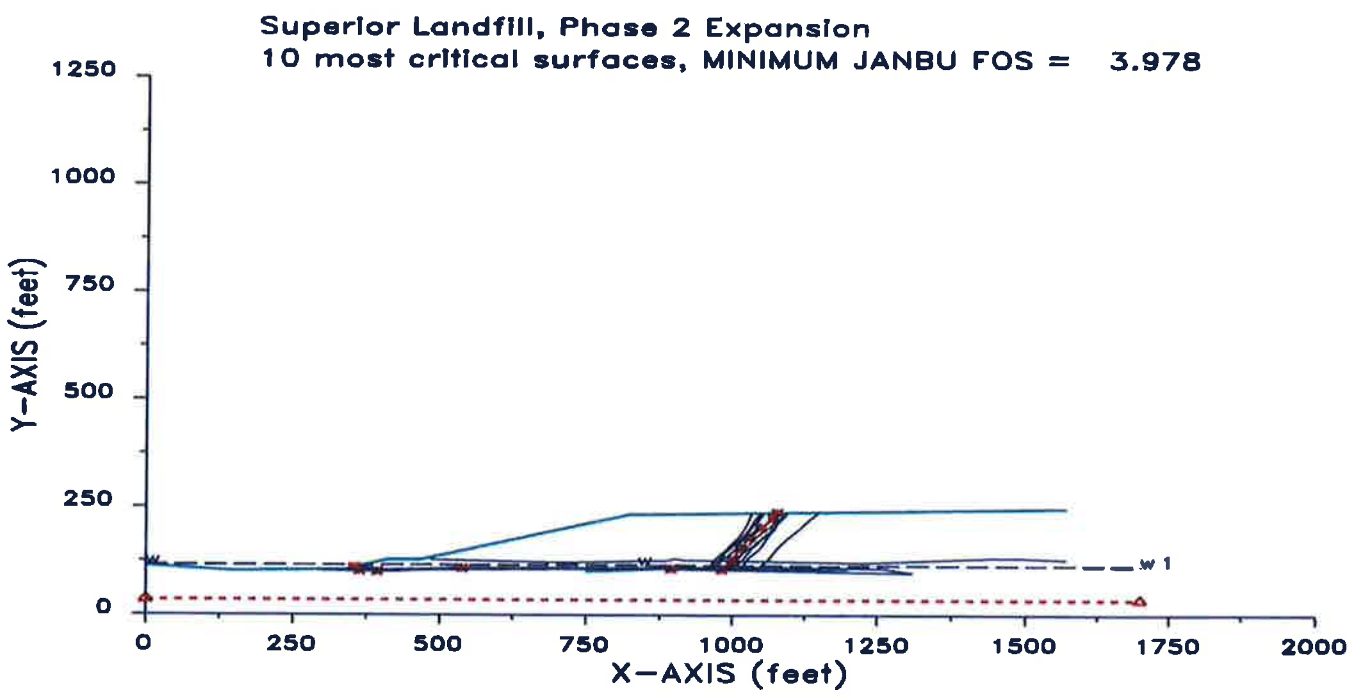

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*        Slope Stability Analysis        *
*              using the                 *
*           Method of Slices             *
*                                        *
*         Copyright (C) 1992 Ä 97        *
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*          All Rights Reserved           *
*                                        *
*  Ver. 5.202                96 Ä 1599   *
******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	114.1	146.9	102.0	1
2	146.9	102.0	341.3	105.6	1
3	341.3	105.6	408.6	128.0	1
4	408.6	128.0	466.7	128.0	1
5	466.7	128.0	822.3	233.4	6
6	822.3	233.4	1571.9	247.5	6

13 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	484.7	128.0	709.8	121.9	1
2	709.8	121.9	886.8	126.0	1
3	886.8	126.0	899.1	130.0	1
4	899.1	130.0	908.9	130.0	1
5	908.9	130.0	915.1	128.0	1
6	915.1	128.0	1228.6	122.0	1
7	1228.6	122.0	1433.7	132.0	1
8	1433.7	132.0	1500.0	132.0	1
9	1500.0	132.0	1571.9	128.3	1
10	804.6	109.0	1040.0	111.9	4
11	1040.0	111.9	1261.2	108.4	4
12	1261.2	108.4	1310.6	97.9	4
13	804.6	109.0	1310.6	97.9	1

ISOTROPIC Soil Parameters

---

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	30.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

1000 trial surfaces will be generated and analyzed.

4 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 30.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	300.0	102.6	420.0	100.0	.0
2	421.0	100.0	547.9	109.4	.0
3	748.9	100.0	900.0	108.5	.0
4	950.0	106.0	1200.0	107.0	.0

```
***************************************************************************
    --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
***************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
***************************************************************************
```

```
    ---------------------------------------------------------------
    USER SELECTED option to maintain strength greater than zero
    ---------------------------------------------------------------
```

```
****************************************************************
**     Factor of safety calculation for surface #   438       **
**     failed to converge within FIFTY iterations             **
**                                                            **
**    The last calculated value of the FOS was   9.0287       **
**    This will be ignored for final summary of results       **
****************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	357.51	111.00
2	373.26	101.01
3	487.63	104.94
4	883.45	107.57
5	1015.60	106.26
6	1016.29	136.25
7	1020.14	166.01
8	1035.67	191.67
9	1036.94	221.64
10	1052.90	237.74

```
****************************************************************
**     Factor of safety calculation for surface #   774       **
**     failed to converge within FIFTY iterations             **
**                                                            **
**    The last calculated value of the FOS was  12.2315       **
**    This will be ignored for final summary of results       **
****************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	287.70	104.61
2	304.80	102.50
3	519.68	107.31
4	878.11	107.27
5	990.34	106.16
6	990.62	136.16
7	1002.86	163.55
8	1007.91	193.12
9	1027.10	216.18
10	1038.34	237.46

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 10 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	354.47	109.98
2	363.39	102.43
3	393.33	100.58
4	538.35	108.69
5	895.02	108.22
6	981.73	106.13
7	1000.74	129.33
8	1014.57	155.96
9	1030.54	181.36
10	1049.97	204.21
11	1071.13	225.47
12	1077.58	238.20

** Corrected JANBU FOS = 3.978 ** (Fo factor = 1.060)

Failure surface No. 2 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	366.86	114.11
2	378.62	109.53
3	407.16	100.28
4	543.45	109.07
5	889.76	107.92
6	954.28	106.02
7	975.34	127.38
8	992.89	151.71
9	1013.43	173.58
10	1028.52	199.51
11	1041.83	226.39
12	1051.53	237.71

** Corrected JANBU FOS = 4.030 ** (Fo factor = 1.062)

Failure surface No. 3 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	321.18	105.23
2	337.38	101.79
3	543.57	109.08
4	893.96	108.16
5	995.72	106.18
6	1009.12	133.02
7	1025.03	158.45
8	1042.64	182.75
9	1063.64	204.17
10	1084.69	225.54
11	1088.33	238.40

** Corrected JANBU FOS = 4.040 ** (Fo factor = 1.058)

Failure surface No. 4 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.40	104.71
2	307.12	102.45
3	478.31	104.25
4	894.18	108.17
5	986.14	106.14
6	1007.23	127.48
7	1025.33	151.40
8	1046.26	172.90
9	1066.04	195.45
10	1074.61	224.20
11	1085.79	238.36

** Corrected JANBU FOS = 4.057 ** (Fo factor = 1.057)

Failure surface No. 5 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	346.97	107.49
2	353.58	101.44
3	494.49	105.44
4	899.39	108.47
5	1013.15	106.25
6	1027.23	132.75
7	1047.93	154.46
8	1061.03	181.45
9	1075.05	207.97
10	1092.23	232.56
11	1096.53	238.56

** Corrected JANBU FOS = 4.105 ** (Fo factor = 1.060)

Failure surface No. 6 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	308.93	105.00
2	312.93	102.32
3	470.54	103.67
4	893.53	108.14
5	1040.97	106.36
6	1061.49	128.24
7	1076.30	154.33
8	1094.86	177.90
9	1115.54	199.64
10	1134.50	222.89
11	1150.48	239.57

** Corrected JANBU FOS = 4.127 ** (Fo factor = 1.054)

Failure surface No. 7 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	366.17	113.88
2	386.26	100.73
3	486.81	104.87
4	881.92	107.48
5	956.58	106.03
6	971.59	132.00
7	991.93	154.05
8	1013.13	175.28
9	1031.63	198.90
10	1047.33	224.46
11	1055.23	237.78

** Corrected JANBU FOS = 4.134 ** (Fo factor = 1.062)

Failure surface No. 8 specified by 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	298.75	104.81
2	301.95	102.56
3	534.82	108.43
4	892.57	108.08
5	966.69	106.07
6	982.28	131.70
7	993.77	159.41
8	1013.02	182.42
9	1025.44	209.73
10	1033.68	237.38

** Corrected JANBU FOS = 4.134 ** (Fo factor = 1.061)

Failure surface No. 9 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	313.60	105.09
2	333.86	101.87
3	541.96	108.96
4	894.57	108.19
5	1000.89	106.20
6	1018.71	130.34
7	1033.39	156.50
8	1053.43	178.82
9	1074.08	200.59
10	1077.42	230.40
11	1078.67	238.22

** Corrected JANBU FOS = 4.175 ** (Fo factor = 1.059)

Failure surface No.10 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	303.51	104.90
2	305.98	102.47
3	515.88	107.03
4	884.35	107.62
5	962.93	106.05
6	983.47	127.92
7	1003.43	150.32
8	1019.02	175.95
9	1040.02	197.37
10	1046.33	226.70
11	1053.52	237.75

** Corrected JANBU FOS = 4.185 ** (Fo factor = 1.059)

```
**********************************************************************
**                                                                  **
**  Out of the   1000 surfaces generated and analyzed by XSTABL,   **
**         2 surfaces were found to have MISLEADING FOS values.    **
**                                                                  **
**********************************************************************
```

The following is a summary of the TEN most critical surfaces

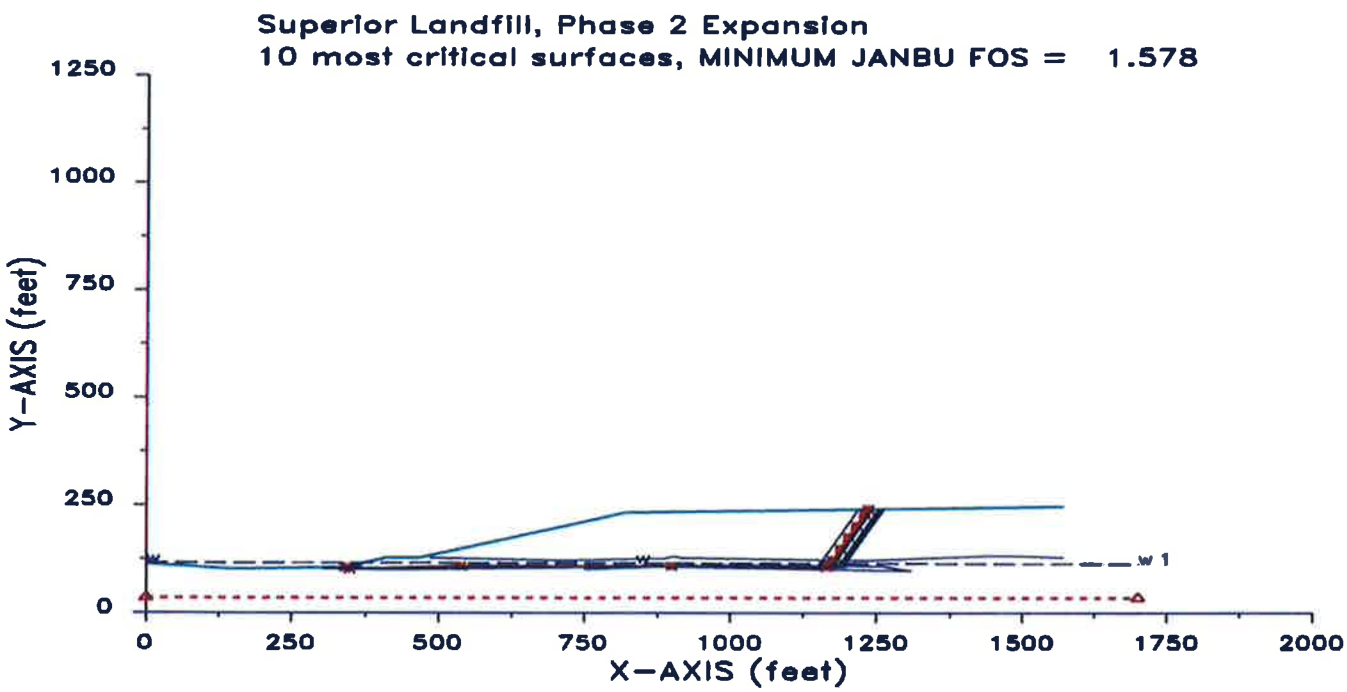
Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	3.978	1.060	354.47	1077.58	2.154E+06
2.	4.030	1.062	366.86	1051.53	2.170E+06
3.	4.040	1.058	321.18	1088.33	2.167E+06
4.	4.057	1.057	293.40	1085.79	2.323E+06
5.	4.105	1.060	346.97	1096.53	2.255E+06
6.	4.127	1.054	308.93	1150.48	2.433E+06
7.	4.134	1.062	366.17	1055.23	2.327E+06
8.	4.134	1.061	298.75	1033.68	2.099E+06

9.	4.175	1.059	313.60	1078.67	2.168E+06
10.	4.185	1.059	303.51	1053.52	2.287E+06

* * * END OF FILE * * *

SU_ABLKQ 4-06-** 14:43



XSTABL File: SU_ABLKQ   4-06-**   14:43

```
*******************************************
*              X S T A B L                *
*                                         *
*        Slope Stability Analysis         *
*              using the                  *
*           Method of Slices              *
*                                         *
*        Copyright (C) 1992 Ä 97          *
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*  Ver. 5.202                 96 Ä 1599   *
*******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

---

6 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	114.1	146.9	102.0	1
2	146.9	102.0	341.3	105.6	1
3	341.3	105.6	408.6	128.0	1
4	408.6	128.0	466.7	128.0	1
5	466.7	128.0	822.3	233.4	6
6	822.3	233.4	1571.9	247.5	6

13 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	484.7	128.0	709.8	121.9	1
2	709.8	121.9	886.8	126.0	1
3	886.8	126.0	899.1	130.0	1
4	899.1	130.0	908.9	130.0	1
5	908.9	130.0	915.1	128.0	1
6	915.1	128.0	1228.6	122.0	1
7	1228.6	122.0	1433.7	132.0	1
8	1433.7	132.0	1500.0	132.0	1
9	1500.0	132.0	1571.9	128.3	1
10	804.6	109.0	1040.0	111.9	4
11	1040.0	111.9	1261.2	108.4	4
12	1261.2	108.4	1310.6	97.9	4
13	804.6	109.0	1310.6	97.9	1

ISOTROPIC Soil Parameters

6 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	30.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

A horizontal earthquake loading coefficient
of .160 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

1000 trial surfaces will be generated and analyzed.

4 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 30.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	300.0	102.6	420.0	100.0	.0
2	421.0	100.0	547.9	109.4	.0
3	748.9	100.0	900.0	108.5	.0
4	950.0	106.0	1200.0	107.0	.0

WARNING - limitation boundaries have been specified !,
These are ignored for RANKINE block analysis

Factors of safety have been calculated by the :

* * * * * SIMPLIFIED JANBU METHOD * * * * *

The 10 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	341.06	105.60
2	348.05	101.56
3	537.34	108.62
4	899.27	108.46
5	1164.47	106.86
6	1167.49	109.88
7	1175.08	123.02
8	1188.93	149.63
9	1202.78	176.24
10	1216.64	202.86
11	1230.49	229.47
12	1236.59	241.19

** Corrected JANBU FOS = 1.578 ** (Fo factor = 1.055)

Failure surface No. 2 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	350.17	108.55
2	362.83	101.24
3	509.73	106.57
4	898.86	108.44
5	1189.71	106.96
6	1192.25	109.49
7	1199.79	122.55
8	1213.64	149.16
9	1227.49	175.77
10	1241.34	202.38
11	1255.20	228.99
12	1261.79	241.67

** Corrected JANBU FOS = 1.594 ** (Fo factor = 1.054)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	355.07	110.18
2	370.87	101.06
3	514.00	106.89
4	898.90	108.44
5	1181.45	106.93
6	1184.14	109.62
7	1191.70	122.71
8	1205.55	149.32
9	1219.40	175.93
10	1233.26	202.54
11	1247.11	229.15
12	1253.55	241.51

** Corrected JANBU FOS = 1.597 ** (Fo factor = 1.055)

Failure surface No. 4 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	322.34	105.25
2	327.98	101.99
3	524.58	107.67
4	894.15	108.17
5	1172.66	106.89
6	1175.53	109.76
7	1183.10	122.87
8	1196.95	149.48
9	1210.80	176.09
10	1224.66	202.70
11	1238.51	229.31
12	1244.77	241.35

** Corrected JANBU FOS = 1.615 ** (Fo factor = 1.054)

Failure surface No. 5 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	358.75	111.41
2	376.90	100.93
3	516.15	107.05
4	896.43	108.30
5	1169.02	106.88
6	1171.96	109.81
7	1179.53	122.94
8	1193.39	149.55
9	1207.24	176.16
10	1221.09	202.77
11	1234.94	229.38
12	1241.14	241.28

** Corrected JANBU FOS = 1.616 ** (Fo factor = 1.055)

Failure surface No. 6 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	351.60	109.03
2	365.18	101.19
3	426.20	100.39
4	898.46	108.41
5	1186.26	106.95
6	1188.86	109.54
7	1196.41	122.62
8	1210.26	149.23
9	1224.12	175.84
10	1237.97	202.45
11	1251.82	229.06
12	1258.35	241.60

** Corrected JANBU FOS = 1.617 ** (Fo factor = 1.054)

Failure surface No. 7 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	315.72	105.13
2	320.88	102.15
3	515.19	106.98
4	897.53	108.36
5	1146.77	106.79
6	1150.14	110.16
7	1157.76	123.36
8	1171.61	149.97
9	1185.46	176.58
10	1199.31	203.19
11	1213.17	229.80
12	1218.93	240.86

** Corrected JANBU FOS = 1.623 ** (Fo factor = 1.054)

Failure surface No. 8 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	340.50	105.59
2	347.45	101.57
3	456.81	102.65
4	892.93	108.10
5	1191.01	106.96
6	1193.52	109.47
7	1201.05	122.53
8	1214.91	149.14
9	1228.76	175.75
10	1242.61	202.36
11	1256.46	228.97
12	1263.09	241.69

** Corrected JANBU FOS = 1.624 ** (Fo factor = 1.054)

Failure surface No. 9 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	346.29	107.26
2	356.49	101.38
3	462.13	103.05
4	894.23	108.18
5	1184.83	106.94
6	1187.46	109.57
7	1195.01	122.64
8	1208.86	149.25
9	1222.71	175.86
10	1236.56	202.47
11	1250.42	229.08
12	1256.92	241.58

** Corrected JANBU FOS = 1.625 ** (Fo factor = 1.054)

Failure surface No.10 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	305.49	104.94
2	309.91	102.39
3	513.93	106.88
4	891.55	108.02
5	1185.02	106.94
6	1187.65	109.56
7	1195.20	122.64
8	1209.05	149.25
9	1222.90	175.86
10	1236.75	202.47
11	1250.60	229.08
12	1257.11	241.58

** Corrected JANBU FOS = 1.626 ** (Fo factor = 1.053)

The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.578	1.055	341.06	1236.59	2.286E+06
2.	1.594	1.054	350.17	1261.79	2.408E+06
3.	1.597	1.055	355.07	1253.55	2.383E+06
4.	1.615	1.054	322.34	1244.77	2.383E+06
5.	1.616	1.055	358.75	1241.14	2.375E+06
6.	1.617	1.054	351.60	1258.35	2.516E+06
7.	1.623	1.054	315.72	1218.93	2.328E+06
8.	1.624	1.054	340.50	1263.09	2.524E+06
9.	1.625	1.054	346.29	1256.92	2.499E+06
10.	1.626	1.053	305.49	1257.11	2.450E+06

* * * END OF FILE * * *

OBJECTIVE: Evaluate the stability of the waste mass to include the co-mingling of CCR at Superior Landfill with respect to failure surfaces passing through the base liner. 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 entire base liner system.

METHOD: Evaluate the stability of the waste mass and base liner system and apply seismic loadings. The Simplified Janbu Method 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 XSTABL output files.

The first step in the evaluation is to input the geometry and layer physical properties into XSTABL and run a static analysis on the landfill mass for the scenario described above. The XSTABL 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 two possible options, as listed below, from top to bottom:

Option 1

- 24" of 2×10^{-3} cm/sec protective cover
- double-sided geocomposite drainage layer
- textured 60 mil HDPE geomembrane
- 24" of 1×10^{-7} cm/sec compacted clay

Option 2

- 24" of 2×10^{-3} cm/sec protective cover
- double-sided geocomposite drainage layer
- textured 60 mil HDPE geomembrane
- geosynthetic clay liner (GCL) (1×10^{-9} cm/sec)
- 24" of 1×10^{-4} cm/sec compacted soil

Both options were modeled in the attached reports. The location of the critical section was as determined based on the global stability analysis (Section C). This section is shown on the attached plan view of the landfill (Figure 5-1)

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	XSTABL Soil Unit ID #	Unit Weight (pcf)	Cohesion (psf)	Peak Friction Angle vs material below (deg)
Co-Mingled Municipal Solid Waste (5:1 Ratio of MSW/CCR)	6	79	500	35
Protective Cover Layer	9	110	0	12
Double-Sided Geocomposite	7	100	0	11
Textured HDPE Geomembrane	8	100	0	12
Geosynthetic Clay Liner (GCL)	10	100	0	12
Compacted Clay	11	120	500	15
Engineered Fill/Cypresshead Formation (Sand Layer)	1	120	0	20
Cypresshead Formation (Clay Layer)	2-5	120	0.25 x Vertical Effective Stress	0

Assume fully drained conditions within the landfill due to the presence of a leachate collection system.

For seismic analysis, Federal Subtitle D regulations state that "Maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration depicted on a seismic hazard map, with a 90 percent or greater probability that the acceleration will not be exceeded in 250 years." The seismic coefficient for the site as referenced in the Site Suitability Report is 0.11g (horizontal) and 0.0g (vertical). See attached Figure 16 from this report. However, the Site Limitations as issued by EPD dated December 11, 2009 requires that the design use a horizontal acceleration of 0.16g.

RESULTS: The XSTABL computer results for the analysis are attached. Figure 5-3 and 5-4 shows the critical cross sections 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	XSTABL file
Option 1 – Janbu Block	1.841	SD1BLKR1
Option 1 – Janbu Block with seismic	1.007	SD1BLQR1
Option 2 – Janbu Block	1.841	SD2BLKR1
Option 2 – Janbu Block with seismic	1.007	SD2BLQR1

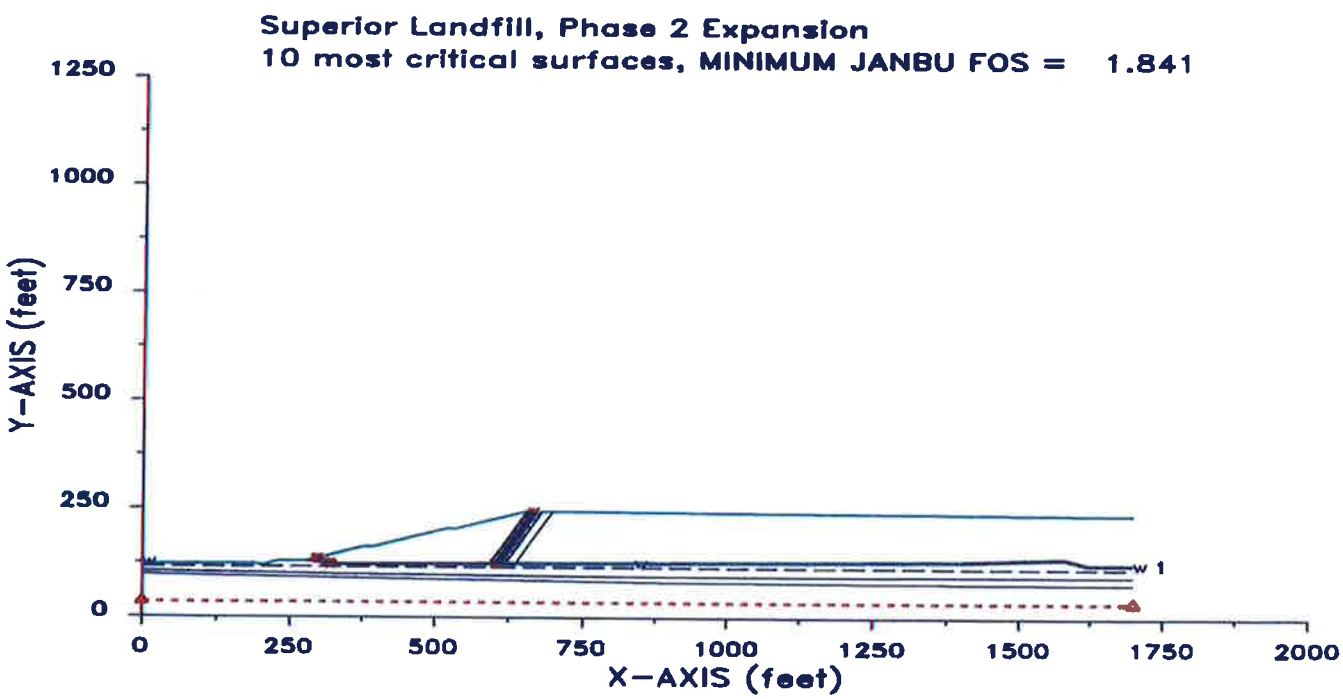
CONCLUSION:

The static stability analysis of the landfill mass failure at the liner interface produced a minimum calculated factor of safety of 1.841. These values are 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.

The proposed materials for the base liner system should be specified to have a minimum interface friction angle of 11 degrees.

SD1BLKR1 4-06-** 14:55



XSTABL File: SD1BLKR1 4-06-** 14:55

```
*******************************************
*              X S T A B L                *
*                                         *
*        Slope Stability Analysis         *
*              using the                  *
*           Method of Slices              *
*                                         *
*         Copyright (C) 1992 Ä 97         *
*   Interactive Software Designs, Inc.    *
*        Moscow, ID 83843, U.S.A.         *
*                                         *
*          All Rights Reserved            *
*                                         *
*  Ver. 5.202                 96 Ä 1599   *
*******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

---

15 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	121.3	102.6	123.4	1
2	102.6	123.4	180.7	123.2	1
3	180.7	123.2	182.9	124.0	1
4	182.9	124.0	184.9	124.0	1
5	184.9	124.0	196.9	120.0	1
6	196.9	120.0	201.5	120.2	1
7	201.5	120.2	228.7	129.1	1
8	228.7	129.1	278.9	130.1	1
9	278.9	130.1	374.5	162.5	6
10	374.5	162.5	391.3	162.9	6
11	391.3	162.9	518.5	205.0	6
12	518.5	205.0	535.7	205.4	6
13	535.7	205.4	648.8	243.8	6
14	648.8	243.8	713.6	245.5	6
15	713.6	245.5	1700.0	238.5	6

36 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	288.7	132.4	321.2	124.2	9
2	321.2	124.2	1403.8	133.8	9
3	1403.8	133.8	1579.0	140.6	9
4	1579.0	140.6	1621.0	127.0	9
5	1621.0	127.0	1700.0	126.6	9
6	288.7	130.4	321.2	122.2	7
7	321.2	122.2	1403.8	131.8	7
8	1403.8	131.8	1579.0	138.6	7

9	1579.0	138.6	1621.0	125.0	7
10	1621.0	125.0	1700.0	124.6	7
11	288.7	130.2	321.2	122.0	8
12	321.2	122.0	1403.8	131.6	8
13	1403.8	131.6	1579.0	138.4	8
14	1579.0	138.4	1621.0	124.8	8
15	1621.0	124.8	1700.0	124.4	8
16	288.7	130.1	321.2	121.9	11
17	321.2	121.9	1403.8	131.5	11
18	1403.8	131.5	1579.0	138.3	11
19	1579.0	138.3	1621.0	124.7	11
20	1621.0	124.7	1700.0	124.3	11
21	278.9	128.1	288.7	128.1	1
22	288.7	128.1	321.2	119.9	1
23	321.2	119.9	1403.8	129.5	1
24	1403.8	129.5	1579.0	136.3	1
25	1579.0	136.3	1621.0	122.7	1
26	1621.0	122.7	1700.0	122.3	1
27	.0	105.8	201.5	102.1	2
28	201.5	102.1	321.2	100.0	3
29	321.2	100.0	648.9	96.6	4
30	648.9	96.6	881.7	94.6	5
31	881.7	94.6	1700.0	96.0	5
32	.0	98.1	201.5	93.4	1
33	201.5	93.4	321.2	90.8	1
34	321.2	90.8	648.9	85.6	1
35	648.9	85.6	882.1	82.1	1
36	882.1	82.1	1700.0	78.2	1

ISOTROPIC Soil Parameters
----

11 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	20.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1
7	110.0	110.0	.0	11.00	.000	.0	1
8	100.0	100.0	.0	12.00	.000	.0	1
9	110.0	110.0	.0	12.00	.000	.0	1
10	100.0	100.0	.0	12.00	.000	.0	1
11	120.0	120.0	500.0	15.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****

PHREATIC SURFACE,

****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

1000 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	288.7	130.3	321.2	122.1	.0
2	322.1	122.1	1403.8	131.7	.0

WARNING - limitation boundaries have been specified !,
These are ignored for RANKINE block analysis

```
***************************************************************
**     Factor of safety calculation for surface #    18      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   3.3831      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.67	135.78
2	297.10	135.04
3	314.84	125.80
4	318.43	122.90
5	318.60	122.75
6	335.55	122.22
7	335.64	122.33
8	337.27	124.34
9	346.51	142.08
10	353.41	155.35

```
***************************************************************
**     Factor of safety calculation for surface #    43      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   4.3998      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	287.78	133.11
2	289.55	132.19
3	293.14	129.28
4	293.31	129.14
5	325.12	122.13
6	325.21	122.24
7	326.84	124.25
8	336.07	141.99
9	340.81	151.08

```
**************************************************************************
    --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
**************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
**************************************************************************
```

```
--------------------------------------------------------------
USER SELECTED option to maintain strength greater than zero
--------------------------------------------------------------
```

```
***************************************************************
**     Factor of safety calculation for surface #    85      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   3.4660      **
**    This will be ignored for final summary of results      **
```

```
***************************************************************

The trial failure surface in question is
defined by the following 10 coordinate points

       Point       x-surf       y-surf
        No.         (ft)         (ft)

         1         295.82       135.83
         2         297.57       134.92
         3         315.31       125.69
         4         318.90       122.78
         5         319.08       122.64
         6         329.22       122.16
         7         329.31       122.27
         8         330.94       124.29
         9         340.18       142.03
        10         345.77       152.76

***************************************************************
**      Factor of safety calculation for surface #   143     **
**      failed to converge within FIFTY iterations           **
**                                                           **
**     The last calculated value of the FOS was   2.8355     **
**     This will be ignored for final summary of results     **
***************************************************************

The trial failure surface in question is
defined by the following  9 coordinate points

       Point       x-surf       y-surf
        No.         (ft)         (ft)

         1         288.14       133.23
         2         290.70       131.89
         3         294.29       128.99
         4         294.47       128.84
         5         323.45       122.11
         6         323.54       122.22
         7         325.17       124.24
         8         334.40       141.98
         9         338.79       150.40

***************************************************************
**      Factor of safety calculation for surface #   210     **
**      failed to converge within FIFTY iterations           **
**                                                           **
**     The last calculated value of the FOS was   2.4291     **
**     This will be ignored for final summary of results     **
***************************************************************

The trial failure surface in question is
defined by the following  9 coordinate points

       Point       x-surf       y-surf
        No.         (ft)         (ft)

         1         294.11       135.25
         2         309.83       127.07
         3         313.42       124.16
         4         313.60       124.02
```

5	337.15	122.23
6	337.24	122.34
7	338.87	124.36
8	348.11	142.10
9	355.35	156.01

```
***************************************************************
**     Factor of safety calculation for surface #   481      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   5.6076      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.54	135.40
2	311.22	126.72
3	314.80	123.81
4	314.98	123.67
5	337.04	122.23
6	337.13	122.34
7	338.76	124.36
8	347.99	142.10
9	355.21	155.96

```
***************************************************************
**     Factor of safety calculation for surface #   488      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   6.4479      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.61	135.08
2	308.23	127.47
3	311.81	124.57
4	311.99	124.42
5	335.72	122.22
6	335.81	122.33
7	337.44	124.34
8	346.67	142.08
9	353.62	155.42

```
***************************************************************
**     Factor of safety calculation for surface #   538      **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   3.1974      **
**    This will be ignored for final summary of results      **
```

```
******************************************************************

The trial failure surface in question is
defined by the following  9 coordinate points

       Point        x-surf       y-surf
        No.          (ft)         (ft)

         1         293.79       135.15
         2         308.80       127.33
         3         312.39       124.42
         4         312.57       124.28
         5         334.88       122.21
         6         334.97       122.32
         7         336.60       124.34
         8         345.84       142.08
         9         352.61       155.08

******************************************************************
**     Factor of safety calculation for surface #   788        **
**     failed to converge within FIFTY iterations              **
**                                                             **
**    The last calculated value of the FOS was   3.7944        **
**    This will be ignored for final summary of results        **
******************************************************************

The trial failure surface in question is
defined by the following  9 coordinate points

       Point        x-surf       y-surf
        No.          (ft)         (ft)

         1         294.69       135.45
         2         311.69       126.60
         3         315.27       123.70
         4         315.45       123.55
         5         330.71       122.18
         6         330.80       122.29
         7         332.43       124.30
         8         341.67       142.04
         9         347.56       153.37

******************************************************************
**     Factor of safety calculation for surface #   938        **
**     failed to converge within FIFTY iterations              **
**                                                             **
**    The last calculated value of the FOS was  33.4156        **
**    This will be ignored for final summary of results        **
******************************************************************

The trial failure surface in question is
defined by the following 10 coordinate points

       Point        x-surf       y-surf
        No.          (ft)         (ft)

         1         295.23       135.63
         2         295.68       135.40
         3         313.42       126.16
         4         317.00       123.26
         5         317.18       123.11
```

6	328.21	122.15
7	328.30	122.26
8	329.93	124.28
9	339.16	142.02
10	344.54	152.35

```
***************************************************************
**     Factor of safety calculation for surface #   979     **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   5.5048     **
**    This will be ignored for final summary of results     **
***************************************************************
```

The trial failure surface in question is
defined by the following 8 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	286.10	132.54
2	288.77	130.38
3	288.94	130.24
4	323.92	122.12
5	324.01	122.22
6	325.64	124.24
7	334.87	141.98
8	339.35	150.59

Factors of safety have been calculated by the :

* * * * *   SIMPLIFIED JANBU METHOD   * * * * *

The 10 most critical of all the failure surfaces examined
are displayed below - the most critical first

Failure surface No. 1 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16
6	604.89	124.61
7	604.98	124.72
8	606.61	126.73
9	615.84	144.47
10	625.08	162.21
11	634.31	179.95
12	643.55	197.69
13	652.78	215.43
14	662.02	233.17
15	667.81	244.30

** Corrected JANBU FOS = 1.841 ** (Fo factor = 1.081)

Failure surface No. 2 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.03	135.91
2	298.26	134.75
3	316.00	125.51
4	319.59	122.61
5	319.76	122.46
6	608.53	124.64
7	608.62	124.75
8	610.25	126.76
9	619.48	144.50
10	628.72	162.24
11	637.95	179.98
12	647.19	197.72
13	656.42	215.46
14	665.66	233.20
15	671.48	244.40

** Corrected JANBU FOS = 1.881 ** (Fo factor = 1.081)

Failure surface No. 3 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.33	135.67
2	296.02	135.31
3	313.76	126.08
4	317.34	123.17
5	317.52	123.03
6	609.90	124.65
7	609.99	124.76
8	611.62	126.78
9	620.85	144.52
10	630.09	162.26
11	639.32	180.00
12	648.56	197.74
13	657.79	215.48
14	667.03	233.22
15	672.87	244.43

** Corrected JANBU FOS = 1.892 ** (Fo factor = 1.081)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.79	135.49
2	312.03	126.51
3	315.61	123.61
4	315.79	123.47
5	612.40	124.68
6	612.49	124.78
7	614.12	126.80
8	623.36	144.54

9	632.59	162.28
10	641.83	180.02
11	651.06	197.76
12	660.30	215.50
13	669.53	233.24
14	675.39	244.50

** Corrected JANBU FOS = 1.893 ** (Fo factor = 1.081)

Failure surface No. 5 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.88	135.52
2	312.31	126.44
3	315.90	123.54
4	316.08	123.39
5	611.98	124.67
6	612.07	124.78
7	613.70	126.79
8	622.94	144.53
9	632.17	162.27
10	641.41	180.01
11	650.64	197.75
12	659.88	215.49
13	669.11	233.24
14	674.97	244.49

** Corrected JANBU FOS = 1.893 ** (Fo factor = 1.081)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.46	135.37
2	310.95	126.79
3	314.54	123.88
4	314.71	123.74
5	602.67	124.59
6	602.76	124.70
7	604.39	126.71
8	613.62	144.45
9	622.86	162.19
10	632.09	179.93
11	641.33	197.67
12	650.56	215.41
13	659.80	233.15
14	665.57	244.24

** Corrected JANBU FOS = 1.894 ** (Fo factor = 1.081)

Failure surface No. 7 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.55	135.41
2	311.27	126.71

3	314.85	123.80
4	315.03	123.66
5	619.15	124.74
6	619.23	124.84
7	620.87	126.86
8	630.10	144.60
9	639.34	162.34
10	648.57	180.08
11	657.81	197.82
12	667.04	215.56
13	676.28	233.30
14	682.20	244.68

** Corrected JANBU FOS = 1.898 ** (Fo factor = 1.080)

Failure surface No. 8 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.09	135.59
2	295.23	135.51
3	312.97	126.28
4	316.56	123.37
5	316.73	123.23
6	599.75	124.56
7	599.84	124.67
8	601.47	126.69
9	610.70	144.43
10	619.94	162.17
11	629.17	179.91
12	638.41	197.65
13	647.64	215.39
14	656.88	233.13
15	662.62	244.16

** Corrected JANBU FOS = 1.898 ** (Fo factor = 1.082)

Failure surface No. 9 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.20	135.96
2	298.79	134.61
3	316.53	125.38
4	320.11	122.47
5	320.29	122.33
6	635.99	124.89
7	636.08	124.99
8	637.71	127.01
9	646.94	144.75
10	656.18	162.49
11	665.41	180.23
12	674.65	197.97
13	683.88	215.71
14	693.12	233.45
15	699.20	245.12

** Corrected JANBU FOS = 1.904 ** (Fo factor = 1.079)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.12	135.26
2	309.88	127.06
3	313.46	124.15
4	313.64	124.01
5	592.94	124.50
6	593.03	124.61
7	594.66	126.62
8	603.89	144.37
9	613.13	162.11
10	622.36	179.85
11	631.60	197.59
12	640.83	215.33
13	650.07	233.07
14	655.75	243.98

** Corrected JANBU FOS = 1.906 ** (Fo factor = 1.082)

```
**********************************************************************
**                                                                  **
**  Out of the   1000 surfaces generated and analyzed by XSTABL,    **
**       11 surfaces were found to have MISLEADING FOS values.      **
**                                                                  **
**********************************************************************
```

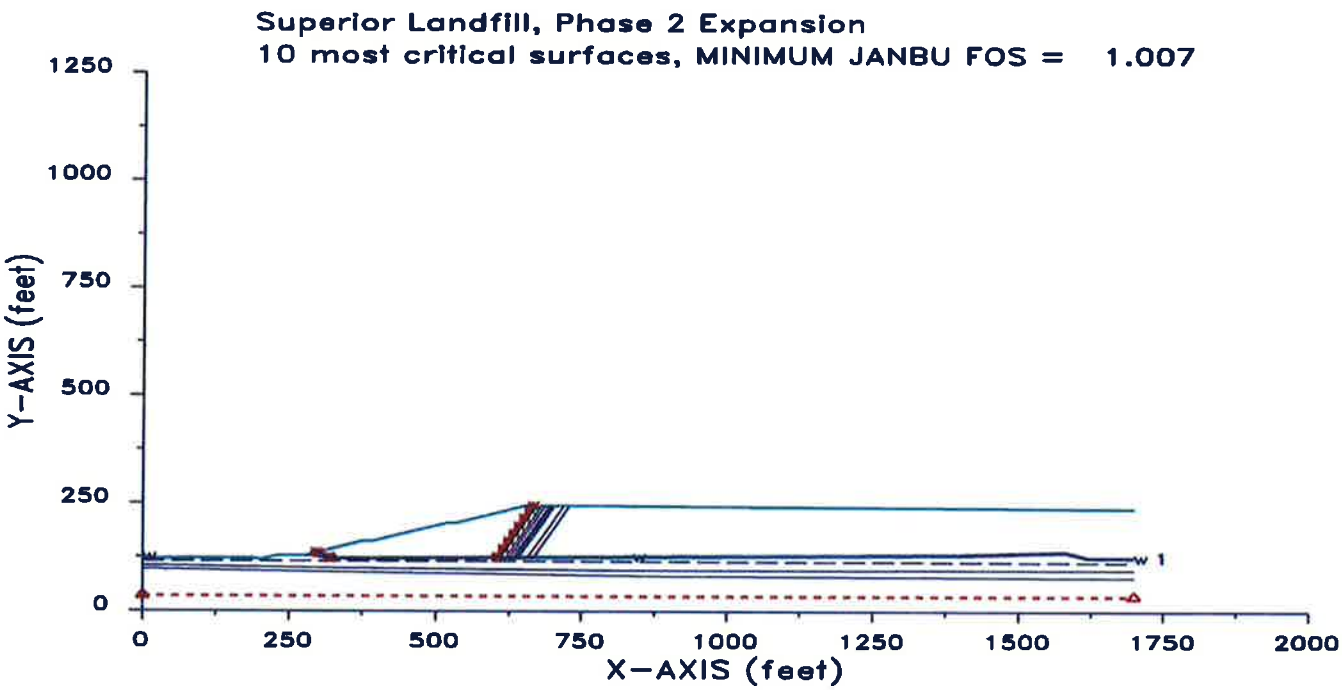
The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.841	1.081	296.41	667.81	5.691E+05
2.	1.881	1.081	296.03	671.48	5.942E+05
3.	1.892	1.081	295.33	672.87	6.002E+05
4.	1.893	1.081	294.79	675.39	6.050E+05
5.	1.893	1.081	294.88	674.97	6.043E+05
6.	1.894	1.081	294.46	665.57	5.775E+05
7.	1.898	1.080	294.55	682.20	6.214E+05
8.	1.898	1.082	295.09	662.62	5.722E+05
9.	1.904	1.079	296.20	699.20	6.569E+05
10.	1.906	1.082	294.12	655.75	5.490E+05

* * * END OF FILE * * *

SD1BLQR1 4-06-** 14:28



XSTABL File: SD1BLQR1 4-06-** 14:28

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******************************************
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*                                        *
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*              using the                 *
*          Method of Slices              *
*                                        *
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*                                        *
*  Ver. 5.202               96 Ä 1599    *
******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

15 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	121.3	102.6	123.4	1
2	102.6	123.4	180.7	123.2	1
3	180.7	123.2	182.9	124.0	1
4	182.9	124.0	184.9	124.0	1
5	184.9	124.0	196.9	120.0	1
6	196.9	120.0	201.5	120.2	1
7	201.5	120.2	228.7	129.1	1
8	228.7	129.1	278.9	130.1	1
9	278.9	130.1	374.5	162.5	6
10	374.5	162.5	391.3	162.9	6
11	391.3	162.9	518.5	205.0	6
12	518.5	205.0	535.7	205.4	6
13	535.7	205.4	648.8	243.8	6
14	648.8	243.8	713.6	245.5	6
15	713.6	245.5	1700.0	238.5	6

36 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	288.7	132.4	321.2	124.2	9
2	321.2	124.2	1403.8	133.8	9
3	1403.8	133.8	1579.0	140.6	9
4	1579.0	140.6	1621.0	127.0	9
5	1621.0	127.0	1700.0	126.6	9
6	288.7	130.4	321.2	122.2	7
7	321.2	122.2	1403.8	131.8	7
8	1403.8	131.8	1579.0	138.6	7

9	1579.0	138.6	1621.0	125.0	7
10	1621.0	125.0	1700.0	124.6	7
11	288.7	130.2	321.2	122.0	8
12	321.2	122.0	1403.8	131.6	8
13	1403.8	131.6	1579.0	138.4	8
14	1579.0	138.4	1621.0	124.8	8
15	1621.0	124.8	1700.0	124.4	8
16	288.7	130.1	321.2	121.9	11
17	321.2	121.9	1403.8	131.5	11
18	1403.8	131.5	1579.0	138.3	11
19	1579.0	138.3	1621.0	124.7	11
20	1621.0	124.7	1700.0	124.3	11
21	278.9	128.1	288.7	128.1	1
22	288.7	128.1	321.2	119.9	1
23	321.2	119.9	1403.8	129.5	1
24	1403.8	129.5	1579.0	136.3	1
25	1579.0	136.3	1621.0	122.7	1
26	1621.0	122.7	1700.0	122.3	1
27	.0	105.8	201.5	102.1	2
28	201.5	102.1	321.2	100.0	3
29	321.2	100.0	648.9	96.6	4
30	648.9	96.6	881.7	94.6	5
31	881.7	94.6	1700.0	96.0	5
32	.0	98.1	201.5	93.4	1
33	201.5	93.4	321.2	90.8	1
34	321.2	90.8	648.9	85.6	1
35	648.9	85.6	882.1	82.1	1
36	882.1	82.1	1700.0	78.2	1

ISOTROPIC Soil Parameters
----

11 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	20.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1
7	110.0	110.0	.0	11.00	.000	.0	1
8	100.0	100.0	.0	12.00	.000	.0	1
9	110.0	110.0	.0	12.00	.000	.0	1
10	100.0	100.0	.0	12.00	.000	.0	1
11	120.0	120.0	500.0	15.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****

PHREATIC SURFACE,

****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

A horizontal earthquake loading coefficient
of .160 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

1000 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	288.7	130.3	321.2	122.1	.0
2	322.1	122.1	1403.8	131.7	.0

WARNING - limitation boundaries have been specified !,
These are ignored for RANKINE block analysis

```
***************************************************************************
    --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
***************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
***************************************************************************
```

```
    ------------------------------------------------------------
    USER SELECTED option to maintain strength greater than zero
    ------------------------------------------------------------
```

Factors of safety have been calculated by the :

* * * * *   SIMPLIFIED JANBU METHOD   * * * * *

The 10 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16
6	604.89	124.61
7	604.98	124.72
8	606.61	126.73
9	615.84	144.47
10	625.08	162.21
11	634.31	179.95
12	643.55	197.69
13	652.78	215.43
14	662.02	233.17
15	667.81	244.30

** Corrected JANBU FOS =   1.007 **   (Fo factor = 1.081)

Failure surface No. 2 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16
6	666.97	125.16
7	667.06	125.27
8	668.69	127.28
9	677.93	145.02
10	687.16	162.76

11	696.40	180.50
12	705.63	198.24
13	714.86	215.98
14	724.10	233.72
15	730.17	245.38

** Corrected JANBU FOS = 1.008 ** (Fo factor = 1.077)

Failure surface No. 3 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.20	135.96
2	298.79	134.61
3	316.53	125.38
4	320.11	122.47
5	320.29	122.33
6	635.99	124.89
7	636.08	124.99
8	637.71	127.01
9	646.94	144.75
10	656.18	162.49
11	665.41	180.23
12	674.65	197.97
13	683.88	215.71
14	693.12	233.45
15	699.20	245.12

** Corrected JANBU FOS = 1.017 ** (Fo factor = 1.079)

Failure surface No. 4 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.17	135.95
2	298.69	134.64
3	316.43	125.40
4	320.02	122.50
5	320.19	122.35
6	656.82	125.07
7	656.91	125.18
8	658.54	127.19
9	667.78	144.93
10	677.01	162.67
11	686.25	180.41
12	695.48	198.15
13	704.72	215.89
14	713.95	233.63
15	720.10	245.45

** Corrected JANBU FOS = 1.027 ** (Fo factor = 1.078)

Failure surface No. 5 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.97	135.21

2	309.39	127.18
3	312.98	124.27
4	313.16	124.13
5	635.02	124.88
6	635.11	124.98
7	636.74	127.00
8	645.97	144.74
9	655.21	162.48
10	664.44	180.22
11	673.68	197.96
12	682.91	215.70
13	692.15	233.44
14	698.22	245.10

** Corrected JANBU FOS = 1.029 ** (Fo factor = 1.079)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.55	135.41
2	311.27	126.71
3	314.85	123.80
4	315.03	123.66
5	619.15	124.74
6	619.23	124.84
7	620.87	126.86
8	630.10	144.60
9	639.34	162.34
10	648.57	180.08
11	657.81	197.82
12	667.04	215.56
13	676.28	233.30
14	682.20	244.68

** Corrected JANBU FOS = 1.030 ** (Fo factor = 1.080)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.03	135.91
2	298.26	134.75
3	316.00	125.51
4	319.59	122.61
5	319.76	122.46
6	608.53	124.64
7	608.62	124.75
8	610.25	126.76
9	619.48	144.50
10	628.72	162.24
11	637.95	179.98
12	647.19	197.72
13	656.42	215.46
14	665.66	233.20
15	671.48	244.40

** Corrected JANBU FOS = 1.031 ** (Fo factor = 1.081)

Failure surface No. 8 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.27	135.65
2	295.81	135.36
3	313.55	126.13
4	317.14	123.22
5	317.32	123.08
6	625.24	124.79
7	625.33	124.90
8	626.96	126.91
9	636.19	144.65
10	645.43	162.39
11	654.66	180.13
12	663.90	197.87
13	673.13	215.61
14	682.37	233.35
15	688.35	244.84

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.080)

Failure surface No. 9 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.12	135.60
2	295.34	135.48
3	313.08	126.25
4	316.67	123.34
5	316.85	123.20
6	631.57	124.85
7	631.65	124.95
8	633.28	126.97
9	642.52	144.71
10	651.75	162.45
11	660.99	180.19
12	670.22	197.93
13	679.46	215.67
14	688.69	233.41
15	694.73	245.00

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.080)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.34	135.33
2	310.59	126.88
3	314.18	123.97
4	314.35	123.83
5	640.81	124.93
6	640.90	125.03
7	642.53	127.05
8	651.77	144.79
9	661.00	162.53

10	670.24	180.27
11	679.47	198.01
12	688.71	215.75
13	697.94	233.49
14	704.06	245.25

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.079)

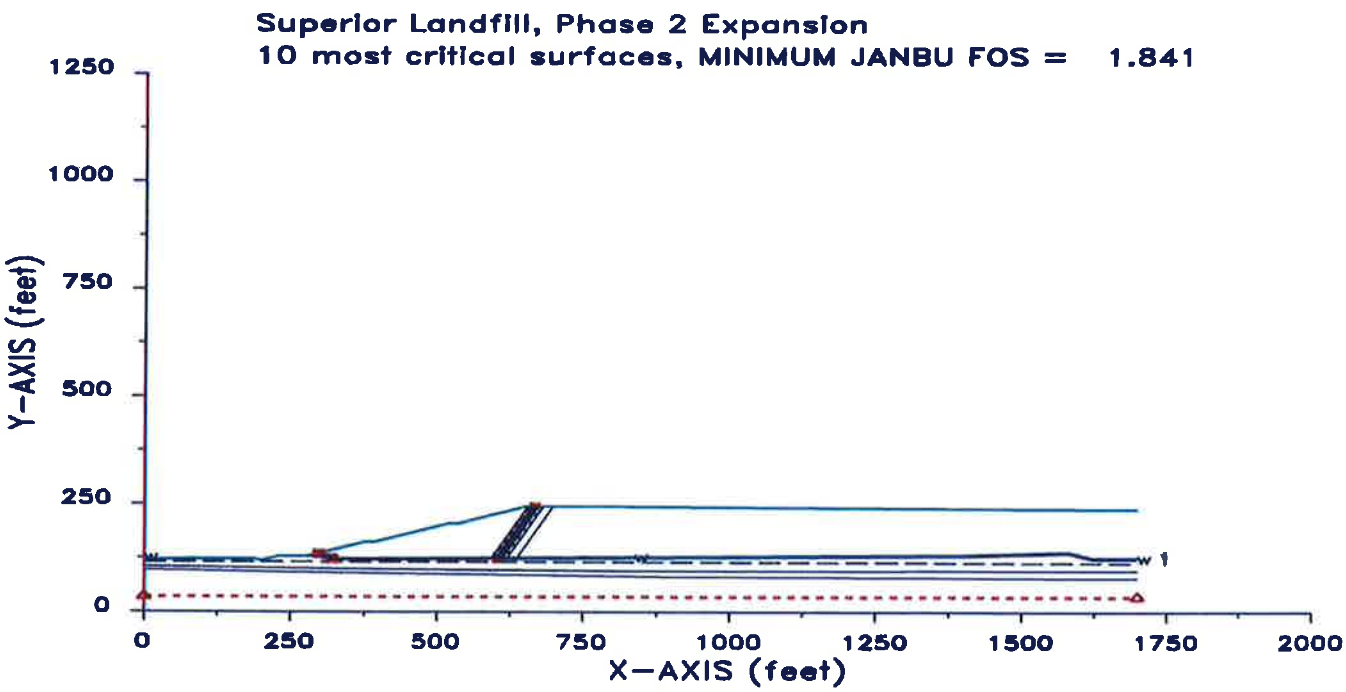
The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.007	1.081	296.41	667.81	5.089E+05
2.	1.008	1.077	296.41	730.17	6.356E+05
3.	1.017	1.079	296.20	699.20	5.881E+05
4.	1.027	1.078	296.17	720.10	6.318E+05
5.	1.029	1.079	293.97	698.22	5.864E+05
6.	1.030	1.080	294.55	682.20	5.546E+05
7.	1.031	1.081	296.03	671.48	5.323E+05
8.	1.032	1.080	295.27	688.35	5.720E+05
9.	1.032	1.080	295.12	694.73	5.855E+05
10.	1.032	1.079	294.34	704.06	6.013E+05

* * * END OF FILE * * *

SD2BLKR1 4-06-** 14:57



XSTABL File: SD2BLKR1   4-06-**   14:57

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******************************************
*              X S T A B L               *
*                                        *
*        Slope Stability Analysis        *
*              using the                 *
*           Method of Slices             *
*                                        *
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*                                        *
*  Ver. 5.202                 96 Ä 1599  *
******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

15 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	121.3	102.6	123.4	1
2	102.6	123.4	180.7	123.2	1
3	180.7	123.2	182.9	124.0	1
4	182.9	124.0	184.9	124.0	1
5	184.9	124.0	196.9	120.0	1
6	196.9	120.0	201.5	120.2	1
7	201.5	120.2	228.7	129.1	1
8	228.7	129.1	278.9	130.1	1
9	278.9	130.1	374.5	162.5	6
10	374.5	162.5	391.3	162.9	6
11	391.3	162.9	518.5	205.0	6
12	518.5	205.0	535.7	205.4	6
13	535.7	205.4	648.8	243.8	6
14	648.8	243.8	713.6	245.5	6
15	713.6	245.5	1700.0	238.5	6

41 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	288.7	132.4	321.2	124.2	9
2	321.2	124.2	1403.8	133.8	9
3	1403.8	133.8	1579.0	140.6	9
4	1579.0	140.6	1621.0	127.0	9
5	1621.0	127.0	1700.0	126.6	9
6	288.7	130.4	321.2	122.2	7
7	321.2	122.2	1403.8	131.8	7
8	1403.8	131.8	1579.0	138.6	7

9	1579.0	138.6	1621.0	125.0	7
10	1621.0	125.0	1700.0	124.6	7
11	288.7	130.2	321.2	122.0	8
12	321.2	122.0	1403.8	131.6	8
13	1403.8	131.6	1579.0	138.4	8
14	1579.0	138.4	1621.0	124.8	8
15	1621.0	124.8	1700.0	124.4	8
16	288.7	130.1	321.2	121.9	10
17	321.2	121.9	1403.8	131.5	10
18	1403.8	131.5	1579.0	138.3	10
19	1579.0	138.3	1621.0	124.7	10
20	1621.0	124.7	1700.0	124.3	10
21	288.7	129.9	321.2	121.7	11
22	321.2	121.7	1403.8	131.3	11
23	1403.8	131.3	1579.0	138.1	11
24	1579.0	138.1	1621.0	124.5	11
25	1621.0	124.5	1700.0	124.1	11
26	278.9	127.9	288.7	127.9	1
27	288.7	127.9	321.2	119.7	1
28	321.2	119.7	1403.8	129.3	1
29	1403.8	129.3	1579.0	136.1	1
30	1579.0	136.1	1621.0	122.5	1
31	1621.0	122.5	1700.0	122.1	1
32	.0	105.8	201.5	102.1	2
33	201.5	102.1	321.2	100.0	3
34	321.2	100.0	648.9	96.6	4
35	648.9	96.6	881.7	94.6	5
36	881.7	94.6	1700.0	96.0	5
37	.0	98.1	201.5	93.4	1
38	201.5	93.4	321.2	90.8	1
39	321.2	90.8	648.9	85.6	1
40	648.9	85.6	882.1	82.1	1
41	882.1	82.1	1700.0	78.2	1

ISOTROPIC Soil Parameters
----

11 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Constant (psf)	Water Surface No.
1	120.0	120.0	.0	20.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1
7	110.0	110.0	.0	11.00	.000	.0	1
8	100.0	100.0	.0	12.00	.000	.0	1
9	110.0	110.0	.0	12.00	.000	.0	1
10	100.0	100.0	.0	12.00	.000	.0	1
11	120.0	120.0	500.0	15.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

```
************************************
         PHREATIC SURFACE,
************************************
```

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

1000 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	288.7	130.3	321.2	122.1	.0
2	322.1	122.1	1403.8	131.7	.0

WARNING - limitation boundaries have been specified !,
These are ignored for RANKINE block analysis

```
**************************************************************
**     Factor of safety calculation for surface #    18     **
**     failed to converge within FIFTY iterations           **
```

```
**                                                                    **
**    The last calculated value of the FOS was    3.3831             **
**    This will be ignored for final summary of results              **
***********************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.67	135.78
2	297.10	135.04
3	314.84	125.80
4	318.43	122.90
5	318.60	122.75
6	335.55	122.22
7	335.64	122.33
8	337.27	124.34
9	346.51	142.08
10	353.41	155.35

```
***********************************************************************
**     Factor of safety calculation for surface #    43              **
**     failed to converge within FIFTY iterations                    **
**                                                                    **
**    The last calculated value of the FOS was    4.3998             **
**    This will be ignored for final summary of results              **
***********************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	287.78	133.11
2	289.55	132.19
3	293.14	129.28
4	293.31	129.14
5	325.12	122.13
6	325.21	122.24
7	326.84	124.25
8	336.07	141.99
9	340.81	151.08

```
*****************************************************************************
   --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
*****************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
*****************************************************************************
```

```
---------------------------------------------------------------
USER SELECTED option to maintain strength greater than zero
---------------------------------------------------------------
```

```
***********************************************************************
```

```
**     Factor of safety calculation for surface #    85     **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   3.4660      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.82	135.83
2	297.57	134.92
3	315.31	125.69
4	318.90	122.78
5	319.08	122.64
6	329.22	122.16
7	329.31	122.27
8	330.94	124.29
9	340.18	142.03
10	345.77	152.76

```
***************************************************************
**     Factor of safety calculation for surface #   143     **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   2.8355      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	288.14	133.23
2	290.70	131.89
3	294.29	128.99
4	294.47	128.84
5	323.45	122.11
6	323.54	122.22
7	325.17	124.24
8	334.40	141.98
9	338.79	150.40

```
***************************************************************
**     Factor of safety calculation for surface #   210     **
**     failed to converge within FIFTY iterations            **
**                                                           **
**    The last calculated value of the FOS was   2.4291      **
**    This will be ignored for final summary of results      **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	294.11	135.25
2	309.83	127.07
3	313.42	124.16
4	313.60	124.02
5	337.15	122.23
6	337.24	122.34
7	338.87	124.36
8	348.11	142.10
9	355.35	156.01

```
**************************************************************
**     Factor of safety calculation for surface #   481     **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   5.6076     **
**    This will be ignored for final summary of results     **
**************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.54	135.40
2	311.22	126.72
3	314.80	123.81
4	314.98	123.67
5	337.04	122.23
6	337.13	122.34
7	338.76	124.36
8	347.99	142.10
9	355.21	155.96

```
**************************************************************
**     Factor of safety calculation for surface #   488     **
**     failed to converge within FIFTY iterations           **
**                                                          **
**    The last calculated value of the FOS was   6.4479     **
**    This will be ignored for final summary of results     **
**************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.61	135.08
2	308.23	127.47
3	311.81	124.57
4	311.99	124.42
5	335.72	122.22
6	335.81	122.33
7	337.44	124.34
8	346.67	142.08
9	353.62	155.42

****

```
**      Factor of safety calculation for surface #   538     **
**      failed to converge within FIFTY iterations           **
**                                                           **
**     The last calculated value of the FOS was   3.1974     **
**     This will be ignored for final summary of results     **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.79	135.15
2	308.80	127.33
3	312.39	124.42
4	312.57	124.28
5	334.88	122.21
6	334.97	122.32
7	336.60	124.34
8	345.84	142.08
9	352.61	155.08

```
***************************************************************
**      Factor of safety calculation for surface #   788     **
**      failed to converge within FIFTY iterations           **
**                                                           **
**     The last calculated value of the FOS was   3.7944     **
**     This will be ignored for final summary of results     **
***************************************************************
```

The trial failure surface in question is
defined by the following 9 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.69	135.45
2	311.69	126.60
3	315.27	123.70
4	315.45	123.55
5	330.71	122.18
6	330.80	122.29
7	332.43	124.30
8	341.67	142.04
9	347.56	153.37

```
***************************************************************
**      Factor of safety calculation for surface #   938     **
**      failed to converge within FIFTY iterations           **
**                                                           **
**     The last calculated value of the FOS was  33.4156     **
**     This will be ignored for final summary of results     **
***************************************************************
```

The trial failure surface in question is
defined by the following 10 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	295.23	135.63
2	295.68	135.40
3	313.42	126.16
4	317.00	123.26
5	317.18	123.11
6	328.21	122.15
7	328.30	122.26
8	329.93	124.28
9	339.16	142.02
10	344.54	152.35

```
*****************************************************************
**     Factor of safety calculation for surface #   979       **
**     failed to converge within FIFTY iterations              **
**                                                             **
**    The last calculated value of the FOS was   5.5048       **
**    This will be ignored for final summary of results       **
*****************************************************************
```

The trial failure surface in question is
defined by the following 8 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	286.10	132.54
2	288.77	130.38
3	288.94	130.24
4	323.92	122.12
5	324.01	122.22
6	325.64	124.24
7	334.87	141.98
8	339.35	150.59

Factors of safety have been calculated by the :

* * * * *   SIMPLIFIED JANBU METHOD   * * * * *

The 10 most critical of all the failure surfaces examined
are displayed below - the most critical first

Failure surface No. 1 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16
6	604.89	124.61
7	604.98	124.72
8	606.61	126.73
9	615.84	144.47
10	625.08	162.21
11	634.31	179.95
12	643.55	197.69

13	652.78	215.43
14	662.02	233.17
15	667.81	244.30

** Corrected JANBU FOS = 1.841 ** (Fo factor = 1.081)

Failure surface No. 2 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.03	135.91
2	298.26	134.75
3	316.00	125.51
4	319.59	122.61
5	319.76	122.46
6	608.53	124.64
7	608.62	124.75
8	610.25	126.76
9	619.48	144.50
10	628.72	162.24
11	637.95	179.98
12	647.19	197.72
13	656.42	215.46
14	665.66	233.20
15	671.48	244.40

** Corrected JANBU FOS = 1.881 ** (Fo factor = 1.081)

Failure surface No. 3 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.33	135.67
2	296.02	135.31
3	313.76	126.08
4	317.34	123.17
5	317.52	123.03
6	609.90	124.65
7	609.99	124.76
8	611.62	126.78
9	620.85	144.52
10	630.09	162.26
11	639.32	180.00
12	648.56	197.74
13	657.79	215.48
14	667.03	233.22
15	672.87	244.43

** Corrected JANBU FOS = 1.892 ** (Fo factor = 1.081)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.79	135.49
2	312.03	126.51
3	315.61	123.61

4	315.79	123.47
5	612.40	124.68
6	612.49	124.78
7	614.12	126.80
8	623.36	144.54
9	632.59	162.28
10	641.83	180.02
11	651.06	197.76
12	660.30	215.50
13	669.53	233.24
14	675.39	244.50

** Corrected JANBU FOS = 1.893 ** (Fo factor = 1.081)

Failure surface No. 5 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.88	135.52
2	312.31	126.44
3	315.90	123.54
4	316.08	123.39
5	611.98	124.67
6	612.07	124.78
7	613.70	126.79
8	622.94	144.53
9	632.17	162.27
10	641.41	180.01
11	650.64	197.75
12	659.88	215.49
13	669.11	233.24
14	674.97	244.49

** Corrected JANBU FOS = 1.893 ** (Fo factor = 1.081)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.46	135.37
2	310.95	126.79
3	314.54	123.88
4	314.71	123.74
5	602.67	124.59
6	602.76	124.70
7	604.39	126.71
8	613.62	144.45
9	622.86	162.19
10	632.09	179.93
11	641.33	197.67
12	650.56	215.41
13	659.80	233.15
14	665.57	244.24

** Corrected JANBU FOS = 1.894 ** (Fo factor = 1.081)

Failure surface No. 7 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.55	135.41
2	311.27	126.71
3	314.85	123.80
4	315.03	123.66
5	619.15	124.74
6	619.23	124.84
7	620.87	126.86
8	630.10	144.60
9	639.34	162.34
10	648.57	180.08
11	657.81	197.82
12	667.04	215.56
13	676.28	233.30
14	682.20	244.68

** Corrected JANBU FOS = 1.898 ** (Fo factor = 1.080)

Failure surface No. 8 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.09	135.59
2	295.23	135.51
3	312.97	126.28
4	316.56	123.37
5	316.73	123.23
6	599.75	124.56
7	599.84	124.67
8	601.47	126.69
9	610.70	144.43
10	619.94	162.17
11	629.17	179.91
12	638.41	197.65
13	647.64	215.39
14	656.88	233.13
15	662.62	244.16

** Corrected JANBU FOS = 1.898 ** (Fo factor = 1.082)

Failure surface No. 9 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.20	135.96
2	298.79	134.61
3	316.53	125.38
4	320.11	122.47
5	320.29	122.33
6	635.99	124.89
7	636.08	124.99
8	637.71	127.01
9	646.94	144.75
10	656.18	162.49
11	665.41	180.23
12	674.65	197.97
13	683.88	215.71

14	693.12	233.45
15	699.20	245.12

** Corrected JANBU FOS = 1.904 ** (Fo factor = 1.079)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.12	135.26
2	309.88	127.06
3	313.46	124.15
4	313.64	124.01
5	592.94	124.50
6	593.03	124.61
7	594.66	126.62
8	603.89	144.37
9	613.13	162.11
10	622.36	179.85
11	631.60	197.59
12	640.83	215.33
13	650.07	233.07
14	655.75	243.98

** Corrected JANBU FOS = 1.906 ** (Fo factor = 1.082)

```
**********************************************************************
**                                                                  **
**  Out of the   1000 surfaces generated and analyzed by XSTABL,    **
**        11 surfaces were found to have MISLEADING FOS values.     **
**                                                                  **
**********************************************************************
```

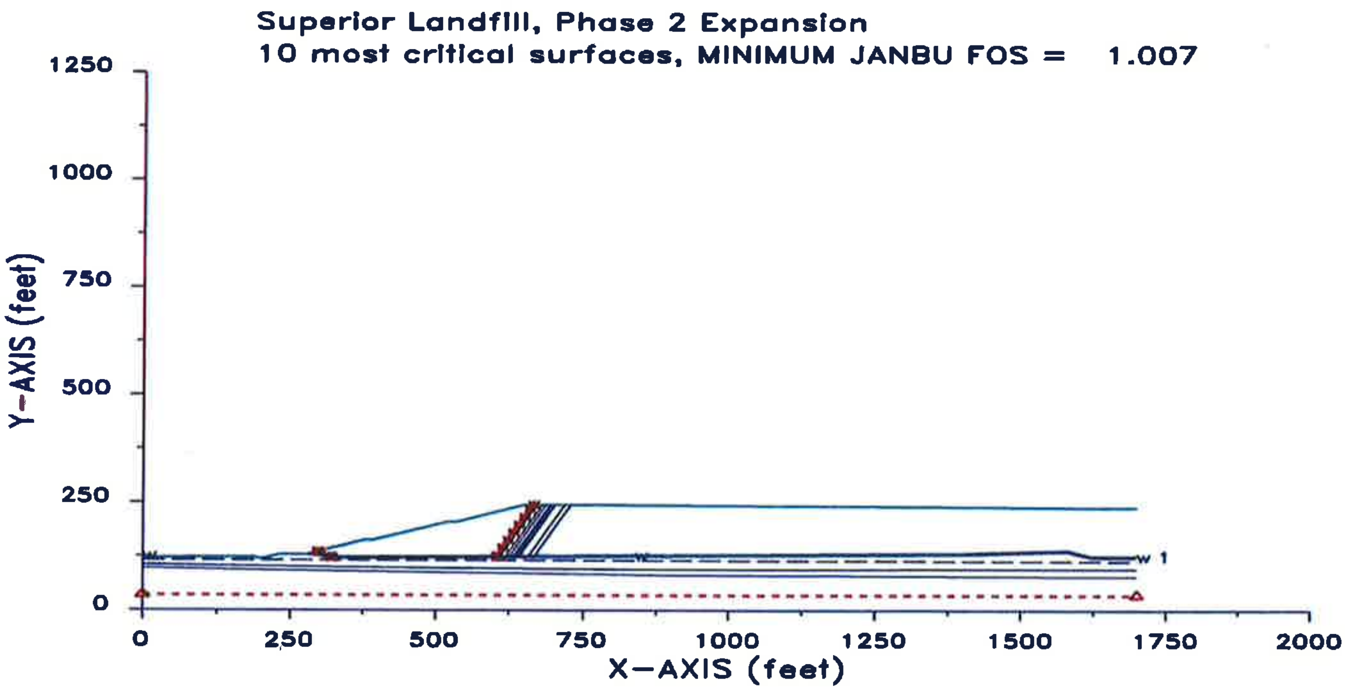
The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.841	1.081	296.41	667.81	5.691E+05
2.	1.881	1.081	296.03	671.48	5.942E+05
3.	1.892	1.081	295.33	672.87	6.002E+05
4.	1.893	1.081	294.79	675.39	6.050E+05
5.	1.893	1.081	294.88	674.97	6.043E+05
6.	1.894	1.081	294.46	665.57	5.775E+05
7.	1.898	1.080	294.55	682.20	6.214E+05
8.	1.898	1.082	295.09	662.62	5.722E+05
9.	1.904	1.079	296.20	699.20	6.569E+05
10.	1.906	1.082	294.12	655.75	5.490E+05

* * * END OF FILE * * *

SD2BLQR1 4-06-•• 14:32



SD2BLQR1.OPT
XSTABL File: SD2BLQR1   4-06-**   14:32

```
******************************************
*              X S T A B L               *
*                                        *
*        Slope Stability Analysis        *
*              using the                 *
*           Method of Slices             *
*                                        *
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*  Ver. 5.202                96 Ä 1599   *
******************************************
```

Problem Description : Superior Landfill, Phase 2 Expansion

SEGMENT BOUNDARY COORDINATES

---

15 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	121.3	102.6	123.4	1
2	102.6	123.4	180.7	123.2	1
3	180.7	123.2	182.9	124.0	1
4	182.9	124.0	184.9	124.0	1
5	184.9	124.0	196.9	120.0	1
6	196.9	120.0	201.5	120.2	1
7	201.5	120.2	228.7	129.1	1
8	228.7	129.1	278.9	130.1	1
9	278.9	130.1	374.5	162.5	6
10	374.5	162.5	391.3	162.9	6
11	391.3	162.9	518.5	205.0	6
12	518.5	205.0	535.7	205.4	6
13	535.7	205.4	648.8	243.8	6
14	648.8	243.8	713.6	245.5	6
15	713.6	245.5	1700.0	238.5	6

41 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	288.7	132.4	321.2	124.2	9
2	321.2	124.2	1403.8	133.8	9
3	1403.8	133.8	1579.0	140.6	9
4	1579.0	140.6	1621.0	127.0	9
5	1621.0	127.0	1700.0	126.6	9
6	288.7	130.4	321.2	122.2	7
7	321.2	122.2	1403.8	131.8	7
8	1403.8	131.8	1579.0	138.6	7

9	1579.0	138.6	1621.0	125.0	7
10	1621.0	125.0	1700.0	124.6	7
11	288.7	130.2	321.2	122.0	8
12	321.2	122.0	1403.8	131.6	8
13	1403.8	131.6	1579.0	138.4	8
14	1579.0	138.4	1621.0	124.8	8
15	1621.0	124.8	1700.0	124.4	8
16	288.7	130.1	321.2	121.9	10
17	321.2	121.9	1403.8	131.5	10
18	1403.8	131.5	1579.0	138.3	10
19	1579.0	138.3	1621.0	124.7	10
20	1621.0	124.7	1700.0	124.3	10
21	288.7	129.9	321.2	121.7	11
22	321.2	121.7	1403.8	131.3	11
23	1403.8	131.3	1579.0	138.1	11
24	1579.0	138.1	1621.0	124.5	11
25	1621.0	124.5	1700.0	124.1	11
26	278.9	127.9	288.7	127.9	1
27	288.7	127.9	321.2	119.7	1
28	321.2	119.7	1403.8	129.3	1
29	1403.8	129.3	1579.0	136.1	1
30	1579.0	136.1	1621.0	122.5	1
31	1621.0	122.5	1700.0	122.1	1
32	.0	105.8	201.5	102.1	2
33	201.5	102.1	321.2	100.0	3
34	321.2	100.0	648.9	96.6	4
35	648.9	96.6	881.7	94.6	5
36	881.7	94.6	1700.0	96.0	5
37	.0	98.1	201.5	93.4	1
38	201.5	93.4	321.2	90.8	1
39	321.2	90.8	648.9	85.6	1
40	648.9	85.6	882.1	82.1	1
41	882.1	82.1	1700.0	78.2	1

ISOTROPIC Soil Parameters

----

11 Soil unit(s) specified

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	120.0	120.0	.0	20.00	.000	.0	1
2	120.0	120.0	456.4	.00	.000	.0	1
3	120.0	120.0	696.6	.00	.000	.0	1
4	120.0	120.0	1789.5	.00	.000	.0	1
5	120.0	120.0	2797.4	.00	.000	.0	1
6	79.0	79.0	500.0	35.00	.000	.0	1
7	110.0	110.0	.0	11.00	.000	.0	1
8	100.0	100.0	.0	12.00	.000	.0	1
9	110.0	110.0	.0	12.00	.000	.0	1
10	100.0	100.0	.0	12.00	.000	.0	1
11	120.0	120.0	500.0	15.00	.000	.0	1

1 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 3 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	115.90
2	838.40	115.40
3	1700.00	113.50

A horizontal earthquake loading coefficient
of .160 has been assigned

A vertical earthquake loading coefficient
of .000 has been assigned

BOUNDARIES THAT LIMIT SURFACE GENERATION HAVE BEEN SPECIFIED

LOWER limiting boundary of 1 segments:

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)
1	.0	35.0	1700.0	35.0

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

The active and passive portions of the sliding surfaces are generated according to the Rankine theory.

1000 trial surfaces will be generated and analyzed.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 20.0 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	288.7	130.3	321.2	122.1	.0
2	322.1	122.1	1403.8	131.7	.0

WARNING - limitation boundaries have been specified !, These are ignored for RANKINE block analysis

```
***************************************************************************
    --  WARNING  --  WARNING  --  WARNING  --  WARNING  --  (# 48)
***************************************************************************
Negative effective stresses were calculated at the base of a slice.
This warning is usually reported for cases where slices have low self
weight and a relatively high "c" shear strength parameter.  In such
cases, this effect can only be eliminated by reducing the "c" value.
***************************************************************************
```

USER SELECTED option to maintain strength greater than zero

Factors of safety have been calculated by the :

* * * * *   SIMPLIFIED JANBU METHOD   * * * * *

The 10 most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16
6	604.89	124.61
7	604.98	124.72
8	606.61	126.73
9	615.84	144.47
10	625.08	162.21
11	634.31	179.95
12	643.55	197.69
13	652.78	215.43
14	662.02	233.17
15	667.81	244.30

** Corrected JANBU FOS = 1.007 ** (Fo factor = 1.081)

Failure surface No. 2 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.41	136.04
2	299.48	134.44
3	317.22	125.21
4	320.80	122.30
5	320.98	122.16

6	666.97	125.16
7	667.06	125.27
8	668.69	127.28
9	677.93	145.02
10	687.16	162.76
11	696.40	180.50
12	705.63	198.24
13	714.86	215.98
14	724.10	233.72
15	730.17	245.38

** Corrected JANBU FOS = 1.008 ** (Fo factor = 1.077)

Failure surface No. 3 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.20	135.96
2	298.79	134.61
3	316.53	125.38
4	320.11	122.47
5	320.29	122.33
6	635.99	124.89
7	636.08	124.99
8	637.71	127.01
9	646.94	144.75
10	656.18	162.49
11	665.41	180.23
12	674.65	197.97
13	683.88	215.71
14	693.12	233.45
15	699.20	245.12

** Corrected JANBU FOS = 1.017 ** (Fo factor = 1.079)

Failure surface No. 4 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.17	135.95
2	298.69	134.64
3	316.43	125.40
4	320.02	122.50
5	320.19	122.35
6	656.82	125.07
7	656.91	125.18
8	658.54	127.19
9	667.78	144.93
10	677.01	162.67
11	686.25	180.41
12	695.48	198.15
13	704.72	215.89
14	713.95	233.63
15	720.10	245.45

** Corrected JANBU FOS = 1.027 ** (Fo factor = 1.078)

Failure surface No. 5 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	293.97	135.21
2	309.39	127.18
3	312.98	124.27
4	313.16	124.13
5	635.02	124.88
6	635.11	124.98
7	636.74	127.00
8	645.97	144.74
9	655.21	162.48
10	664.44	180.22
11	673.68	197.96
12	682.91	215.70
13	692.15	233.44
14	698.22	245.10

** Corrected JANBU FOS = 1.029 ** (Fo factor = 1.079)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.55	135.41
2	311.27	126.71
3	314.85	123.80
4	315.03	123.66
5	619.15	124.74
6	619.23	124.84
7	620.87	126.86
8	630.10	144.60
9	639.34	162.34
10	648.57	180.08
11	657.81	197.82
12	667.04	215.56
13	676.28	233.30
14	682.20	244.68

** Corrected JANBU FOS = 1.030 ** (Fo factor = 1.080)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	296.03	135.91
2	298.26	134.75
3	316.00	125.51
4	319.59	122.61
5	319.76	122.46
6	608.53	124.64
7	608.62	124.75
8	610.25	126.76
9	619.48	144.50
10	628.72	162.24
11	637.95	179.98
12	647.19	197.72
13	656.42	215.46

14	665.66	233.20
15	671.48	244.40

** Corrected JANBU FOS = 1.031 ** (Fo factor = 1.081)

Failure surface No. 8 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.27	135.65
2	295.81	135.36
3	313.55	126.13
4	317.14	123.22
5	317.32	123.08
6	625.24	124.79
7	625.33	124.90
8	626.96	126.91
9	636.19	144.65
10	645.43	162.39
11	654.66	180.13
12	663.90	197.87
13	673.13	215.61
14	682.37	233.35
15	688.35	244.84

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.080)

Failure surface No. 9 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	295.12	135.60
2	295.34	135.48
3	313.08	126.25
4	316.67	123.34
5	316.85	123.20
6	631.57	124.85
7	631.65	124.95
8	633.28	126.97
9	642.52	144.71
10	651.75	162.45
11	660.99	180.19
12	670.22	197.93
13	679.46	215.67
14	688.69	233.41
15	694.73	245.00

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.080)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	294.34	135.33
2	310.59	126.88
3	314.18	123.97
4	314.35	123.83

5	640.81	124.93
6	640.90	125.03
7	642.53	127.05
8	651.77	144.79
9	661.00	162.53
10	670.24	180.27
11	679.47	198.01
12	688.71	215.75
13	697.94	233.49
14	704.06	245.25

** Corrected JANBU FOS = 1.032 ** (Fo factor = 1.079)

The following is a summary of the TEN most critical surfaces

Problem Description : Superior Landfill, Phase 2 Expansion

	Modified JANBU FOS	Correction Factor	Initial x-coord (ft)	Terminal x-coord (ft)	Available Strength (lb)
1.	1.007	1.081	296.41	667.81	5.089E+05
2.	1.008	1.077	296.41	730.17	6.356E+05
3.	1.017	1.079	296.20	699.20	5.881E+05
4.	1.027	1.078	296.17	720.10	6.318E+05
5.	1.029	1.079	293.97	698.22	5.864E+05
6.	1.030	1.080	294.55	682.20	5.546E+05
7.	1.031	1.081	296.03	671.48	5.323E+05
8.	1.032	1.080	295.27	688.35	5.720E+05
9.	1.032	1.080	295.12	694.73	5.855E+05
10.	1.032	1.079	294.34	704.06	6.013E+05

* * * END OF FILE * * *

Liner System Analysis

ATLANTIC COAST CONSULTING, INC.

1

2

3

4

Design Calculations Notebook

IN THIS SECTION:

Liner System Analysis

CCR Liner System Analysis

HELP Model Analysis

ATLANTIC COAST CONSULTING, INC.

OBJECTIVE:

Evaluate the performance of the leachate collection system as shown on the Superior Landfill & Recycling Center D&O Plans using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3.07. This design analysis is for evaluation of materials proposed within the co-mingled MSW/CCR cells only.

METHODOLOGY:

Using the HELP Model, evaluate the leachate collection system with different fill heights to verify that each meets the design guidelines. Each of the scenarios described below cannot result in more than 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 Savannah, Georgia, the mean monthly precipitation for Savannah, GA and temperature for Savannah, Georgia. The peak daily rainfall from the synthetically generated record was adjusted to match the 25-year 24-hour storm event precipitation for Savannah, Georgia, the closest rainfall data site published in the Georgia Stormwater Management Manual, (i.e., 7.80 inches) for simulation terms longer than one year.

- The simulation terms modeled were 50 years for all conditions with over 50 feet of waste. The initial waste placement scenario (10 feet) was modeled using a one year simulation and the 50 feet of waste scenarios were modeled with a simulation term of 10 years.

- All calculations were performed for a unit acre area.

- The base liner slope was set at 2% with a drainage length of 325.

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

    - Saturated hydraulic conductivity of 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. The model results presented in these calculations assumes default hydraulic conductivity for less than 50' heights and 10-4 cm/sec hydraulic conductivity for heights of 50' and more.

    - Parameters for the drainage geocomposite used in the base leachate collection system were taken from the design calculations presented in the section labeled Base Liner Geocomposite Analysis.

- The soil modeled for use as intermediate cover and general fill was HELP soil material #12.

- The vegetative cover was selected as "fair" when utilized. Vegetative cover was used on all scenarios that had 100% runoff. Scenarios that were modeled with 25% and 50% runoff assumed bare ground conditions.

- The leachate collection system was modeled for scenarios to include 10' depth of waste representing initial cell startup, 50' depth of waste representing a stage hallway through filing operations and 118.5' depth of waste representing the final height of waste prior to landfill closure.

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

- 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 hole per acre. These assumptions will result in modeling that assumes the worst case for the peak daily head on the base liner.

The liner system is described as follows from top to bottom:

24 inches of protective cover soil
Double-sided geocomposite drainage layer
60-Mil HDPE Liner
24 inches of $1x10^{-7}$ cm/sec compacted clayey soil

RESULTS:

A summary of the scenarios modeled are presented in Table 1 on the following page. The peak head on the base liner occurs in scenario 5 with 118.5 feet of waste resulting in 9.6 inches.

CONCLUSION:

Each of the Scenarios modeled meet the design guidelines. Therefore, either of the liner design will provide for sufficient leachate collection.

Table 1

Results Summary

TABLE 1

HELP Model Analysis - Summary CCR Cells

File Name	Scenario	Description						Maximum Base Liner Head per Peak Daily Value (inches)	Drainage Collected From LCS 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)	Geonet Core Thickness Modeled (inches)
		Base Liner Option	Final Cover Option	Waste Depth (ft)	Runoff (%)	Recirculation (%)	Simulation Term (yrs)								
rb1.out	1	1	-	10	0	-	1	0.12	0.19	33,324	683	-	-	673	0.20
rb2.out	2	1	-	50	25	-	10	0.16	0.09	33,544	687	-	-	314	0.20
rb3.out	3	1	-	50	100	-	10	0.13	0.07	25,754	528	-	-	253	0.20
rb4.out	4	1	-	118.5	50	-	50	4.51	0.04	25,524	523	-	-	150	0.20
rb5.out	5	1	-	118.5	100	-	50	9.60	0.04	29,436	603	-	-	159	0.20

Scenario #1:

10' of initial waste
0% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3A.D10
OUTPUT DATA FILE:            c:\help3\RB1.OUT


TIME:  11:59     DATE:   5/12/2017


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     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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 =      0.3165 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.419999997000E-04 CM/SEC


                                 LAYER  2
                                 --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
```

MATERIAL TEXTURE NUMBER 18

THICKNESS	=	120.00 INCHES
POROSITY	=	0.6710 VOL/VOL
FIELD CAPACITY	=	0.2920 VOL/VOL
WILTING POINT	=	0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3024 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	=	0.3980 VOL/VOL
FIELD CAPACITY	=	0.2440 VOL/VOL
WILTING POINT	=	0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2449 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20 INCHES
POROSITY	=	0.8500 VOL/VOL
FIELD CAPACITY	=	0.0100 VOL/VOL
WILTING POINT	=	0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1008 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	8.85999966000 CM/SEC
SLOPE	=	2.00 PERCENT
DRAINAGE LENGTH	=	325.0 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	=	0.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 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 100. FEET.

SCS RUNOFF CURVE NUMBER	=	95.40	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.064	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	56.225	INCHES
TOTAL INITIAL WATER	=	56.225	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13 DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	51
END OF GROWING SEASON (JULIAN DATE)	=	341
EVAPORATIVE ZONE DEPTH	=	10.0 INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00 %

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 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	1.44	1.39	2.17	0.40	1.99	5.39
	6.22	7.78	5.26	3.53	0.72	4.39
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	1.736	1.676	2.355	0.271	1.806	4.247
	5.693	5.086	3.361	3.241	0.186	1.841
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	1.3311	0.0000	0.0003	0.0000	0.0019	0.2935
	1.0354	1.4150	2.6159	1.5280	0.0000	0.9592
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	0.0139	0.0000	0.0000	0.0000	0.0000	0.0032
	0.0108	0.0148	0.0282	0.0160	0.0000	0.0100
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

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

	INCHES		CU. FEET	PERCENT
PRECIPITATION	40.68	(0.000)	147668.4	100.00
RUNOFF	0.000	(0.0000)	0.00	0.000
EVAPOTRANSPIRATION	31.496	(0.0000)	114331.70	77.425
LATERAL DRAINAGE COLLECTED FROM LAYER 4	9.18025	(0.00000)	33324.320	22.56700
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000	(0.00000)	0.013	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.008	(0.000)		
CHANGE IN WATER STORAGE	0.003	(0.0000)	12.35	0.008

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 1

	(INCHES)	(CU. FT.)
PRECIPITATION	3.25	11797.500

RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 4	0.18539	672.95660
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00019
AVERAGE HEAD ON TOP OF LAYER 5	0.060	
MAXIMUM HEAD ON TOP OF LAYER 5	0.119	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	2.5 FEET	
SNOW WATER	0.36	1307.9432

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4243

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.2100

*** 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	3.7805	0.3150
2	36.3158	0.3026
3	5.8662	0.2444
4	0.0180	0.0900
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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Scenario #2:

50' of waste
25% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3B.D10
OUTPUT DATA FILE:            c:\help3\RB2.OUT


TIME:  12: 3      DATE:   5/12/2017


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     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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   =       0.3152 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.419999997000E-04 CM/SEC


                                 LAYER  2
                                 --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
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MATERIAL TEXTURE NUMBER 0

THICKNESS	=	600.00	INCHES
POROSITY	=	0.6710	VOL/VOL
FIELD CAPACITY	=	0.2920	VOL/VOL
WILTING POINT	=	0.0770	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3032	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00	INCHES
POROSITY	=	0.3980	VOL/VOL
FIELD CAPACITY	=	0.2440	VOL/VOL
WILTING POINT	=	0.1360	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02	CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0517	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	3.00000000000	CM/SEC
SLOPE	=	2.00	PERCENT
DRAINAGE LENGTH	=	325.0	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	=	0.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 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 500. FEET.

SCS RUNOFF CURVE NUMBER	=	95.00	
FRACTION OF AREA ALLOWING RUNOFF	=	25.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.048	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	201.821	INCHES
TOTAL INITIAL WATER	=	201.821	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.39	2.51	4.54	3.25	5.17	6.28
	7.57	8.21	6.07	2.19	1.52	2.89
STD. DEVIATIONS	2.30	2.78	1.73	1.65	3.62	2.52
	3.18	2.46	1.92	1.44	0.71	1.23
RUNOFF						
TOTALS	0.218	0.399	0.373	0.255	0.725	0.660
	0.691	1.104	0.735	0.139	0.070	0.165
STD. DEVIATIONS	0.238	1.068	0.278	0.224	1.098	0.504
	0.683	0.745	0.494	0.169	0.102	0.132
EVAPOTRANSPIRATION						
TOTALS	2.179	1.936	3.082	2.736	3.404	3.925
	4.692	5.011	3.619	2.143	1.147	1.381
STD. DEVIATIONS	0.538	0.611	0.781	1.289	1.408	0.830
	1.343	0.905	1.068	0.994	0.622	0.519
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.9427	0.6067	0.7267	0.8396	0.7809	0.8404
	0.7166	0.5005	0.4268	0.5905	0.9683	1.3013
STD. DEVIATIONS	0.5657	0.5567	0.5173	0.4584	0.4924	0.3949

	0.5282	0.3694	0.3109	0.3914	0.5859	0.5084

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	0.0291	0.0206	0.0224	0.0268	0.0241	0.0268
	0.0221	0.0154	0.0136	0.0182	0.0308	0.0401
STD. DEVIATIONS	0.0174	0.0190	0.0160	0.0146	0.0152	0.0126
	0.0163	0.0114	0.0099	0.0121	0.0187	0.0157

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	53.60 (7.623)	194560.7	100.00
RUNOFF	5.533 (2.0837)	20086.21	10.324
EVAPOTRANSPIRATION	35.255 (2.7476)	127977.04	65.777
LATERAL DRAINAGE COLLECTED FROM LAYER 4	9.24084 (4.38246)	33544.262	17.24102
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001 (0.00000)	0.034	0.00002
AVERAGE HEAD ON TOP OF LAYER 5	0.024 (0.011)		
CHANGE IN WATER STORAGE	3.568 (7.0879)	12953.21	6.658

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	7.80	28314.000

RUNOFF	2.792	10135.0869
DRAINAGE COLLECTED FROM LAYER 4	0.08662	314.44363
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00025
AVERAGE HEAD ON TOP OF LAYER 5	0.083	
MAXIMUM HEAD ON TOP OF LAYER 5	0.164	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	3.3 FEET	
SNOW WATER	0.68	2452.8115

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4315
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.9267	0.3272
2	217.3759	0.3623
3	5.9056	0.2461
4	0.0482	0.2410
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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CCR Liner System Analysis

HELP Model Analysis

ATLANTIC COAST CONSULTING, INC.

Scenario #3:

50' of waste
100% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:        c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:    c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:      c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:    c:\help3\SUPR3B.D10
OUTPUT DATA FILE:             c:\help3\RB3.OUT


TIME:  12: 6      DATE:   5/12/2017


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     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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 =        0.3132 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.419999997000E-04 CM/SEC


                                   LAYER  2
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
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MATERIAL TEXTURE NUMBER 0

THICKNESS	=	600.00 INCHES
POROSITY	=	0.6710 VOL/VOL
FIELD CAPACITY	=	0.2920 VOL/VOL
WILTING POINT	=	0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3022 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00 INCHES
POROSITY	=	0.3980 VOL/VOL
FIELD CAPACITY	=	0.2440 VOL/VOL
WILTING POINT	=	0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20 INCHES
POROSITY	=	0.8500 VOL/VOL
FIELD CAPACITY	=	0.0100 VOL/VOL
WILTING POINT	=	0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0497 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	3.00000000000 CM/SEC
SLOPE	=	2.00 PERCENT
DRAINAGE LENGTH	=	325.0 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	=	0.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 A FAIR STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 500. FEET.

SCS RUNOFF CURVE NUMBER	=	87.60	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.040	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	201.179	INCHES
TOTAL INITIAL WATER	=	201.179	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.39	2.51	4.54	3.25	5.17	6.28
	7.57	8.21	6.07	2.19	1.52	2.89
STD. DEVIATIONS	2.30	2.78	1.73	1.65	3.62	2.52
	3.18	2.46	1.92	1.44	0.71	1.23
RUNOFF						
TOTALS	0.234	0.702	0.474	0.281	1.198	0.932
	0.950	1.831	1.096	0.139	0.074	0.132
STD. DEVIATIONS	0.309	1.996	0.533	0.402	2.118	0.980
	1.315	1.546	0.950	0.291	0.193	0.144
EVAPOTRANSPIRATION						
TOTALS	2.186	1.878	3.107	2.737	3.390	3.986
	4.727	4.993	3.605	2.160	1.186	1.390
STD. DEVIATIONS	0.525	0.594	0.733	1.249	1.381	0.800
	1.379	0.893	1.033	1.007	0.640	0.509
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.7520	0.4677	0.5588	0.6649	0.6309	0.6952
	0.5985	0.4085	0.3183	0.3080	0.6871	1.0050
STD. DEVIATIONS	0.4346	0.4496	0.4177	0.3568	0.3707	0.3423

	0.4224	0.2812	0.2130	0.2095	0.4613	0.3788

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	0.0232	0.0159	0.0172	0.0212	0.0195	0.0222
	0.0185	0.0126	0.0101	0.0095	0.0219	0.0310
STD. DEVIATIONS	0.0134	0.0154	0.0129	0.0114	0.0114	0.0109
	0.0130	0.0087	0.0068	0.0065	0.0147	0.0117

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

	INCHES		CU. FEET	PERCENT
PRECIPITATION	53.60	(7.623)	194560.7	100.00
RUNOFF	8.044	(4.0695)	29200.24	15.008
EVAPOTRANSPIRATION	35.345	(2.7656)	128301.73	65.944
LATERAL DRAINAGE COLLECTED FROM LAYER 4	7.09477	(3.28210)	25754.027	13.23701
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001	(0.00000)	0.029	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.019	(0.009)		
CHANGE IN WATER STORAGE	3.114	(6.1666)	11304.73	5.810

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	7.80	28314.000

RUNOFF	6.286	22819.1445
DRAINAGE COLLECTED FROM LAYER 4	0.06960	252.65901
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00021
AVERAGE HEAD ON TOP OF LAYER 5	0.067	
MAXIMUM HEAD ON TOP OF LAYER 5	0.132	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	2.3 FEET	
SNOW WATER	0.68	2452.8115

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4363
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.9150	0.3262
2	212.2641	0.3538
3	5.8560	0.2440
4	0.0389	0.1945
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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CCR Liner System Analysis

HELP Model Analysis

Atlantic Coast Consulting, Inc.

Scenario #4:

118.50' of waste
50% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3C.D10
OUTPUT DATA FILE:            c:\help3\RB4.OUT


TIME:  12: 9      DATE:   5/12/2017


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     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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 =      0.3262 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  = 0.419999997000E-04 CM/SEC


                               LAYER  2
                               --------

                  TYPE 1 - VERTICAL PERCOLATION LAYER
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MATERIAL TEXTURE NUMBER 0

THICKNESS	=	1422.00	INCHES
POROSITY	=	0.6710	VOL/VOL
FIELD CAPACITY	=	0.2920	VOL/VOL
WILTING POINT	=	0.0770	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2955	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00	INCHES
POROSITY	=	0.3980	VOL/VOL
FIELD CAPACITY	=	0.2440	VOL/VOL
WILTING POINT	=	0.1360	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02	CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2242	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.569000006000	CM/SEC
SLOPE	=	2.00	PERCENT
DRAINAGE LENGTH	=	325.0	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	=	0.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 500. FEET.

SCS RUNOFF CURVE NUMBER	=	95.00	
FRACTION OF AREA ALLOWING RUNOFF	=	50.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.156	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	440.324	INCHES
TOTAL INITIAL WATER	=	440.324	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 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	2.72	2.97	4.09	3.04	4.80	6.35
	7.51	6.88	5.65	2.08	1.65	2.94
STD. DEVIATIONS	1.63	1.78	1.58	1.77	2.32	2.63
	3.18	2.75	2.74	1.50	1.20	1.38
RUNOFF						
TOTALS	0.291	0.417	0.540	0.488	0.921	1.269
	1.404	1.497	1.177	0.264	0.150	0.347
STD. DEVIATIONS	0.331	0.736	0.376	0.481	0.887	1.085
	1.061	0.963	0.944	0.320	0.201	0.332
EVAPOTRANSPIRATION						
TOTALS	2.037	2.123	3.079	2.380	3.235	3.914
	4.624	4.120	3.302	1.796	1.165	1.570
STD. DEVIATIONS	0.541	0.539	0.724	1.122	1.328	1.076
	1.380	1.367	1.054	0.910	0.707	0.473
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.7382	0.5934	0.6414	0.5602	0.6717	0.6359
	0.5788	0.4571	0.3502	0.3604	0.5601	0.8838
STD. DEVIATIONS	0.3347	0.3324	0.3406	0.3385	0.3361	0.3122

	0.2936	0.2772	0.2600	0.3059	0.3339	0.3351

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	0.2182	0.1621	0.1327	0.1289	0.1534	0.1415
	0.1039	0.0799	0.0627	0.0612	0.1007	0.2142
STD. DEVIATIONS	0.3301	0.2395	0.1987	0.2144	0.1693	0.2149
	0.0668	0.0629	0.0611	0.0568	0.0681	0.1897

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	50.66 (7.415)	183910.3	100.00
RUNOFF	8.765 (2.4907)	31816.82	17.300
EVAPOTRANSPIRATION	33.343 (3.4576)	121036.02	65.813
LATERAL DRAINAGE COLLECTED FROM LAYER 4	7.03142 (2.44357)	25524.053	13.87853
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00004 (0.00002)	0.136	0.00007
AVERAGE HEAD ON TOP OF LAYER 5	0.130 (0.099)		
CHANGE IN WATER STORAGE	1.524 (4.4705)	5533.30	3.009

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	7.92	28749.600

RUNOFF	5.021	18225.4102
DRAINAGE COLLECTED FROM LAYER 4	0.04135	150.11642
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000002	0.00600
AVERAGE HEAD ON TOP OF LAYER 5	2.592	
MAXIMUM HEAD ON TOP OF LAYER 5	4.508	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	42.3 FEET	
SNOW WATER	1.84	6680.3433

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4333
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.4084	0.2840
2	496.7753	0.3493
3	5.9388	0.2474
4	0.1700	0.8498
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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ATLANTIC COAST CONSULTING, INC.

Scenario #5:

118.50' of waste
100% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3C.D10
OUTPUT DATA FILE:            c:\help3\RB5.OUT


TIME:  11:53     DATE:   5/12/2017


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

     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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


     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  12
           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 =       0.3132 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  = 0.419999997000E-04 CM/SEC


                                  LAYER  2
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
```

```
               MATERIAL TEXTURE NUMBER   0
THICKNESS                      =    1422.00   INCHES
POROSITY                       =      0.6710 VOL/VOL
FIELD CAPACITY                 =      0.2920 VOL/VOL
WILTING POINT                  =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.2963 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.999999975000E-04 CM/SEC


                          LAYER  3
                          --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
               MATERIAL TEXTURE NUMBER   0
THICKNESS                      =     24.00    INCHES
POROSITY                       =      0.3980 VOL/VOL
FIELD CAPACITY                 =      0.2440 VOL/VOL
WILTING POINT                  =      0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.2440 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.200000009000E-02 CM/SEC


                          LAYER  4
                          --------

              TYPE 2 - LATERAL DRAINAGE LAYER
               MATERIAL TEXTURE NUMBER   0
THICKNESS                      =      0.20    INCHES
POROSITY                       =      0.8500 VOL/VOL
FIELD CAPACITY                 =      0.0100 VOL/VOL
WILTING POINT                  =      0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.1303 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.569000006000      CM/SEC
SLOPE                          =      2.00    PERCENT
DRAINAGE LENGTH                =    325.0     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            =      0.00    HOLES/ACRE
FML INSTALLATION DEFECTS       =      1.00    HOLES/ACRE
FML PLACEMENT QUALITY          =  3 - GOOD


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

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 A FAIR STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 500. FEET.

SCS RUNOFF CURVE NUMBER	=	87.60	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.040	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	441.250	INCHES
TOTAL INITIAL WATER	=	441.250	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 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	2.72	2.97	4.09	3.04	4.80	6.35
	7.51	6.88	5.65	2.08	1.65	2.94
STD. DEVIATIONS	1.63	1.78	1.58	1.77	2.32	2.63
	3.18	2.75	2.74	1.50	1.20	1.38
RUNOFF						
TOTALS	0.138	0.282	0.283	0.357	0.764	1.013
	1.092	1.304	0.995	0.151	0.064	0.160
STD. DEVIATIONS	0.248	0.915	0.337	0.518	1.118	1.296
	1.166	1.137	1.073	0.281	0.165	0.273
EVAPOTRANSPIRATION						
TOTALS	2.071	2.153	3.158	2.476	3.350	4.056
	4.758	4.194	3.343	1.880	1.218	1.570
STD. DEVIATIONS	0.511	0.527	0.694	1.132	1.363	1.094
	1.392	1.387	1.039	0.973	0.711	0.495
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.8222	0.6572	0.7481	0.6317	0.7507	0.7381
	0.6958	0.5199	0.4388	0.4463	0.6849	0.9755
STD. DEVIATIONS	0.3615	0.3639	0.3801	0.3800	0.3754	0.3366

	0.3530	0.3209	0.2988	0.3664	0.3748	0.3442

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	0.5480	0.4744	0.3419	0.2695	0.3879	0.3544
	0.2625	0.1433	0.1006	0.1047	0.1744	0.4992
STD. DEVIATIONS	0.8534	0.9022	0.6007	0.5736	0.7289	0.6784
	0.4511	0.2653	0.1810	0.1459	0.2184	0.5672

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	50.66 (7.415)	183910.3	100.00
RUNOFF	6.605 (2.8731)	23975.23	13.036
EVAPOTRANSPIRATION	34.228 (3.5006)	124247.62	67.559
LATERAL DRAINAGE COLLECTED FROM LAYER 4	8.10920 (2.89551)	29436.387	16.00584
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00008 (0.00008)	0.285	0.00015
AVERAGE HEAD ON TOP OF LAYER 5	0.305 (0.330)		
CHANGE IN WATER STORAGE	1.722 (4.9066)	6250.83	3.399

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	7.92	28749.600

RUNOFF	6.663	24185.8574
DRAINAGE COLLECTED FROM LAYER 4	0.04378	158.93210
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000004	0.01326
AVERAGE HEAD ON TOP OF LAYER 5	6.074	
MAXIMUM HEAD ON TOP OF LAYER 5	9.602	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	68.0 FEET	
SNOW WATER	1.84	6680.3433

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4363
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.3370	0.2781
2	507.4013	0.3568
3	6.1932	0.2580
4	0.1700	0.8498
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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Base Liner Geocomposite Analysis

OBJECTIVE:

Evaluate the performance of geocomposite drainage system to be used in Superior Landfill & Recycling Center in co-mingled MSW/CCR waste cells. The analysis applies to the leachate collection rates for different stages of the landfill's life. For application purposes the geocomposite is designed to provide leachate collection for initial operations with larger leachate flows and less weight through post closure with less leachate flow and high pressure due to increased waste thickness.

METHODOLOGY:

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

Project #	I010-415			
Project Name:	Superior CCR Management	By: JST	Date:	5/10/2017
Subject:	Geocomposite Design for CCR	Chk'd: RBB	Date:	5/12/2017

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

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

Input Parameters

L=	325 (ft)	Max horizontal drainage length of slope
β=	2% slope, or	
	0.02 radians, or	(gradient)
	1.15 degree	Slope Angle
λccr=	79 lb/ft^3	(Co-Mingled MSW/CCR)

HELP Model Analysis Results

Stage	Thickness of solid waste, t_{waste}	Peak imprangement rate into the LCRS drainage layer, qi
I - Initial Operation	10 ft	3.38E-07 ft/sec
II - Active Operation	50 ft	1.75E-07 ft/sec
III - Closure	118.5 ft	7.45E-08 ft/sec

Reduction Factors & Factor of Safety

	Chemical Clogging Reduction Factor		Biological Clogging Reduction Factor		Creep Reduction Factor	
Stage	RF_{cc}	GRI-GC8	RF_{bc}	GRI-GC8	RF_{cr}	GSE
I - Initial Operation	1.2		1.1		1.01	
II - Active Operation	1.5		1.2		1.13	
III - Closure	2		1.3		1.33	

Overall Factor of Safety (Narejo and Richardson 2003)

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

Solution

	Normal Stess	Design require transmissivity of LCRS	
Stage	$\sigma=\lambda_{waste}*t_{waste}$	$\theta_{req}=(q_i*L)/\sin\beta$	
I - Initial Operation	790 lb/ft^2	5.49E-03 ft^2/sec	5.10E-04 m^2/sec
II - Active Operation	3950 lb/ft^2	2.85E-03 ft^2/sec	2.65E-04 m^2/sec
III - Closure	9361.5 lb/ft^2	1.21E-03 ft^2/sec	1.12E-04 m^2/sec

	Allowable transmissivity of LCRS	Specified 100-hour transmissivity of LCRS	
Stage	$\theta_{allow}=\theta_{req}*FS$	$\theta_{100}=\theta_{allow}*RF_{cr}*RF_{cc}*RF_{bc}$	
I - Initial Operation	1.10E-02 ft^2/sec	1.46E-02 ft^2/sec	1.36E-03 m^2/sec
II - Active Operation	8.55E-03 ft^2/sec	1.74E-02 ft^2/sec	1.62E-03 m^2/sec
III - Closure	4.84E-03 ft^2/sec	1.67E-02 ft^2/sec	1.56E-03 m^2/sec

***Use GSE 200 mil FabriNet HF Geocomposite double sided with 8oz. Geotextile (or approved equal)**

Published 100-hour transmissivity of GSE 200 Mil FabriNet HF (Figure A-3)

	Normal Stess	θ_{100}	
Stage	$\sigma=\lambda_{waste}*t_{waste}$ (lb/ft^2)	(ft^2/sec)	(m^2/sec)
I - Initial Operation	790	6.46E-03	6.00E-04
II - Active Operation	3950	3.34E-03	3.10E-04
II - Closure	9361.5	1.08E-03	1.00E-04

Conclusion

	Published 100-hour		Specified 100-hour transmissivity of LCRS for HELP model use $\theta_{HELP}=\theta_{100}/(RF_{cr}*RF_{cc}*RF_{bc})$	
Stage	θ_{100} (ft^2/sec)		(ft^2/sec)	(m^2/sec)
I - Initial Operation	6.46E-03	>	4.84E-03	4.50E-04
II - Active Operation	3.34E-03	>	1.64E-03	1.52E-04
III - Closure	1.08E-03	>	3.11E-04	2.89E-05

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

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]):

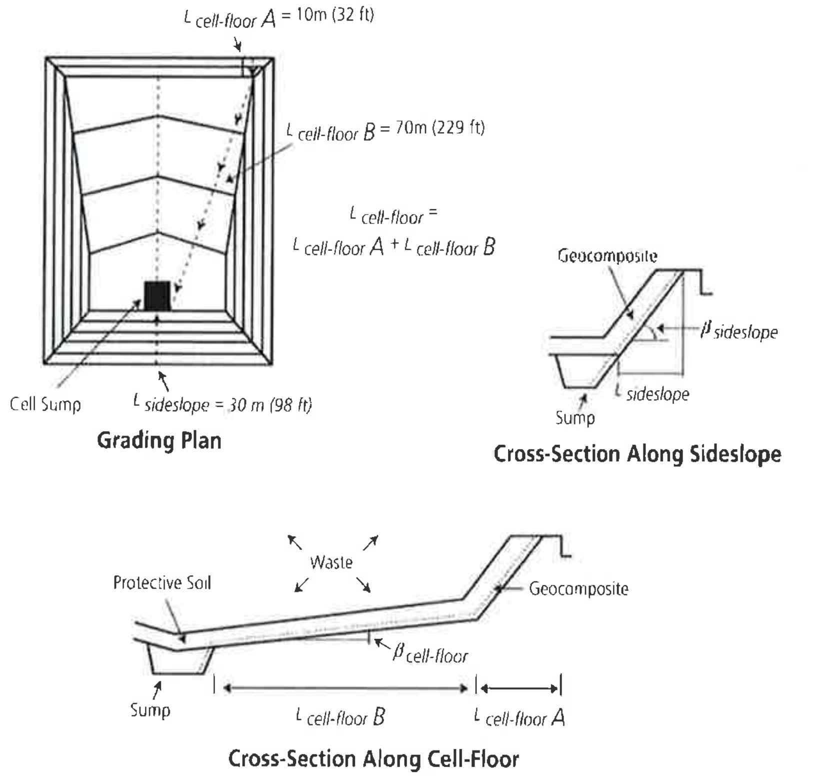

Figure 1. Simplified schematic of design geometry for example problem.

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

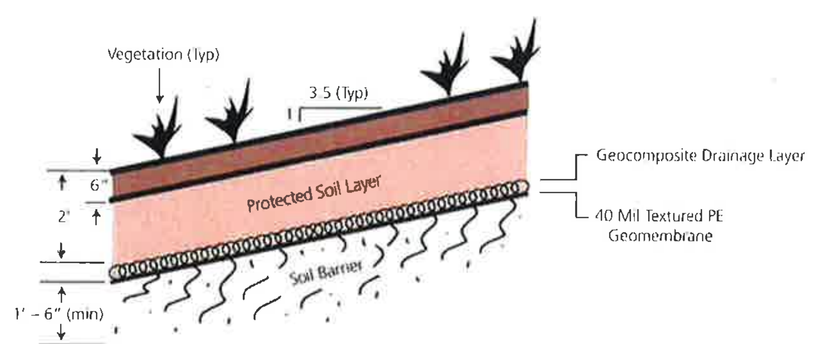

Figure 2. Design of final cover system.

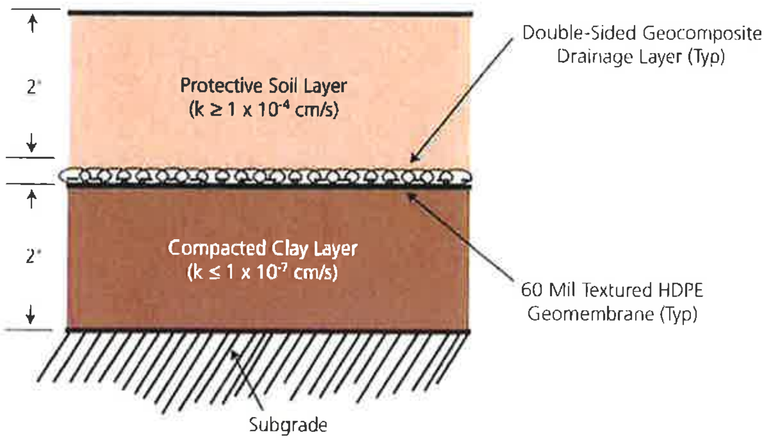

Figure 3. Design of bottom liner system.

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 sideslope = 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:

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

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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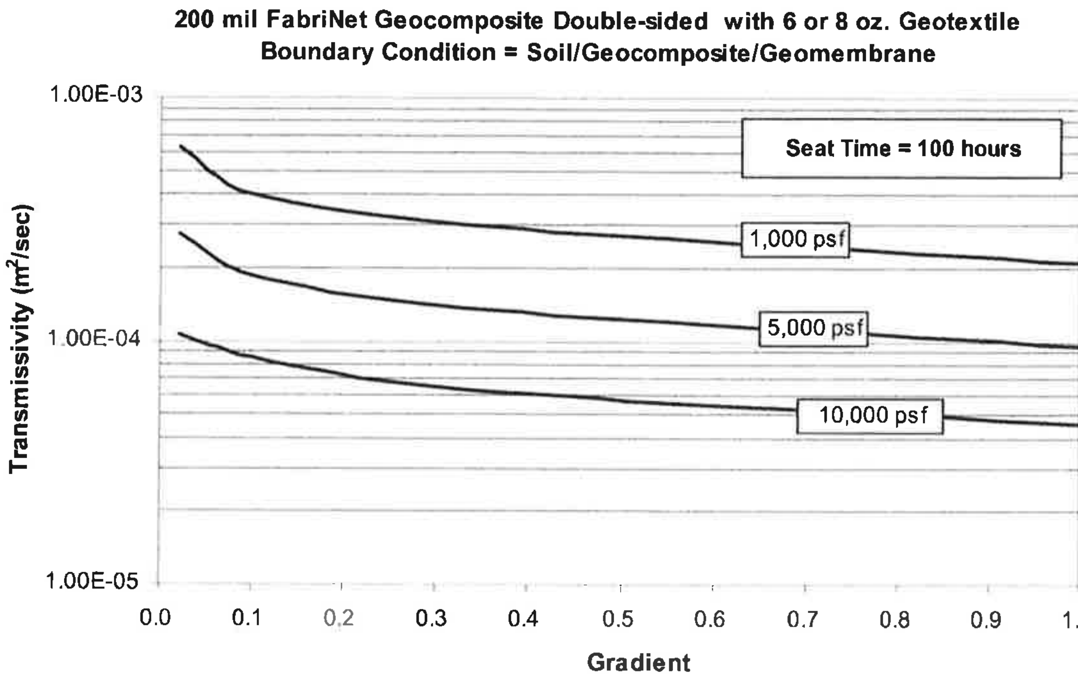

Figure A-3 Performance Transmissivity of a 200 mil FabriNet Geocomposite under Soil

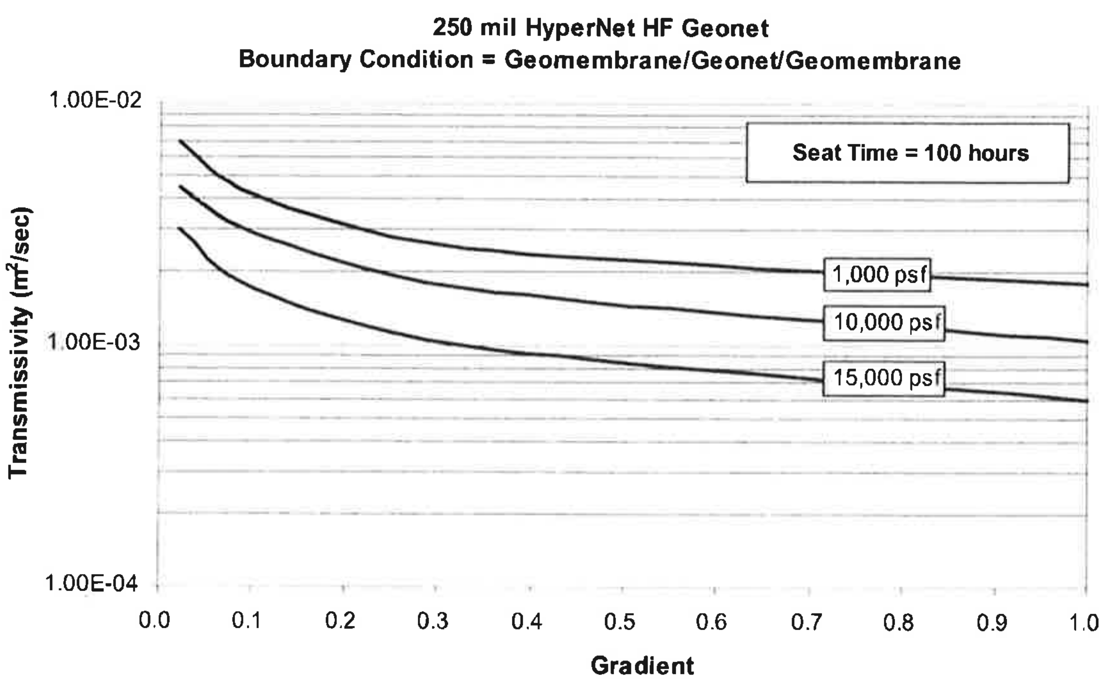

Figure A-4 Performance Transmissivity of a 250 mil HyperNet HF Geonet.

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

Base Grade Settlement Analysis

ATLANTIC COAST CONSULTING, INC.

Design Calculations Notebook

IN THIS SECTION:

Base Grade Settlement Analysis

1

2

3

4

OBJECTIVE: Evaluate the base grade settlements as a result of the change in stress in the subgrade soils due to placement of waste in the landfill.

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 first step in the evaluation was to input the geometry and soils and waste mass and the physical properties of the soils and waste at discreet points along a selected cross section into a Microsoft Excel spreadsheet and perform a one-dimensional settlement analysis at each analysis location. 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_0 = initial void ratio,
σ_0' = effective vertical stress at the middle of the layer after excavation, but before loading, and
$\Delta\sigma_0'$ = 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_α = *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 selected cross section location is shown in Figure 4-1. The results of a previously completed subsurface exploration outlined in the report "Report of the Phase I and Phase II Hydrogeologic/Geotechnical Investigation for Superior Landfill and Recycling Center" by SEC Donohue, Inc., dated April, 1992 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 4-2.

Soil Layer Data:

The subgrade soil was divided in 6 different layers at each analysis location to represent distinct strata of the Cypresshead Formation encountered during previous subsurface explorations. The following subgrade soil material properties were used for each layer based on experience and the references cited above.

Layer 1 – Silty Sand

This layer was modeled as an elastic soil with a modulus of 252,000 psf, which was estimated using a correlation to the average SPT blow count of 18 bpf, and a correlation factor of 7 tsf/bpf. In the analysis locations where engineered fill was needed to reach the subgrade elevation, the engineered fill was assumed to have the same elastic properties as well. The layer was assumed to have a total unit weight of 120 psf. The thickness of this layer (including any fill placed to reach subgrade elevations) ranged from 12.24 ft to 34.86 ft. The groundwater surface was observed to pass through this layer at all locations.

Layer 2 – Clay

This layer was modeled as a normally consolidated soil layer with a Compression Index of 0.67 and an initial void ratio of 1.77, which were based on previous laboratory test results for samples from this layer. The layer was assumed to have a total unit weight of 100.9 psf. The thickness of this layer ranged from 7.06 ft to 16.22 ft.

Layers 3-6 – Sand

The stratum between the bottom of clay and the top of Coosawhatchie Formation was divided in three layers, and was modeled as an elastic soil with a modulus of 740,000 psf, which was estimated using a correlation to the average SPT blow count of 37 bpf, and a correlation factor of 10 tsf/bpf. The layers were assumed to have a total unit weight of 120 psf. The thickness of these layers ranged from 11.50 ft to 14.90 ft. The bottom of the Cypresshead Formation was assumed to be at an elevation of -65 ft MSL, marking the base of all compressible strata.

The placement of engineered fill (unit weight 120 pcf), liner soil (unit weight 120 pcf), municipal solid waste (unit weight 79 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 is slope and, any induced tensile stresses.

RESULTS: The output for the spreadsheet computation of the base grade settlement analysis is attached. As indicated the subgrade settlement ranges from 1.151 to 4.230ft under the landfill liner. Based on this computed settlement, the maximum tensile stress in the liner system is anticipated to be 0.18% (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.	1	2	3	4	5	6	7	8	9	10
Horizontal Distance	0.00	44.28	85.78	161.41	186.17	219.95	400.00	548.35	700.00	900.00
Top of Final Cover Elevation (ft MSL)					38.73	47.17	92.11	129.14	133.53	139.18
Top of Waste Elevation (ft MSL)					35.12	43.56	88.50	125.59	130.02	135.68
Top of Liner Elevation (ft MSL)					32.60	23.10	23.99	24.72	25.47	26.47
Subgrade Elevation (ft MSL)	20.16	19.97	31.71	32.55	28.45	19.10	19.99	20.72	21.47	22.47
Existing Ground Elevation (ft MSL)	20.16	19.97	19.63	19.45	19.21	18.85	18.91	19.20	19.60	19.71
Groundwater Elevation (ft MSL)	14.30	14.15	14.21	14.12	14.09	14.06	13.98	13.71	13.57	13.26
Cut (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fill (ft)	0.00	0.00	12.08	13.10	9.24	0.25	1.07	1.52	1.87	2.76
Fill Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Liner Soil Thickness (ft)	0	0	0	0	4.15	4.00	4.00	4.00	4.00	4.00
Liner Soil Density (pcf)	120	120	120	120	120	120	120	120	120	120
Cover Soil Thickness (ft)	0	0	0	0	3.61	3.61	3.61	3.61	3.51	3.50
Cover Soil Density (pcf)	120	120	120	120	120	120	120	120	120	120
Waste Thickness (ft)	0	0	0	0	2.52	20.46	64.51	100.81	104.55	109.21
Waste Density (pcf)	70.0	70.0	70.0	70.0	70.0	79.0	79.0	79.0	79.0	79.0
Change in Stress (psf)	0.00	0.00	1450.15	1572.58	2216.10	2559.41	6138.37	9059.48	9385.05	9858.79
Layer 1 (Silty Sand N = 18)										
Top Elevation (ft MSL)	20.16	19.97	31.71	32.55	28.45	19.10	19.99	20.72	21.47	22.47
Botton Elevation (ft MSL)	1.65	1.23	0.84	0.18	-0.02	-0.20	-1.11	-2.32	-1.75	2.80
Mid Point Elevation (ft MSL)	10.90	10.60	16.28	16.36	14.22	9.45	9.44	9.20	9.86	9.84
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	18.51	18.74	30.87	32.37	28.47	19.30	21.09	23.04	23.22	25.27
Initial Stress (psf)	898.46	902.54	1981.31	2082.23	1715.59	870.28	988.80	1100.87	1164.86	1302.48
Elastic Modulus (psf)	252000	252000	252000	252000	252000	252000	252000	252000	252000	252000
Layer Settlement (ft)	0.000	0.000	0.178	0.202	0.250	0.196	0.514	0.828	0.865	0.989
Layer 2 (Clay)										
Top Elevation (ft MSL)	1.65	1.23	0.84	0.18	-0.02	-0.20	-1.11	-2.32	-1.75	-2.80
Botton Elevation (ft MSL)	-5.41	5.91	6.37	7.15	-7.39	7.64	8.93	10.75	-9.88	11.72
Mid Point Elevation (ft MSL)	1.879	2.340	-2.762	-3.489	-3.705	-3.919	-5.020	-6.535	5.817	7.260
Soil Density (pcf)	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9
Layer Thickness (ft)	7.06	7.14	7.21	7.33	7.38	7.44	7.83	8.43	8.13	8.92
Initial Stress (psf)	1567.3466	1579.6289	3009.1199	3155.7281	2677.4066	1569.2242	1746.9366	1926.6841	1990.1486	2201.966
Initial Void Ratio	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Compression Index	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Layer Settlement (ft)	0.000	0.000	0.298	0.311	0.467	0.756	1.239	1.542	1.489	1.593
Layer 3 (Sand N = 37)										
Top Elevation (ft MSL)	-5.41	-5.91	-6.37	-7.15	-7.39	-7.64	-8.93	-10.75	-9.88	-11.72
Botton Elevation (ft MSL)	20.33	-20.69	21.02	-21.62	-21.79	-21.98	22.95	-24.31	23.66	25.04
Mid Point Elevation (ft MSL)	-12.86	-13.30	-13.70	-14.39	-14.59	-14.81	-15.94	-17.53	-16.77	-18.38
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	14.90	14.77	14.66	14.46	14.40	14.34	14.02	13.56	13.78	13.32
Initial Stress (psf)	2132.3044	2142.5046	3570.0397	3713.3315	3234.1597	2125.4622	2301.2873	2479.4896	2543.4997	2757.292
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.000	0.000	0.029	0.031	0.043	0.050	0.116	0.166	0.175	0.177
Layer 4 (Sand N = 37)										
Top Elevation (ft MSL)	-20.31	-20.68	-21.02	-21.67	-21.79	-21.98	-22.95	-24.31	-23.66	-25.04
Botton Elevation (ft MSL)	-35.20	-35.45	35.68	-36.08	-36.20	36.32	-36.97	-37.88	37.44	38.36
Mid Point Elevation (ft MSL)	-27.76	-28.07	-28.35	-28.85	-29.00	-29.15	-29.96	-31.10	-30.55	-31.70
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	14.90	14.77	14.66	14.46	14.40	14.34	14.02	13.57	13.78	13.32
Initial Stress (psf)	2990.4091	2993.4121	4414.3722	4546.3052	4063.6976	2951.452	3108.6493	3260.8336	3337.2075	3524.524
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.000	0.000	0.029	0.031	0.043	0.050	0.116	0.166	0.175	0.177
Layer 5 (Sand N = 37)										
Top Elevation (ft MSL)	-35.20	-35.45	-35.68	-36.08	-36.20	-36.32	-36.97	-37.88	-37.44	-38.36
Botton Elevation (ft MSL)	-50.10	-50.23	50.34	50.54	-50.60	50.66	50.98	-51.44	-51.22	51.68
Mid Point Elevation (ft MSL)	-42.65	-42.84	-43.01	-43.31	-43.40	-43.49	-43.97	-44.66	-44.33	-45.02
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	14.90	14.77	14.66	14.46	14.40	14.34	14.02	13.56	13.78	13.32
Initial Stress (psf)	3848.5166	3844.3196	5258.7046	5379.279	4893.2355	3777.4388	3916.0112	4042.1776	4130.9154	4291.756
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.000	0.000	0.029	0.031	0.043	0.050	0.116	0.166	0.175	0.177
Layer 6 (Sand N = 37)										
Top Elevation (ft MSL)	-50.10	-50.23	-50.34	-50.54	-50.60	-50.66	-50.98	-51.44	-51.22	-51.68
Botton Elevation (ft MSL)	-65.00	-65.00	65.00	65.00	65.00	-65.00	-65.00	65.00	-65.00	65.00
Mid Point Elevation (ft MSL)	-57.55	-57.61	-57.67	-57.77	-57.80	-57.83	-57.99	-58.22	-58.11	-58.34
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	14.90	14.77	14.66	14.46	14.40	14.34	14.02	13.56	13.78	13.32
Initial Stress (psf)	4706.6241	4695.2272	6103.0371	6212.2499	5722.7734	4603.4257	4723.3731	4823.2336	4924.6203	5058.988
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.000	0.000	0.029	0.031	0.043	0.050	0.116	0.166	0.175	0.177
Total Settlement (ft)	0.000	0.000	0.590	0.636	0.890	1.151	2.218	3.034	3.053	3.292
Initial Length of Liner Segment (ft)						35.08	180.05	148.35	151.65	200.00
Final Length of Liner Segment (ft)						35.01	180.06	148.36	151.65	200.00
Strain (%, Tensile Negative)						0.20	0.00	0.00	0.00	0.00
Initial Liner Slope (ft/f)						-0.28	0.005	0.005	0.005	0.005
Final Liner Slope (ft/ft)						-0.25	-0.001	-0.001	0.005	0.004

Point No.	11	12	13	14	15	16	17	18	19	20
Horizontal Distance	1100.00	1187.88	1214.35	1218.34	1255.55	1400.00	1600.00	1836.47	2000.00	2133.89
Top of Final Cover Elevation (ft MSL)	144.81	147.28	146.99	146.88	145.90	142.09	136.81	130.57	84.08	46.03
Top of Waste Elevation (ft MSL)	141.31	143.78	143.49	143.38	142.40	139.59	133.31	126.92	80.44	42.39
Top of Liner Elevation (ft MSL)	27.48	27.92	35.71	35.71	24.81	24.08	23.08	21.89	21.08	20.41
Subgrade Elevation (ft MSL)	23.48	23.92	31.53	31.54	20.81	20.08	19.08	17.89	17.08	16.41
Existing Ground Elevation (ft MSL)	19.41	19.31	18.93	18.26	18.19	17.64	18.19	14.96	15.59	16.33
Groundwater Elevation (ft MSL)	12.97	12.84	12.80	12.79	12.74	12.54	12.40	12.03	11.70	11.40
Cut (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fill (ft)	4.07	4.61	12.60	13.28	2.62	2.44	0.89	2.93	1.49	0.08
Fill Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Liner Soil Thickness (ft)	4.00	4.00	4.18	4.17	4.00	4.00	4.00	4.00	4.00	4.00
Liner Soil Density (pcf)	120	120	120	120	120	120	120	120	120	120
Cover Soil Thickness (ft)	3.50	3.50	3.50	3.50	3.50	2.50	3.50	3.65	3.64	3.64
Cover Soil Density (pcf)	120	120	120	120	120	120	120	120	120	120
Waste Thickness (ft)	113.83	115.86	107.78	107.67	117.59	115.51	110.23	105.03	59.36	21.98
Waste Density (pcf)	79.0	79.0	79.0	79.0	79.0	79.0	79.0	79.0	79.0	79.0
Change in Stress (psf)	10380.74	10606.14	10947.92	11019.93	10504.01	10198.09	9714.97	9566.97	5785.04	2662.82
Layer 1 (Silty Sand N = 18)										
Top Elevation (ft MSL)	23.48	23.92	31.53	31.54	20.81	20.08	19.08	17.89	17.08	16.41
Botton Elevation (ft MSL)	-3.15	-3.28	-3.32	-3.32	-3.37	-3.51	-3.61	-3.55	-3.39	-3.06
Mid Point Elevation (ft MSL)	10.17	10.32	14.11	14.11	8.72	8.29	7.74	7.17	6.85	6.68
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	26.63	27.20	34.85	34.86	24.18	23.59	22.69	21.44	20.47	19.47
Initial Stress (psf)	1422.77	1474.75	2172.43	2173.97	1199.95	1149.89	1076.54	983.14	925.25	873.36
Elastic Modulus (psf)	252000	252000	252000	252000	252000	252000	252000	252000	252000	252000
Layer Settlement (ft)	1.097	1.145	1.514	1.524	1.008	0.955	0.875	0.814	0.470	0.206
Layer 2 (Clay)										
Top Elevation (ft MSL)	-3.15	-3.28	-3.32	-3.32	-3.37	-3.51	-3.61	-3.55	-3.39	-3.06
Botton Elevation (ft MSL)	-12.88	13.50	13.71	-13.74	14.04	15.25	16.95	18.40	18.93	18.97
Mid Point Elevation (ft MSL)	-8.015	-8.390	-8.515	-8.530	-8.705	-9.380	-10.280	-10.975	-11.160	-11.015
Soil Density (pcf)	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9
Layer Thickness (ft)	9.73	10.22	10.39	10.42	10.67	11.74	13.34	14.85	15.54	15.91
Initial Stress (psf)	2377.0145	2454.847	3376.1195	3378.521	2101.7335	2055.275	1986.811	1886.4705	1813.929	1740.3635
Initial Void Ratio	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Compression Index	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Layer Settlement (ft)	1.717	1.795	1.577	1.587	2.008	2.202	2.485	2.813	2.338	1.551
Layer 3 (Sand N = 37)										
Top Elevation (ft MSL)	12.88	-13.50	-13.71	-13.74	-14.04	-15.25	-16.95	-18.40	-18.93	-18.97
Botton Elevation (ft MSL)	25.91	-26.37	26.53	-26.55	26.78	-27.69	28.96	-30.05	30.45	-30.48
Mid Point Elevation (ft MSL)	-19.40	-19.94	-20.12	-20.15	-20.41	-21.47	-22.96	-24.23	-24.69	-24.73
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	13.03	12.87	12.82	12.81	12.74	12.44	12.01	11.65	11.52	11.51
Initial Stress (psf)	2939.581	3022.238	3945.343	3948.034	2674.043	2639.542	2589.494	2507.853	2444.85	2378.119
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.183	0.184	0.190	0.191	0.181	0.171	0.158	0.151	0.090	0.041
Layer 4 (Sand N = 37)										
Top Elevation (ft MSL)	-25.91	-26.37	-26.53	-26.55	-26.78	-27.69	-28.96	-30.05	-30.45	-30.48
Botton Elevation (ft MSL)	-38.94	39.25	39.35	39.37	39.52	-40.13	40.97	-41.70	-41.97	41.99
Mid Point Elevation (ft MSL)	-32.43	-32.81	-32.94	-32.96	-33.15	-33.91	-34.97	-35.88	-36.21	-36.24
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	13.03	12.88	12.82	12.82	12.74	12.44	12.01	11.65	11.52	11.51
Initial Stress (psf)	3690.109	3763.838	4683.775	4686.178	3407.867	3356.086	3281.27	3178.893	3108.402	3041.095
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.183	0.185	0.190	0.191	0.181	0.171	0.158	0.151	0.090	0.041
Layer 5 (Sand N = 37)										
Top Elevation (ft MSL)	-38.94	-39.25	-39.35	-39.37	-39.52	-40.13	-40.97	-41.70	-41.97	-41.99
Botton Elevation (ft MSL)	51.97	52.12	52.18	-52.19	52.26	-52.56	52.99	53.35	-53.48	-53.49
Mid Point Elevation (ft MSL)	-45.46	-45.69	-45.77	-45.78	-45.89	-46.35	-46.98	-47.53	-47.73	-47.74
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	13.03	12.87	12.83	12.82	12.74	12.43	12.02	11.65	11.51	11.50
Initial Stress (psf)	4440.637	4505.438	5422.495	5424.61	4141.691	4072.342	3973.334	3849.933	3771.666	3703.783
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.183	0.184	0.190	0.191	0.181	0.171	0.158	0.151	0.090	0.041
Layer 6 (Sand N = 37)										
Top Elevation (ft MSL)	-51.97	-52.12	-52.18	-52.19	-52.26	-52.56	-52.99	-53.35	-53.48	-53.49
Botton Elevation (ft MSL)	65.00	65.00	65.00	-65.00	65.00	65.00	-65.00	-65.00	65.00	65.00
Mid Point Elevation (ft MSL)	-58.49	-58.56	-58.59	-58.60	-58.63	-58.78	-59.00	-59.18	-59.24	-59.25
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	13.03	12.88	12.82	12.81	12.74	12.44	12.01	11.65	11.52	11.51
Initial Stress (psf)	5191.165	5247.038	6161.215	6162.754	4875.515	4788.598	4665.398	4520.973	4434.93	4366.471
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.183	0.185	0.190	0.191	0.181	0.171	0.158	0.151	0.090	0.041
Total Settlement (ft)	3.546	3.677	3.850	3.875	3.739	3.842	3.990	4.230	3.169	1.923
Initial Length of Liner Segment (ft)	200.00	87.88	27.58	3.98	38.75	144.45	200.00	236.47	163.53	133.89
Final Length of Liner Segment (ft)	200.00	87.88	27.62	3.98	38.79	144.45	200.00	236.47	163.54	133.90
Strain (%, Tensile Negative)	0.00	0.00	-0.18	0.00	-0.10	0.00	0.00	0.00	-0.01	-0.01
Initial Liner Slope (ft/f)	0.005	0.005	0.291	0.001	-0.291	-0.005	-0.005	-0.005	-0.005	-0.005
Final Liner Slope (ft/ft)	0.004	0.004	0.284	-0.005	-0.287	-0.006	-0.006	-0.006	0.002	0.004

Point No.	21	22	23	24	25	26	27	28	29
Horizontal Distance	2165.49	2165.49	2252.20	2252.20	2465.81	2501.69	2522.49	2562.41	2600.00
Top of Final Cover Elevation (ft MSL)	37.05								
Top of Waste Elevation (ft MSL)	33.41								
Top of Liner Elevation (ft MSL)	30.95								
Subgrade Elevation (ft MSL)	26.75	30.93	30.07	13.50	13.50	25.00	25.00	12.21	10.94
Existing Ground Elevation (ft MSL)	16.60	17.00	17.74	18.66	15.50	14.44	13.75	12.21	10.94
Groundwater Elevation (ft MSL)	11.33	11.28	11.14	11.03	10.64	10.55	10.51	10.42	10.31
Cut (ft)	0.00	0.00	0.00	5.16	2.00	0.00	11.25	0.00	0.00
Fill (ft)	10.15	13.93	12.33	0.00	0.00	10.56	0.00	0.00	0.00
Fill Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Liner Soil Thickness (ft)	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liner Soil Density (pcf)	120	120	120	120	120	120	120	120	120
Cover Soil Thickness (ft)	3.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cover Soil Density (pcf)	120	120	120	120	120	120	120	120	120
Waste Thickness (ft)	2.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Density (pcf)	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Change in Stress (psf)	2331.00	1671.60	1479.60	-619.20	-240.00	1267.20	1350.00	0.00	0.00
Layer 1 (Silty Sand N = 18)									
Top Elevation (ft MSL)	26.75	30.93	30.07	13.50	13.50	25.00	25.00	12.21	10.94
Botton Elevation (ft MSL)	-2.97	-2.90	-2.70	-2.51	-1.86	-1.71	-1.62	-1.46	-1.30
Mid Point Elevation (ft MSL)	11.89	14.02	13.69	5.50	5.82	11.65	11.69	5.38	4.82
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	29.72	33.83	32.77	16.01	15.36	26.71	26.62	13.67	12.24
Initial Stress (psf)	1818.14	2200.46	2125.01	615.22	620.83	1670.93	1670.83	505.39	390.58
Elastic Modulus (psf)	252000	252000	252000	252000	252000	252000	252000	252000	252000
Layer Settlement (ft)	0.275	0.224	0.192	-0.039	-0.015	0.134	0.143	0.000	0.000
Layer 2 (Clay)									
Top Elevation (ft MSL)	-2.97	-2.90	-2.70	2.51	-1.86	-1.71	-1.62	-1.46	1.30
Botton Elevation (ft MSL)	-18.96	-18.94	-18.86	18.73	18.08	-17.97	-17.73	-17.45	-17.14
Mid Point Elevation (ft MSL)	-10.965	-10.920	-10.780	-10.620	-9.970	-9.790	-9.675	-9.455	-9.220
Soil Density (pcf)	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9	100.9
Layer Thickness (ft)	15.99	16.04	16.16	16.22	16.22	16.16	16.11	15.99	15.84
Initial Stress (psf)	2981.8875	3483.538	3379.864	1388.539	1375.435	2751.256	2747.6055	1206.8955	1048.008
Initial Void Ratio	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Compression Index	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Layer Settlement (ft)	0.970	0.660	0.616	-1.006	-0.327	0.643	0.676	0.000	0.000
Layer 3 (Sand N = 37)									
Top Elevation (ft MSL)	-18.96	-18.94	18.86	-18.73	-18.08	-17.87	-17.73	-17.45	-17.14
Botton Elevation (ft MSL)	-30.47	30.46	30.39	30.30	29.81	29.65	29.54	29.34	-29.11
Mid Point Elevation (ft MSL)	-24.72	-24.70	-24.63	-24.52	-23.95	-23.76	-23.64	-23.40	23.13
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	11.51	11.52	11.53	11.57	11.73	11.78	11.81	11.89	11.97
Initial Stress (psf)	3621.183	4124.084	4023.008	2033.99	2025.494	3401.6	3397.851	1857.135	1697.664
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.036	0.026	0.023	-0.010	-0.004	0.020	0.022	0.000	0.000
Layer 4 (Sand N = 37)									
Top Elevation (ft MSL)	-30.47	-30.46	-30.39	-30.30	-29.81	-29.65	-29.54	29.34	-29.11
Botton Elevation (ft MSL)	41.98	-41.97	-41.93	41.87	41.54	-41.44	-41.36	-41.23	-41.07
Mid Point Elevation (ft MSL)	-36.23	-36.22	-36.16	-36.09	-35.68	-35.55	-35.45	-35.29	-35.09
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	11.51	11.51	11.54	11.57	11.73	11.79	11.82	11.89	11.96
Initial Stress (psf)	4284.159	4787.348	4687.424	2700.422	2701.142	4080.416	4078.395	2541.999	2386.848
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.036	0.026	0.023	-0.010	-0.004	0.020	0.022	0.000	0.000
Layer 5 (Sand N = 37)									
Top Elevation (ft MSL)	-41.98	-41.97	-41.93	-41.87	-41.54	41.44	-41.36	-41.23	-41.07
Botton Elevation (ft MSL)	53.49	-53.49	53.46	-53.43	-53.27	53.22	-53.18	53.13	53.04
Mid Point Elevation (ft MSL)	-47.74	-47.73	-47.70	-47.65	-47.41	-47.33	-47.27	-47.17	-47.06
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	11.51	11.52	11.53	11.56	11.73	11.78	11.82	11.88	11.97
Initial Stress (psf)	4947.135	5450.612	5351.84	3366.566	3376.79	4759.232	4759.227	3226.575	3076.032
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.036	0.026	0.023	-0.010	-0.004	0.020	0.022	0.000	0.000
Layer 6 (Sand N = 37)									
Top Elevation (ft MSL)	-53.49	-53.49	-53.46	-53.43	-53.27	-53.22	-53.18	-53.11	-53.04
Botton Elevation (ft MSL)	65.00	-65.00	65.00	65.00	-65.00	65.00	-65.00	65.00	65.00
Mid Point Elevation (ft MSL)	-59.25	-59.25	-59.23	-59.22	-59.14	-59.11	-59.09	-59.06	-59.02
Soil Density (pcf)	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
Layer Thickness (ft)	11.51	11.51	11.54	11.57	11.73	11.78	11.82	11.89	11.96
Initial Stress (psf)	5610.111	6113.876	6016.256	4032.71	4052.438	5437.76	5440.059	3911.151	3765.216
Elastic Modulus (psf)	740000	740000	740000	740000	740000	740000	740000	740000	740000
Layer Settlement (ft)	0.036	0.026	0.023	-0.010	-0.004	0.020	0.022	0.000	0.000
Total Settlement (ft)	1.390								
Initial Length of Liner Segment (ft)	33.28								
Final Length of Liner Segment (ft)	33.12								
Strain (%, Tensile Negative)	0.49								
Initial Liner Slope (ft/f)	0.330								
Final Liner Slope (ft/ft)	0.347								

Leachate Collection Pipe Design

Atlantic Coast Consulting, Inc.

Design Calculations Notebook

IN THIS SECTION:

Leachate Collection Pipe Design

1

2

3

4

Project #: 1002-415
Project Name: Superior - CCR Mod
Subject: Leachate Pipe Design

By: RB Date 05/08/17
Checked: JT Date

Leachate Collection Pipe Design

Determine the required thickness of the PVC 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 feet of gravel (see detail).

Schedule	80		
PVC Pipe Material Code=	12454		ASTM D1784
compressive yield, σ_y =	2000	psi	(See Appendix 52C, Table 52C-1, Ch 52 of Part 636 Structural Eng National Eng Handbook, 2005)
Normal outer Diameter, B_c=	6.625	inches	
minimum wall thickness, t=	0.432	inches	
Average Inner Diameter, B_i=	5.761	inches	
mean radius, r= $(B_i+2t)/2$ =	3.31	inches	
Equivalent SDR, SDR = B_c/t =	15		
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	79	lb/ft^3	(When MSW to CCR ratio by weight is at maximum 5:1)

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	ft =	240 lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	2.5	ft =	300 lb/ft^2
P_{MSW} = Pressure from MS Wastes =	MSW unit weight,	70	(lb/ft^3) * Depth of Stacked waste,	8	ft =	560 lb/ft^2
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	79.0	(lb/ft^3) * Depth of Stacked MSW/CCR,	110	ft =	8690 lb/ft^2

P_s = 9,790 psf For Full Cell, P_T= 9790 psf (PL and PI = 0)
= 68 psi

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	ft	
r_1 =	2	ft	
r_2 =	6.32	ft	
P_{L1} =	5,730	psf	Due to wheel load directly above point on pipe
P_{L2} =	18	psf	Due to wheel at the other end of the axle
P_L=	5,730	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 5,970 psf, or
41.5 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

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

r_{cent} = radius of centroidal axis of pipe, in	r_{cent} =	3.31	in	
M_s = one-dimensional modulus of soil, psi	M_s =	3,000	(Table 52-2, Structural Eng Handbook. 2005, NRCS)	
E = apparent modulus of elasticity of pipe material, psi	E =	119,000	(See page 52-12C, long term modulus and temperature adjustment (AWWA))	
A = profile wall average cross sectional area, in^2/in	A =	0.432	in	

S_A = 0.28
VAF = 1.07

$$P_{rd} = (VAF)wH$$

P_{rd} = radial directed earth pressure, psf
w = unit weight of cover, pcf
H = depth of cover, ft
wH = P_6 for post closure condition

P_{rd} = 10,427 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 = 555.2 psi
Allowable Compressive Stress, psi = 2000

Since 555.2 psi is < 2000 psi; design OK

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

$$S = \frac{P_t \cdot Bc}{288 \cdot t}$$ (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= 521.3 psi Since 521.3 psi is < 2000 psi so OK ; FS= 3.8

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= 340,000 (See page 52-11, short term modulus and temperature adjustment (AWWA))

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio SDR= 15

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

μ = Poisson's Ratio μ = 0.41

M_s = one-dimensional modulus of soil, psi M_s = 3,000 (Table 52-2, Structural Eng Handbook. 2005, NRCS)

E_s = 1,290.5 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 = 9790 psf

ε_s= 5.27 %

R_F= 134.2

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 0.8

$$\frac{\Delta X}{D_I}(100) = Df * \varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_I= inside pipe Diameter, (in)

$\%\Delta X/D_I$= 4.21 % Since 4.21 is < 7.5 OK; FS= 1.78

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), = 122.5

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= 1.0

B'= 1.0

E'= 3000 psi

E= 119,000 psi (See page 52-12C, long term modulus and temperature adjustment (AWWA))

SDR= 15

P_{wc}= 283.9 psf ≥ 68 psi so OK ; FS= 4.2

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ATTACHMENT I

CCR AND MSW CHARACTERIZATION DATA

October 2016 Leachate Sample Results
R&B Site 2 Landfill

	Parameter	CCR Leachate	MSW Leachate	Units
General Chemistry/Water Quality	Alkalinity, Total	87.8	3000	mg/L
	Chemical Oxygen Demand	17.2	1190	mg/L
	Field pH	5.78	6.95	SU
	Field Turbidity	2.4	44.1	NTU
	Specific Conductance	1020	10600	uS/cm
	Sulfate	378	1.5	mg/L
	Temperature	23.8	28.8	Celsius
	Total Dissolved Solids	711	4330	mg/L
Metals	Antimony	ND	0.013	mg/L
	Arsenic	ND	0.072	mg/L
	Barium	0.048	1.4	mg/L
	Beryllium	ND	ND	mg/L
	Boron	0.21	NR	mg/L
	Calcium	59.7	14.9	mg/L
	Chloride	22.2	1710	mg/L
	Chromium	ND	0.029	mg/L
	Cobalt	0.62	0.03	mg/L
	Copper	ND	ND	mg/L
	Fluoride	0.34	NR	mg/L
	Lead	ND	ND	mg/L
	Nickel	0.09	0.2	mg/L
	Selenium	ND	0.01	mg/L
	Silver	ND	ND	mg/L
	Thallium	ND	ND	mg/L
	Vanadium	ND	0.042	mg/L
	Zinc	ND	0.0058	mg/L

Notes:

ND = Not detected
NR = Not required
mg/L = milligrams per liter
uS/cm = milliSiemens per centimeter
SU = Standard Units
NTU = nephelometric turbidity units

ATTACHMENT II

AGRU LINER COMPATIBILITY CERTIFICATION

15 May 2017

John Workman
Waste Management

RE: LEACHATE COMPATIBILITY CERTIFICATION

Dear Mr. Workman,

I have reviewed the leachate analysis for the October 2016 CCR Leachate that you provided to us. Polyethylene geomembranes are compatible with and unaffected by the constituent contained therein. We expect no deleterious effects in performance as a result of exposure to this. I have also attached a technical note from CP Chem that details chemical compatibility of polyethylene in more detail. If you have any additional questions or concerns, please let me know.

Sincerely,

Nathan Ivy

Nathan Ivy
Corporate Quality Control/Technical Manager
Agru America

Another quality product from
Chevron Phillips Chemical Company LP
The Woodlands, Texas

MARLEX®
POLYETHYLENE
PREMIUM EXTRUSION AND RIGID PACKAGING RESINS

PE TIB-2 PACKAGING PROPERTIES

INTRODUCTION

The growth of plastic materials into the packaging market has been phenomenal in recent years. The versatility and design flexibility of high density polyethylene (HDPE) lends itself to injection molded, blow molded, extruded and rotationally molded applications. Technological developments such as coextrusion with barrier resins allow packages to be tailored to meet product-specific requirements, thus expanding the market at an ever-increasing rate.

Chevron Phillips Chemical Company LP (Chevron Phillips Chemical) has provided almost 50 years of plastic product development and processing expertise to the packaging industry. Marlex® high density polyethylene resins from Chevron Phillips Chemical continue to offer the excellent balance of physical and chemical properties needed for packaging applications: toughness, chemical resistance, gas/liquid permeation resistance and environmental stress-crack resistance. Realizing the increasing demands being placed on packaging materials by the proliferation of new products, Chevron Phillips Chemical continues to work closely with the packaging industry to develop improved Marlex® HDPE resins.

The feasibility of packaging a product in any plastic container depends heavily on the shelf life and display conditions to which it will be subjected. The only way to ensure the suitability of any package/product combination is to test it under representative conditions. Most resin suppliers and processors are equipped to evaluate the effect of the product on the package, but any evaluation of changes to the product itself requires specialized expertise, and generally must be tested by the manufacturer of that product.


Top-load testing of Marlex® HDPE containers

PACKAGING PROPERTIES

The suitability of Marlex® HDPE for packaging applications is related to the density, melt index and molecular weight distribution of the resin. As the density increases, for example, the stiffness, softening temperature, resistance to permeation, and chemical resistance of the finished item will increase. Conversely, when melt index decreases, impact strength (toughness) will increase. Environmental stress-crack resistance (ESCR) is dependent on molecular weight distribution as well as density and melt index. In any one resin series, when density is constant, ESCR improves as the melt index decreases.

Marlex® HDPE molding and extrusion grade resins meet specifications published in the Federal Register by the Food and Drug Administration. The critical guidelines are covered in their document 21 CFR 177.1520.

Although it is difficult to recommend a particular grade of Marlex® HDPE for packaging applications without knowing the use environment, the following guidelines can assist in resin selection:

1. High melt index (lower molecular weight) resins are recommended for injection molded containers, due to the processing requirements.

2. For extrusion, thermoforming or blow molding, when maximum part rigidity is the primary objective, a low melt index (higher molecular weight), high density resin is recommended.

3. To obtain maximum environmental stress-crack resistance for extruded, thermoformed or blow molded packaging applications, a low-melt index (higher molecular weight) copolymer should be used.

Table 1 summarizes the general HDPE packaging guidelines based on packaging tests performed to date. From these tests, it can be determined which classes of products are packageable in HDPE. For example, most alcohols, ketones, or water soluble and water-based chemicals are packageable in HDPE, while some strong oxidizing agents (even though they are water based) cannot be successfully contained for any reasonable storage period.

Aromatic hydrocarbons permeate polyethylenes beyond acceptable packaging limits, and halogenated hydrocarbons permeate small polyethylene containers almost 100% in a short period of time.

TABLE 1

General Guidelines for HDPE Packaging

Water-Based Products

Most water-based products like household bleach and detergents are packageable. Gas permeation may be a problem with some products. Oxygen permeation into a container causes catsup to darken, and carbon dioxide is quickly lost from a carbonated beverage.

Aliphatic Hydrocarbons

High molecular weight products such as mineral oils, vegetable oils and motor oil can be packaged, although some consideration should be given to package deformation and permeability. Package size becomes important for such low molecular weight products as heptane and hexane. DOT regulations should also be reviewed.

Aromatic Hydrocarbons

Most of these products permeate excessively and cause package deformation. Typical products are benzene and orange oil.

Halogenated Hydrocarbons

Permeation levels are high and package deformation excessive. Carbon tetrachloride is an example.

Alcohols, Ketones, Aldehydes

Most of these products are packageable. Some may cause stress-cracks, but good resin selection can eliminate this problem. Package size is often the determining factor in many cases. Ethylene glycol and ethyl alcohol are both packageable.

Acids

Most acids are packageable; however, strong oxidizing acids like concentrated nitric acid and fuming sulfuric are exceptions. Two commercially packaged products are hydrofluoric acid and battery acid, which is dilute sulfuric.

PACKAGING TEST RESULTS

Data on the packageability of various products (such as food products, pharmaceuticals, industrial chemicals, etc.) in Marlex® high density polyethylene is presented in Appendix I. Although this data is useful in determining the effect a product will have on the resin, the importance of package design cannot be ignored. Such factors as wall thickness, part size and part geometry can make the difference between an acceptable or unacceptable package. This is especially true for those products that affect the package by such means as permeation, softening or distortion.

CHEMICAL RESISTANCE

To be suitable as a packaging material, the plastic must not have a chemical reaction to the product being packaged. The level of chemical resistance can be measured by the retention or loss of its physical properties. Chemical resistance is especially dependent on temperature, and the storage shelf life may have a significant bearing. Marlex® HDPE is considered a very effective packaging material, since it is one of the most chemically resistant plastics commercially available.

The chemical resistance data shown in Appendix I was obtained by immersing ASTM D638, Type IV tensile bars in the testing media for as long as three months at 80°F, 120°F and 150°F, then checking for weight change, tensile strength, staining, softening and embrittlement. The results are reported as follows:

Excellent
This product had no effect on Marlex® HDPE.

Good
Slight absorption occurs, but has little or no effect on the physical properties.

Fair
A loss of physical properties occurs. Package design and use conditions will determine whether or not HDPE can be used.

Poor
Significant loss of strength, softening or embrittlement occurs. High density polyethylenes are unsuitable for prolonged contact.

These classifications have been based on continuous exposure to the product for extended periods of time. A rating of "poor" does not always mean that the chemical environment would have an adverse effect on a Marlex® HDPE package. If the exposure period were very short, even at an elevated temperature, the package might still be acceptable. Only sufficient testing can confirm the suitability of the package. Additional chemical resistance data are shown in Appendix II.

PERMEABILITY

Permeation is one of the main factors governing the use of HDPE containers in product packaging. Primarily, permeation is considered a physical migration of a product through the container walls and its subsequent vaporization from outside surfaces. Obviously, an appreciable loss of product during shelf storage would prohibit a container's use in packaging applications. A weight loss of 3% per year (with no visual changes or substantial permeation of an essential component) is generally recognized as the maximum product loss acceptable.

If permeation is borderline, i.e., slightly above 3%, packaging in a large container may still prove acceptable due to the increased volume/surface-area ratio.

The permeability results shown in Appendix I were obtained using 4 oz. Boston Round bottles, filled with the liquid and stored for 4 months at 80°F. The bottles were weighed periodically and the average loss rate of the contents per week was established. The average loss per year was then calculated, and expressed as a percent of the original liquid weight. This is similar to the procedure described in ASTM D2684.

PRODUCT ALTERATION

As a result of permeation, product alteration can occur. There is the possibility that outside elements could permeate into a container and cause a weight gain. However, a weight gain or loss in a complex mixture of chemicals could change the concentration of key ingredients in the total product, making the package unreliable. For example, many perfumes and cosmetic products cannot be packaged in HDPE because, while the product base is contained, the scent is lost.

Another form of product alteration is the reaction of the product with a minute quantity of oxygen permeating through the walls into the headspace of the container. Normally, this small amount of oxygen is not prohibitive. In some products, however, a discoloration or an actual change of the active ingredients can occur. Product taste is another factor to be considered.

These potential product alterations highlight the necessity to pre-determine the effects of a proposed package on the product.

ENVIRONMENTAL STRESS-CRACK RESISTANCE

The environmental stress crack resistance of a container is a combination of the inherent resistance of the resin, the design and molding quality of the finished container, and the type of product packaged.

Under certain conditions, HDPE may exhibit mechanical failure by cracking. Even though ESCR test results may be negative under a given set of circumstances, there are several options that can be used to help rectify the situation. For example, a more resistant (higher molecular weight) resin, or a change in container design or manufacturing technique may be employed separately or in combination to overcome many environmental stress-crack problems.

To determine whether or not a liquid product will cause stress-crack, tests can be run on compression molded sheets using ASTM D1693. This is commonly referred to as the Bell Laboratory bent strip test. Often, it is desirable to test the container itself for stress-crack resistance. In this case, ASTM D2561 is a suitable test procedure. Appendix I includes the results of stress-crack testing.

GAS PERMEABILITY

As indicated by the data in Appendix I, high density polyethylene is an excellent barrier for many products, including gases. Table 2 summarizes the permeability rate of some common gases through Marlex® HDPE. Since the permeability rate is influenced by the density of the barrier as well as functional groups of the permeating gas, these rates are considerably lower than those obtained with low density polyethylene.

TABLE 2
Gas Permeability of Marlex® HDPE

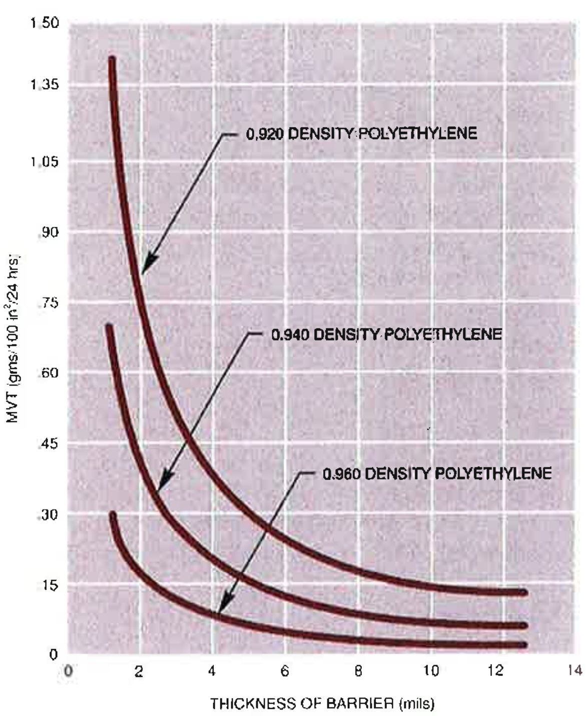
Gas	Rate cc/mil/24 hrs/100 in^2
Carbon Dioxide	345
Ethane	236
Hydrogen	321
Natural Gas	113
Oxygen	111
Freon 12	95
Helium	247
Nitrogen	53
Sulfur Dioxide	306

WATER VAPOR TRANSMISSION

In many packaging applications, HDPE is used because of its moisture barrier properties. As with other gases and liquids, the density of the barrier affects the transmission rate; i.e., the higher the density the more efficient the barrier.

Figure 1 shows the effect of film thickness and density on the water vapor transmission through three polyethylene resins of different densities. This indicates that at any given film thickness the high density film is the superior barrier. These data were obtained by ASTM E96, Procedure E, which specifies a temperature of 100°F and 90% relative humidity.

FIGURE 1
Effect of Film Thickness on Water Vapor Transmission



SUMMARY

The list of products packaged in HDPE has grown considerably in recent years. Chevron Phillips Chemical has established itself as a leader in the plastics packaging arena by offering consistently high quality Marlex® HDPE resins, backed by knowledgeable Plastics Technical Center support. Our outstanding technical staff has developed specialized grades of Marlex® resins to meet the varying requirements of such products as light weight milk bottles, durable and resealable motor oil "cans", and laundry detergent/bleach containers.

For additional information on a Marlex® resin suited to your packaging needs, please contact our Sales and Marketing groups for help. Detailed contact information is provided at the end of this document.

Support Information

The appendixes on the following pages present detailed packageability and chemical resistance information for our Marlex® HDPE resins.

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress Cracking?	Remarks
Acids				
Acetic, 1 - 10%	E	<3	Yes	
Acetic, 10 - 60%	E	<3	Yes	
Acetic, 80-100%	E	<3	Yes	
Aqua Regia	P	<3	-	Attack occurs at ambient temperature.
Chromic, 20%	E	<3	No	
Cleaning Solution (Dichromate-Sulfuric)	G	<3	No	Staining and brittleness will occur at elevated temperature.
Citric	E	<3	No	
Gallic	E	<3	No	
Hydrochloric, 10%	E	<3	No	A slight staining may occur at elevated temperature.
Hydrochloric. 35%	E	<3	No	A slight staining may occur at elevated temperature.
Hydrochloric, Conc.	E	<3	No	A slight staining may occur at elevated temperature.
Hydrofluoric, 75%	E	<3	No	
Lactic, 10 - 90%	E	<3	No	
Nitric, 0 - 30%	G	<3	No	A slight staining may occur at elevated temperature.
Nitric, 30 - 50%	G	<3	No	Staining will occur at elevated temperature.
Nitric, 95 - 98%	P	<3	-	Staining and brittleness will occur at ambient temperature.
Phosphoric, 30 - 90%	E	<3	No	
Stearic, 100%	E	-	No	
Sulfuric, 70%	G	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Sulfuric, 80%	G	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Sulfuric, Fuming	P	<3	No	Stiffening and embrittlement will occur at elevated temperature.
Bases				
Ammonium Hydroxide, 30%	E	<3	No	
Barium Hydroxide, 30%	E	<3	No	
Calcium Hydroxide, 30%	E	<3	No	
Potassium Hydroxide, 30%	E	<3	No	
Sodium Hydroxide, 30%	E	<3	No	

Legend: E – Excellent G – Good F – Fair P – Poor

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Food & Food Products				
Beet Juice	E	<3	No	A slight staining will occur.
Beer	E	<3	No	
Carrot Juice	E	<3	No	
Catsup (tomato based sauce)	E	<3	No	A slight staining will occur.
Cherries	E	<3	No	A slight staining will occur.
Cider	E	<3	Yes	
Cocoa, hot	E	<3	No	
Coffee, hot	E	<3	No	
Cola	E	<3	No	
Dyes (Vegetable)	E	<3	No	
Gelatine	E	Nil	No	
Gin	E	<3	No	
Glucose, Saturated	E	<3	No	
Lard	G	<3	Yes	Container distortion may occur.
Lemon Juice	E	<3	No	
Margarine	G	<3	Yes	
Marmalade & Jam	E	<3	No	
Milk	E	<3	No	
Molasses	E	<3	No	
Orange Extract	E	<3	No	
Prune Juice	E	<3	No	A slight staining will occur.
Salt (sodium chloride)	E	Nil	No	
Sugar	E	Nil	No	
Tomato Juice	E	<3	No	A slight staining will occur.
Vinegar	E	<3	Yes	
Vanilla Extract	E	<3	Yes	
Whiskey	E	<3	No	
Wine	E	<3	No	
Yeast	E	Nil	No	

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Household, Toiletries & Pharmaceutical Products				
Bleaches	E	<3	No	
Deodorants (all types)	E	<3	No	
Detergents (standard)	E	<3	Yes	
Detergents (heavy duty)	E	<3	Yes	
Dry Cleaners	G	<3	Yes	
Glycerine	E	<3	No	
Hair Oil	E	<3	Yes	
Hair Shampoo	E	<3	Yes	
Hair Wave Lotions	E	<3	Yes	
Hand Creams	E	<3	Yes	
Hydrogen Peroxide, 3%	E	<3	No	
Inks	E	<3	No	A slight staining may occur.
Iodine (tincture)	G	<3	No	A light staining and embrittlement may occur after prolonged use.
Lighter Fluid	G	High	Yes	
Lipstick	E	Nil	No	Some staining may occur.
Mascara	E	Nil	No	
Mercurochrome	G	<3	No	Some staining may occur after prolonged use.
Nail Polish	F	4	Yes	Some softening will occur after prolonged contact
Rouge	E	Nil	No	
Shaving Lotion	G	<3	Yes	Some stiffening will occur.
Shoe Polish (liquid)	G	High	Yes	Some stiffening will occur.
Shoe Polish (paste)	G	-	Yes	Some staining will occur.
Soap	E	<3	Yes	
Suntan Lotion	E	<3	No	
Turpentine	P	8.5	No	
Wax (liquid & paste)	E	<3	Yes	

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Industrial Chemicals				
Acetone	G	3.4	No	A slight softening will occur.
Alums (all types) Conc.	E	<3	No	
Ammonium Nitrate, Sat'd	E	<3	No	
Amyl Acetate	G	4.0	No	A slight softening will occur.
Amyl Alcohol, 100%	E	<3	Yes	
Amyl Chloride, 100%	G	High	No	Softening will occur.
Benzaldehyde	E	<3	No	
Benzene	G	High	No	
Boric Acid, Conc. Solution	E	<3	No	
Butyl Alcohol	E	<3	No	
Calcium Chloride Saturated Solution	E	<3	No	
Carbon Tetrachloride	P	80	Yes	Softening and part deformation will occur at elevated temperature.
Chlorobenzene	P	High	Yes	Softening and part deformation will occur
Chloroform	P	High	Yes	Softening and part deformation will occur
Cyclohexanol	G	<3	Yes	
Developers, Photographic	E	<3	No	
Dibutylphthalate	E	<3	No	
Ethylene Glycol	E	<3	No	
Ethyl Acetate	F	9	No	Softening and part deformation will occur.
Ethyl Alcohol	E	<3	Yes	
Ethyl Ether	F	140	No	Softening and part distortion will occur.
Ethylene Chloride	P	High	No	Softening and part distortion will occur.
Formaldehyde, 40%	E	<3	No	
Furfural, 100%	E	<3	No	
Gasoline	G	High	No	
Glycerol	E	<3	No	
Mercury	E	Nil	No	
Methyl Alcohol	E	<3	Yes	
Phenol, 90%	E	<3	No	
Pickling & Plating Solution	E	<3	No	Sulfuric acid/nitric acid mixtures will cause embrittlement at high temp.

APPENDIX 1

Packageability of Various Products in Marlex® HDPE

Product	Chemical Resistance	Permeability % Loss/Year	Can Cause Stress-Cracking?	Remarks
Industrial Chemicals				
Potassium Dichromate	E	Nil	No	
Propyl Alcohol	E	<3	Yes	
Silver Nitrate Solution	E	<3	No	
Sodium Bicarbonate, Sat'd.	E	<3	No	
Toluene	P	High	No	Softening, swelling and part distortion will occur.
Trichloroethylene	P	High	No	Softening, swelling and part distortion will occur.
Oils				
Camphor	F	High	No	A slight softening will occur.
Castor	G	<3	Yes	A slight softening will occur at elevated temperature
Cottonseed	G	<3	Yes	A slight softening and part distortion will occur at high temp.
Linseed	G	<3	No	A slight softening and part distortion will occur at elevated temperature
Mineral	G	<3	Yes	A slight softening and part distortion will occur.
Motor Oil (SAE 10)	G	<3	No	A slight softening and part distortion will occur at high temp.
Orange	G	High	No	A slight softening and part distortion will occur
Peppermint	G	High	Yes	A slight softening and part distortion will occur
Transformer	G	<3	No	A slight softening and part distortion will occur
Vegetable	G	<3	Yes	A slight softening and part distortion will occur at high temp.
Pine	G	High	Yes	A slight softening and part distortion will occur.

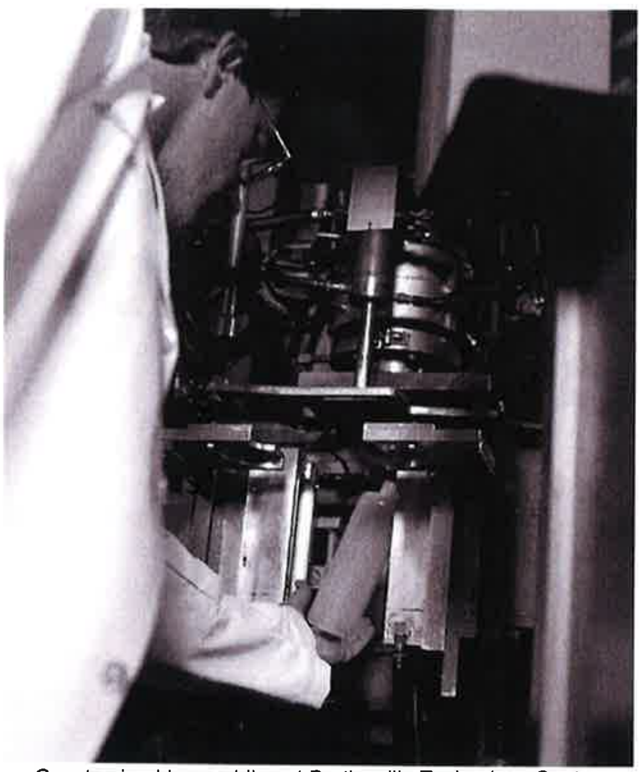
Legend: E – Excellent G – Good F – Fair P – Poor

APPENDIX II

Chemical Resistance of Polyethylene

Chemical attack may be accompanied by any one, or a combination of the following: swelling, discoloration, brittleness or loss of strength. The following data are derived from laboratory tests using non-stressed immersed specimens under static conditions. The ratings shown are based mainly on chemical attack, solvent swelling and changes in physical properties under such conditions.

Legend: "S" - Satisfactory
"O" - Some attack
"U" - Unsatisfactory



Coextrusion blow molding at Bartlesville Technology Center

	High Density	
Reagent	70 ºF	140 ºF
Acrylic Emulsions	S	S
Aluminum Chloride Dilute	S	S
Aluminum Chloride Concentrated	S	S
Aluminum Fluoride Concentrated	S	S
Aluminum Sulfate Concentrated	S	S
Ammonia 100% Dry Gas	S	S
Ammonium Carbonate	S	S
Ammonium Chloride Saturated	S	S
Ammonium Fluoride 20%	S	S
Ammonium Metaphosphate Saturated	S	S
Ammonium Persulfate Saturated	S	S
Ammonium Sulfate Saturated	S	S
Ammonium Sulfide Saturated	S	S
Ammonium Thiocyanate Saturated	S	S
Aniline 100%	S	--
Antimony Chloride	S	S
Barium Carbonate Saturated	S	S
Barium Chloride Saturated	S	S
Barium Sulfate Saturated	S	S
Barium Sulfide Saturated	S	S
Benzene Sulfonic Acid	S	S
Bismuth Carbonate Saturated	S	S
Black Liquor	S	S
Borax Cold Saturated	S	S
Boric Acid Dilute	S	S
Bromic Acid 10%	S	S
Bromine Liquid 100%	O	U
Butanediol10%	S	S
Butanediol 60%	S	S
Butanediol100%	S	S
Butyl Acetate 1 00%	O	U
Calcium Bisulfide	S	S
Calcium Carbonate Saturated	S	S
Calcium Chlorate Saturated	S	S
Calcium Hypochlorite Bleach Solution	S	S
Calcium Nitrate 50%	S	S
Calcium Sulfate	S	S
Carbon Dioxide 100% Dry	S	S
Carbon Dioxide 100% Wet	S	S
Carbon Dioxide Cold Saturated	S	S
Carbon Disulfide	--	U
Carbon Monoxide	S	S
Chlorine Liquid	O	U
Chlorosulfonic Acid 100%	U	U
Chrome Alum Saturated	S	S
Chromic Acid 50%	S	O
Cider	S	S
Coconut Oil Alcohols	S	S
Copper Chloride Saturated	S	S
Copper Cyanide Saturated	S	S
Copper Fluoride 2%	S	S
Copper Nitrate Saturated	S	S
Copper Sulfate Dilute	S	S
Copper Sulfate Saturated	S	S
Cuprous Chloride Saturated	S	S
Cyclohexanone	U	U

Reagent	High Density 70 °F	High Density 140 °F
Dextrin Saturated	S	S
Dextrose Saturated	S	S
Disodium Phosphate	S	S
Diethylene Glycol	S	S
Emulsions Photographic	S	S
Ethyl Chloride	O	U
Ferric Chloride Saturated	S	S
Ferric Nitrate Saturated	S	S
Ferrous Chloride Saturated	S	S
Ferrous Sulfate	S	S
Fluoboric Acid	S	S
Fluorine	S	U
Fluosilicic Acid 32%	S	S
Fluosilicic Acid Concentrate	S	S
Formic Acid 20%	S	S
Formic Acid 50%	S	S
Formic Acid 100%	S	S
Fructose Saturated	S	S
Fuel Oil	S	U
Glycol	S	S
Glycolic Acid 30%	S	S
Hydrobromic Acid 50%	S	S
Hydrocyanic Acid Saturated	S	S
Hydrochloric Acid 30%	S	S
Hydrofluoric Acid 40%	S	S
Hydrofluoric Acid 60%	S	S
Hydrogen 100%	S	S
Hydrogen Bromide 10%	S	S
Hydrogen Chloride Gas Dry	S	S
Hydroquinone	S	S
Hydrogen Sulfide	S	S
Hypochlorous Acid Concentrated	S	S
Lead Acetate Saturated	S	S
Magnesium Carbonate Saturated	S	S
Magnesium Chloride Saturated	S	S
Magnesium Hydroxide Saturated	S	S
Magnesium Nitrate Saturated	S	S
Magnesium Sulfate Saturated	S	S
Mercuric Chloride	S	S
Mercuric Cyanide Saturated	S	S
Mercurous Nitrate Saturated	S	S
Methyl Ethyl Ketone 100%	U	U
Methyl Bromide	O	U
Methylsulfuric Acid	S	S
Methylene Chloride 100%	U	U
Nickel Chloride Saturated	S	S
Nickel Nitrate Concentrated	S	S
Nickel Sulfate Saturated	S	S
Nicotinic Acid	S	S
Nitric Acid <50%	S	O
Nitrobenzene 100%	U	U
Oleum Concentrated	U	U
Oxalic Acid Dilute	S	S
Oxalic Acid Saturated	S	S
Petroleum Ether	U	U
Phosphoric Acid 0 - 30%	S	S
Phosphoric Acid 90%	S	S
Photographic Solutions	S	S
Potassium Bicarbonate Saturated	S	S
Potassium Borate 1%	S	S
Potassium Bromate 10%	S	S

Reagent	High Density 70 °F	High Density 140 °F
Potassium Bromide Saturated	S	S
Potassium Carbonate	S	S
Potassium Chlorate Saturated	S	S
Potassium Chloride Saturated	S	S
Potassium Chromate 40%	S	S
Potassium Cyanide Saturated	S	S
Potassium Ferri/Ferro Cyanide	S	S
Potassium Fluoride	S	S
Potassium Nitrate Saturated	S	S
Potassium Perborate Saturated	S	S
Potassium Perchlorate 10%	S	S
Potassium Permanganate 20%	S	S
Potassium Sulfate Concentrated	S	S
Potassium Sulfide Concentrated	S	S
Potassium Sulfite Concentrated	S	S
Potassium Persulfate Saturated	S	S
Propargyl Alcohol	S	S
Propylene Glycol	S	S
Rayon Coagulating Bath	S	S
Sea Water	S	S
Shortening	S	S
Silicic Acid	S	S
Sodium Acetate Saturated	S	S
Sodium Benzoate 35%	S	S
Sodium Bisulfate Saturated	S	S
Sodium Bisulfite Saturated	S	S
Sodium Borate	S	S
Sodium Bromide Oil Solution	S	S
Sodium Carbonate Concentrated	S	S
Sodium Carbonate	S	S
Sodium Chlorate Saturated	S	S
Sodium Chloride Saturated	S	S
Sodium Cyanide	S	S
Sodium Dichromate Saturated	S	S
Sodium Ferricyanide Saturated	S	S
Sodium Ferrocyanide	S	S
Sodium Fluoride Saturated	S	S
Sodium Nitrate Sodium Sulfate	S	S
Sodium Sulfide 25% to Saturated	S	S
Sodium Sulfite Saturated	S	S
Stannous Chloride Saturated	S	S
Stannic Chloride Saturated	S	S
Starch Solution Saturated	S	S
Sulfuric Acid <50%	S	S
Sulfuric Acid 96%	O	U
Sulfuric Acid 98% Concentrated	O	U
Sulfurous Acid	S	S
Tannic Acid 1 0%	S	S
Tartaric Acid Saturated	--	--
Tetralin	U	U
Tetrahydrofuran	O	O
Transformer Oil	S	O
Trichloroacetic Acid 10%	S	S
Trisodium Phosphate Saturated	S	S
Urea	S	S
Urine	S	S
Wetting Agents	S	S
Xylene	U	U
Zinc Chloride Saturated	S	S
Zinc Sulfate Saturated	S	S

If we may be of further assistance, please contact our Polyethylene Sales and Marketing team. Contact information is available at this web site http://www.cpchem.com/index.asp, along with links to our polyethylene resins and MSDS sheets.

Additional information regarding the chemical resistance of Marlex® polyethylene is presented in other Plastic Technical Center publications. This data is provided for use only as guidelines in preliminary determination of packageability because chemical compatibility is highly dependent on storage and use conditions. Furthermore, many products are combinations of chemicals so the ultimate compatibility with the packaging material involves testing the combination of the product material and its proposed container.

Last revised April 2005

ATTACHMENT III

LINER SYSTEM ANALYSIS

WASTE MANAGEMENT

WASTE MANAGEMENT OF GEORGIA, INC.

3001 LITTLE NECK ROAD | SAVANNAH, GEORGIA 31419

SUPERIOR LANDFILL & RECYLING CENTER
CCR MANAGEMENT & GROUNDWATER PLANS

PERMIT #: 025-070D(MSWL)

SUPPLEMENTAL DESIGN CALCULATIONS

ATLANTIC COAST CONSULTING, INC.

May 2017

Design Calculations Notebook

Table of Contents

ATLANTIC COAST CONSULTING, INC.

Sections:

1

2

Liner System Analysis

ATLANTIC COAST CONSULTING, INC.

1

2

Design Calculations Notebook

IN THIS SECTION:

Liner System Analysis

HELP Model Analysis

OBJECTIVE:

Evaluate the performance of the leachate collection system as shown on the Superior Landfill & Recycling Center D&O Plans using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3.07. This design analysis is for evaluation of materials proposed within the co-mingled MSW/CCR cells only.

METHODOLOGY:

Using the HELP Model, evaluate the leachate collection system with different fill heights to verify that each meets the design guidelines. Each of the scenarios described below cannot result in more than 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 Savannah, Georgia, the mean monthly precipitation for Savannah, GA and temperature for Savannah, Georgia. The peak daily rainfall from the synthetically generated record was adjusted to match the 25-year 24-hour storm event precipitation for Savannah, Georgia, the closest rainfall data site published in the Georgia Stormwater Management Manual, (i.e., 7.80 inches) for simulation terms longer than one year.

- The simulation terms modeled were 50 years for all conditions with over 50 feet of waste. The initial waste placement scenario (10 feet) was modeled using a one year simulation and the 50 feet of waste scenarios were modeled with a simulation term of 10 years.

- All calculations were performed for a unit acre area.

- The base liner slope was set at 2% with a drainage length of 325.

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

    - Saturated hydraulic conductivity of 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. The model results presented in these calculations assumes default hydraulic conductivity for less than 50' heights and 10-4 cm/sec hydraulic conductivity for heights of 50' and more.

    - Parameters for the drainage geocomposite used in the base leachate collection system were taken from the design calculations presented in the section labeled Base Liner Geocomposite Analysis.

- The soil modeled for use as intermediate cover and general fill was HELP soil material #12.

- The vegetative cover was selected as "fair" when utilized. Vegetative cover was used on all scenarios that had 100% runoff. Scenarios that were modeled with 25% and 50% runoff assumed bare ground conditions.

- The leachate collection system was modeled for scenarios to include 10' depth of waste representing initial cell startup, 50' depth of waste representing a stage hallway through filing operations and 118.5' depth of waste representing the final height of waste prior to landfill closure.

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

- 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 hole per acre. These assumptions will result in modeling that assumes the worst case for the peak daily head on the base liner.

The liner system is described as follows from top to bottom:

24 inches of protective cover soil
Double-sided geocomposite drainage layer
60-Mil HDPE Liner
24 inches of $1x10^{-7}$ cm/sec compacted clayey soil

RESULTS:

A summary of the scenarios modeled are presented in Table 1 on the following page. The peak head on the base liner occurs in scenario 5 with 118.5 feet of waste resulting in 9.6 inches.

CONCLUSION:

Each of the Scenarios modeled meet the design guidelines. Therefore, either of the liner design will provide for sufficient leachate collection.

Table 1

Results Summary

TABLE 1

HELP Model Analysis - Summary CCR Cells

File Name	Scenario	Description						Maximum Base Liner Head per Peak Daily Value (inches)	Drainage Collected From LCS 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)	Geonet Core Thickness Modeled (inches)
		Base Liner Option	Final Cover Option	Waste Depth (ft)	Runoff (%)	Recirculation (%)	Simulation Term (yrs)								
rb1.out	1	1	-	10	0	-	1	0.12	0.19	33,324	683	-	-	673	0.20
rb2.out	2	1	-	50	25	-	10	0.16	0.09	33,544	687	-	-	314	0.20
rb3.out	3	1	-	50	100	-	10	0.13	0.07	25,754	528	-	-	253	0.20
rb4.out	4	1	-	118.5	50	-	50	4.51	0.04	25,524	523	-	-	150	0.20
rb5.out	5	1	-	118.5	100	-	50	9.60	0.04	29,436	603	-	-	159	0.20

Scenario #1:

10' of initial waste
0% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3A.D10
OUTPUT DATA FILE:            c:\help3\RB1.OUT


TIME:  11:59     DATE:   5/12/2017


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

     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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   =        0.3165 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.419999997000E-04 CM/SEC


                                  LAYER  2
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
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MATERIAL TEXTURE NUMBER 18

THICKNESS	=	120.00 INCHES
POROSITY	=	0.6710 VOL/VOL
FIELD CAPACITY	=	0.2920 VOL/VOL
WILTING POINT	=	0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3024 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	=	0.3980 VOL/VOL
FIELD CAPACITY	=	0.2440 VOL/VOL
WILTING POINT	=	0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2449 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20 INCHES
POROSITY	=	0.8500 VOL/VOL
FIELD CAPACITY	=	0.0100 VOL/VOL
WILTING POINT	=	0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1008 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	8.85999966000 CM/SEC
SLOPE	=	2.00 PERCENT
DRAINAGE LENGTH	=	325.0 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	=	0.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4270 VOL/VOL
FIELD CAPACITY	=	0.4180 VOL/VOL
WILTING POINT	=	0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06 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 100. FEET.

SCS RUNOFF CURVE NUMBER	=	95.40	
FRACTION OF AREA ALLOWING RUNOFF	=	0.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.064	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	56.225	INCHES
TOTAL INITIAL WATER	=	56.225	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 1

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	1.44	1.39	2.17	0.40	1.99	5.39
	6.22	7.78	5.26	3.53	0.72	4.39
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	1.736	1.676	2.355	0.271	1.806	4.247
	5.693	5.086	3.361	3.241	0.186	1.841
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	1.3311	0.0000	0.0003	0.0000	0.0019	0.2935
	1.0354	1.4150	2.6159	1.5280	0.0000	0.9592
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	0.0139	0.0000	0.0000	0.0000	0.0000	0.0032
	0.0108	0.0148	0.0282	0.0160	0.0000	0.0100
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

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	40.68 (0.000)	147668.4	100.00
RUNOFF	0.000 (0.0000)	0.00	0.000
EVAPOTRANSPIRATION	31.496 (0.0000)	114331.70	77.425
LATERAL DRAINAGE COLLECTED FROM LAYER 4	9.18025 (0.00000)	33324.320	22.56700
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00000 (0.00000)	0.013	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.008 (0.000)		
CHANGE IN WATER STORAGE	0.003 (0.0000)	12.35	0.008

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 1

	(INCHES)	(CU. FT.)
PRECIPITATION	3.25	11797.500

RUNOFF	0.000	0.0000
DRAINAGE COLLECTED FROM LAYER 4	0.18539	672.95660
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00019
AVERAGE HEAD ON TOP OF LAYER 5	0.060	
MAXIMUM HEAD ON TOP OF LAYER 5	0.119	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	2.5 FEET	
SNOW WATER	0.36	1307.9432

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4243

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.2100

*** 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	3.7805	0.3150
2	36.3158	0.3026
3	5.8662	0.2444
4	0.0180	0.0900
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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Scenario #2:

50' of waste
25% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:        c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:    c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:      c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:    c:\help3\SUPR3B.D10
OUTPUT DATA FILE:             c:\help3\RB2.OUT


TIME:  12: 3     DATE:   5/12/2017


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

     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
           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    =       0.3152 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.419999997000E-04 CM/SEC


                                   LAYER  2
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
```

MATERIAL TEXTURE NUMBER 0

THICKNESS	=	600.00	INCHES
POROSITY	=	0.6710	VOL/VOL
FIELD CAPACITY	=	0.2920	VOL/VOL
WILTING POINT	=	0.0770	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3032	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00	INCHES
POROSITY	=	0.3980	VOL/VOL
FIELD CAPACITY	=	0.2440	VOL/VOL
WILTING POINT	=	0.1360	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02	CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.0517	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	3.00000000000	CM/SEC
SLOPE	=	2.00	PERCENT
DRAINAGE LENGTH	=	325.0	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	=	0.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 500. FEET.

SCS RUNOFF CURVE NUMBER	=	95.00	
FRACTION OF AREA ALLOWING RUNOFF	=	25.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.048	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	201.821	INCHES
TOTAL INITIAL WATER	=	201.821	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.39	2.51	4.54	3.25	5.17	6.28
	7.57	8.21	6.07	2.19	1.52	2.89
STD. DEVIATIONS	2.30	2.78	1.73	1.65	3.62	2.52
	3.18	2.46	1.92	1.44	0.71	1.23
RUNOFF						
TOTALS	0.218	0.399	0.373	0.255	0.725	0.660
	0.691	1.104	0.735	0.139	0.070	0.165
STD. DEVIATIONS	0.238	1.068	0.278	0.224	1.098	0.504
	0.683	0.745	0.494	0.169	0.102	0.132
EVAPOTRANSPIRATION						
TOTALS	2.179	1.936	3.082	2.736	3.404	3.925
	4.692	5.011	3.619	2.143	1.147	1.381
STD. DEVIATIONS	0.538	0.611	0.781	1.289	1.408	0.830
	1.343	0.905	1.068	0.994	0.622	0.519
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.9427	0.6067	0.7267	0.8396	0.7809	0.8404
	0.7166	0.5005	0.4268	0.5905	0.9683	1.3013
STD. DEVIATIONS	0.5657	0.5567	0.5173	0.4584	0.4924	0.3949

	0.5282	0.3694	0.3109	0.3914	0.5859	0.5084

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	0.0291	0.0206	0.0224	0.0268	0.0241	0.0268
	0.0221	0.0154	0.0136	0.0182	0.0308	0.0401
STD. DEVIATIONS	0.0174	0.0190	0.0160	0.0146	0.0152	0.0126
	0.0163	0.0114	0.0099	0.0121	0.0187	0.0157

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	53.60 (7.623)	194560.7	100.00
RUNOFF	5.533 (2.0837)	20086.21	10.324
EVAPOTRANSPIRATION	35.255 (2.7476)	127977.04	65.777
LATERAL DRAINAGE COLLECTED FROM LAYER 4	9.24084 (4.38246)	33544.262	17.24102
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001 (0.00000)	0.034	0.00002
AVERAGE HEAD ON TOP OF LAYER 5	0.024 (0.011)		
CHANGE IN WATER STORAGE	3.568 (7.0879)	12953.21	6.658

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	7.80	28314.000

RUNOFF	2.792	10135.0869
DRAINAGE COLLECTED FROM LAYER 4	0.08662	314.44363
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00025
AVERAGE HEAD ON TOP OF LAYER 5	0.083	
MAXIMUM HEAD ON TOP OF LAYER 5	0.164	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	3.3 FEET	
SNOW WATER	0.68	2452.8115

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4315

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.2100

*** 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	3.9267	0.3272
2	217.3759	0.3623
3	5.9056	0.2461
4	0.0482	0.2410
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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Atlantic Coast Consulting, Inc.

Scenario #3:

50' of waste
100% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3B.D10
OUTPUT DATA FILE:            c:\help3\RB3.OUT


TIME:  12: 6      DATE:   5/12/2017


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

     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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


     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  12
          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   =       0.3132 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.419999997000E-04 CM/SEC


                                  LAYER  2
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
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                    MATERIAL TEXTURE NUMBER   0
THICKNESS                        =     600.00    INCHES
POROSITY                         =       0.6710 VOL/VOL
FIELD CAPACITY                   =       0.2920 VOL/VOL
WILTING POINT                    =       0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT       =       0.3022 VOL/VOL
EFFECTIVE SAT. HYD. COND.        =  0.999999975000E-04 CM/SEC


                         LAYER  3
                         --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
                    MATERIAL TEXTURE NUMBER   0
THICKNESS                        =      24.00    INCHES
POROSITY                         =       0.3980 VOL/VOL
FIELD CAPACITY                   =       0.2440 VOL/VOL
WILTING POINT                    =       0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT       =       0.2440 VOL/VOL
EFFECTIVE SAT. HYD. COND.        =  0.200000009000E-02 CM/SEC


                         LAYER  4
                         --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                    MATERIAL TEXTURE NUMBER   0
THICKNESS                        =       0.20    INCHES
POROSITY                         =       0.8500 VOL/VOL
FIELD CAPACITY                   =       0.0100 VOL/VOL
WILTING POINT                    =       0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT       =       0.0497 VOL/VOL
EFFECTIVE SAT. HYD. COND.        =   3.00000000000      CM/SEC
SLOPE                            =       2.00    PERCENT
DRAINAGE LENGTH                  =     325.0     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              =       0.00    HOLES/ACRE
FML INSTALLATION DEFECTS         =       1.00    HOLES/ACRE
FML PLACEMENT QUALITY            =  3 - GOOD


                         LAYER  6
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TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 A FAIR STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 500. FEET.

SCS RUNOFF CURVE NUMBER	=	87.60	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.040	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	201.179	INCHES
TOTAL INITIAL WATER	=	201.179	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR SAVANNAH GEORGIA AND STATION LATITUDE = 32.13 DEGREES

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AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 10

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.39	2.51	4.54	3.25	5.17	6.28
	7.57	8.21	6.07	2.19	1.52	2.89
STD. DEVIATIONS	2.30	2.78	1.73	1.65	3.62	2.52
	3.18	2.46	1.92	1.44	0.71	1.23
RUNOFF						
TOTALS	0.234	0.702	0.474	0.281	1.198	0.932
	0.950	1.831	1.096	0.139	0.074	0.132
STD. DEVIATIONS	0.309	1.996	0.533	0.402	2.118	0.980
	1.315	1.546	0.950	0.291	0.193	0.144
EVAPOTRANSPIRATION						
TOTALS	2.186	1.878	3.107	2.737	3.390	3.986
	4.727	4.993	3.605	2.160	1.186	1.390
STD. DEVIATIONS	0.525	0.594	0.733	1.249	1.381	0.800
	1.379	0.893	1.033	1.007	0.640	0.509
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.7520	0.4677	0.5588	0.6649	0.6309	0.6952
	0.5985	0.4085	0.3183	0.3080	0.6871	1.0050
STD. DEVIATIONS	0.4346	0.4496	0.4177	0.3568	0.3707	0.3423

0.4224	0.2812	0.2130	0.2095	0.4613	0.3788

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	0.0232	0.0159	0.0172	0.0212	0.0195	0.0222
	0.0185	0.0126	0.0101	0.0095	0.0219	0.0310
STD. DEVIATIONS	0.0134	0.0154	0.0129	0.0114	0.0114	0.0109
	0.0130	0.0087	0.0068	0.0065	0.0147	0.0117

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

	INCHES		CU. FEET	PERCENT
PRECIPITATION	53.60	(7.623)	194560.7	100.00
RUNOFF	8.044	(4.0695)	29200.24	15.008
EVAPOTRANSPIRATION	35.345	(2.7656)	128301.73	65.944
LATERAL DRAINAGE COLLECTED FROM LAYER 4	7.09477	(3.28210)	25754.027	13.23701
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00001	(0.00000)	0.029	0.00001
AVERAGE HEAD ON TOP OF LAYER 5	0.019	(0.009)		
CHANGE IN WATER STORAGE	3.114	(6.1666)	11304.73	5.810

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 10

	(INCHES)	(CU. FT.)
PRECIPITATION	7.80	28314.000

RUNOFF	6.286	22819.1445
DRAINAGE COLLECTED FROM LAYER 4	0.06960	252.65901
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000000	0.00021
AVERAGE HEAD ON TOP OF LAYER 5	0.067	
MAXIMUM HEAD ON TOP OF LAYER 5	0.132	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	2.3 FEET	
SNOW WATER	0.68	2452.8115

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4363
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.9150	0.3262
2	212.2641	0.3538
3	5.8560	0.2440
4	0.0389	0.1945
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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CCR Liner System Analysis

HELP Model Analysis

ATLANTIC COAST CONSULTING, INC.

Scenario #4:

118.50' of waste
50% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3C.D10
OUTPUT DATA FILE:            c:\help3\RB4.OUT


TIME:  12: 9     DATE:   5/12/2017


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     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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   =       0.3262 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =   0.419999997000E-04 CM/SEC


                                   LAYER  2
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
```

MATERIAL TEXTURE NUMBER 0

THICKNESS	=	1422.00	INCHES
POROSITY	=	0.6710	VOL/VOL
FIELD CAPACITY	=	0.2920	VOL/VOL
WILTING POINT	=	0.0770	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2955	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04	CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00	INCHES
POROSITY	=	0.3980	VOL/VOL
FIELD CAPACITY	=	0.2440	VOL/VOL
WILTING POINT	=	0.1360	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02	CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20	INCHES
POROSITY	=	0.8500	VOL/VOL
FIELD CAPACITY	=	0.0100	VOL/VOL
WILTING POINT	=	0.0050	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2242	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.569000006000	CM/SEC
SLOPE	=	2.00	PERCENT
DRAINAGE LENGTH	=	325.0	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	=	0.00	HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00	HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD	

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 500. FEET.

SCS RUNOFF CURVE NUMBER	=	95.00	
FRACTION OF AREA ALLOWING RUNOFF	=	50.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.156	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	440.324	INCHES
TOTAL INITIAL WATER	=	440.324	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 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	2.72	2.97	4.09	3.04	4.80	6.35
	7.51	6.88	5.65	2.08	1.65	2.94
STD. DEVIATIONS	1.63	1.78	1.58	1.77	2.32	2.63
	3.18	2.75	2.74	1.50	1.20	1.38
RUNOFF						
TOTALS	0.291	0.417	0.540	0.488	0.921	1.269
	1.404	1.497	1.177	0.264	0.150	0.347
STD. DEVIATIONS	0.331	0.736	0.376	0.481	0.887	1.085
	1.061	0.963	0.944	0.320	0.201	0.332
EVAPOTRANSPIRATION						
TOTALS	2.037	2.123	3.079	2.380	3.235	3.914
	4.624	4.120	3.302	1.796	1.165	1.570
STD. DEVIATIONS	0.541	0.539	0.724	1.122	1.328	1.076
	1.380	1.367	1.054	0.910	0.707	0.473
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.7382	0.5934	0.6414	0.5602	0.6717	0.6359
	0.5788	0.4571	0.3502	0.3604	0.5601	0.8838
STD. DEVIATIONS	0.3347	0.3324	0.3406	0.3385	0.3361	0.3122

	0.2936	0.2772	0.2600	0.3059	0.3339	0.3351

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	0.2182	0.1621	0.1327	0.1289	0.1534	0.1415
	0.1039	0.0799	0.0627	0.0612	0.1007	0.2142
STD. DEVIATIONS	0.3301	0.2395	0.1987	0.2144	0.1693	0.2149
	0.0668	0.0629	0.0611	0.0568	0.0681	0.1897

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	50.66 (7.415)	183910.3	100.00
RUNOFF	8.765 (2.4907)	31816.82	17.300
EVAPOTRANSPIRATION	33.343 (3.4576)	121036.02	65.813
LATERAL DRAINAGE COLLECTED FROM LAYER 4	7.03142 (2.44357)	25524.053	13.87853
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00004 (0.00002)	0.136	0.00007
AVERAGE HEAD ON TOP OF LAYER 5	0.130 (0.099)		
CHANGE IN WATER STORAGE	1.524 (4.4705)	5533.30	3.009

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	7.92	28749.600

RUNOFF	5.021	18225.4102
DRAINAGE COLLECTED FROM LAYER 4	0.04135	150.11642
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000002	0.00600
AVERAGE HEAD ON TOP OF LAYER 5	2.592	
MAXIMUM HEAD ON TOP OF LAYER 5	4.508	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	42.3 FEET	
SNOW WATER	1.84	6680.3433

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4333
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.4084	0.2840
2	496.7753	0.3493
3	5.9388	0.2474
4	0.1700	0.8498
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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Atlantic Coast Consulting, Inc.

Scenario #5:

118.50' of waste
100% Runoff

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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\SUPER1.D4
TEMPERATURE DATA FILE:       c:\help3\SUPER1.D7
SOLAR RADIATION DATA FILE:   c:\help3\SUPER1.D13
EVAPOTRANSPIRATION DATA:     c:\help3\SUPER1.D11
SOIL AND DESIGN DATA FILE:   c:\help3\SUPR3C.D10
OUTPUT DATA FILE:            c:\help3\RB5.OUT


TIME:  11:53     DATE:   5/12/2017


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

     TITLE:  Superior Landfill, Site 2, Phase 2 - Active Condition

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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  12
          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   =       0.3132 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.419999997000E-04 CM/SEC


                                  LAYER  2
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
```

MATERIAL TEXTURE NUMBER 0

THICKNESS	=	1422.00 INCHES
POROSITY	=	0.6710 VOL/VOL
FIELD CAPACITY	=	0.2920 VOL/VOL
WILTING POINT	=	0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2963 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999975000E-04 CM/SEC

LAYER 3

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	24.00 INCHES
POROSITY	=	0.3980 VOL/VOL
FIELD CAPACITY	=	0.2440 VOL/VOL
WILTING POINT	=	0.1360 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2440 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.200000009000E-02 CM/SEC

LAYER 4

TYPE 2 - LATERAL DRAINAGE LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	0.20 INCHES
POROSITY	=	0.8500 VOL/VOL
FIELD CAPACITY	=	0.0100 VOL/VOL
WILTING POINT	=	0.0050 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1303 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.569000006000 CM/SEC
SLOPE	=	2.00 PERCENT
DRAINAGE LENGTH	=	325.0 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	=	0.00 HOLES/ACRE
FML INSTALLATION DEFECTS	=	1.00 HOLES/ACRE
FML PLACEMENT QUALITY	=	3 - GOOD

LAYER 6

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 16

THICKNESS	=	24.00	INCHES
POROSITY	=	0.4270	VOL/VOL
FIELD CAPACITY	=	0.4180	VOL/VOL
WILTING POINT	=	0.3670	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.4270	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.100000001000E-06	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 A FAIR STAND OF GRASS, A SURFACE SLOPE OF 3.% AND A SLOPE LENGTH OF 500. FEET.

SCS RUNOFF CURVE NUMBER	=	87.60	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	3.040	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.710	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.100	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	441.250	INCHES
TOTAL INITIAL WATER	=	441.250	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
SAVANNAH GEORGIA

STATION LATITUDE	=	32.13	DEGREES
MAXIMUM LEAF AREA INDEX	=	0.00	
START OF GROWING SEASON (JULIAN DATE)	=	51	
END OF GROWING SEASON (JULIAN DATE)	=	341	
EVAPORATIVE ZONE DEPTH	=	10.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	7.90	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	68.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	71.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	78.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	73.00	%

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

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

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

3.09	3.17	3.83	3.16	4.62	5.69
7.37	6.65	5.19	2.27	1.89	2.77

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

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
49.20	51.60	58.40	66.00	73.30	78.60
81.20	80.80	76.60	66.90	57.50	51.00

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR SAVANNAH GEORGIA
AND STATION LATITUDE = 32.13 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	2.72	2.97	4.09	3.04	4.80	6.35
	7.51	6.88	5.65	2.08	1.65	2.94
STD. DEVIATIONS	1.63	1.78	1.58	1.77	2.32	2.63
	3.18	2.75	2.74	1.50	1.20	1.38
RUNOFF						
TOTALS	0.138	0.282	0.283	0.357	0.764	1.013
	1.092	1.304	0.995	0.151	0.064	0.160
STD. DEVIATIONS	0.248	0.915	0.337	0.518	1.118	1.296
	1.166	1.137	1.073	0.281	0.165	0.273
EVAPOTRANSPIRATION						
TOTALS	2.071	2.153	3.158	2.476	3.350	4.056
	4.758	4.194	3.343	1.880	1.218	1.570
STD. DEVIATIONS	0.511	0.527	0.694	1.132	1.363	1.094
	1.392	1.387	1.039	0.973	0.711	0.495
LATERAL DRAINAGE COLLECTED FROM LAYER 4						
TOTALS	0.8222	0.6572	0.7481	0.6317	0.7507	0.7381
	0.6958	0.5199	0.4388	0.4463	0.6849	0.9755
STD. DEVIATIONS	0.3615	0.3639	0.3801	0.3800	0.3754	0.3366

	0.3530	0.3209	0.2988	0.3664	0.3748	0.3442

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	0.5480	0.4744	0.3419	0.2695	0.3879	0.3544
	0.2625	0.1433	0.1006	0.1047	0.1744	0.4992
STD. DEVIATIONS	0.8534	0.9022	0.6007	0.5736	0.7289	0.6784
	0.4511	0.2653	0.1810	0.1459	0.2184	0.5672

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

	INCHES	CU. FEET	PERCENT
PRECIPITATION	50.66 (7.415)	183910.3	100.00
RUNOFF	6.605 (2.8731)	23975.23	13.036
EVAPOTRANSPIRATION	34.228 (3.5006)	124247.62	67.559
LATERAL DRAINAGE COLLECTED FROM LAYER 4	8.10920 (2.89551)	29436.387	16.00584
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.00008 (0.00008)	0.285	0.00015
AVERAGE HEAD ON TOP OF LAYER 5	0.305 (0.330)		
CHANGE IN WATER STORAGE	1.722 (4.9066)	6250.83	3.399

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PEAK DAILY VALUES FOR YEARS 1 THROUGH 50

	(INCHES)	(CU. FT.)
PRECIPITATION	7.92	28749.600

RUNOFF	6.663	24185.8574
DRAINAGE COLLECTED FROM LAYER 4	0.04378	158.93210
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.000004	0.01326
AVERAGE HEAD ON TOP OF LAYER 5	6.074	
MAXIMUM HEAD ON TOP OF LAYER 5	9.602	
LOCATION OF MAXIMUM HEAD IN LAYER 4 (DISTANCE FROM DRAIN)	68.0 FEET	
SNOW WATER	1.84	6680.3433

MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4363
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.2100

*** 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	3.3370	0.2781
2	507.4013	0.3568
3	6.1932	0.2580
4	0.1700	0.8498
5	0.0000	0.0000
6	10.2480	0.4270
SNOW WATER	0.000	

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OBJECTIVE:

Evaluate the performance of geocomposite drainage system to be used in Superior Landfill & Recycling Center in co-mingled MSW/CCR waste cells. The analysis applies to the leachate collection rates for different stages of the landfill's life. For application purposes the geocomposite is designed to provide leachate collection for initial operations with larger leachate flows and less weight through post closure with less leachate flow and high pressure due to increased waste thickness.

METHODOLOGY:

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

Project #	I010-415				
Project Name:	Superior CCR Management	By:	JST	Date:	5/10/2017
Subject:	Geocomposite Design for CCR	Chk'd:	RBB	Date:	5/12/2017

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

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

Input Parameters

L=	325 (ft)	Max horizontal drainage length of slope
β=	2% slope, or	
	0.02 radians, or	(gradient)
	1.15 degree	Slope Angle
λccr=	79 lb/ft^3	(Co-Mingled MSW/CCR)

HELP Model Analysis Results

Stage	Thickness of solid waste, t_{waste}	Peak imprAingement rate into the LCRS drainage layer, qi
I - Initial Operation	10 ft	3.38E-07 ft/sec
II - Active Operation	50 ft	1.75E-07 ft/sec
III - Closure	118.5 ft	7.45E-08 ft/sec

Reduction Factors & Factor of Safety

	Chemical Clogging Reduction Factor		Biological Clogging Reduction Factor		Creep Reduction Factor	
Stage	RF_{cc}	GRI-GC8	RF_{bc}	GRI-GC8	RF_{cr}	GSE
I - Initial Operation	1.2		1.1		1.01	
II - Active Operation	1.5		1.2		1.13	
III - Closure	2		1.3		1.33	

Overall Factor of Safety (Narejo and Richardson 2003)

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

Solution

Stage	Normal Stess $\sigma=\lambda_{waste}*t_{waste}$	Design require transmissivity of LCRS $\theta_{req}=(q_i*L)/\sin\beta$	
I - Initial Operation	790 lb/ft^2	5.49E-03 ft^2/sec	5.10E-04 m^2/sec
II - Active Operation	3950 lb/ft^2	2.85E-03 ft^2/sec	2.65E-04 m^2/sec
III - Closure	9361.5 lb/ft^2	1.21E-03 ft^2/sec	1.12E-04 m^2/sec

Stage	Allowable transmissivity of LCRS $\theta_{allow}=\theta_{req}*FS$	Specified 100-hour transmissivity of LCRS $\theta_{100}=\theta_{allow}*RF_{cr}*RF_{cc}*RF_{bc}$	
I - Initial Operation	1.10E-02 ft^2/sec	1.46E-02 ft^2/sec	1.36E-03 m^2/sec
II - Active Operation	8.55E-03 ft^2/sec	1.74E-02 ft^2/sec	1.62E-03 m^2/sec
III - Closure	4.84E-03 ft^2/sec	1.67E-02 ft^2/sec	1.56E-03 m^2/sec

***Use GSE 200 mil FabriNet HF Geocomposite double sided with 8oz. Geotextile (or approved equal)**

Published 100-hour transmissivity of GSE 200 Mil FabriNet HF (Figure A-3)

Stage	Normal Stess $\sigma=\lambda_{waste}*t_{waste}$ (lb/ft^2)	θ_{100} (ft^2/sec)	(m^2/sec)
I - Initial Operation	790	6.46E-03	6.00E-04
II - Active Operation	3950	3.34E-03	3.10E-04
II - Closure	9361.5	1.08E-03	1.00E-04

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	6.46E-03	>	4.84E-03	4.50E-04
II - Active Operation	3.34E-03	>	1.64E-03	1.52E-04
III - Closure	1.08E-03	>	3.11E-04	2.89E-05

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

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]):

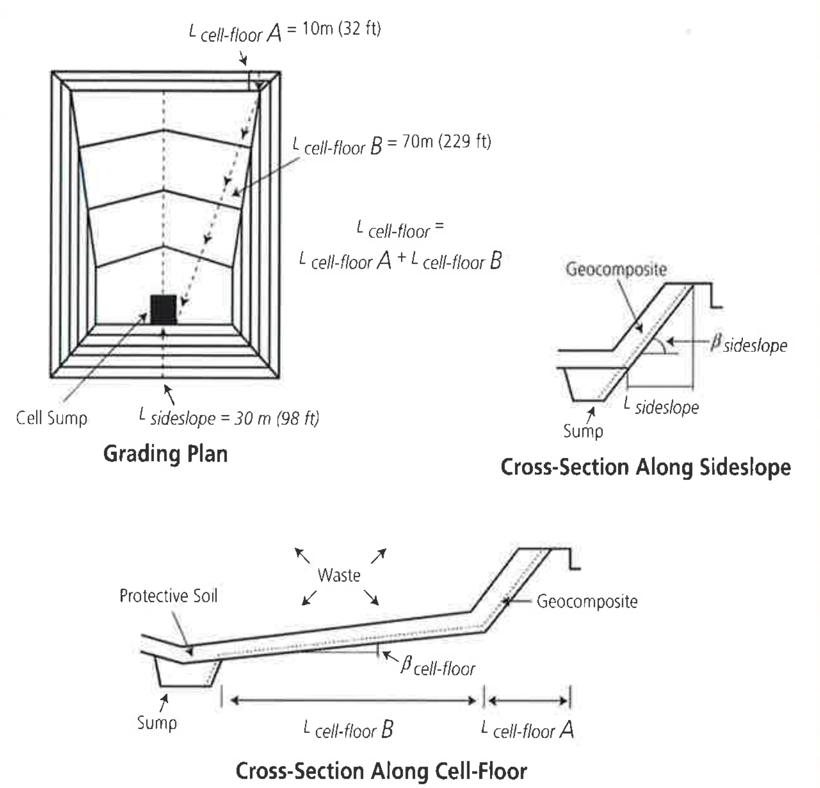

Figure 1. Simplified schematic of design geometry for example problem.

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

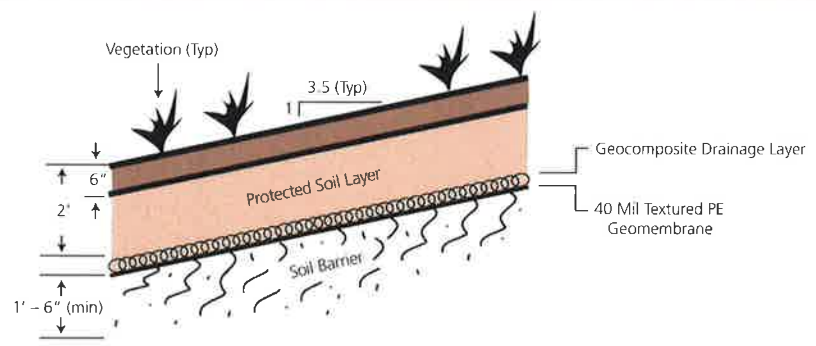

Figure 2. Design of final cover system.

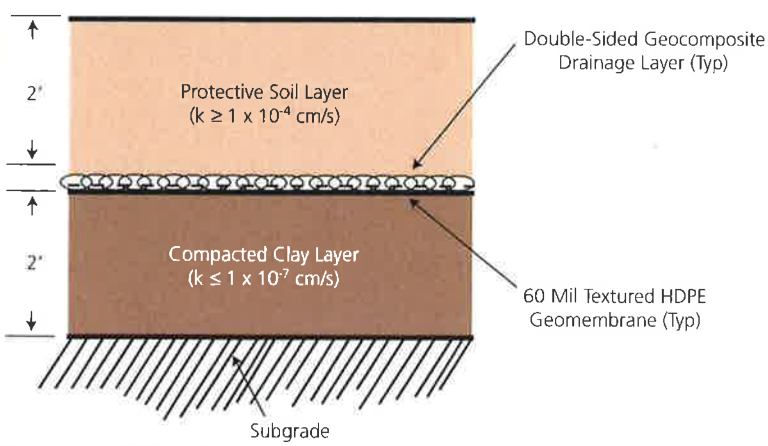

Figure 3. Design of bottom liner system.

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 sideslope = 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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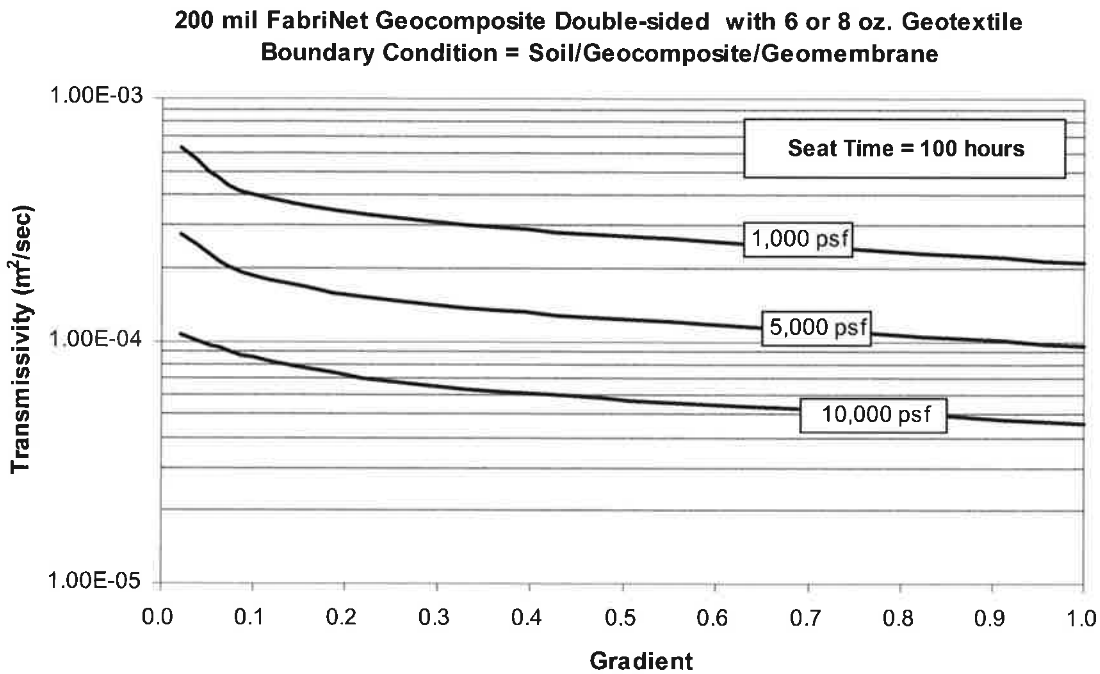

Figure A-3 Performance Transmissivity of a 200 mil FabriNet Geocomposite under Soil

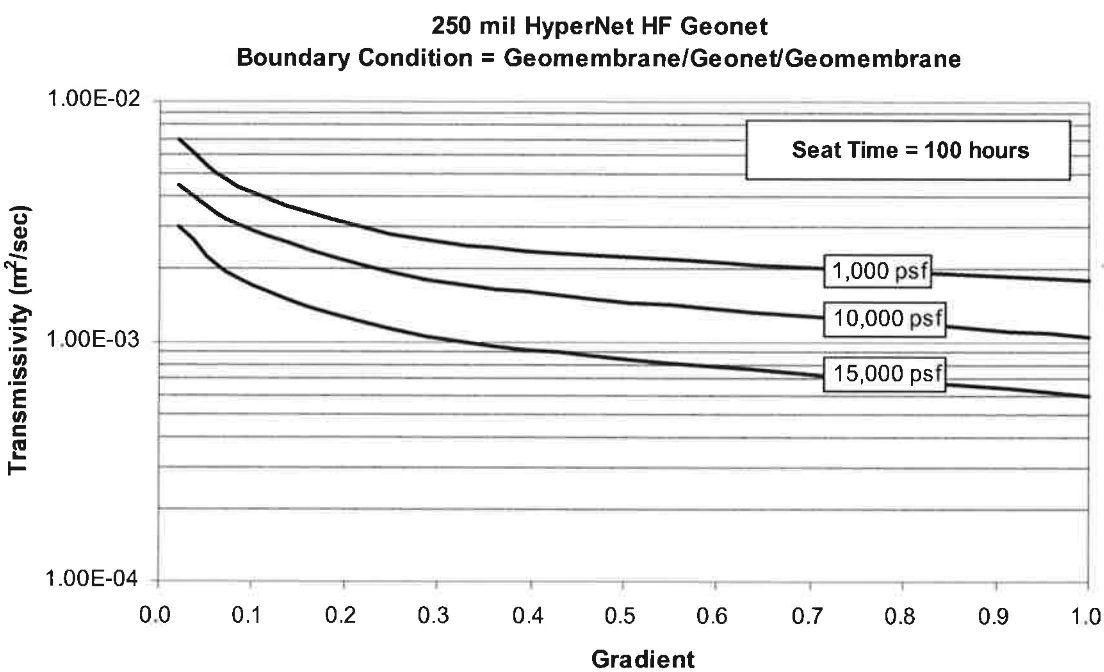

Figure A-4 Performance Transmissivity of a 250 mil HyperNet HF Geonet.

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

Leachate Collection Pipe Design

ATLANTIC COAST CONSULTING, INC.

1

2

Design Calculations Notebook

IN THIS SECTION:

Leachate Collection Pipe Design

Leachate Collection Pipe Design

Determine the required thickness of the PVC 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 feet of gravel (see detail).

Schedule	**80**		
PVC Pipe Material Code=	12454		ASTM D1784
compressive yield, σ_y =	2000	psi	(See Appendix 52C, Table 52C-1, Ch 52 of Part 636 Structural Eng National Eng Handbook, 2005)
Normal outer Diameter, B_c=	6.625	inches	
minimum wall thickness, t=	0.432	inches	
Average Inner Diameter, B_i=	5.761	inches	
mean radius, r= $(B_i+2t)/2$ =	3.31	inches	
Equivalent SDR, SDR = B_c/t =	15		
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	79	lb/ft^3	(When MSW to CCR ratio by weight is at maximum 5:1)

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	ft =	240 lb/ft^2
P_{FC} = Pressure from Final Cover =	Final Cover unit weight,	120	(lb/ft^3) * Depth of Final Cover,	2.5	ft =	300 lb/ft^2
P_{MSW} = Pressure from MS Wastes =	MSW unit weight,	70	(lb/ft^3) * Depth of Stacked waste,	8	ft =	560 lb/ft^2
$P_{MSW/CCR}$ = Pressure from $_{MSW/CCR}$ =	MSW/CCR unit weight,	79.0	(lb/ft^3) * Depth of Stacked MSW/CCR,	110	ft =	8690 lb/ft^2

P_s = 9,790 psf   For Full Cell, P_T= 9790 psf (PL and PI = 0)

= 68 psi

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	ft	
r_1 =	2	ft	
r_2 =	6.32	ft	
P_{L1} =	5,730	psf	Due to wheel load directly above point on pipe
P_{L2} =	18	psf	Due to wheel at the other end of the axle
P_L=	5,730	psf	

Internal Pressure due to Vacuum

P_I= 0 psf

For an empty cell, $P_T = P_S + P_L + P_I$ = 5,970 psf, or

41.5 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

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

r_{cent} = radius of centroidal axis of pipe, in	r_{cent} =	3.31	in
M_s = one-dimensional modulus of soil, psi	M_s =	3,000	(Table 52-2, Structural Eng Handbook. 2005, NRCS)
E = apparent modulus of elasticity of pipe material, psi	E =	119,000	(See page 52-12C, long term modulus and temperature adjustment (AWWA))
A = profile wall average cross sectional area, in^2/in	A =	0.432	in

S_A = 0.28
VAF = 1.07

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} = 10,427 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 = 555.2 psi
Allowable Compressive Stress, psi = 2000

Since 555.2 psi is < 2000 psi; design OK

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

$$S = \frac{P_t \cdot Bc}{288 \cdot t}$$ (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= 521.3 psi Since 521.3 psi is < 2000 psi so OK ; FS= 3.8

Project #: 1002-415
Project Name: Superior - CCR Mod
Subject: Leachate Pipe Design

By: RB Date 05/08/17
Checked: JT Date

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= 340,000 (See page 52-11, short term modulus and temperature adjustment (AWWA))

E_s = Secant modulus of soil, (psi)

SDR= standard dimension ratio — SDR= 15

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

μ = Poisson's Ratio — μ = 0.41

M_s = one-dimensional modulus of soil, psi — M_s = 3,000 (Table 52-2, Structural Eng Handbook. 2005, NRCS)

E_s = 1,290.5 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 = 9790 psf

ε_s= 5.27 %

R_F= 134.2

Using Watkins-Gaube Graph (Figure 3-6)

D_F= 0.8

$$\frac{\Delta X}{D_i}(100) = Df * \varepsilon_s$$

ΔX= horizontal deflection or change in diameter, (in)

D_i= inside pipe Diameter, (in)

$\%\Delta X/D_i$= 4.21 % Since 4.21 is < 7.5 OK; FS= 1.78

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), = 122.5

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= 1.0

B'= 1.0

E'= 3000 psi

E= 119,000 psi (See page 52-12C, long term modulus and temperature adjustment (AWWA))

SDR= 15

P_{wc}= 283.9 psf ≥ 68 psi so OK ; FS= 4.2