1.3 GENERAL TESTING REQUIREMENTS

This CQA Plan includes references to test procedures of the ASTM and the GRI. Test procedure references are always to the latest approved version up to the date of this document, unless specifically stated otherwise in this document.

Testing will be performed in strict accordance with the referenced test procedure and the description included in this plan, unless indicated otherwise. Any deviations to test procedures called out in this plan must be approved, in writing, by the CQA Officer or Company prior to commencement of any work.

2.0 CQA ROLES, RESPONSIBILITIES, AND QUALIFICATIONS

2.1 CQA OFFICER

The CQA Officer will supervise and be responsible for all observations, testing, and related construction documentation as described in this CQA Plan. The CQA Officer will be responsible for preparing the construction acceptance report to certify substantial compliance with appropriate permit and regulatory agency. The CQA Officer will be a professional engineer registered in the state of Wisconsin. The Company or operator shall notify the Wisconsin Department of Natural Resources (WDNR) of the designated CQA Officer and provide the department with that person's contact information.

The CQA Officer may delegate daily observation, documentation, testing, and sampling duties to a qualified technician or engineer with experience in the assigned aspect of construction that will serve as the Resident Project Representative (RPR). Although these duties may be delegated, the CQA Officer will retain the responsibility for these activities.

2.2 RESIDENT PROJECT REPRESENTATIVE

The RPR will carry out daily observation, documentation, testing, and sampling duties under the direct supervision of the CQA Officer. The RPR will be a qualified technician or engineer with experience in the assigned aspect of construction. The RPR will observe and document construction and installation procedures. The RPR will prepare daily summary reports and will routinely transmit the reports to the CQA Officer. The RPR will immediately notify the CQA Officer of problems or deviations from the CQA Plan or construction plans and specifications. Reporting, documentation, and resolution of problems and deficiencies will be carried out as described in Section 4.0. The RPR will not have authority to approve design or specification changes without the consent of the CQA Officer and the Company.

2.3 SOILS TESTING LABORATORY

The soils testing laboratory retained will be experienced in construction soil testing in accordance with ASTM and other applicable standards. The selected laboratory will be responsive to the project needs by providing test results within reasonable time frames. This will include providing verbal communication on the status of ongoing tests and immediate communication of test results as needed to facilitate ongoing construction. Final laboratory reports will be certified by the soil testing laboratory and submitted to the CQA Officer.

2.4 GEOSYNTHETICS TESTING LABORATORY / LABORATORIES

The geosynthetics testing laboratory/laboratories will have experience in testing geosynthetics in accordance with standards developed by ASTM, GRI, and other applicable test standards. The selected laboratory/laboratories will be responsive to the project needs by providing test results within reasonable time frames. Final laboratory reports will be certified by the geosynthetics testing laboratory/laboratories and will be submitted to the CQA Officer.

2.5 CONSTRUCTION CONTRACTOR

The Construction Contractor's role will be to furnish earthwork, construction, and piping installation; and to provide overall construction responsibility for the completion of the pond closures, and Dry Ash Disposal Facility liner and final cover components. The Construction Contractor will be experienced in landfill construction and be familiar with geosynthetic installations. The term "Contractor" is used interchangeably with "Construction Contractor" in this plan.

2.6 GEOSYNTHETICS INSTALLER

The Geosynthetics Installers are the companies hired by the Contractor to install the geosynthetic components referenced in this plan, and to perform the nondestructive seam testing of the geomembranes required by this plan. The term "Installer" is used throughout this plan when reference is made to the tasks and responsibilities of a Geosynthetics Installer.

The Installer will be trained and qualified to install the various geosynthetic components covered by this plan. The Installer of the geomembrane will be approved and/or licensed by the manufacturer. The Installer will submit a copy of the approval letter or license to the CQA Officer and/or Company.

Prior to confirmation of any contractual agreements, the Installer of the geomembranes will provide the CQA Officer and/or the Company with the following written information, which must be approved by the CQA Officer and/or Company.

- Corporate background and information.

- Installation capabilities:
  Information on equipment and personnel.
  Resumes of personnel.
  Quality control manual for installation.

- A list of at least 10 completed facilities, totaling a minimum of two million square feet for which the Installer has completed the installation of polyethylene geomembrane. For each installation, the following information will be provided:
  Purpose of facility, its location, and date of installation.
  Project manager, designer, manufacturer, and fabricator (if any).
  Thickness and type of polyethylene geomembrane and the surface area of the installed geomembrane.

The Installer of the geomembranes will provide a copy of the tensiometer certification, indicating the date in which the tensiometer was calibrated prior to start of any seaming operations. The Installer is responsible for delays caused to the project until tensiometer certification is delivered to the RPR.

Tensiometers used in the state of Wisconsin are required to be calibrated within 90 days prior to the start of the project. The Installer is responsible to meet this requirement, and must supply a copy of the certification at the time of mobilization to the job site.

All personnel performing geomembrane-seaming operations will be qualified by experience and by successfully passing seaming tests for the seaming methods to be used. At least one seamer shall have experience seaming a minimum of one million square feet of polyethylene geomembrane using the same type of seaming apparatus in use at the site. The most experienced seamer, the “master seamer,” will provide direct supervision, as required, over less experienced seamers. No field seaming will take place without a master seamer present.

The Installer of the geomembranes will provide the CQA Officer with a list of proposed seaming and testing personnel, and their professional records, prior to the installation of the geomembranes. The CQA Officer and Company will review this document. The CQA Officer and/or Company will not accept any proposed seaming personnel deemed insufficiently experienced. The Installer will designate one representative as the Superintendent, who will represent the Installer at all site meetings, and who will be responsible for acting as the Installer’s spokesman on site.

3.0 PRECONSTRUCTION ACTIVITIES

3.1 PRECONSTRUCTION MEETING

Prior to commencement of each phase of construction at the ash disposal facility, a preconstruction meeting will be held. This meeting will include the parties involved in the construction, including the CQA Officer or designated representative, the RPR, the Construction Contractor, and the Company.

The purpose of this meeting is to begin the planning and coordination of construction tasks, to identify potential problems that might cause difficulties and/or delays in construction, to properly interpret the design intent, and to present the CQA Plan to all of the parties involved. It is important that the rules regarding testing, repairs, etc., be known and accepted by each party to this plan.

Specific topics considered for this meeting include the following:

- Review critical design details of the project, including the plans and specifications.
- Review measures for pond dewatering or dredging.
- Review measures for sediment dewatering/conditioning including geotextile tubes if used for dewatering.
- Review measures for surface water runoff and siltation control.
- Make appropriate modifications to the CQA Plan (if necessary).
- Review the roles and responsibilities of each party.
- Review lines of authority and communication.
- Review methods for documenting and reporting and for distributing documents and reports.

- Review requirements of the soil testing laboratory and the geosynthetics testing laboratory regarding sample sizes, methods of collection, and shipment. Also, review turn times for sample data and their implications on the construction schedule, pending receipt of acceptance data.

- Review the number and locations of the tests required for soil and geosynthetic components.

- Review methods of subbase grade or soil barrier layer surface preparation and approval prior to GCL and geomembrane placement.

- Outline procedures for packaging and storing archive samples.

- Review repair procedures.

- Review the time schedule for all operations.

- Establish procedures for deployment of materials over completed geomembranes emphasizing protection of the geomembrane.

- Observe where the site survey benchmarks are located, and review methods for maintaining vertical and horizontal control.

- Review permit documentation requirements.

- Review the survey documentation tables and plans that identify the locations where survey documentation information is required.

- Conduct a site walk-around to review material storage locations and general conditions relative to construction.

- Set up a time and place for regular construction progress meetings.

Minutes prepared by the CQA Officer or other party designated by Company will be distributed to all parties involved in the construction project.

3.2 GEOSYNTHETIC PRECONSTRUCTION SUBMITTAL

Prior to the installation of geosynthetic materials, a preconstruction submittal will be prepared and submitted to the WDNR. The submittal will contain, at a minimum, the following:

- Identification of the fabricators and Installers selected for the geomembrane and other geosynthetics.

- Information on the chosen geosynthetic products.

- Certification from the GCL manufacturer that the GCL product is free of broken-off needles from the needle punching process.

- Final version of the CQA Plan, incorporating input from the selected Installer, and documenting qualifications of the third-party CQA firm and testing laboratories.

- Any modifications to the installation plan, with final proposed version of the panel layout diagram and any revisions to the details of seaming, patching, penetrations, use of prefabricated specialty sections, or repair methods.

- Any changes in geosynthetics acceptance values, test method references, and/or test procedures.

- For final cover with sand drainage layer, include filter analyses for:

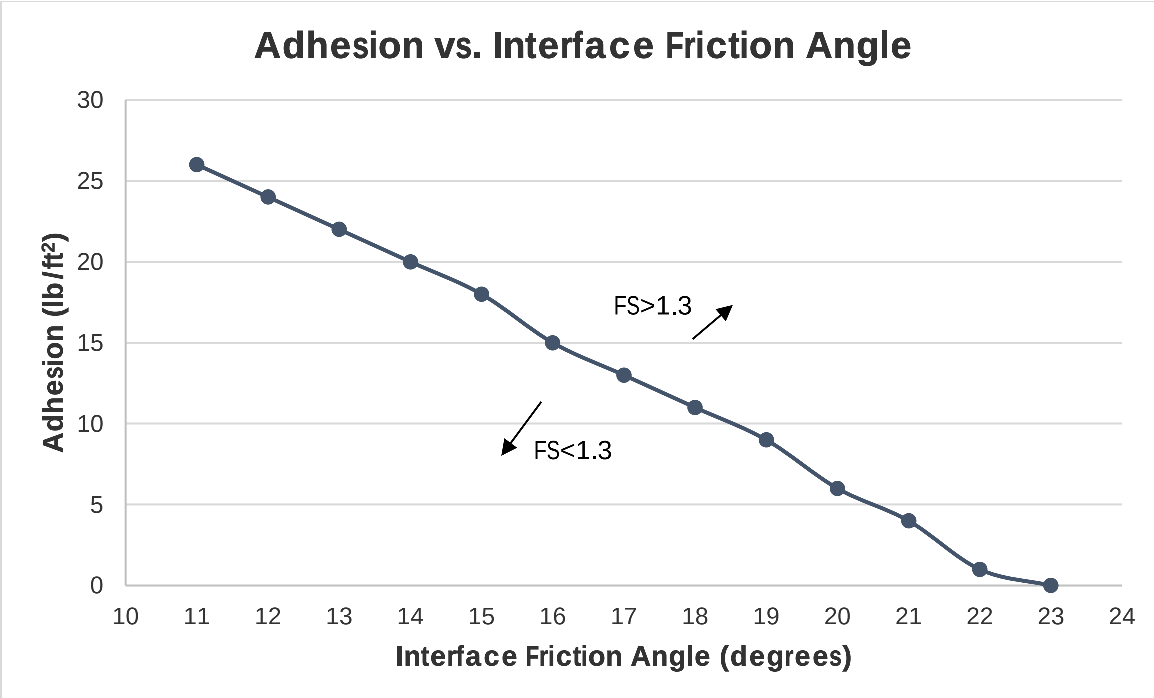
  Drainage layer sand and rooting zone soil to determine if a geotextile filter is required.

  Drain sock around intermediate drain pipes in drainage layer to be compatible with drainage layer sand particle sizes and permeability.

- Results of direct shear testing (ASTM D5321 or D6243) performed on the applicable geosynthetic interfaces and other required tests, as presented in the table below. This table also specifies the required minimum acceptance values required for the testing.

Construction Item	Required Peak Interface Friction Angle or Other Testing	Minimum Required Acceptance Value(1)
Liner System Construction	Subbase Soil or Select Clay Fill/GCL(3)	(5)
	GCL/Textured HDPE Geomembrane(2)	(5)
	Textured HDPE Geomembrane/Drainage Layer (4)	(5)
	GCL Hydrated Internal Shear Strength(2)	59 psf
Final Cover Construction	Barrier Layer Soil/GCL(2)	20.6 degrees
	GCL/Textured LLDPE Geomembrane(2)	20.6 degrees
	Textured LLPE Geomembrane/Drainage Layer(4)	20.6 degrees
	Textured LLDPE Geomembrane/Geocomposite	20.6 degrees
	Geocomposite/Rooting Zone (4)	20.6 degrees
	GCL Hydrated Internal Shear Strength(2)	131 psf

Notes:
1. Direct shear testing of wet interface at normal stresses of 200, 400, and 600 psf. Use a maximum shear rate of 0.004 inch/minute for interfaces with soil or GCL.
2. GCL hydrated for 48 hours under 300 psf and for 24 hours under load prior to shear. Barrier layer soil compacted wet of optimum to 90 percent of modified Proctor maximum dry density or 95 percent of standard Proctor maximum dry density.
3. Select clay fill compacted to 90 percent of modified Proctor maximum dry density at moisture contents of at least 2 percent wet of optimum. Subbase soil compacted to 90 percent of modified Proctor maximum dry density. Select clay fill compacted to 95 percent of standard Proctor maximum dry density at moisture contents of at least optimum. Subbase soil compacted to 95 percent of standard Proctor maximum dry density.
4. Drainage layer or rooting zone prepared by lightly tamping.
5. Required test values are shown on the adhesion vs. interface friction angle figure below.



Direct shear testing is to be performed for each construction event unless the materials to be used are the same as those that were tested for a previous construction event. The CQA Officer and Company shall determine whether testing is required for each construction event.

3.3 GEOSYNTHETIC PRECONSTRUCTION MEETING

Prior to placement of geosynthetics, a geosynthetic preconstruction meeting will be held. This meeting will include the parties involved in the construction, including the CQA Officer, the RPR, the Construction Contractor, the Geosynthetic Installer, the Company, and possibly a WDNR representative.

The purpose of this meeting is to establish the lines of communication; define the Contractor's role and responsibility during the geosynthetic deployment; and review the proposed panel layout, planned seaming methods, Installer's CQC Plan, and this CQA Plan defining the rules regarding testing, repairs, etc.

Specific topics considered for this meeting include the following:

- Review critical design details of the project, including plans and specifications.
- Review Contractor's plan for surface water control.
- Make appropriate modifications to the CQA Plan (if necessary).
- Review the roles and responsibilities of each party.
- Review the lines of authority and communication.

- Review methods for documenting, reporting, and distributing documents and reports.
- Review requirements of the Geosynthetic Testing Laboratory regarding sample sizes, methods of collection, and shipment. Review turn times for samples and their implications on the construction schedule.
- Review the number and frequency of tests.
- Review methods of subbase grade or grading layer surface preparation and approval prior to geosynthetic placement.
- Establish rules for writing on the geosynthetic (i.e., who is authorized to write, what can be written, and which color of paint).
- Outline procedures for packing and storing of samples.
- Review geosynthetic panel layout drawing and numbering system.
- Establish appropriate times for trial seams, size of destructive tests, and chain of custody for destructive samples.
- Review repair procedures.
- Review the time schedule for all operations.
- Review final walk-through procedures.
- Review proposed method to deploy materials over geosynthetic material.
- Review survey requirements prior to Installer de-mobilizing from site.
- Set timetable for regular construction meeting.

Minutes prepared by the CQA Officer or other party designated by the Company will be distributed to all parties involved in the construction project.

4.0 GENERAL CONSTRUCTION OBSERVATION AND DOCUMENTATION

This section describes general documentation procedures to be implemented, including the use of forms, the identification and resolution of problems or deficiencies, and photographic documentation.

4.1 PROGRESS MEETINGS

Progress meetings will be held regularly at a location set by Company. At a minimum, field supervisory and CQA personnel will attend the meeting. The purposes of the meeting are as follows:

- Discuss safety issues or current safety topics.
- Review work activity and location since last meeting.

- Discuss Contractor's and Installer's personnel and equipment assignments.
- Review work schedule.
- Discuss possible problems or issues to resolve.
- Review test data.
- Review data documentation requirements and submittal status.

Minutes prepared by Company-designated representative will be transmitted to all parties involved.

4.2 DAILY REPORTS

A daily summary report will be prepared by the CQA Officer, or the RPR, under the direct supervision of the CQA Officer, for each day of activity and will include the following information:

- Date, project name, location, report preparer's name, and the names of representatives on-site performing CQA.

- Time work starts and ends each construction workday, along with the duration and reason for work stoppages (i.e., weather delay, equipment shortage or problem, labor shortage, etc.).

- Data on weather conditions, including temperature, wind speed and direction, cloud cover, and precipitation.

- Construction Contractor's workforce roster, equipment in use, and materials delivered or removed from the job site.

- Identification and discussion of any major deviations from the approved plan and corrective actions taken.

- Chronological description of work in progress, including locations and type of work performed.

- Summary of meetings held and a list of those in attendance.

- Summary of relevant conversations that pertain to the project and who conversations were with.

- Identification of laboratory samples collected, marked, and delivered to laboratory, or clear reference to the document containing such information.

- An accurate record of calibrations, recalibrations, or standardizations performed on field testing equipment, including actions taken as a result of re-calibrations, plus the results of other data recording, such as geomembrane seam barrel temperature.

Each representative will prepare field data sheets containing the following information:

- Test number, sample location, and test required.
- Type of documentation.
- The procedures used.
- Test data.

- Field test results.
- Personnel involved in the documentation and sampling activities.
- Initials of the person performing the documentation and initials of the person checking the documentation.

4.3 FORMS, CHECKLISTS, AND DATA SHEETS

Forms developed for the purpose of documenting the construction and geosynthetic installation are to be supplied to the Company's assigned Project Manager prior to the start of construction and/or installation for review and approval. Additional forms developed during the course of the project to document specific aspects of the project will also be supplied to the Company's assigned Project Manager for review and approval.

4.4 PROBLEM/DEFICIENCY IDENTIFICATION AND CORRECTIVE ACTION FORMS, CHECKLISTS, AND DATA SHEETS

Problem and/or deficiency identification and corrective action will be documented in the daily summary report when a construction material or activity is observed or tested that does not meet the requirements set forth in this CQA Plan. The Summary report should clearly reference other reports, photographs, or forms that contain data or observations leading to the determination of the problem or deficiency. Problem and/or deficiency identification and corrective action documentation may include the following information:

- A description of the problem or deficiency, including reference to supplemental data or observations responsible for determining the problem or deficiency.

- The location of the problem or deficiency, including how and when the problem or deficiency was discovered, and an estimate of how long the problem or deficiency has existed.

- A list of possible causes of the problem or deficiency.

- A recommended corrective action for resolving the problem or deficiency. If the corrective action has already been implemented, then the observations and documentation to show that the problem or deficiency has been resolved must be included.

- All parties involved in the corrective action and those responsible for resolution.

- If the problem or deficiency has not been resolved by the end of the day that it was discovered, the daily summary report must clearly state that it is an unresolved problem or deficiency. Subsequent daily summary reports will indicate the status of the problem or deficiency until it is resolved.

- A problem or deficiency report or log may be created to track problems or deficiencies as the project progresses.

If the problem or deficiency has not been resolved, the CQA Officer and the preparer will discuss the necessary corrective actions. The CQA Officer will work with the Company and the Contractor to implement actions as necessary to resolve the problem or deficiency. A description of such problems or deficiencies and corrective actions implemented will be included in the Construction Documentation Report.

The CQA Officer, working with the Company and the Contractor, will determine if the problem or deficiency is an indication of a situation that may require changes to the plans or specifications and/or the CQA Plan. The CQA Officer and the Company must approve revisions to the plans or specifications or the CQA Plan. WDNR will be consulted prior to making changes to the CQA Plan or specifications, if needed, to obtain their concurrence. Documentation of changes will be incorporated into the Construction Documentation Report.

4.5 PHOTOGRAPHIC DOCUMENTATION

Photographs will be taken to document all aspects of the installation, problems, deficiencies, and corrective actions. Photographs in any format will be stored in a permanent protective file by the CQA Officer or the RPR. All photographs in all formats are to be turned over to the Company upon completion of the Documentation Report. The Company will designate whom the photographs are returned to.

For photographs provided in the final documentation report, the following information will be recorded:

- Date.
- Location where photograph was taken, including information regarding the orientation of the photograph. (e.g., looking north).
- Description of the subject matter.
- Unique identifying number for reference in other reports.
- Name or initials of photographer.

4.6 SURVEYING

Documentation surveying requirements for the pond closure components, and for the Dry Ash Disposal Facility liner system and composite cover system component are defined in the respective sections. All required thicknesses noted in each section are measured vertically. Personnel experienced in construction surveying will perform required surveying.

Documentation surveys shall be stamped by a registered land surveyor or Professional Engineer licensed in the State of Wisconsin.

4.7 DOCUMENTATION REPORT

A report documenting all aspects of construction will be prepared. The report will be prepared in accordance with the requirements of NR 516. A Professional Engineer registered in the state of Wisconsin will certify the report. In addition to the Dry Ash Disposal Facility liner and cover construction, the documentation report will include the following sections:

- Introduction
- Preconstruction Activities
- Pond Closure Excavation/Grading
- Dry Ash Disposal Facility coal combustion residuals (CCR) Filling/Grading
- Surface Drainage Features

- Construction Quality Assurance / Quality Control Plan
- Restoration

5.0 PRIMARY AND SECONDARY ASH POND CLOSURE

5.1 GENERAL

This section includes the quality assurance requirements for the Primary Ash Pond and Secondary Ash Pond excavation/removal and final grading.

5.2 PROCEDURES AND OBSERVATIONS

The RPR will observe the removal and final grading activities in the Primary and Secondary Ash Ponds, and will document relevant observations to support certification of the following requirements:

- Dewatering procedures, schedule, and discharge location.
- Primary and Secondary Ash Pond excavation/removal procedures, material dewatering procedures and dewatering location, schedule, and dewatering discharge location.
- Visual observations to confirm removal of CCR and approvals (see Subsection 5.3).
- Final grading of the Primary and Secondary Ash Pond after the Owner issues written approval of CCR removal.

5.3 FIELD MONITORING AND SAMPLING, LABORATORY TESTING, AND ACCEPTANCE CRITERIA

The RPR may collect periodic water quality control samples for laboratory testing during Primary and Secondary Ash Ponds dewatering discharge, for laboratory testing, to verify the results of sampling completed by the Contractor. Testing will follow the requirements detailed in Specification 31 22 40.

The contractor will not proceed with filling/grading of the Primary and Secondary Ash Ponds until the CQA Officer and Owner have approved CCR excavation/removal activities within the Primary and Secondary Ash Ponds in writing.

6.0 DRY ASH DISPOSAL FACILITY FILLING AND GRADING

6.1 GENERAL

This section includes the quality assurance requirements for the Dry Ash Disposal Facility, including placement, compaction, and grading of fill material above the liner system to develop subgrades/top of CCR grades within the Dry Ash Disposal Facility.

Fill material consists of accumulated sediment, CCR, impacted soil, possible concrete or construction debris, and other materials removed during implementation of the Ash Pond Closure. Fill material may be obtained from the following sources:

- CCR in the Primary Ash Pond and Secondary Ash Pond.
- Demolition materials.

Field tests and survey measurements will be recorded in the daily summary reports (see Section 4.2) as record construction data, including locations (by coordinates) and elevations of all field tests and laboratory sample points.

6.2 PROCEDURES AND OBSERVATIONS

The RPR will observe the fill placement and compaction, and final cover subgrade grading activities in the Dry Ash Disposal Facility; and will document relevant observations to support certification of the following requirements:

- The RPR will observe the final cover subgrade preparation to document that the CCR fill materials are in substantial conformance with the placement specifications.

- For existing erosion stone that will not be salvaged, mixing of erosion stone with granular material to fill voids between stone pieces.

- Adequate moisture conditioning and/or mixing of wet fill to prevent future appreciable settlement of fill below closure area final cover.

- Fill placement in lift thicknesses of 12 inches or less prior to compaction with a large self-propelled compactor. The RPR will assess the adequacy of compaction based on visual observation of the fill surface at the time of compaction.

- Final grading and compaction of Dry Ash Disposal Facility fill areas (final cover subgrade) prior to final cover construction in accordance with 40 CFR 257.102(d)(2). The RPR will observe whether the final subgrade is suitable based on a rut depth of no more than one inch when the subgrade is traversed by rubber-tired vehicles.

6.3 FIELD MONITORING AND SAMPLING, LABORATORY TESTING, AND ACCEPTANCE CRITERIA

The Dry Ash Disposal Facility final cover subgrade areas will be acceptable for stabilization confirmation, by proof rolling or other method approved by Engineer, when filling is complete to the approximate design final cover subgrades, as determined by the RPR.

The Dry Ash Disposal Facility final cover areas will be acceptable for final cover construction when filling is complete to the approximate design final cover subgrade, as determined by the RPR, and the subgrade has been accepted.

6.4 SURVEYING

The Dry Ash Disposal Facility final cover subgrades will be surveyed as described in **Section 7.4.** All survey measurements will be recorded in the daily summary reports (see Subsection 4.2) as record construction data.

7.0 SUBGRADE PREPARATION AND SUBBASE GENERAL FILL

7.1 GENERAL

This section includes the quality assurance requirements for preparation of the subgrade prior to placement of the Dry Ash Disposal Facility liner and final cover system, including placement, compaction, and grading of general fill soil required to establish the subbase grade below the liner. General fill soil will consist of inorganic soil with primarily sand-size particles from site cuts and the on-site overburden berm/stockpiles. General fill soil in direct contact with the GCL will have a maximum particle size of 2 inches. All subbase field tests, soil sample types, and survey measurements will be recorded in the daily summary reports (see Subsection 4.2) as record construction data, including locations (by coordinates) and elevations of all field tests and laboratory sample points.

7.2 PROCEDURES AND OBSERVATIONS

The RPR will observe the subgrade preparation for the liner and final cover areas, and the general fill placement activities to establish the disposal facility subbase grades. The RPR will document relevant observations to support certification of the following requirements:

- The RPR will observe the disposal facility liner system subbase preparation, including subgrade preparation and general fill placement to establish the subbase grades, to document that the compacted subbase is in substantial conformance with the placement specifications.

- For fill placed to establish the disposal facility subbase grades, the RPR will periodically observe loads of general fill for general conformance to material specifications and may randomly sample loads. The RPR will perform routine conformance sampling as defined in Subsection 7.3 (Sampling Requirements and Acceptance Criteria).

- All trees, stumps, roots, boulders, debris, and other material capable of deteriorating in situ material strength or of creating a preferential pathway for contaminants shall be completely removed.

- No frozen soil will be used for backfilling. Any frozen soil in the compaction work area will be removed.

- Loose lift thickness for general fill soil compaction will not exceed 12 inches.

- Upon completion of the disposal facility final ash grades, the RPR will visually observe the final cover subgrade for signs of soft or yielding spots. Any soft or yielding spots will be excavated and replaced with compacted ash fill.

- Unacceptable compaction density as defined by Subsection 7.3 (Sampling Requirements and Acceptance Criteria), will be reported to the CQA Officer by the RPR. Corrective action will consist of moisture-conditioning of the soil and/or additional compactive effort as necessary.

- Upon completion of the final grades, the RPR will visually observe the subgrade for signs of soft or yielding spots. Any soft or yielding spots will be excavated and replaced with compacted fill. General fill placed for the liner system subbase will be placed in accordance with **Subsection 7.2**.

- Stones and other penetrating objects 2 inches or larger protruding from the surface of the liner subbase grade or the cover subgrade will be removed. The RPR will observe the liner subbase and cover subgrade during this process, and will document the removal of stones and other objects by the Contractor. The top of the liner system subbase and cover subgrade shall be smooth-drum rolled to provide a smooth surface for placement of the liner and cover layers. Ruts greater than one inch will be repaired by filling with acceptable general fill and smooth-drum rolling.

- Field densities using methods described in **Subsection 7.3.1** will be measured to document that the in-place soil is in substantial conformance with the required density below the liner system.

7.3 SAMPLING REQUIREMENTS AND ACCEPTANCE CRITERIA

Field and laboratory sampling frequencies are based on the area or volume of material placed to establish the disposal facility subbase grades, as specified in s. NR 516.07. This section describes the required analyses, methods, sample frequencies, and acceptance limits. The RPR will perform field tests and will collect soil samples for laboratory analysis.

7.3.1 Field Testing

The following field testing methods will be used by the RPR during construction:

Parameter	Test Method
Soil density and moisture content	ASTM D6938

Field density and moisture content tests will be performed on a 100-foot grid pattern for each 1-foot thickness of compacted subbase general fill placed below the liner system. The grid pattern will be offset on alternate lifts. In confined areas where compaction equipment is hindered or hand compaction is necessary, a minimum of two field density and moisture content tests will be performed for each 1-foot thickness of subbase fill. The RPR will conduct a minimum of one field density test per 5,000 cubic yards.

7.3.2 Field Testing Acceptance Criteria

Acceptance criteria for field density will require soil compaction to a minimum of 90 percent of the Modified Proctor (ASTM D1557) maximum dry density, or a minimum of 95 percent of the Standard Proctor (ASTM D698) maximum dry density.

7.3.3 Laboratory Testing

Routine laboratory testing of the subbase fill below the liner system will be performed on samples of the subbase fill borrow area. Soil characteristics will be determined from representative samples.

Representative (grab) samples will be obtained on the basis of three criteria. First, an initial sample will be obtained from the subbase fill borrow source and analyzed prior to construction. This will confirm soil characteristics and provide an initial maximum dry density and optimum moisture content for field moisture/density testing. Second, routine samples will be obtained for every

5,000 cubic yards placed. Third, in the event that changes in physical appearance or soil characteristics are observed, a sample will be obtained and analyzed. The maximum dry density and optimum moisture content values used for compaction testing may be adjusted during the course of subbase construction based on the results of the above sampling.

The following laboratory test method will be performed by the Soils Testing Laboratory on samples collected by the RPR:

Parameter	Test Method
Moisture/Density using Modified or Standard Proctor compaction	ASTM D1557 [(a,b)] or ASTM D698 [(a,b)]
Atterberg Limits	ASTM D4318
Grain-size analysis	ASTM D6913/D7928 [(c)]

Notes:
(a) Five-point Proctor analysis required for first and second sampling criteria.
(b) A one-point Proctor analysis may be utilized for representative samples collected for the third sampling criteria (apparent changes in soil quality) to verify applicability of previously analyzed moisture-density relationships. If the result does not verify applicability, then a five-point analysis will be performed in accordance with the first sampling criteria.
(c) Distribution to be reported through the 0.002 mm particle size.

Samples of the borrow area or stockpiled soil will be collected by the RPR prior to the use of the material and whenever physical appearance or other changes are noticeable. These samples will be submitted to the Soils Testing Laboratory for the above testing.

7.4 SURVEYING

The Dry Ash Disposal Facility subbase grades and final ash grades will be surveyed on a 50-foot grid pattern (or a 100-foot grid pattern for final cover construction areas greater than 4 acres) and at key locations. Key locations include breaks in grade, toes of slopes, midpoints, and tops of sideslopes. In the alignment for leachate collection lines, the bottom of trench elevations will be surveyed at 25-foot intervals (±0.1 foot tolerance).

8.0 SELECT CLAY FILL

8.1 GENERAL

This section includes the quality assurance requirements for placement, backfilling, and compaction of select clay fill. Compacted select clay fill will be used in constructing the Dry Ash Disposal Facility liner.

The select clay fill will be obtained from off-site clay borrow sources.

All field tests, soil sample types, and survey measurements will be recorded in the daily summary reports (see **Subsection 4.2**) as record construction data, including locations (by coordinates) and elevations of all field tests and laboratory sample points.

8.2 PROCEDURES AND OBSERVATIONS

The RPR will observe compacted select clay fill construction activities and will document relevant observations to support certification of the following requirements:

- The RPR will confirm the uniformity of the removed soil to be used as select clay fill. Soil placement will be monitored for segregation and removal of unsuitable material and for changes in soil type, color, texture, and moisture content.

- The Construction Contractor will segregate and/or remove unsuitable materials such as granular soil, silty or sandy clay not meeting acceptance criteria, boulders, cobbles, and organic material. A maximum clod size of 4 inches is allowed. Clods should be able to be broken down with normal construction equipment.

- The RPR will observe clay placement and will measure field densities and moisture contents, using methods described in **Subsection 8.3** (Sampling Requirements and Acceptance Criteria), to document that the compacted clay liner is in substantial conformance with the placement specifications and that soil placement has been conducted in a manner to achieve a uniform, homogeneous clay mass.

- Voids created by nuclear density gauge (NDG) probes or Shelby tubes will be backfilled with granular bentonite.

- Compaction equipment used shall have a minimum static weight of 30,000 pounds.

- Clay layers will be constructed in lift heights no greater than 6 inches after compaction using footed compaction equipment having feet at least as long as the loose lift height.

- Each lift of clay will be sufficiently compacted to ensure that the clay is completely remolded.

- Areas of unacceptable hydraulic conductivity, density, or moisture content, as defined by **Subsection 8.3** (Sampling Requirements and Acceptance Criteria), will be documented by the RPR. Corrective action will consist of moisture-conditioning of the soil and/or additional compactive effort as necessary. Methods for moisture-conditioning soil are described in the next bullet item. Following corrective actions, such areas will be retested.

- If necessary, surfaces of liner to receive successive lifts of clay will be moisture-conditioned either by scarification and addition of water where desiccated, or by discing and air drying where saturated to promote effective bonding of lifts. Following scarification, water will be applied with a spray bar applicator or equivalent method to achieve uniform distribution.

- Clay placement will be performed in a manner to achieve continuous and complete keying together of clay liner construction areas. Stepped joints will be utilized to connect lateral segments of clay liner construction by excavating a minimum of two steps with a minimum width of 5 feet along the edge of the existing liner and overlapping them.

- No frozen soil will be used for select clay fill liner construction. Frozen soil in the compaction work area will be removed.

- Stones 2 inches or larger and other penetrating objects protruding from the surface of the final lift of compacted select clay fill will be removed to avoid puncturing the geomembrane. Stones or other penetrating objects larger than 4 inches in the lower lifts will be removed. The RPR will observe the liner during this process and will document the removal of stones and other objects by the Contractor. Voids made by the removal of stones or other objects will be filled with clay soil or bentonite, and the entire liner surface will be rolled with a smooth-drum compactor. Ruts greater than 1 inch will be repaired by filling in with compacted select clay fill and smooth-drum rolling.

- Preconstruction planning will be undertaken to sequence construction activities to minimize the length of time any completed clay surface will be exposed prior to receiving protective cover. Protective cover will be provided by the installation of the geomembrane and shall be completed in the same construction season as the geomembrane construction.

8.3 SAMPLING REQUIREMENTS AND ACCEPTANCE CRITERIA

Field and laboratory sampling frequencies are based on the area or volume of material placed, as specified in s. NR 516.06. This section describes the required analyses, methods, sample frequencies, and acceptance limits. The RPR will perform field tests and will collect soil samples for laboratory analysis.

8.3.1 Field Testing

The following field testing methods will be used by the RPR during construction:

Parameter	Test Method
Moisture content and soil density	ASTM D6938

Field density and moisture content tests will be performed on a 100-foot grid pattern for each 1-foot thickness of compacted select clay fill placed. The grid pattern will be offset on alternate lifts. In confined areas where compaction equipment is hindered or hand compaction is necessary, a minimum of two field density and moisture content tests will be performed for each 1-foot thickness of clay placed.

8.3.2 Field Testing Acceptance Criteria

Acceptance criteria for field density will require soil compaction to a minimum of 90 percent of the Modified Proctor (ASTM D1557) maximum dry density, or a minimum of 95 percent of the Standard Proctor (ASTM D698) maximum dry density. Moisture content requirements will be at least 2 percent wet of optimum if using the Modified Proctor, and at least wet of optimum if using the Standard Proctor, in accordance with s. NR 504.06(2)(f)(3). The acceptable range will be based on Proctor moisture-density relationships and compaction versus permeability relationships.

8.3.3 Laboratory Testing

Routine laboratory testing of the clay liner soil will be performed on samples from the clay borrow area and on the in-place clay soil samples collected by the RPR. Samples for determining in-place properties will be collected by pushing Shelby tubes. Soil characteristics will be determined from representative samples and from Shelby tube samples.

8.3.4 Undisturbed Sample Analysis

One undisturbed sample will be taken for each acre or less for every 1-foot thickness of clay placed and will be submitted to the Soils Testing Laboratory.

The following analyses will be performed on all undisturbed samples obtained:

Parameter	Test Method
Moisture content and dry density	ASTM D2216 and D7263
Atterberg limits	ASTM D4318
Grain-size analysis	ASTM D6913/D7928 [a]

Note:
[a] Distribution to be reported through 0.002 mm particle size.

One of every three undisturbed samples will also be analyzed for hydraulic conductivity as follows:

Parameter	Test Method [a]
Hydraulic conductivity	ASTM D5084 or SW 846 EPA Method 9100

Note:
[a] Using effective stresses no greater than 5 psi and hydraulic gradients of 30 or less.

8.3.5 Representative Sample Analysis

Representative (grab) samples will be obtained on the basis of three criteria. First, an initial sample will be obtained from the clay borrow source and analyzed prior to construction. This will confirm soil characteristics and provide an initial maximum dry density and optimum moisture content for field moisture/density testing. Second, routine samples will be obtained for every 5,000 cubic yards placed. Third, in the event that changes in physical appearance or soil characteristics are observed, a sample will be obtained and analyzed. The maximum dry density and optimum moisture content values used for compaction testing may be adjusted during the course of liner construction based on the results of the above sampling.

The following laboratory analyses will be performed on all representative samples obtained:

Parameter	Test Method
Moisture-density relationship using	ASTM D1557 [a, b]
Modified/Standard Proctor compaction	ASTM D698 [a, b]
Atterberg limits	ASTM D4318
Grain-size analysis	ASTM D6913/D7928 [c]

Notes:
[a] Five-point Proctor analysis required for first and second sampling criteria.

(b) A one-point Proctor analysis may be utilized for representative samples collected for the third sampling criteria (apparent changes in soil quality) to verify applicability of previously analyzed moisture-density relationships. If the result does not verify applicability, then a five-point analysis will be performed in accordance with the first sampling criteria.
(c) Distribution to be reported through the 0.002 mm particle size.

8.3.6 Laboratory Testing Acceptance Criteria

- A minimum 50 percent by weight which passes the #200 sieve.
- A saturated hydraulic conductivity of 1×10^{-7} cm/s or less, when compacted to 90 percent Modified or 95 percent Standard Proctor density.
- An average liquid limit of 25 or greater, with no values less than 20.
- An average plasticity index of 12 or greater, with no values less than 10.

8.4 THICKNESS DOCUMENTATION

The top of clay liner grades will be surveyed on the same 50-foot grid pattern and at key locations surveyed for subbase grades. Key locations include breaks in grade, toes of slopes, mid-points, and tops of sideslopes. In the alignment for leachate collection lines, bottom of trench elevations will be surveyed at 25-foot intervals in the same locations surveyed for trench undercuts. The clay liner thickness will be determined at surveyed locations and reported in a tabular fashion. The minimum acceptable liner thickness will be 2 feet (+0.1 foot tolerance) measured vertically.

9.0 GRADING LAYER SOIL

9.1 GENERAL

This section includes the quality assurance requirements for placement, compaction, and grading of the Dry Ash Disposal Facility final cover grading layer soil. Grading layer soil will be soil excavated/removed from site cuts or from the on-site overburden berm/stockpiles, with primarily fine-grained to fine-sand sized particles and a maximum particle size of 2 inches.

All survey measurements will be recorded in the daily summary reports (see **Subsection 4.2**) as record construction data.

9.2 PROCEDURES AND OBSERVATIONS

The RPR will observe grading layer soil placement activities and will document relevant observations to support certification requirements. The RPR will periodically observe loads of grading layer material for general conformance to material specifications. Ruts greater than 1 inch will be repaired by filling in with acceptable grading layer soil and smooth-drum rolling.

9.3 THICKNESS DOCUMENTATION

Top of grading layer grades will be surveyed on an approximate 50-foot grid (or 100-foot grid for areas greater than 4 acres), and at other key locations such as breaks in grade and toes of slope. The minimum acceptable thickness will be 0.25 foot (+0.1 foot tolerance) for the grading layer.

10.0 DRAINAGE MATERIALS

10.1 GENERAL

Drainage material includes:

Dry Ash Disposal Facility Liner System:

- Leachate drainage layer
- Drainage filter
- Coarse aggregate bedding

Dry Ash Disposal Facility Final Cover System:

- Final cover drainage layer
- Coarse aggregate bedding

Leachate drainage layer material will consist of imported sand. Other drainage materials will consist of imported material. Limestone and dolomite stone will not be used for the liner system drainage materials unless no other suitable material is reasonably available.

All drainage material sample types and survey measurements will be recorded in the daily summary reports (see Subsection 4.2) as record construction data, including locations (by coordinates) of all laboratory sample points.

10.2 PROCEDURES AND OBSERVATIONS

The RPR will observe drainage material placement activities and will document relevant observations to support certification of the following requirements:

- The RPR will periodically observe loads of drainage material for general conformance to material specifications and may randomly sample loads. The RPR will perform routine conformance sampling as defined in Subsection 10.3.

- No trucks or heavy equipment will travel directly on the geosynthetics. Only low ground pressure tracked equipment [less than 5 pounds per square inch (psi)] may operate over the geosynthetics when there is a minimum 12-inch-thick layer of drainage material in-place. Rubber-tired equipment may not travel over the geosynthetics unless a minimum of three feet of drainage material is in place. Procedures for deployment of drainage material overlying the geomembrane will be planned at the preconstruction meeting. Special requirements for geomembrane protection and equipment necessary to deploy materials must be approved by the CQA Officer.

- Care will be exercised during placement of the drainage material to prevent undue damage to pipes and geosynthetics. Aggregate will not be dropped from a height greater than 3 feet above the pipe trench.

- A geotextile cushion will be placed between the geomembrane and the coarse aggregate bedding material in the leachate collection trenches.

- A minimum of 6 inches of coarse aggregate bedding material will be placed under leachate collection pipes prior to pipe placement, and a minimum of 12 inches of coarse aggregate bedding material will be placed over the top of the leachate collection pipes.

- If drainage material is stockpiled on site prior to use, measures will be taken to minimize contamination by fines such as wind-blown particles and surface soil during loading operations.

10.3 SAMPLING REQUIREMENTS AND ACCEPTANCE CRITERIA

Field sampling and laboratory testing frequencies are based on proportionate sampling of construction areas or volumes of material placed as specified by s. NR 516.06. This section describes the required analyses, methods, sampling frequencies, and acceptance limits. The RPR will collect soil samples for laboratory analysis.

10.3.1 Field Testing

No field testing will be required for drainage material. However, as stated in Subsection 10.2 above, the RPR will perform visual inspection of this material for conformance to material specifications and may randomly sample deliveries.

10.3.2 Laboratory Testing

Representative (grab) samples may be obtained from the proposed leachate drainage layer, drainage filter, final cover drainage layer, and coarse aggregate bedding material sources prior to delivery of the material. The source sampling frequency will be dependent on the apparent uniformity of the source and must be approved by the CQA Officer.

Grab samples of drainage material will be collected and analyzed as follows:

Soil Type	Frequency	Parameter	Test Method
Final Cover Drainage Layer/Leachate Drainage Layer	1/1,000 CY [(a)]	Grain-size	ASTM D6913[(b)]
Final Cover Drainage Layer/Leachate Drainage Layer	1/2,500 CY [(c)]	Remolded hydraulic conductivity	ASTM D2434
Drainage Filter	1/1,000 LF of trench[(d)]	Grain-size	ASTM D6913[(b)]
Coarse aggregate bedding (along leachate collection piping)	1/1,000 LF of trench[(d)]	Grain-size	ASTM D6913 or C136[(b)]
Coarse aggregate bedding (along final cover toe or intermediate drain pipe)	1/1,000 CY	Grain-size	ASTM D6913 or C136[(b)]

Notes:
(a) For lesser volumes, a minimum of four samples will be tested.
(b) Testing is required only to the #200 sieve.
(c) For lesser volumes, a minimum of two samples will be tested.
(d) For documentation areas with less than 3,000 feet of pipe trench, a minimum of three samples will be tested.

Laboratory Testing Acceptance Criteria

The final cover drainage layer will consist of imported material and have the following properties:

- Contain no more than 5 percent by weight of fines passing the #200 sieve.
- Have a maximum particle diameter of ¼ inch.
- Have a remolded hydraulic conductivity of at least 1 x 10^{-2} cm/s or greater at the anticipated field density.

Filter calculations will need to be performed as described in Section 3.2 to determine final cover drainage layer material filter requirements with rooting zone soil and intermediate drain pipe drain sock.

The leachate drainage layer will consist of imported sand and have the following properties:

- Contain no more than 5 percent by weight of fines passing the #200 sieve.
- Have a maximum particle diameter of ¼ inch.
- Have a remolded hydraulic conductivity of at least 1 x 10^{-2} cm/s or greater at the anticipated field density.

Drainage filter will consist of imported material and have the following gradation:

Sieve Size	% Passing by Weight
1-inch	100
3/4-inch	90-100
3/8-inch	60-95
#4	20-70
#8	5-40
#16	0-15
#30	0-5

An alternate drainage filter specification will be determined by the CQA Officer if the leachate drainage layer or coarse aggregate bedding material is altered.

Coarse aggregate bedding will consist of Wisconsin Department of Transportation (WisDOT) Size No. 2 Coarse Aggregate, adjusted to have 100 percent passing the 1½ inch sieve, and have the following properties:

- Have a uniformity coefficient less than four.
- Contain no more than 5 percent by weight passing the #4 sieve.
- Have a maximum particle diameter of 1½ inches.
- Have a subrounded particle shape.

Filter calculations will need to be performed to confirm that the leachate drainage layer is compatible with the drainage filter.

10.4 THICKNESS DOCUMENTATION

The finished elevation of the leachate drainage layer will be surveyed on a 50-foot grid, which coincides with the grid used for the liner system subbase surface. The finished elevation of the final cover drainage layer will be surveyed on a 50-foot grid (or 100-foot grid for areas greater than

4 acres), which coincides with the grid used for the grading layer surface. The minimum acceptable thickness will be 1 foot (+ 0.1 foot tolerance). The contractor may use a GPS dozer and hand-held GPS station to control thickness.

Coarse aggregate bedding placed along leachate collection pipe alignments will be surveyed for elevation prior to pipe placement and following pipe backfilling at 25-foot intervals to document the thickness of bedding placed below pipe inverts and above the top of pipe. The minimum acceptable pipe bedding thickness for the leachate collection pipe will be 6 inches below and 12 inches above the piping (+0.1 foot tolerance).

10.5 LEACHATE DRAINAGE PIPING

Leachate that enters the leachate drainage layer will flow to a leachate collection pipe in each constructed module. All leachate collection piping will consist of a 6-inch standard dimension ratio (SDR) 11 HDPE and shall be installed as recommended by the manufacturer. Each leachate collection pipe will be placed at the bottom of the module. The leachate collection piping will be sloped at 0.5 percent and will be bedded in coarse aggregate.

10.6 FINAL COVER DRAINAGE PIPING

Surface water that enters the final cover drainage layer will flow to corrugated polyethylene pipe that will be placed at the toe of the slope and at intermediate locations. The subsurface water collection piping will be sloped at a minimum of 0.5 percent, and will be bedded in coarse aggregate at the final cover toe and in drainage material for intermediate drainage pipes.

11.0 ROOTING ZONE SOIL

11.1 GENERAL

This section includes the quality assurance requirements for placement and grading of the rooting zone soil within the Dry Ash Disposal Facility final cover. The rooting zone soil will be soil with primarily sand-sized particles excavated/removed from site cuts or from the on-site overburden berms/stockpiles.

11.2 PROCEDURES AND OBSERVATIONS

The RPR will observe rooting zone soil layer placement activities and will document relevant observations to support certification requirements.

11.3 SAMPLING REQUIREMENTS AND LABORATORY TESTING

Field sampling and laboratory testing of the rooting zone material is required to determine the filter requirements between the rooting zone soil and granular drainage layer, or between the rooting zone soil and the geotextile of the geocomposite drainage layer. A minimum of one rooting zone sample per phase of final cover construction will be collected for laboratory testing. The RPR will collect soil samples for laboratory analysis.

One or more representative (grab) samples will be obtained from the proposed rooting zone material source(s) prior to hauling/delivery of the material. The source sampling frequency will be dependent on the apparent uniformity of the source and must be approved by the CQA Officer.

Grab samples of rooting zone material will be collected and analyzed as follows:

Parameter	**Test Method**
Grain-size analysis	ASTM D6913

Filter calculations will need to be performed to determine if the rooting zone material is compatible with the granular drainage layer without a filter, or to determine the geotextile properties of the geocomposite drainage layer to be compatible with the rooting zone material.

11.4 THICKNESS DOCUMENTATION

Top of rooting zone will be documented on an approximate 50-foot grid (or 100-foot grid for areas greater than 4 acres) and at other key locations, such as breaks in grade, toes of slope, midpoints, and tops of slopes. The minimum acceptable thickness will be one foot (+0.1-foot tolerance). Thickness of the rooting zone layer will be monitored during placement through the use of 6-inch-diameter, 3-foot-long cardboard tubes placed on the geomembrane. Marks will be placed on the tubes at 1 foot perpendicular to the drainage layer for reference during rooting zone layer placement.

12.0 TOPSOIL AND SEEDING

This section includes the CQA requirements for excavating and placing topsoil and for fertilizing, seeding, mulching, and watering topsoil for vegetation. Topsoil is the final layer of soil material installed in the Dry Ash Disposal Facility final cover, along the outside slopes of the perimeter berms, along the ditches, and in other perimeter areas. A clay topsoil, having a USCS group symbol of lean clay (CL) or fat clay (CH), will be placed within the Dry Ash Disposal Facility final cover areas to minimize surface water infiltration. Topsoil will be obtained from on-site topsoil or imported from off-site source identified by the Contractor.

All survey measurements will be recorded in the daily summary reports (see **Subsection 4.2**) as record construction data.

12.1 PROCEDURES AND OBSERVATIONS

The RPR will observe topsoil placement activities and will document relevant observations to support certification of the following requirements:

- The RPR will confirm the source and uniformity of topsoil used. Soil excavation and placement will be monitored for minimization of inorganic soil not compatible for establishment of vegetation.
- Prior to seeding, the topsoil will be worked to prepare a suitable seedbed.
- Fertilizing, seeding, and mulching will be performed in a timely manner.

12.2 SAMPLING REQUIREMENTS AND LABORATORY TESTING

Field sampling and laboratory testing of the final cover clay topsoil material is required to determine the USCS group symbol. A minimum of one clay topsoil sample per phase of final cover construction will be collected for laboratory testing The RPR will collect soil samples for laboratory analysis.

One or more representative (grab) samples will be obtained from the proposed clay topsoil material source(s) prior to hauling/delivery of the material. The source sampling frequency will be dependent on the apparent uniformity of the source and must be approved by the CQA Officer.

Grab samples of clay topsoil material will be collected and analyzed as follows:

Parameter	Test Method
Atterberg limits	ASTM D4318
Grain-size analysis	ASTM D6913

12.3 ACCEPTANCE CRITERIA

The topsoil will be suitable for establishment and long-term maintenance of the selected vegetation seed mix with appropriate fertilization. Clay topsoil for the final cover will have a USCS group symbol of CL or CH based on the results of the laboratory testing.

The following seed mix from WisDOT specification Section 360 “Seeding,” Right of Way Permanent Seed Mixture No. 20 shall be used on the Dry Ash Disposal Facility final cover:

- 6 percent Kentucky Bluegrass
- 24 percent Hard Fescue
- 40 percent Tall Fescue
- 30 percent Perennial Rye Grass

The final cover seeding rate will be 3 pounds per 1,000 square feet.

12.4 THICKNESS DOCUMENTATION

The thickness of topsoil placement on the Dry Ash Disposal Facility final cover will be documented on a 50-foot grid (or 100-foot grid for areas greater than 4 acres). Thickness will be determined by surveying or other acceptable method approved by the Company. The minimum acceptable topsoil thickness for the final cover will be 0.5 foot (+0.1 foot tolerance). The minimum acceptable thickness for all other areas will be 4 inches.

13.0 GEOTEXTILE

13.1 GENERAL

This section of the CQA Plan applies to the non-woven geotextile used as a geomembrane cushion in the Dry Ash Disposal Facility liner system, as a filter, and as a separator for other construction activities.

13.2 PRE-INSTALLATION

13.2.1 Manufacturing

The geotextile will be supplied to the site in factory rolls. Prior to the delivery of any geotextile rolls, the Geotextile Manufacturer will provide the CQA Officer with the Manufacturer’s Quality Control Plan (MQCP) used for the production of the geotextile.

The Geotextile Manufacturer will provide certification, based on tests performed in accordance with the methods listed in **Tables 13-1**, **13-2**, and **13-3**, that the geotextile supplied under this plan will meet the material specifications listed in **Tables 13-1**, **13-2**, and **13-3**. These tests may be performed by the Geotextile Manufacturer's laboratory or a laboratory contracted by the manufacturer. Additionally, the manufacturer will provide certification that the MQCP was fully implemented for the geotextile materials supplied under this plan. The manufacturer shall provide documentation to verify the results of the manufacturer's CQC Plan implementation required by the CQA Officer.

The geotextile rolls will be tested and evaluated prior to acceptance. The CQA Officer may perform/require additional testing (i.e., conformance testing) as required by detailed specifications or as required in the judgment of the CQA Officer to verify that the geotextile meets the specifications.

13.2.2 Delivery, Handling, and Storage of Geotextile Rolls

Each geotextile roll to be used at the Dry Ash Disposal Facility will be marked by the Geotextile Manufacturer with the following information (on a durable gummed label, or equivalent, on the inside of the core, and on the outside of the protective wrapping for the roll):

- Name of manufacturer
- Style and type number
- Roll length and width
- Batch (or lot) number
- Nominal product thickness
- Date of manufacture
- Roll number

The Geotextile Manufacturer will use the following guidelines in packaging, wrapping, and preparing all geotextile rolls for shipment:

- When cores are required, those that have a crushing strength sufficient to avoid collapse or other damage while in use will be used.

- Each roll will be covered with a wrapping material that will protect the geotextile from damage due to shipment, water, sunlight, or contaminants.

The following practices will be used as minimum in receiving and storing geotextile rolls in the designated storage area at the job site:

- While unloading or transferring the geotextile rolls from one location to another, care will be taken to prevent damage to the wrapping or the geotextile itself. If practicable, the Installer/Contractor may use forklift trucks fitted with poles that can be inserted into the cores of rolls. The poles will be at least two-thirds the length of the rolls, to prevent breaking the cores and possibly damaging the geotextile. Rolls will not be dragged.

- The geotextile rolls will be stored in such a manner so as to ensure that they are adequately protected from the following:
  Precipitation
  Ultraviolet radiation, including sunlight

Strong oxidizing chemicals, acids or bases
Flames, including welding sparks
Temperatures in excess of 160°F
Soiling

The RPR will observe and document, throughout the pre-installation, installation, and post-installation periods, that the Installer provides adequate handling equipment used for moving geotextile rolls and that the equipment and handling methods used do not pose unnecessary risk of damage. The Installer/ Contractor is responsible for the means and methods to implement the work.

The Installer will be responsible for ensuring that all materials installed meet specifications. The RPR will maintain a log of geotextile roll deliveries. The following information, at a minimum, will be recorded on the log for each shipment received at the job site:

- Date of delivery at the job site
- For each roll of geotextile, the roll number and batch (or lot) number

13.3 INSTALLATION

This section describes the quality assurance requirements applicable to the installation, observation, and documentation of geotextile.

13.3.1 Placement

The Installer will install all geotextile in such a manner as to ensure that it is not damaged and in a manner that complies with the following requirements:

- In the presence of wind, all geotextile will be secured by suitable methods. The temporary securing material will be left in place until replaced with cover material, if applicable.

- In-place geotextile will be cut with special care to protect other materials from damage that could be caused by the cutting of the geotextile.

- The Installer will take necessary precautions to prevent damage to any underlying layers during placement of geotextile.

- During placement of geotextile, care will be taken not to entrap in the geotextile any stones, excessive dust, or moisture that could damage the geotextile.

- A visual examination of the geotextile will be carried out over the entire surface after the installation by Installer to ensure that no potentially harmful objects, such as needles, are present.

- RPR will observe and document that the above items are performed by the Installer.

13.3.2 Seams and Overlaps

The following requirements will be met with regard to seaming and overlapping of geotextile rolls:

- Geotextile seams will be continuously sewn unless heat bonding is approved by the CQA Officer and Company. Geotextile will be overlapped 6 inches prior to seaming. The sewing method and stitch type will be per manufacturer's recommendation, but must be approved by the CQA Officer. Overlapping of geotextile without sewing may be acceptable for certain applications (e.g., seams under riprap) with approval from the CQA Officer and Company.

- Sewing will be performed with thread made from the same base material as the geotextile, or suitable equivalent.

- The Installer will pay particular attention to seams to ensure that no materials could be inadvertently trapped beneath the geotextile.

The RPR will be responsible for observing and documenting that the Installer performs the above provisions in an acceptable manner.

13.4 POST-INSTALLATION

13.4.1 Final Examination

The RPR will perform a final geotextile examination after the installation of each geotextile layer has been completed. The objectives of the final examination are as follows:

- To examine for the presence of holes, tears, or other deterioration.

- To examine geotextile for excessive tension due to stretching of the fabric during installation.

- To examine for the presence of foreign objects (e.g., stones, soil clods) beneath the geotextile.

If there will be an extended time delay between completion of the geotextile and the start of the installation of any other cover, then the Installer will make provisions, by temporarily securing the geotextile by using suitable methods, to protect the geotextile from wind uplift. The RPR will document the placement of the temporary securing methods in the daily report. Geotextiles will be covered with designated overlying material within 30 days of installation to prevent extended exposure to sunlight.

13.4.2 Placement of Soils Materials

The Construction Contractor will place all soil materials located on top of a geotextile in such a manner as to minimize the following:

- Damage to the geotextile and underlying layers.
- Slippage of the geotextile on underlying layers.
- Excessive tensile stresses imposed on the geotextile.

Table 13-1. Geotextile Filter Acceptance Specifications

Property	Units	Type of Criterion	Acceptance Value[1]	Test Method
Apparent Opening Size	Mm	Range	0.074-0.180	ASTM D4751
Grab Tensile Properties[2]				ASTM D4632
Tensile Strength	lb	Minimum	200	
Break Elongation	%	Minimum	50	
Permittivity	gal/min/ft^2	Minimum	90	ASTM D4491
Mass Per Unit Area	oz/yd^2	Minimum	7.2	ASTM D5261
Puncture Resistance (pin) [(3)]	lb	Minimum	100	ASTM D4833
Puncture Resistance (CBR) [(3)]	lb	Minimum	500	ASTM D6241
Trapezoidal Tear[2]	lb	Minimum	80	ASTM D4533
UV Resistance[4]	%	Minimum	70	ASTM D7238

Notes:
1. Values are based on discussions with acceptable manufacturers and represent production values at the time this document was prepared. Minimum values are based on -2 standard deviations from the average production values.
2. These tests will be performed and results reported in both the machine and cross directions.
3. Geotextile to meet puncture resistance (pin) or puncture resistance (CBR) specification.
4. Evaluation to be based on 2.0-inch strip tensile specimens after 500 hours exposure.
5. Filter calculations will need to be performed as described in **Section 3.2** to determine final cover drainage layer material filter requirements with rooting zone soil and intermediate drain pipe drain sock. The geotextile properties for these filters may be different than the geotextile filter properties in **Table 13-1**.

Table 13-2. Geotextile Cushion Acceptance Criteria

Property	Units	Test Method	12 oz/yd^2 Acceptable Value	16 oz/yd^2 Acceptable Value	32 oz/yd^2 Acceptable Value
Grab tensile properties[(1)]					
Tensile strength	lb	ASTM D4632	300	370	500
Break elongation	%	ASTM D4632	50	50	50
Mass per unit area	oz/yd^2	ASTM D5261	12	16	32
Puncture (CBR) strength[(2)]	lb	ASTM D6241	800	900	1,700
Puncture (pin) strength[(2)]	lb	ASTM D4833	140	170	300
Trapezoidal tear strength	lb	ASTM D4533	115	145	215
UV resistance[(3)]	%	ASTM D7238	70	70	70

Notes:
1. These tests will be performed and results reported in both the machine and cross directions.
2. Geotextile to meet puncture resistance (pin) or puncture resistance (CBR) specification.
3. Evaluation to be on 2-inch strip tensile specimens after 500 hours exposure.
4. All values are minimum average except UV resistance, which is a minimum value.
5. Geotextile cushion between aggregate and geomembrane liner may consist of one layer of 32 ounce per square yard (osy) geotextile, two layers of 16 osy geotextile, or three layers of 12 osy geotextile.

Table 13-3. Geotextile Separator Acceptance Criteria

Property	Units	Test Method	Value(1)
Grab tensile properties			
Tensile strength	lb	ASTM D4632	305
Break elongation	%	ASTM D4632	15
Puncture Strength (pin)(2)	lb	ASTM D4833	140
Puncture Strength (CBR)(2)	lb	ASTM D6241	800
Apparent Opening Size	mm	ASTM D4751	0.60
Permittivity	S^{-1}	ASTM D4491	0.40

Notes:
1. All numerical values represent minimum average roll values except apparent opening size, which is a maximum average value. Average test results from all rolls in a lot must conform to the tabulated values.
2. Geotextile to meet puncture resistance (pin) or puncture resistance (CBR) specification.

14.0 GEOSYNTHETIC CLAY LINER

This section covers the quality assurance requirements for Pre-installation (includes GCL manufacturer), Installation, and Post-installation. The terms Pre-installation, Installation, and Post-Installation are applicable only to the GCL installation and do not apply to the overall construction of the Dry Ash Disposal Facility.

14.1 GENERAL

This section of the CQA Plan applies to the GCL used in the Dry Ash Disposal Facility liner system and the final cover.

14.2 PRE-INSTALLATION

Pre-installation activities are designed to help ensure that a high-quality product is being manufactured and that it is properly delivered, handled, and stored to maintain its quality.

14.2.1 Manufacturer's Quality Control Plan

The manufacturer of each component of the GCL and the GCL itself shall have a MQCP to ensure their product meets all the stated minimum properties. These manufacturers include the bentonite supplier, the geotextile manufacturer, and the GCL manufacturer.

Bentonite Supplier

The bentonite supplier shall have a MQCP, which is adhered to in the manufacturing process. This plan shall include the following information:

- Documentation that the bentonite is sodium bentonite.
- Testing that demonstrates that the bentonite meets specified gradation requirements.
- Testing that indicates that the bentonite meets specified index test requirements.
- Testing that demonstrates that the bentonite has not been treated with synthetic chemicals or polymers for the final cover system.

Polymer-enhanced bentonite is required for the liner system GCL.

At a minimum, the manufacturer shall perform the tests shown in **Table 14-1**.

Geotextile Manufacturer

The geotextile manufacturer shall have a MQCP, which is adhered to in their manufacturing process. This plan shall include the following provisions:

- Testing that demonstrates that the product is made of specified polymers.
- Testing that demonstrates that the product meets certain minimum average roll values (for geotextile).

GCL Manufacturer

The GCL Manufacturer shall have a MQCP, which describes the procedures for accomplishing quality in the final product. At a minimum, the manufacturer shall perform the tests shown in **Table 14-1**.

This MQCP shall also dictate the following requirements:

- Overlap alignment lines are to be marked on the edges.
- Completed rolls are to be securely wrapped in plastic.
- Completed rolls are to be stored indoors. Provisions are to be in place to prevent rolls from being stacked too high, to be kept dry, and to prevent damage during handling.
- Quality Control certification is to be provided.

14.2.2 Materials

The GCL shall consist of a layer of pure sodium bentonite clay encapsulated between two geotextiles, and shall comply with all of the manufacturing processes and physical/chemical criteria listed in this section. Polymer-enhanced bentonite shall be used for the liner system GCL.

The bentonite clay utilized in the manufacturing of the GCL, as well as any accessory bentonite clay provided for the seaming and detail work, shall meet the manufacturer's requirements, as specified in their MQCP. The bentonite used in the manufacturing of the GCL shall also meet the requirements of **Table 14-1**.

The geotextile components of the GCL, and the geosynthetics clay liner itself, shall meet the minimum requirements of their respective MQCP. The GCL shall also meet the requirements of **Table 14-1**.

14.2.3 GCL Delivery, Handling, and Storage

The GCL panels shall be supplied to the site in factory-produced rolls. The manufacturer shall supply GCL panels to the job site in standard factory roll dimensions.

Each roll of GCL supplied to the site shall be labeled with the following information:

- Name of manufacturer
- Product type and identification number
- Batch (or lot) number
- Date manufactured
- Roll number

The GCL Manufacturer will ensure that the crushing strength of all GCL roll cores will be sufficient to avoid collapse or other damage while in use.

The rolls of GCL are to be carefully unloaded by the Contractor upon delivery to the site. At a minimum, the following practices should be followed in receiving and storing GCL rolls:

- While unloading or transferring the GCL rolls from one location to another, prevent damage to the GCL.

- For standard rolls, a steel support should be inserted through the roll core. The slings or lifting chains should be attached at one end to the support pipe and the other end to the bucket of a front-end loader or lifting device. A spreader bar should be used to support and spread the slings. The bar and support pipe must be long enough to prevent damage to the edges of the GCL during hoisting.

- Alternate methods of unloading or transferring GCL rolls must be approved by the RPR.

- The rolls of GCL will be stored in their original, unopened, wrapped cover in a clean, dry area. The GCL should be stored off the ground on pallets or by other suitable techniques that provide continuous support over the entire length of the roll. The stored GCL shall be covered with a heavy, protective tarpaulin or stored beneath a roof. Care should be used to protect the GCL from the following:
  Precipitation
  Ultraviolet radiation
  Strong oxidizing chemicals, acids, and bases
  Flames, including welding sparks
  Temperatures in excess of 160°F

The RPR will be responsible, throughout the pre-installation, installation, and post-installation periods, for observing and documenting that the Installer provides adequate handling equipment used for moving GCL rolls and that the equipment used does not damage the GCL.

The RPR will be responsible for making certain that the manufacturer, type, and thickness of each roll are correct. The RPR will maintain a log of all GCL delivered to the job site. The following information, at a minimum, will be recorded on the log for each shipment delivered to the job site:

- Date of receipt of delivery at job site.
- For each GCL roll delivered to the site, the roll number and batch (or lot) number.

14.2.4 Submittals

Prior to GCL installation, the GCL Manufacturer and GCL Installer will submit the following information to the CQA Officer.

GCL Manufacturer/Production Information

- Corporate background and information.
- MQCP for bentonite, geotextile, and GCL manufacturers.
- Project reference list consisting of the principal details of at least ten projects totaling at least eight million square feet of GCL installation, if required by the RPR or the CQA Officer.
- Results of tests conducted by the bentonite supplier and the geotextile supplier to document the quality of the materials used to manufacture the GCL rolls assigned to the job.
- Copy of Quality Control certifications, signed by the manufacturer. Each quality control certificate shall include roll identification numbers and results of quality control tests.
- Written certification from the manufacturer that the GCL meets the project specifications, that the GCL has been continuously inspected and found to be needle-free through magnetic and metal detection tests, that the bentonite will not shift during transportation or installation, and that the bentonite and geotextile materials meet the manufacturer's specifications.

GCL Installer Information

- Corporate background information.
- Project reference list of at least five projects totaling one million square feet, if required by RPR or CQA Officer.
- List of personnel performing field operations, along with pertinent experience information, if required by RPR or CQA Officer.

The proposed panel placement diagram identifying placement of the GCL panels and seams, as well as additional details that deviate from the engineering drawings, shall be submitted prior to installation if required by the CQA Officer. The layout should be drawn to scale, shall include information such as dimensions and details, and shall be adequate for use as a construction plan.

14.3 INSTALLATION

The following installation procedures are designed to ensure the effectiveness of the GCL in meeting its design requirements and to simplify the deployment procedures. These procedures are to be followed by the Installer, unless the Installer proposes alternate procedures in writing to the CQA Officer and the CQA Officer approves these alternate procedures.

14.3.1 Testing Requirements

This subsection describes the test methods, including sampling procedures and frequencies (if applicable), and the role of the Geosynthetic Testing Laboratory in testing the GCL roll samples. Unless specified otherwise, all sampling procedures will be performed in accordance with the referenced test method defined in this section.

Testing Methods

GCL roll samples will be collected at the Manufacturer's plant by a technician of the Geosynthetic Testing Laboratory or on site by the RPR and Contractor. Sample sizes shall be as required by the Geosynthetic Testing Laboratory. GCL samples will be collected and tested in accordance with the test methods specified in GCL roll samples will be collected at the Manufacturer's plant by a technician of the Geosynthetic Testing Laboratory or on site by the RPR and Contractor. Sample sizes shall be as required by the Geosynthetic Testing Laboratory. GCL samples will be collected and tested in accordance with the test methods specified in **Table 14-1**.

The Geosynthetic Testing Laboratory will be responsible for performing the tests on samples submitted to them. Results of tests performed will be reported to the RPR and CQA Officer. Retesting of GCL rolls for quality assurance purposes, because of failure to meet any or all of the acceptance specifications in this section, can only be authorized by the CQA Officer or Company.

Procedures for Determining GCL Roll Test Failures

Table 14-1 lists the specifications that are applicable to the GCL. For any referenced test method that requires the testing of multiple specimens, the criteria in **Table 14-1** shall be met based on the average results of the multiple specimen tests.

The following Procedure will be used for interpreting results relative to acceptance or rejection of rolls, lots, and shipments of GCL to the site:

- If the test values meet the stated specifications, then the roll and batch will be accepted for use at the job site. If the sample represents all rolls from an entire shipment, then the entire shipment will also be considered accepted.

- If the result does not meet the specification, then the roll and the batch shall be retested at Contractor's expense using specimens either from the original roll sample or from another sample collected by the RPR. For retesting, two additional tests shall be performed for the failed test procedure. (Each additional test shall consist of multiple specimen tests if multiple specimens are called for in the failed test procedure.) If both of the retests are acceptable, then the roll and batch shall be considered to have passed this particular acceptance test; if either of the two additional tests fails, then the roll and batch shall be considered unsuitable without further recourse. RPR may obtain samples from other rolls in the batch. On the basis of testing these samples, the CQA Officer may choose to accept a portion of the batch while rejecting the remainder.

If retesting does not result in passing test results as defined in the preceding paragraph, or if there is any other nonconformity with the material specifications, the Contractor shall withdraw the rolls from use in the project at the Contractor's sole risk, cost, and expense. Once withdrawn, the same rolls shall not be resubmitted for use. Cost and expense for removing this GCL from the site and replacing it with acceptable GCL shall be the sole risk and responsibility of the Contractor.

14.3.2 Required Equipment

The following installation equipment is required on site:

- Front-end loader, crane, or other similar equipment. The selected piece of equipment shall not cause damage to the subgrade, such as rutting. The Installer shall verify in the presence of the RPR that the selected piece of equipment does not damage the subgrade.
- A spreader bar to prevent slings from damaging the ends of the rolls.
- Several steel pipes to be inserted into the roll's core for lifting.
- Wooden pallets for aboveground storage of the GCL rolls.
- Heavy waterproof tarps for protecting all GCL rolls.
- Sandbags for securing the GCL during installation and for the tarps.
- Adhesive or tape for securing patches.
- Granular bentonite for seams, patches, and penetrations.

14.3.3 Surface/Subgrade Preparation

GCL installation will not begin until a proper subgrade has been prepared to accept the GCL. Base material will be select clay fill for the liner and grading layer for the final cover. Foreign materials and protrusions should be removed, and all cracks and voids should be filled, and the surface made smooth and uniformly sloping. Unless otherwise required by the contract specification and drawings, the prepared surface should be free from excessive moisture, loose earth, or rocks larger than 2 inches in diameter, rubble, and other foreign matter. The subgrade should be uniformly compacted to ensure against localized settlement and rutting under wheel loads, and should be smoothed with a smooth drum or vibratory roller.

The surface on which the GCL is to be placed should be maintained in a firm, clean, and smooth condition; free of standing water during GCL installation. Vehicle traffic on the subgrade of the GCL shall be restricted to the minimum weight and number of machines needed to deploy the GCL. Vehicles shall be operated to minimize the formation of ruts and surface deformations.

14.3.4 Deployment

As each roll is moved from the storage area, the Installer or RPR should remove the labels for storage in the project file.

The rolls of GCL should be brought to the area to be lined with a front-end loader and support pipe set up such that the roll of GCL is fully supported across its length. A spreader bar or similar device should be used to prevent the lifting chains or slings from damaging the edges. Dragging of the GCL should be minimized.

The Contractor shall ensure that, and the RPR will verify that, the following criteria are being met:

- The equipment used does not damage the GCL by handling, excessive heat, leakage of hydrocarbons, or by other means.

- The prepared surface underlying the GCL has not deteriorated since previous acceptance, and that it is still acceptable at the time of GCL placement.

- Personnel working on the GCL do not smoke, wear damaging clothing, or engage in other activities that could damage the GCL.

- The method used to unroll the GCL does not cause damage to the GCL, and/or the subgrade.

- The method used to place the rolls minimizes wrinkles (especially wrinkles between adjacent panels).

Do not place GCL during precipitation, in the presence of excessive moisture, in any area of ponded water, or during excessive winds. The GCL must be dry when installed and must be dry when covered.

The non-woven side of the GCL should face upwards, and the scrim side of the GCL should face downwards (unless otherwise dictated by project requirements). The GCL will be placed over the prepared surface in such a manner, which minimizes material handling.

The GCL panels should be placed in a manner that ensures sufficient overlap as described in **Subsection 14.3.5**. Whenever possible, horizontal seams should not occur on slopes steeper the 7H:1V. If horizontal seams are required on slopes, seams should be staggered to provide no end seams within 25 feet up- or downslope on adjacent panels.

The cover material (i.e., geomembrane) should be placed over the GCL during the same day as the placement of the GCL. Only those GCL rolls, which can be covered that same day, should be unpacked and placed in position.

When wind conditions can affect installation, the GCL installation should be started at the upwind side of the project and proceed downwind. The leading edge of the GCL should be secured at all times with sandbags or other means sufficient to hold it down during high winds.

The GCL should be installed in a relaxed condition and should be free of tension or stress upon completion of the installation. Stretching of the GCL to fit will not be allowed. Deployed rolls (panels) should be straightened by the installation personnel to smooth out creases or irregularities.

The RPR will visually inspect the geotextile quality, bentonite uniformity, and the degree of hydration, if any, of the GCL. Any areas in need of repair shall be marked.

14.3.5 Seaming

Once the first panel has been deployed, adjoining panels should be laid with a 6-inch minimum overlap on longitudinal seams, and 20 inches on the panel end seams, depending on project specifications. Six inch and 20-inch overlap lines shall be marked on the GCL to assist in obtaining the proper overlap. When connecting GCL panels from a prior construction phase to a new construction phase, a minimum 1-foot overlap should be provided between the previously placed panels and the newly placed panels. All dirt, gravel, or other debris should be removed from the overlap area of the GCL.

Seam overlaps, whenever possible, should be placed such that the direction of flow is from the top panel to the underlying panel to form a shingle effect.

If the GCL requires a granular bentonite seam, then the overlapping panel edge should be pulled back and granular sodium bentonite should be poured continuously along all seams and lap areas for the panel edge to the 6-inch lap line, at a minimum application rate of one-quarter pound per lineal foot.

14.3.6 Patches/Repairs

Irregular shapes, cuts, or tears in the installed GCL should be covered with sufficient GCL to provide a 12-inch overlap in all directions beyond the damaged area. A layer of granular bentonite shall be placed in the overlap zone in accordance with the Manufacturer’s recommendations. An epoxy-based adhesive, or other approved method, shall be used to secure the patch during backfill operations.

14.3.7 Penetration Seals

The GCL should be sealed around penetrations, pipes, and structures in accordance with the recommendations of the GCL manufacturer.

14.3.8 Covering GCL

Only the amount of GCL that can be inspected, repaired, and covered in the same day should be deployed. The GCL must be covered the same day it is installed.

Geosynthetics

When covering the GCL, precautions shall be taken to prevent damage to the GCL by restricting heavy equipment traffic. Place a slip-sheet over the GCL to allow the textured geomembrane to slide into its proper position. The slip-sheet shall be removed after the geomembrane is in place.

Any leading edge of panels of GCL left unprotected must be covered with heavy, waterproof tarp that is secured and protected with sandbags or other ballast.

GCL Panels at the End of a Phase

This section applies to GCL panels located at the end of a phase of construction that will be connected to GCL panels during construction of a future phase. The edge of the GCL panels shall be protected from excess soil moisture contact by placement of plastic construction film rolled over both the top and bottom sides for at least a 2-foot width along the edge of the GCL panels. The overlying geomembrane shall extend beyond the edge of the GCL. Soil shall be placed over the edges of the geosynthetics to divert water away from the buried edges and to impose overburden pressure to minimize swelling of the GCL.

14.3.9 Submittals

During GCL installation, the GCL Installer shall submit the following information to the CQA Officer:

- Daily records/logs prepared by the Installer documenting work performed, personnel involved, general working conditions, and any problems encountered or anticipated on the project. These records shall be submitted on a weekly basis.
- Copy of subgrade acceptance forms by the Installer.
- Quality control documentation.

Table 14-1. GCL Material Tests, Test Methods, and Acceptance Criteria

	Property	Test Method	Units	Criterion	Acceptance Value(1)	Minimum Conformance Testing Frequency(2)(3)
Bentonite properties	Free swell	ASTM D5890	ml/2g	Minimum	24	1/100,000 sf
	Fluid loss	ASTM D5891	ml	Maximum	18	Not required
Physical GCL Properties	Grab strength(6)	ASTM D6768	lb/in	MARV(4)	23	1/100,000 sf
	Bentonite mass per unit area(5)	ASTM D5993	psf	Minimum	0.75	1/40,000 sf
	Peel strength(6)	ASTM D6496	lb/in	Minimum	2.1	1/100,000 sf
	Index flux	ASTM D5887	$m^3/m^2/sec$	Maximum	1×10^{-8}	1/100,000 sf
	Permeability	ASTM D5887	cm/sec	Maximum	5×10^{-9}	Not required
	Hydraulic Conductivity(7)	ASTM D6766	cm/sec	Maximum	5×10^{-9}	Note 8
	Loss on Ignition	ASTM D7626 modified	Percent	Note 9	Note 9	1 test(10)
	Fann Viscosity	API 13A Section 9 modified	Centipose	Note 9	Note 9	1 test(10)

Notes:

1. Values are based on representative manufacturer's product data current acceptable industry standards and practice.
2. CQA Officer to coordinate conformance testing at the specified frequencies (minimum) on the GCL rolls supplied to the project.
3. Conformance testing is not required if GCL manufacturer provides testing documentation at the required frequency prior to shipping.
4. MARV = Minimum average roll value.
5. Bentonite mass/unit area reported at zero percent moisture content.
6. Grab and peel strength testing performed in the machine and cross direction. Acceptance value is for the machine direction (MD) test.
7. Hydraulic conductivity (compatibility) test for the liner GCL performed using site-generated leachate.
8. One test is required for the liner GCL. The test must be repeated if there is a change in site's coal combustion residuals (CCR) properties, or if the GCL product or the polymer used to enhance the bentonite in the GCL changes.
9. Testing of polymer-enhanced bentonite from liner GCL. Manufacturer's test results will be used to compare with results from conformance testing coordinated by CQA Officer.
10. CQA Officer to coordinate conformance testing of polymer-enhanced liner GCL rolls supplied to the project.
11. Refer to **Section 3.2** for direct shear test requirements.

15.0 GEOMEMBRANE

15.1 GENERAL

This section of the CQA Plan applies to the polyethylene geomembranes used in the Dry Ash Disposal Facility liner and final cover systems.

15.2 PRE-INSTALLATION

This section describes the quality control measures that are applicable to the polyethylene resin manufacturers, geomembrane manufacturers, and finished geomembrane roll delivery to the site prior to installation. The geomembrane must be fabricated from polyethylene resin.

In the event that geomembrane materials are obtained from a different manufacturer or are made from different resins, seam samples formed by joining the original and the proposed geomembrane may be tested to confirm the construction compatibility of the two-geomembrane materials. Prior to the use of the new geomembrane material, a minimum of two seamed samples (as described above) may be submitted to the geosynthetics laboratory for destructive seam testing as described in Subsection 15.4.5. The CQA Officer will review the testing results prior to authorizing the use of the new geomembrane material.

The geomembrane will be supplied to the site in factory rolls. <u>No factory seams will be used to prepare larger panels of geomembrane for delivery to the site</u>.

15.2.1 Manufacturing

Material Specifications

The required geomembrane material for final cover construction is textured 40-mil LLDPE. The approved geomembrane material for the liner system construction is textured 60-mil HDPE.

Quality Control Requirements

Prior to the delivery of any geomembrane rolls to the site, the Geomembrane Manufacturer will provide the Company and/or the CQA Officer with the following information:

- The resin supplier, location of supplier's production plant(s), and resin brand name and product number.
- Any results of tests conducted by the Geomembrane Manufacturer and/or the Resin Manufacturer testing laboratories to document the quality of the resin used in fabricating the geomembrane.
- The Quality Control Plan that the Geomembrane Manufacturer will be using for the geomembrane being supplied.

Every roll of geomembrane for delivery to the site must be manufactured and inspected by the Geomembrane Manufacturer according to the following requirements:

- First quality polyethylene resin must be used.

- The geomembrane must contain no more than a maximum of 1 percent by weight of additives, filler, or extenders, excluding carbon black.

- The geomembrane must have no striations, roughness (except where textured geomembrane is specified), or bubbles on the surface.

- The geomembrane must be free of holes, blisters, undispersed raw materials, or any other sign of contamination by foreign matter.

The Geomembrane Manufacturer will routinely perform density (ASTM D1505) and melt index (ASTM D1238) tests on the raw resin to document the quality of the HDPE or LLDPE resin used to manufacture the geomembrane rolls assigned to this project.

Manufacturer's Certification

The Geomembrane Manufacturer will test the geomembrane produced for the site according to the test methods and frequencies listed in Table 15-1. The Geomembrane Manufacturer will provide certification, based on tests performed by either the Geomembrane Manufacturer's laboratory or other outside laboratory contracted by the Geomembrane Manufacturer that the geomembrane supplied under this plan will meet the specifications presented in Table 15-2, except as noted in Subsection 15.3.1 under Procedures for Determining Geomembrane Roll Test Failures. Additionally, the manufacturer will provide certification that the MQCP was fully implemented for the geomembrane material supplied under this plan. The manufacturer will provide documentation to verify results of the MQCP implementation if requested by the CQA Officer.

15.2.2 Delivery, Handling, and Storage of Geomembrane Rolls

The geomembrane will be protected during shipment from excessive heat or cold, puncture, cutting, or other damaging or deleterious conditions. The geomembrane rolls will be stored on site in a designated area and will be protected from long-term ultraviolet exposure prior to actual installation.

Each geomembrane roll will be marked by the Geomembrane Manufacturer with the following information (on a durable gummed label, or equivalent, on the inside of core):

- Name of manufacturer
- Product type and identification number (if any)
- Roll length and width
- Batch (or lot) number
- Nominal product thickness
- Date manufactured
- Roll (or field panel) number

When cores are required for preparing geomembrane for shipment, the manufacturer will use cores with sufficient crushing strength to prevent collapse or other damage while in use.

The following practices will be used as a minimum in receiving and storing geomembrane rolls in the designated storage area at the job site:

- While unloading or transferring the geomembrane rolls from one location to another, care will be taken to prevent damage to the geomembrane itself. The preferred method involves using a spreader-bar, straps, and a loader. Rolls will not be dragged.

- Geomembrane rolls will be stored in a manner so as to ensure that they are adequately protected from the following:
  Equipment damage
  Strong oxidizing chemicals, acids, or bases
  Flames, including welding sparks
  Temperature in excess of 160°F
  Dust and dirt

The RPR will observe and document, throughout the pre-installation, installation, and post-installation periods that the Installer provided adequate handling equipment for moving geomembrane rolls and that the equipment and the handling methods used do not pose unnecessary risk of damage. The Installer is responsible for the means and methods to implement the work.

The Installer will be responsible for ensuring that all material installed meet specifications (i.e., that the roll marking label information indicates required specifications and properly represents materials). The RPR will maintain a log of geomembrane roll deliveries. The following information, at a minimum, will be recorded on the log for each shipment received at the job site:

- Date of delivery at job site.
- For each geomembrane roll, the roll number and batch (or lot) number.

15.3 INSTALLATION

This section includes discussion of geomembrane roll testing requirements, earthwork required for geomembrane placement, placement of the geomembrane, defects and repairs of geomembrane, and requirements applicable to other materials in contact with the geomembrane. **Subsection 16.4** describes the installation and testing requirements for geomembrane seams.

All parties involved in the installation of the geomembranes will be familiar with geomembrane and will focus on protecting the geomembrane from damage during construction activities.

15.3.1 Testing Requirements

This subsection describes the test methods, including sampling procedures and frequencies, and the role of the geosynthetics-testing laboratory in testing the geomembrane roll samples. **Subsection 15.2.1**, under Quality Control Requirements, describes the test methods that are performed on an infrequent basis to demonstrate the uniformity of resin used to fabricate geomembrane shipped to the job site. Seam testing is described in **Subsections 15.4.4** and **15.4.5**.

Testing Methods

A representative of the Geosynthetic Testing Laboratory at the geomembrane manufacturer's plant will collect geomembrane roll samples. The rate of sampling will be one per 100,000 square feet of geomembrane produced for delivery to the site. At least one sample will also be obtained for each geomembrane production batch for each shipment. The Installer will not ship to, or receive at the site, geomembrane from more than two production batches in any single shipment without the prior written approval of the CQA Officer and/or Company.

Samples collected will be of a size determined by the Geosynthetic Testing Laboratory. The laboratory technician will indicate the MD on the sample.

Table 15-1 lists the tests and the test methods to be performed on HDPE or LLDPE geomembrane roll samples. The specifications and methods used in evaluating the results are discussed below under "Procedures for Determining Geomembrane Roll Test Failures." Unless specified otherwise, sample specimens will be prepared in accordance with the referenced test method. The results for tear resistance and each of the tensile property tests will be reported for both the machine and cross direction.

The Geosynthetics Testing Laboratory will be responsible for performing the tests on samples submitted to them as described above under Test Methods. The results of the tests performed will be reported to the CQA Officer and the RPR.

Retesting of geomembrane rolls for quality assurance purposes because of failure to meet any or all of the acceptance specifications listed in **Table 15-2** can only be authorized by the CQA Officer and/or Company.

The Geomembrane Manufacturer and/or Installer may perform their own tests according to the methods and procedures defined in **Table 15-1**; however, the results will only be applicable to their own quality control needs. The results will not be substituted for the quality assurance testing described herein.

Procedures for Determining Geomembrane Roll Test Failures

Table 13-2 lists the acceptance specifications for HDPE and LLDPE geomembranes. For those tests where results are reported for both machine and cross direction, each result will be compared to the listed specification to determine acceptance.

The following procedure will be used for interpreting results:

- If the test values meet the stated specification in **Table 15-2**, then the roll and the lot will be accepted for use at the job site. If the sample represents all rolls from an entire shipment, then the entire shipment will also be considered accepted.

- If the result does not meet the specifications, then the roll and the batch may be retested using specimens either from the original roll sample or from another sample collected by the Geosynthetic Laboratory technician or the RPR. For retesting, two additional tests will be performed for the failed test procedure. (Each additional test will consist of multiple specimen tests if multiple specimens are called for in the test procedure). If both of the retests are acceptable, then the roll and batch will be considered to have passed this particular acceptance test; if either of the two additional tests fail, then the roll and batch will be considered unsuitable without further recourse. The CQA Officer may obtain samples from other rolls in the batch. On the basis of testing these samples, the CQA Officer may choose to accept a portion of the batch while rejecting the remainder.

If retesting does not result in passing test results as defined in the preceding paragraph, or if there is any other nonconformity with the material specifications, then the Installer will withdraw the rolls from use in the project at the Installer's sole risk and expense. The Installer will be responsible at his/her sole risk, cost, and expense for removing this geomembrane from the site and replacing it with acceptable geomembrane.

15.3.2 Earthwork

The Construction Contractor will be responsible for preparing the supporting soil according to the plans and specifications. For the installation of any of the geomembrane, the Installer will certify in writing that the surface on which the geomembrane will be installed is acceptable. This certification of acceptance will be reported by the Installer prior to the start of geomembrane installation in the area under consideration. Unacceptable areas noted by the Installer will be immediately reported to the RPR.

The installation surface will also be examined by the RPR. The daily observation will be documented in the daily report. The Construction Contractor or Installer will rework areas determined to be unacceptable until acceptable.

15.3.3 Placement

Location and Panel Layout Drawing

A panel layout drawing for the geomembrane installation covered by this plan will be prepared by the Installer prior to the installation and submitted to the CQA Officer and Company. The proposed panel layout drawing will show the proposed location and orientation of geomembrane panels to be installed in relation to slope, collection trenches, anchor trench, and phase boundaries. The panel layout drawing will be submitted to the WDNR prior to the preconstruction meeting if required. The Company and CQA Officer will review the proposed panel layout drawing and document that it is consistent with accepted practice and the construction plans and specifications.

Installation Techniques

Geomembrane panels will be installed by placing one at a time, and each panel will be seamed by the end of the day on which it was placed. Panels shall be installed such that all seams run perpendicular to the contour lines of the slope.

The RPR will document that the condition of the supporting soil has not changed detrimentally during installation. The RPR will notify the Installer and the Construction Contractor of any damage done (i.e., rutting by equipment used to deploy geomembrane) to the supporting soil prior to panel seaming. It is the responsibility of the Installer to remove the deployed panel to allow the Construction Contractor to repair the supporting soil. The RPR will observe and document the repair of the supporting soil. The RPR will inform the Installer that the method of deployment will be observed during further deployment, and if damage to supporting soil continues, deployment will be stopped and an alternate means of deployment is to be developed. The RPR will document these events and conversations in the daily summary report.

The Installer will take the following precautions while installing the geomembrane:

- Ensure the equipment used does not damage the geomembrane by the way it is handled, by excessive heat, by leakage of hydrocarbons, or by other means.
- Ensure fuel storage on the geomembrane has secondary containment.
- Ensure the personnel working on the geomembrane do not smoke, wear damaging clothing, or engage in other activities that could damage the geomembrane.

- Ensure that the method used to deploy the geomembrane does not cause scratches or crimps in the geomembrane.

- Ensure that the method used to deploy the rolls minimizes wrinkles.

- Ensure that the geomembrane is adequately loaded to prevent wind uplift.

- Minimize the amount of direct contact with the geomembrane and limit the number of personnel that are allowed on the geomembrane once QC and QA is completed.

- Ensure that only approved equipment is allowed on the surface of the geomembrane (i.e., generators, test equipment). The use of motorized vehicles is not permitted without written approval from the Company and the CQA Officer and/or the RPR.

Weather Conditions

Geomembrane will not be placed in an area of ponded water or during precipitation events. Geomembrane may not be deployed in the presence of excessive winds unless approved by the CQA Officer or Company. The Installer must receive written approval from the CQA Officer or Company to deploy geomembrane in temperature below 32°F.

Damages

The RPR will examine each panel for damage after placement and will determine which panels, or panel portions, should be rejected, repaired, or accepted. Damaged panels or portions that have been rejected will be marked, removed, and recorded by the RPR.

15.3.4 Defects and Repairs

This section applies to all defects and repairs resulting from examinations, tests, or visual observations performed on the geomembrane material itself and on the seams used in joining rolls in the field.

Identification

All seam and non-seam areas of the geomembrane will be examined and documented by the RPR for identification of defects, holes, blisters, undispersed raw material, and any signs of contamination by any foreign matter. Because light reflected by the geomembrane helps to detect defects, the surface of the geomembrane will be clean at the time of examination. The RPR will complete a final examination of the geomembrane in areas in which both the Installer and the RPR have completed their QC and QA, respectively. The RPR will document areas in which a final examination has been completed, and the Installer will limit personnel access to the completed area. The RPR and the Installer will perform a final examination over the entire geomembrane at the completion of the project. The Installer and/or the Construction Contractor will clean any area that is insufficiently clean to complete the final examination.

Evaluation

Each suspect area identified will be nondestructively tested using the vacuum box test method, air test, or spark test method. The RPR will approve the proper test method for each suspect location.

Repair Procedures

Any portion of the geomembrane exhibiting a flaw or failing a destructive or nondestructive test will be repaired. Several procedures exist for the repair of these areas. The procedures available include the following:

- Patching is used to repair large holes, tears, undispersed raw materials, and contamination by foreign matter.

- Grinding and rewelding are used to repair small sections of extruded seams.

- Spot welding or seaming is used to repair small tears, pinholes, or other minor, localized flaws.

- Capping is used to repair large lengths of failed seams.

- Other procedures may be used at the recommendation of the Installer if agreed upon by the CQA Officer and the RPR.

- Removal and replacement is used to replace non-conforming or damaged panels or portions thereof.

The repair procedures, materials, and techniques will be approved in advance of the specific repair by the CQA Officer, RPR, and Installer. At a minimum, the following provisions will be satisfied:

- Patches or caps will extend at least 6 inches beyond the edge of the defect, and all corners of patches will be rounded with a radius of at least 3 inches.

- The type of geomembrane (i.e., smooth or textured) used for repairs will be approved by the RPR prior to completing repairs.

Examination of Repairs

Each repair will be numbered and logged by the RPR. Each repair will be nondestructively tested according to **Subsection 15.4.4**. Repairs that pass the above testing will be considered to be adequate, except that large caps may be of sufficient extent to require destructive seam sampling and testing, at the discretion of the RPR, according to the provisions of **Subsection 15.4.5**.

Failed tests indicate that the repair was inadequate, and the repair will be redone and retested until a passing result is obtained. The RPR will document that all repairs have been subjected to nondestructive testing and will record the number of each repair, the date, and the test outcome.

Large Wrinkles

When seaming of the geomembrane is completed, the RPR will examine the geomembrane for wrinkles. Wrinkles that are higher than they are wide should be smoothed, cut, and seamed by the Installer. The wrinkle repair will be done in accordance with the equipment and procedures described in **Subsections 15.4.2** and **15.4.3** (General Seaming Procedures), respectively, and it will be nondestructively tested using the vacuum box test method described in **Subsection 15.4.4**.

15.4 FIELD SEAMING

This section covers the quality assurance procedures on seams used to join the rolls of geomembrane into a continuous layer. The installation of each of the geomembranes at the landfill will include 100 percent nondestructive testing of all field seams for joining adjacent rolls of geomembranes to document that no openings or gaps exist between geomembrane sheets. In addition, destructive testing will be performed at a routine interval for determining the strength and mode of failure of field seams in both the shear and peel modes.

The allowable field seam methods, equipment, personnel qualifications, and destructive and nondestructive testing methods are described in this section.

15.4.1 Panel/Seam Layout

No horizontal seams will be allowed on slopes greater than 5 horizontal to 1 vertical. In corners and at other odd-shaped geometric intersections, the number of horizontal seams will be minimized. A seam numbering system comparable and compatible with the geomembrane roll numbering system will be agreed upon at the preconstruction meeting (Subsection 3.3).

15.4.2 Seaming Equipment

The approved process for production field seaming (roll to roll) are the dual hot wedge (fusion-type) seam method and the extrusion fillet welding process. The extrusion fillet weld process will be used for specialty seams and repair seams (nonproduction). No other processes can be used without prior written authorization from the CQA Officer and the RPR. Only equipment that has been specifically approved by make and model will be used. Dual track welding should be used on panel to panel seams whenever possible.

Dual Hot Wedge Process

The Installer will meet the following requirements regarding the use, availability, and cleaning of the equipment to be used at the job site:

- An automated self-propelled type of apparatus will be used.
- The welding apparatus will be equipped to continuously monitor applicable temperatures.
- One spare operable seaming device will be maintained on site at all times.
- Equipment used for seaming will not damage the geomembrane.
- The geomembrane will be protected in areas of heavy traffic to prevent damage discussed in Subsection 15.3.3.
- For cross seams, the edge of the cross seam will be ground to a smooth incline (top and bottom) prior to welding.
- For cross seams, the intersecting dual hot wedge seam will be patched using the extrusion fillet process described below.

- The electric generator for the equipment will be placed on a smooth base in such a way that no damage occurs to the geomembrane. Similarly, a smooth insulating plate or fabric will be placed beneath the hot equipment after use.

The Installer will keep records for each seamer performing dual hot wedge seaming, including welding machine I.D. number, ambient temperature, and machine operating temperatures. These data will be recorded at intervals as agreed upon at the preconstruction meeting.

Extrusion Fillet Process

The Installer will meet the following requirements regarding the use, availability, and cleaning of the extrusion welding equipment to be used at the job site:

- The welding equipment will be equipped to continuously monitor temperature at the nozzle.
- One spare seaming device will be maintained on site at all times.
- Equipment used for seaming will not damage the geomembrane.
- The geomembrane will be protected in areas of heavy traffic to prevent damage.
- The extruder will be cleaned and purged prior to beginning seaming, and at any time seaming operations are stopped, until all heat-degraded extrudate has been removed from the barrel. Purged extrudate will not be placed on the geomembrane.
- The electric generator for the equipment will be placed on a smooth base in such a way that no damage occurs to the geomembrane. Similarly, a smooth insulating plate or fabric will be placed beneath the hot equipment after use.
- Grinding geomembrane surfaces for welding preparation will not be performed more than one hour prior to seaming.

The Installer and, if applicable, the Geomembrane Manufacturer will provide documentation to the CQA Officer regarding the quality of the extrudate used in the welding apparatus. At a minimum, the extrudate will be compatible with the base material and will contain the same grade and quality of polyethylene resins as used in the base material.

The Installer will keep records for each seamer performing extrusion weld seaming, including welding machine I.D. number, extrudate, and ambient temperature. These data will be recorded at intervals as agreed upon at the preconstruction meeting.

15.4.3 Initial Requirements

Personnel Qualifications

All personnel performing seaming operations will be qualified by experience and successfully passing seaming tests for the type of seaming equipment to be used. At least one seamer will have experience in seaming a minimum one million square feet of polyethylene geomembrane using the same type of seaming apparatus used at the ash disposal facility. The most experienced seamer, the "master seamer," will have direct supervisory responsibility at the job site.

The Installer will provide a list of proposed seaming personnel and their experience records to the CQA Officer and the RPR for their review and approval.

Weather Conditions

The weather conditions under which geomembrane seaming can be performed are as follows:

- Unless otherwise authorized in writing by the CQA Officer, no seaming will be attempted or performed at an ambient temperature below 32°F (0°C) or above 104°F (40°C).

- Geomembrane will be dry and protected from wind.

- Seaming will not be performed in areas where ponded water has collected below the surface of the geomembrane.

If the Installer wishes to use methods that may allow seaming at ambient temperatures below 32°F or above 104°F, the Installer will demonstrate and certify that the methods and techniques used to perform the seaming produce seams that are entirely equivalent to seams produced at temperatures above 50°F and below 104°F, and that the overall quality of the geomembrane will not be adversely affected.

The RPR will document the following:

- Ambient temperature at which seaming is performed.
- Any precipitation events that occurred at the site, including the time of such occurrences, the intensity, and the amount of the event.

The RPR will inform the CQA Officer if any of the weather conditions are not being fulfilled. The CQA Officer will stop or postpone the geomembrane seaming when weather conditions are unacceptable.

Overlapping and Temporary Bond

The Installer will be responsible for ensuring that the following requirements are met:

- Panels of geomembrane will have a finished overlap of a minimum of 3 inches for extrusion welding and 4 inches for fusion welding; but in any event, sufficient overlap will be provided to allow peel tests to be performed on the seam.

- No solvents or adhesives will be used on the geomembrane unless the CQA Officer has approved the product in writing. Approval can only be obtained by submitting samples and data sheets to the CQA Officer for evaluation.

- Procedures used to temporarily bond adjacent geomembrane panels must not damage the geomembrane; in particular, the temperature of the hot air at the nozzle of any spot-welding apparatus will be controlled such that the geomembrane is protected at all times against potential damage.

Trial Seams

Trial seams will be made on fragments of geomembrane to document that seaming conditions are adequate. For each seaming apparatus used and for each seamer, such trial seams will be made at the beginning of each seaming period, following work interruptions, following changes to machine settings for temperature or speed, at changes in weather, and at least once for every five hours of seaming activities. Trial seams are to be run using the materials the seaming will be used for (i.e., smooth to smooth, smooth to textured, textured to textured). At a minimum, one trial seam per welding machine will be made at the start of each day by each seaming technician performing welding that day. Also, each seamer will make at least two trial seams each full day of welding.

The trial seams will be examined by the Installer and RPR for squeeze-out, foot pressure applied by the seaming equipment, and general appearance. If the seam fails any of these examinations, it will be repeated. If the second trial seam fails these examinations, the welding apparatus and seamer are not allowed to seam until the Installer can demonstrate the cause of the failure. Once the Installer has made the necessary corrections to the welding equipment, the seamer and apparatus are required to pass two trial seams prior to beginning seaming. The RPR will document the reason for the failure and all subsequent trial seams.

The trial seam samples will be at least 3 feet long by 1 foot wide after seaming, with the seam centered lengthwise. Seam overlap will be as indicated above under Overlapping and Temporary Bond.

Three adjoining specimens, each 1-inch wide, will be cut from each end of the trial seam sample by the Installer. The specimens will be tested by the Installer in shear and peel, respectively, using a field tensiometer. If a specimen fails, then the entire test will be repeated using two additional specimens cut from each end of the trial seam sample. If the second set of specimens also fails, then the seaming apparatus and seamer will not be accepted and will not be used for seaming until the deficiencies are corrected and two successful trial seams are achieved.

The remainder of the trial seam sample will be identified and marked by the RPR as follows:

- The sample will be assigned a number and marked as to welding apparatus used and the seamers name.
- The date, time, applicable welding equipment operating temperatures, and ambient temperature at the time of seaming will be noted.
- Whether the sample passes or fails will be recorded.

The RPR will observe trial seam procedures and record on field log forms. The RPR will retain the trial weld sample as an archive sample.

Seam Preparation

The Installer will ensure that the following conditions for each of the geomembrane installations covered by this plan are met:

- Prior to seaming, the seam area is clean and free of moisture, dust, dirt, debris of any kind, and foreign material.
- If seam overlap grinding is required, then the grinding process will be completed according to the Geomembrane Manufacturer's instructions within one hour of the seaming operation, and in a way that will not damage the geomembrane or cause excessive striation of the geomembrane surface.

- Seams will be aligned so as to minimize the number of wrinkles and fishmouths.

General Seaming Procedures

Unless otherwise specified, the general seaming procedures to be used by the Installer for each of the geomembrane installations covered by this plan, and observed by the RPR, will be as follows:

- A firm subbase will be provided to achieve proper support for seaming.
- Fishmouths or wrinkles at the seam overlaps will be cut along the ridge of the wrinkle in order to achieve a flat overlap. The cut fishmouths or wrinkles will be seamed, and any portion where the overlap is inadequate will then be patched with the same geomembrane (including thickness) extending a minimum of 6 inches beyond the cut in all directions.
- If seaming operations are to be conducted at night, adequate illumination will be provided.

15.4.4 Nondestructive Testing

Each field seam will be nondestructively tested over its full length using one of the methods described in this section. The purpose of nondestructive testing is to determine the continuity of the seams.

Nondestructive testing, at this stage of development, does not provide any information on the strength of seams. Seam strengths will be determined by destructive testing methods that are described in **Subsection 15.4.5**. Failure of any of the nondestructive or destructive tests will require the repair of the failed section according to the procedures contained in **Subsection 15.3.4**.

Nondestructive testing as described in this section will be performed on seams for every geomembrane installation covered by this plan. The recommended test methods for conducting the nondestructive seam testing are the air pressure test for dual hot wedge seams, the vacuum box test for extrusion fillet welds, and leak location testing. These three nondestructive testing methods are described below.

The RPR will perform the following documentation tasks:

- Observe nondestructive seam testing and examine seams for squeeze-out, foot pressure, and general appearance. Failure of these criteria will be considered as failure of the seam and repair or reconstruction will be required.
- Document location, date, test unit number, name of tester, and outcome of all testing.
- Inform the Installer and CQA Officer of any required repairs.
- Document that appropriate repairs are made and that the repairs are retested nondestructively with passing results.

Air Pressure Testing

The following test procedures are applicable only to dual hot wedge seams. The equipment for performing the test should meet the following minimum requirements:

- An air compressor or hand pump equipped with a pressure gauge and regulator capable of producing and sustaining a pressure between 25 to 30 pounds per square inch gauge (psig) and mounted on a cushion to protect the geomembrane surface.
- Fittings, rubber hose, valves, etc., to operate the equipment, and a sharp hollow needle or other approved pressure feed device.

Air pressure testing will be performed according to the following procedure (ASTM D5820 and GRI GM 6):

1. Seal both ends of the seam to be tested.
2. Insert needle or other approved pressure feed device into the air space at one end of the dual hot wedge seam.
3. Energize the air compressor or hand pump to the pressure indicated in **Table 15-3**, based on the material type and thickness. Maintain the indicated pressure during a two-minute stabilization period. At the end of the stabilization period, record the time and the pressure in the seam.
4. Remove the flexible hose that connects the pressure gauge to the air pump. Observe the pressure gauge for the evaluation period indicated in **Table 15-3**. Record the time and pressure in the seam at the end of the test period.
5. If the pressure difference between the two recorded readings exceeds the maximum allowable pressure drop indicated in **Table 15-3**, or if the pressure does not stabilize within the evaluation period, one more pressure-monitoring interval is allowed.
6. If the pressure loss over both evaluation intervals exceeds the allowable pressure drop, or if the pressure does not stabilize, then the seam fails the test.
7. If the pressure loss over either evaluation interval does not exceed the allowable pressure drop, then the seam may be deemed by the Installer to have passed the test.
8. The Installer must verify that the air channel tested was not obstructed by noting a release of air pressure at the end of the tested seam interval opposite the pressure gauge. If this does not happen, the air channel is blocked and the Installer must take the appropriate steps to ensure that the entire seam passes a non-destructive test.

For any seam interval that fails the air pressure nondestructive test, additional nondestructive testing or visual inspection will be used to identify, if possible, the faulty area of the seam. The faulty area will be repaired and retested. If the faulty area cannot be identified, then the entire seam will be repaired and retested.

Vacuum Box Test

Vacuum box testing (ASTM D5641) is to be used on those seams made by the extrusion fillet process, to locate precisely the defects identified from air pressure testing, or to evaluate suspect seam and non-seam areas as discussed in Subsection 15.3.4.

Vacuum box testing equipment must meet the following minimum standards:

- A five-sided vacuum box with an open bottom, a clear viewing panel on top and a pliable gasket attached to the bottom.
- A vacuum pump and gauge capable of achieving a minimum vacuum of 2 pounds psig [4 inches of mercury (Hg)] and a maximum vacuum of 5 psig.

The following procedure will be used in performing the vacuum box test:

1. Clean the seams to be tested so that they are relatively free from soil or foreign objects that might prohibit a good seal from being formed between the vacuum chamber and the geomembrane.
2. Energize the vacuum pump to a minimum of 4 inches Hg of vacuum (or approximately 2 psig).
3. Wet a strip of geomembrane approximately twice the size of the vacuum box with the soapy solution.
4. Place and center the vacuum box with the gasket in contact with the geomembrane surface over the wetted area of the seam.
5. Applying a normal force to the top of the vacuum box, close the bleed valve and open the vacuum valve. Check to make certain that a tight seal is created between the geomembrane and the vacuum box.
6. With the vacuum drawn, use the viewing panel to examine the geomembrane seam for bubbles resulting from the flow of air through the seam.
7. Remove the vacuum box by first closing the vacuum valve and then opening the bleed valve. Proceed to Step 8 if bubbles appear in Step 6. If no bubbles appear in Step 6, then proceed directly to Step 9.
8. If bubbles appear through the geomembrane, mark the defective area for repair according to the provisions of Subsection 15.3.4. All repairs will be tested until nondestructive results are passing.
9. Move the vacuum box along the seam to be tested, overlapping the previously tested area by no less than 3 inches.

15.4.5 Destructive Seam Testing

Destructive seam testing will be performed on the geomembrane seams covered by this plan. Destructive seam testing is performed to determine the strength of the seam in both shear and peel failure modes. Destructive seam testing will be performed within 24 hours of sampling either in an on-site laboratory by personnel under the direction of the CQA Officer or within 24 hours after it is received at the geosynthetics testing laboratory.

Location and Sampling Frequency

The RPR will select locations where seam samples will be cut out for the destructive testing. Test locations will be determined during seaming at the RPR's discretion. Suspicion of excess crystallinity, contamination, offset welds, or any other potential causes of an imperfect seam may prompt selection of such locations. The Installer will not be informed in advance of any location where seam samples will be taken.

The minimum frequency of sample collection will be one test location per every 500 linear feet of seam length per welding apparatus, or every 1,000 linear feet if leak location testing is completed. This minimum frequency will be taken as an average for the entire installation area.

Sampling Procedure

Samples will be cut under the direction of the RPR as the seaming progresses. For each sample location, the following information will be documented:

- Assigned sample number.
- Sample location on layout drawing.
- The reason for collecting the sample (e.g., as part of statistical testing program, suspicious seam, etc.). Record this by the sample number.
- For the peel test, which geomembrane is the top and which is the bottom with respect to seams performed using dual hot wedge (fusion) weld techniques.

Specimens for qualitative field testing will be taken and tested prior to shipping of the laboratory sample. Samples for field tensiometer testing shall be 1 inch wide by 12 inches long with the seam centered parallel to the width. The distance between the two samples will be 42 inches measured from inside edge to inside edge. If both samples pass the field tensiometer test described below under **Field Test Methods**, then the sample for laboratory testing will be taken according to the procedure described below.

The sample for laboratory testing will be located between the two samples used for field-testing. Therefore, the laboratory sample will be 12 inches wide by 42 inches long with the seam centered lengthwise. The sample will be cut by the Installer into three parts and distributed as follows:

- A sample, 12 inches by 12 inches, will be kept by the Installer for testing, if so desired.
- A sample, 12 inches by 12 inches, will be given to the Company for record storage.
- A sample, 12 inches by 18 inches, will be transmitted to the Geosynthetics Testing Laboratory by the RPR.

The Installer, in accordance with the repair procedures described in **Subsection 15.3.4**, will immediately repair all holes cut into the geomembrane resulting from destructive seam sampling. The repaired area will be nondestructively tested in accordance with the requirements of **Subsection 15.4.4.**

End-of-Seam Sampling

In addition to the 42-inch sample cut for laboratory testing, an additional sample will be cut from each end of each continuous production field seam 100 lineal feet in length or longer for field-testing as described below. These samples, often referred to as bones, need to be only 1 inch wide and can be cut from the portion of the seam that extends into/past the anchor trench so as not to require an additional repair.

Field Test Methods

The three 1-inch-wide samples described above under Sampling Procedure, as well as the end-of-seam samples described above under End-of-Seam Sampling, will be field-tested for peel and two samples tested for shear. Testing will be performed using a field tensiometer or equivalent device to qualitatively determine the mode of failure. The tensile testing machine will be equipped with electrically controlled and smoothly moving jaw separation apparatus, will be capable of adjustments and defined settings for jaw separation rate, and will display jaw separation rates and tensile loadings exerted on the geomembrane samples. Tensile testing machines will be accompanied by documentation for calibration conducted within three months of the start of geomembrane installation. Geomembrane samples will be prepared for field analyses by use of templates and cutting tools that prepare uniformly sized samples.

The seam will be considered passing if the failure in both peel and shear does not occur within the seam. If the samples fail the field tensiometer test, then the repair procedures of **Subsection 15.3.4** for the holes left by the cutout samples, and the seam reconstruction procedures for the repair of the defective seam, discussed later in this subsection, will be implemented.

Laboratory Test Methods

Laboratory testing of the destructive seam samples will be performed by the Geosynthetics Testing Laboratory under the direction of the CQA Officer. All destructive seam tests, whether performed on a trial seam sample (as described above) or on samples cut out from productions seams, will be performed in general accordance with the methodology of ASTM D6392, which stipulates that at least five specimens will be tested in shear and five in peel. Samples will be cut in alternating order (e.g., shear & peel, peel & shear) and will also be tested in the order of cutting, to determine if any trend in seam quality along the length of the sample exists. All specimens will be cut as 1-inch-wide strips to ensure that the seam does not exceed the test gauge length of the specimen.

The following tests will be performed on each seam sample submitted for laboratory testing:

- **Shear and peel maximum tension** is the maximum load per unit width of a 1-inch-wide specimen expressed in pounds per inch of width in both the shear and peel mode, according to ASTM D6392 and GRI GM19a.

- **Shear elongation at break** is the extension at break expressed as a percentage of the initial distance between the edge of the fused track and the nearer grip. This distance should be the same on both sides of the seam and is usually 2 inches. No referenced ASTM test exists for this procedure as defined; however, the specimen will be elongated to a maximum of 100 percent with any failures of individual specimens noted. For specimens that fail below 100 percent elongation, the value at which failure occurred will be noted on the results.

- **Peel seam separation** estimates the area of seam interface separation expressed as a percentage of the original area.

Also, for both the seam shear and peel tension test, an indication will be given for each specimen tested that defines the locus of the failure. The loci will be defined in accordance with GRI GM19.

For shear tests, the following values will be reported for each specimen tested:

- Maximum tension in pounds per inch.
- Elongation at break indicating at what percentage the specimen failed (up to a tested maximum of 100).
- The locus of failure using the above designations.

For peel test, the following values will be reported for each specimen tested:

- Maximum tension in pounds per inch.
- Seam separation expressed as percent of original seam area.
- Locus of failure.

For each set of five specimens, the mean and standard deviation will be calculated and reported for the shear maximum tension and peel maximum tension.

Role of Testing Laboratory

The Geosynthetics Testing Laboratory will be responsible for performing the tests on samples submitted to them as described above. The results of tests performed will be reported to the CQA Officer and the RPR. Retesting of seams, because of failure to meet any or all of the specifications listed below, can only be authorized by the CQA Officer.

The Geomembrane Manufacturer and/or the Installer may perform their own quality control testing in accordance with the methods and procedures defined above under Laboratory Test Methods; however, the results, if substantially different from those obtained by the Geosynthetics Testing Laboratory or on-site laboratory, may only be used to request a retesting by the Geosynthetics Testing Laboratory or on-site testing laboratory. All quality assurance test results from the Geosynthetics Testing Laboratory or on-site laboratory govern over any test results from the Geomembrane Manufacturer or Installer. Only the CQA Officer or Company is authorized to approve a retesting request.

Procedures for Determining Destructive Seam Test Failures

The procedures described in this section apply to the destructive testing procedures defined above under Field Test Methods and Laboratory Test Methods. Procedures for repairing failed seams are given in **Subsection 15.3.4** of this plan.

The results from the shear and peel tests for the HDPE and LLDPE geomembrane will be evaluated against the criteria presented in **Table 15-4**.

All of the tabular criteria for each respective geomembrane type must be met for a given seam to be considered acceptable.

The installer has the following two options in determining the repair boundary whenever a seam has failed either the field tensiometer testing or laboratory destructive testing:

- The seam can be reconstructed between any two previously tested and passed destructive seam test locations.
- The Installer can trace the welding path to an intermediate location (at a 10-foot minimum from the point of the failed test in each direction) and request that the field tensiometer tests be performed at these intermediate locations. If the field tensiometer sample results are acceptable, then the seam will be reconstructed between these intermediate locations. If either sample fails, then the process will be repeated until acceptable destructive seam tests have been performed in both directions away from the original failed sample location. All retesting of seams according to this procedure will use the sampling methodology described earlier in this plan under Sampling Procedure.
- The tracing of a failed seam test will continue until the seam boundary is located; tracking will continue into previous day's work, if needed.

For seams reconstructed due to a failing destructive seam sample that are in excess of 50 feet long, an additional sample taken from the reconstructed zone must pass destructive seam testing.

The RPR will be responsible for documenting all actions, including test results submitted by the Geosynthetics Testing Laboratory, taken in conjunction with seam testing. The RPR will also be responsible for keeping the CQA Officer informed on seam testing results and seaming process.

15.5 POST-INSTALLATION

Each component covered by this plan will be examined by the RPR. Any defects, whether due to failed seams, pinholes, or other penetrations, will be repaired.

Placement of the sand drainage layer material or final cover geocomposite drainage layer will proceed as soon as practical following the RPR's testing and acceptance of completed geomembrane areas. The drainage material will provide ultraviolet protection, thermal installation, and protection from physical damage.

Low ground pressure tracked equipment (less than 5 psi) will be used to place the sand drainage layer material over the geomembrane, or to place final cover rooting zone material over the geocomposite and geomembrane. A minimum of 1 foot of cover material is required between the geomembrane and the low ground pressure equipment. A minimum of 2 feet of cover soil is required between the geomembrane and all other tracked or flotation wheeled equipment. A minimum of 3 feet of cover soil is required between the geomembrane and all rubber-tired vehicles. To prevent movement of the geomembrane and folding of wrinkles, placement of the drainage material shall be performed during cooler temperatures to the extent possible using methods of placement, which minimize wrinkling. Any noncompliance with the above requirements will be reported by the RPR to the CQA Officer.

15.6 ELECTRICAL RESISTIVITY LEAK DETECTION SURVEY

Upon completion of construction of the leachate collection system for each phase of development, an electrical resistivity leak detection survey will be performed over the entire surface of the lined area in accordance with ASTM D7007 or an equivalent method approved by the CQA Officer and Company.

15.6.1 Electrical Resistivity Contractor Requirements

The electrical resistivity testing contractor shall have a minimum of five years of experience in performing electrical leak location surveys including surveying at least one million square feet of geomembrane using this method on at least five different projects, unless otherwise approved by the Company.

15.6.2 Test Procedure

The leak location contractor shall demonstrate in a manner acceptable to the CQA Officer and Company that the leak detection equipment and field procedures are capable of detecting a 0.25-inch-diameter leak using an actual or artificial leak. The leak detection capability must be demonstrated when the leak is midway between four measurement grid points; detecting the leak when the measurement is directly over the leak will not be sufficient. The peak-to-peak signal amplitude must be at least three times the peak-to-peak signal obtained under the same conditions with the excitation signal disconnected. The leak location survey must be conducted such that the leak detection measurements are no further apart than the spacing used to demonstrate the leak detection capability.

The Contractor will prepare the lined area for the leak location survey, including performing the following tasks:

- Insulating the edges of the geomembrane by leaving a width of dry exposed geomembrane around the perimeter of the geomembrane. This can be accomplished by only partially backfilling the anchor trench, leaving a strip uncovered around the perimeter, or extending the geomembrane outside the anchor trench and leaving its edge exposed.

- Isolating any other electrical paths, if present, that connect the drainage layer on the geomembrane to earth ground.

- Removing any standing water on the surface of the drainage layer covering the primary liner. The survey cannot be done if the ground is frozen or if there is ice or snow on top of the gravel.

- If necessary, wetting the area to be surveyed with water (via water truck, hoses, or other method approved by the CQA Officer) in order to maintain good electrical contact with the drainage layer material during the survey.

If any leaks are indicated by the leak location survey, the Contractor shall excavate the drainage layer around the area of the leak, open the geotextile, and electrically isolate the leak from the surrounding drainage material. The leak location contractor will then record measurements in the area around the excavation to determine if additional leaks are in the area. The Geomembrane Installer shall repair the leak, vacuum box test the repair, and repair the geotextile. The Contractor will then backfill the area around the repaired leak. Resistivity testing shall be completed over required areas to confirm additional leaks in the area are not present/marked by original detected defect.

The CQA Officer will observe the electrical resistivity testing.

15.6.3 Reports

Upon completion of each leak survey, the electrical resistivity contractor shall submit a report to the CQA Officer and the Company documenting the results of the leak location survey. The report shall document the methodology used, the locations and descriptions of the leaks, and a diagram of the facility showing the approximate leak locations.

Table 15-1. Geomembrane Tests and Test Methods

Property	Test Method	Minimum Manufacturer's Testing Frequency (1)	Minimum Conformance Testing Frequency (2)
Asperity height	ASTM D7466	Every 2nd roll(3)	Not required
Carbon black content	ASTM D4218(4)	1/20,000 lb	Not required
Carbon black dispersion	ASTM D5596	1/45,000 lb	Not required
Melt flow index	ASTM D1238	1/batch	1/100,000 sf(5)
Density	ASTM D1505/D792	1/200,000 lb	1/100,000 sf(5)
Tear resistance	ASTM D1004	1/45,000 lb	Not required
Puncture resistance	ASTM D4833	1/45,000 lb	Not required
Tensile properties(6) Break stress Break elongation Yield stress (HDPE) Yield elongation (HDPE)	ASTM D6693 Type IV specimen	1/20,000 lb	1/100,000 sf(7)
Single point notched constant load (SPNCL)(8,9)	ASTM D5397	1 per every 2 resin lots	(11)
Oxidative induction time (OIT) – percent retained after 90 days(10)	ASTM D8117	1/formulation	Not required
Thickness	ASTM D5994 (textured)	10 times/roll	5 places/roll

Notes:
1. Manufacturer to perform quality control testing at the specified frequencies (minimum) on the geomembrane rolls supplied to the project.
2. CQA Officer to coordinate conformance testing at the specified frequencies (minimum) on the geomembrane rolls supplied to the project.
3. Alternate the measurement side for double-sided textured sheet.
4. Other methods such as D1603 (tube furnace) or D6370 (TGA) are acceptable if an appropriate correlation to D4218 (muffle furnace) can be established.
5. In addition to the minimum frequency noted, a minimum of one test for each batch of resin used to manufacture the rolls delivered on site must be performed, unless documentation is provided which shows the manufacturer performed testing at the same frequencies.
6. MD and cross machine direction (XMD) average values should be on the basis of five test specimens each direction.
   Yield elongation is calculated using a gauge length of 1.3 inches.
   Break elongation is calculated using a gauge length of 2.0 inches.
7. In addition to the minimum frequency noted, a minimum of one test for each batch of resin used to manufacture the rolls delivered on site must be performed.
8. For evaluation of stress crack resistance.
9. Not tested on LLDPE products per GRI GM17.
10. Evaluate samples at 30 and 60 days to compare with 90-day response.
11. A minimum of one test for each batch of HDPE resin used to manufacture rolls delivered on site unless documentation is provided that shows manufacturer performed testing at the same frequency.

Table 15-2. HDPE / LLDPE Textured Geomembrane Acceptance Criteria

Property	Units	Type of Criterion	60-mil HDPE Acceptable Value(1)	40-mil LLDPE Acceptable Value(1)
Asperity height	Mils	Minimum average	16	16
Carbon black content	%	Range	2.0-3.0	2.0-3.0
Carbon black dispersion	N/A	Range	Note 2	Note 2
Melt flow index	g/10 min	Maximum	1.0	1.0
Density	g/ml	Maximum (LLDPE)/Minimum average (HDPE)	0.940	0.939
Tear resistance	Lb	Minimum average	42	22
Puncture resistance	Lb	Minimum average	90	44
Tensile Properties (3)				
Break stress	lb/in	Minimum average	90	60
Break elongation	%	Minimum average	100	250
Yield stress	lb/in	Minimum average	126	Not applicable
Yield elongation	%	Minimum average	12	Not applicable
Thickness	Mil	Minimum average	57(4)	38(5)

Notes:
1. Values for HDPE are primarily from Table 2(a) of GRI GM13 standards. Values for LLDPE are primarily from Table 2(a) of GRI GM17 standards.
2. Carbon black dispersion (only near spherical agglomerates) for ten different views: nine views in Category 1 or 2, and no more than one view in Category 3.
3. MD and XMD average values to be on basis of five test specimens each direction. Break elongation is calculated using gauge length of 2.0 inches. Yield elongation is calculated using a gauge length of 1.3 inches.
4. Lowest allowable individual for eight out of ten values is 54 mil. Lowest allowable individual of ten values is 51 mil.
5. Lowest allowable individual for eight out of ten values is 36 mil. Lowest allowable individual of ten values is 34 mil.
6. Refer to **Section 3.2** for direct shear test requirements.

Table 15-3. Geomembrane Air Pressure Testing Standards and Acceptance Values (1)

Geomembrane Type and Thickness(2)	Air Inflation Schedule		Evaluation Time (Minutes)(3)	Maximum Allowable Pressure Drop (psi)
	Minimum Pressure (psi)	Maximum Pressure (psi)		
40-mil LLDPE	20	30	2	4.0
60-mil HDPE	27	30	5	3.0

Notes:
1. All values are based on GRI Test Method GM6, revised 1994.
2. All values apply to both smooth and textured geomembrane for the type and thickness indicated.
3. Evaluation time starts after the initial 2-minute stabilization period.

Table 15-4. Geomembrane Seam Tests, Test Methods, and Acceptance Criteria

Property	Test Method	Units	Type of Criterion	60-mil HDPE Acceptance Values[1]	40-mil LLDPE Acceptance Values[1]
Shear strength[2]	ASTM D6392	ppi	Minimum	120	60
Shear elongation[3]	GRI GM19a	%	Minimum	50	50
Peel strength[2] Fusion	ASTM D6392	ppi	Minimum	91	50
Peel strength[2] Extrusion	ASTM D6392	ppi	Minimum	78	44
Peel separation	GRI GM19a	%	Maximum	25	25

Notes:

1. Values are based on GRI standard specification GM19a. For double fusion welded seams, both tracks shall be tested for compliance with values listed. The following are unacceptable locus-of-break codes:

   Fusion: AD and AD-BRK greater than 25 percent.

   Extrusion: AD1, AD2, and AD-WLD.

   Separation in plane (SIP) is acceptable if strength, shear elongation, and peel separation criteria are met.
2. Five out of five test specimens must pass the locus-of-break, shear elongation, and peel separation.
3. Five out of the five test specimens must meet these requirements.
4. Omit elongation measurements for field testing.

16.0 PIPING

16.1 GENERAL

This section includes quality assurance requirements for piping used throughout the facility. Piping will be used in the Dry Ash Disposal Facility in the construction of the following items:

- Leachate head well
- Leachate collection piping
- Leachate collection sump side slope riser
- Leachate force mains

This section is divided into three major subheadings, which cover the quality assurance requirements for pre-installation (includes piping manufacturers and fabricators), installation, and post-installation (includes the final observation and documentation of piping installations prior to installation of other materials over and around the pipe). The terms pre-installation, installation, and post-installation are applicable only to the piping installation and do not apply to the overall construction of the landfill facility.

Individual pipe sizes and SDRs to be used for each individual pipe installation are not detailed in this section; the construction plans and specifications will be used for the determination of correct size and wall thickness.

16.2 PRE-INSTALLATION

16.2.1 Manufacturing

16.2.1.1 High Density Polyethylene

HDPE pipe must be made from extra high molecular weight (EHMW) polyethylene (PE) resin, and must also have a cell classification of 445574C (PE 4710) as defined by ASTM D3350.

16.2.1.2 Polyvinyl Chloride

All polyvinyl chloride (PVC) pipe fittings must be PVC molded fittings. Extruded fittings may not be used unless specifically approved in writing by the CQA Officer.

16.2.1.3 Pipe Fabrication

The Piping Fabricator will be responsible for perforating the pipe delivered by the Piping Manufacturer according to the plans and specifications.

16.2.1.4 Delivery, Handling, and Storage

Pipe will be protected during shipment from excessive heat or cold, puncture, or other damaging or deleterious conditions. The pipe will be stored on site in a manner suitable to protect it from long-term ultraviolet exposure prior to actual installation.

The RPR will be responsible throughout the pre-construction, construction, and post-construction periods for observing and documenting that the Contractor provides adequate handling equipment for moving pipe and that the equipment and handling methods used do not pose any risk of damage.

The RPR will maintain a log of pipe deliveries throughout the installation. The pipe size and type at a minimum will be recorded on the log for each shipment received at the job site.

16.3 INSTALLATION

16.3.1 Connections

16.3.1.1 HDPE Pipe

Unless approved otherwise by the CQA Officer, HDPE pipe connections will be made by the butt fusion procedure. The following procedure will be used regarding butt fusion seams:

- Seams will be made at the Manufacturer’s recommended temperature for fusing pipe and fittings.
- For pipe diameter sizes 4 inches (nominal) and larger, seams will be made using the hydraulic fusion machines. For pipe diameters of less than 4 inches, manual fusion equipment can be used.

- Care will be taken to make certain that adequate pressures are used for fusing pipes and that sufficient cooling periods are allowed prior to testing, bending, or backfilling of pipe sections.

Joints for corrugated pipe must be made with snap couplings.

16.3.1.2 PVC Pipe

Unless approved otherwise by the CQA Officer, all PVC pipe connections will be made according to the Standard Practice for Making Solvent-Cemented Joints with PVC pipe and fittings, ASTM D2855. Particular care will be taken regarding required set and cure times for solvent-cemented joints, which vary for ambient temperature conditions. Joints will not be subjected to stresses by moving or backfilling prior to the specified set times, ASTM D2855. Only original quality solvent cement may be used since expired shelf life and deteriorated cements may cause inadequate connections. The solvent cement shall comply with the requirements of ASTM D2564 and shall be applied in strict accordance with manufacturer's specifications.

16.3.1.3 Placement

Pipe placement will be done in accordance with the following procedure and requirements:

- Piping will be bedded and backfilled according to the plans and specifications.

- Piping placement will not be performed in the presence of excessive moisture. The RPR will document that this condition is fulfilled. Additionally, the RPR will document that the supporting backfill has not been damaged by weather conditions. The RPR will inform the CQA Officer if any of the above conditions are not fulfilled for evaluation of the necessity of corrective action.

- The prepared surface underlying the piping will not show evidence of deterioration since previous acceptance and must be acceptable prior to piping placement.

- The method used to place the piping will not cause damage to the piping and will not disturb the supporting backfill.

- The pipe bedding material will be shovel-sliced, or compacted to the spring line of the pipe to ensure proper bedding.

- Observations and measurements will be made to ensure that the pipes are of the specified size and dimension ratio, manufactured of the specified material, and that pipe perforations are sized and spaced as specified.

- The RPR will observe and document all pipe installation. Deviations from the plans and specifications will be brought to the attention of the CQA Officer for evaluation and the necessity of corrective action.

- Each piping system will be flushed with water. Jet flushing will be used wherever possible. Hydraulic flushing will be performed for other accessible points. The RPR will observe and document that each flushing operation is carried out and will document that the pipes are free flowing. Any system that does not flush properly will be immediately reported to the CQA Officer, and corrective action will be taken to remedy the problem.

- All piping will be located as noted in the plans and specifications. Locations, grades, and size requirements are specified on the details of the plan set. Observations and surveying measurements will be made to ensure that the pipes are placed at the specified locations and grades. Deviations from the plans and specifications will be brought to the attention of the CQA Officer for evaluation of the necessity of corrective action.

- Non-perforated pipe will be pressure tested. Pipes shall be pressure tested at 5 psi for 60 minutes. A system pressure of 4.5 or greater after 60 minutes will be considered passing. The RPR will observe and document that this operation is carried out and that the pipes are airtight.

- A video camera inspection will be conducted on all leachate collection pipes after the pipe cleaning. The video camera inspection shall extend a minimum of 300 feet into the base grade of each collection line. The RPR will observe and document the video inspection. Any obstructions, damage, or other concerns will be immediately reported to the CQA Officer for evaluation and the necessity for corrective action.

16.3.2 Damage

The RPR will examine each pipe after placement for damage. The RPR will advise the CQA Officer as to which pipes will be rejected, repaired, or accepted. Damaged pipes or portions of pipes that have been rejected will be marked and removed from the installation area and documented by the RPR.

16.4 POST-INSTALLATION

Pipe invert elevation will be documented every 25 linear feet by survey or every 50 feet if a total station or laser equipment is used, as well as at key points, including changes in grade, intersections, and end points. The minimum allowable tolerance for grade is 0.10 foot at each location. The minimum average slope shall be in accordance with the design drawings.

17.0 RAIN COVER

17.1 GENERAL

This section of the CQA Plan applies to the rain cover used to divert clean storm water away from the leachate collection system in the Dry Ash Disposal Facility during CCR placement prior to completion of the final cover.

17.2 PRE-INSTALLATION

17.2.1 Manufacturing

The rain cover will be supplied to the site in fabricated panels. Prior to delivery of any rain cover panels, the Rain Cover Manufacturer will provide certification, based on tests performed in accordance with the methods listed in **Table 17-1**, that the rain cover supplied under this plan will meet the material specifications listed in **Table 17-1**.

17.2.1.1 Delivery, Handling, and Storage

Rain cover panels will be packaged in UV protected wrap marked with the manufacturer's name and the product identification. Panels will be off-loaded using a forklift or similar equipment and stored on pallets. Care will be taken while unloading or transferring panels to prevent damage to the wrapping or the rain cover panel itself. The Installer/Contractor is responsible for ensuring that each rain cover panel meets the specifications, and is responsible for the means and methods to implement the work. The RPR will maintain a log of rain cover panel deliveries including any observed damage to panels during delivery and unloading.

17.3 INSTALLATION

17.3.1 Placement

The Installer will install all rain cover in such a manner as to ensure that it is not damaged and in a manner that complies with the following requirements:

- Prior to placement, inspect subgrade to confirm it is suitable for rain cover placement.
- Position and deploy rain cover panels in accordance with Manufacturer instructions.
- Avoid deploying rain cover during windy conditions.
- Observe panels for defects or damage. Repair or replace damaged or defective panels as approved by the CQA Officer.
- Only deploy rain cover panels that will be seamed during the day of placement.
- Install ballast while panels are deployed and seamed. Place panels loosely to accommodate expansion and contraction due to changing weather and temperature.
- Secure perimeter of rain cover with ballast or in anchor trenches.
- RPR will observe and document that the above items are performed by the Installer/Contractor.

17.3.2 Seams and Overlaps

The following requirements will be met with regard to seaming and overlapping of rain cover panels:

- Panel seams will be continuously sewn. The sewing method and stitch type will be per Manufacturer's recommendation, but must be approved by the CQA Officer.
- Sewing will be performed with thread meeting the Manufacturer's recommendations.
- Repair defective seams by cutting out the defective seam and re-seaming. Missing stitches in seam areas can be made by sewing a section 24 inches before and after the defect. Single seams that require repair over more than 20 percent of the total seam length will be completely removed and re-sewn.

The RPR will be responsible for observing and documenting that the Installer/Contractor performs the above provisions in an acceptable manner.

17.4 POST-INSTALLATION

17.4.1 Final Examination

The RPR will perform a final rain cover examination after the installation has been completed. The objectives of the final examination are as follows:

- To examine for the presence of holes, tears, or other deterioration.
- To examine for completion of seaming.
- To examine rain cover for excessive tension due to stretching of the material during installation.
- To examine for the presence of foreign objects (e.g., stones, debris) beneath the rain cover.
- To examine that installation of ballast and/or use of anchor trenches appears to meet the Manufacturer's recommendations.

Table 17-1. Rain Cover Acceptance Criteria

Property	Units	Test Method	Value(1)
Grab tensile properties (3) Tensile strength Break elongation	 lb %	ASTM D7004 ASTM D7004	 76 14
Puncture Strength (CBR)	lb	ASTM D6241	220
Thickness (2)	mils	ASTM D751	10
Weight	$lb/1000 ft^2$	ASTM D751	53
Tongue Tear	lb	ASTM D5884	40
Bursting Strength (4)	$lb/in.^2$	ASTM D3786	85
Water Vapor Transmission (WVT) (6)	g/m^2-day	ASTM E96	0.7
Oxidative Induction Time (OIT) (a) Standard OIT (b) High Pressure OIT	 min. min.	 ASTM D3895 ASTM D5885	 (5) 1000
UV Resistance (a) Strength and Elongation retained after 10,000 light hours (b) Response to bending	fluorescent light method	ASTM D7238 ASTM D7003 GRI GM16	 50% no cracking

Notes:

1. All numerical values are based on GRI standard specification GM22 and represent minimum or minimum average values, except WVT, which is a maximum value. Average test results from all rolls in a lot must conform to the tabulated values.
2. The thickness value is measured in the valleys created by the scrim reinforcement, i.e., ply to ply thickness between scrim should be measured.
3. If the reinforcement is aligned in any direction other than the machine and transverse directions, specimen shall be cut such that reinforcing yarns are oriented parallel to the central axis of the tension testing machine.
4. Test should be conducted on an ASTM D3786 Mullen Burst type device with a diaphragm under the product. In addition, the center of the circular test specimen should be equidistant between sets of parallel yarns.
5. Not recommended since the high temperatures of the STD-OIT test produces an unrealistic result for some of the antioxidants used in these materials.
6. Performed at 23° ±0.5°C temperature and 50 percent ±5 percent relative humidity.

18.0 GEOCOMPOSITE

18.1 GENERAL

This section covers the quality assurance requirements for pre-installation, installation, and post installation of geocomposites. The terms pre-installation, installation, and post-installation are applicable only to the geocomposite and do not apply to the overall construction of the final cover systems. Geocomposite will be installed for the drainage layer (geocomposite) within the final cover in areas where geocomposite drainage layer will be installed in place of sand drainage layer.

18.2 PRE-INSTALLATION

18.2.1 Manufacturing

The geotextile portion of the geocomposite will be composed of a nonwoven, needle punched, polyester or polypropylene geotextile. The geocomposite manufacturer will ensure that the geotextile portion of the geocomposite meets the material specifications listed in **Table 18-1**.

The geonet portion of the geocomposite must be fabricated for HDPE resin, and fabricated geonet must be classified as Type III, Class C, and Category 4 or 5, as defined by ASTM D1248. The geonet will be manufactured by extruding two sets of strands to form a three-dimensional structure to provide planar flow. The geocomposite manufacturer will ensure that the geonet portion of the geocomposite meets the material specifications listed in **Table 18-1**. The geocomposite manufacturer will ensure that the geocomposite meets the transmissivity specification listed in **Table 18-1**.

The geocomposite rolls will be tested by the manufacturer and evaluated by the CQA Officer prior to acceptance. The CQA Officer may perform/require additional testing (i.e., conformance testing) as required by detailed specifications or as required in the judgment of the CQA Officer to verify that the geocomposite meets the specifications.

18.2.2 Delivery, Handling, and Storage of Geocomposite Rolls

Each geocomposite roll, for use at the landfill facility, will be marked by the geocomposite manufacturer with the following information (on a durable gummed label, or equivalent, on the side core and on the outside protective wrapping for the roll):

- Name of manufacturer
- Style and type number
- Roll length and width
- Batch (or lot) number, if applicable
- Date manufactured
- Direction of unrolling
- Roll number

The geocomposite manufacturer will use the following guidelines in packing, wrapping, and preparing all geocomposite rolls for shipment:

- When cores are required, those that have a crushing strength sufficient to avoid collapse or other damage while in use will be used.

- Each roll will be covered with a wrapping material that will protect the geotextile from damage due to shipment, water, sunlight, or contaminants.

At a minimum, the following practices will be followed in receiving and storing geocomposite rolls in the covered storage area at the job site:

- While unloading or transferring the geocomposite rolls from one location to another, care will be taken to prevent damage to the geocomposite.

- If practicable, forklift trucks fitted with poles that can be inserted into the cores of the rolls will be used.

- The poles will be at least two-thirds the length of the rolls to avoid breaking the cores and possibly damaging the geocomposite.

- Rolls will not be dragged.

- The geocomposite rolls will be stored in a manner so as to ensure that they are adequately covered to protect the geocomposite from the following:
  Precipitation
  Ultraviolet radiation
  Strong oxidizing chemicals, acids, or bases
  Flames, including welding sparks
  Temperature in excess of 160°F

The RPR will be responsible throughout the pre-installation, installation, and the post-installation periods for observing and documenting that the installer provides adequate handling equipment used for moving geocomposite rolls and that the equipment used does not damage the geocomposite rolls.

The RPR will maintain a log of geocomposite roll deliveries. The following information, at a minimum, will be recorded on the log for each shipment received at the job site:

- Date of delivery at the job site.
- For each geocomposite roll, the following information: roll number and batch (or lot) number, if applicable.

18.3 TESTING REQUIREMENTS

Refer to Table 18-1 for transmissivity conformance testing requirements for the geocomposite drainage layer to be in the final cover. Refer to Table 18-1 for hydraulic conductivity ratio or gradient ratio testing requirements for the upper geotextile of the geocomposite drainage layer. Refer to Section 3 for direct shear testing requirements.

18.4 INSTALLATION

18.4.1 Placement

The installer will install all geocomposite in such a manner so as to ensure that it is not damaged in any way, and in a manner that complies with the following:

- The geocomposite will be securely anchored, as shown on the Drawings and specifications, and then rolled down slope in such a manner so as to continually keep the geocomposite in tension. The geocomposite will be positioned by hand after being unrolled to minimize wrinkles, if needed. Horizontal placement of the geocomposite on sideslopes will not be allowed.
- In the presence of wind, all geocomposite will be secured by suitable means. The temporary weighted material will be left in place until replaced with cover material as shown on the design drawings and specifications.
- Cutting will be done according to manufacturer's recommendations.
- The installer will take necessary precautions to prevent damage to any underlying layers during placement of the geocomposite.
- During placement of geocomposite, care will be taken not to entrap any stones, excessive dust, or moisture that could cause clogging of the drainage system, and/or stones that could damage the adjacent geomembrane.
- The geocomposite will not be welded or tack-welded to the geomembrane.

The RPR will observe and document that the installer performs each of the above steps. Any noncompliance with the above requirements will be recorded and reported by the RPR.

18.4.2 Overlaps and Joining

The following requirements will be used with regard to the overlapping and joining of geocomposite rolls:

General

- The installer will pay particular attention to the overlapped areas to ensure that no earthen or foreign materials could be inadvertently trapped beneath the geocomposite.

Geotextile Portion of Geocomposite

- The geotextile portion of the geocomposite will be overlapped 4 to 6 inches.
- Geotextile seams will be continuously sewn unless heat bonding is approved by the CQA Officer and Owner. The sewing method and stitch type will be per manufacturer's recommendation, but must be approved by the CQA Officer. Overlapping of geotextile without sewing may be acceptable for certain applications with approval from the CQA Officer and Owner.
- Sewing will be performed with thread made from the same base material as the geotextile, or suitable equivalent.

Geonet Portion of Geocomposite

- The geonet portion will be overlapped a minimum of 4 inches.
- Ties will secure geonet overlaps.
- Tying will be performed with pull ties. Ties will be white or brightly colored for easy identification. Metallic devices will not be used under any circumstances.
- Ties will be placed at 5-foot intervals along the length of the panels and at 12-inch intervals at end-to-end connections of panels.

The RPR will observe and document that the installer performs each of the above steps. Any noncompliance with the above requirements will be reported by the RPR to the CQA Officer.

18.4.3 Repairs

Any tears or other defects in the geocomposite will be repaired by placing a patch with minimum overlaps described in **Section 18.4.2**. The patch will be secured to the original geocomposite by tying every 6 inches. If the tear or other defect width is more than 50 percent of the roll width, the damaged area will be cut out and replaced with new geocomposite. Tying will be as indicated in **Section 18.4.2**. These procedures apply to seams and/or patches required for piping penetrations in the final cover.

The RPR will examine and document that the repair of any geocomposite is performed according to the above procedure.

18.5 POST-INSTALLATION

Final Acceptance

The RPR will perform a final geocomposite examination after installation has been completed. The objectives of this step are as follows:

- To examine the geocomposite for the presence of tears or defects.
- To examine overlaps to make certain that they are in conformance with the requirements of **Subsection 18.4.2**.

If any portion of the geocomposite requires repairs due the above examination, they will then be performed according to the procedures in **Subsection 18.4.3**.

If there will be an extended delay between completion of the geocomposite and the start of the installation of any overlaying cover, the installer will make provisions, by placing temporary securing means, to protect the geocomposite from wind uplift.

18.5.1 Placement of Soil Materials

The contractor will place all soil materials located on top of the geocomposite in such a manner so as to minimize the following:

- Damage to the geocomposite.
- Slippage of the geocomposite on underlying layers.
- Excessive tensile stresses imposed on the geocomposite.

Low ground pressure tracked equipment (less than 5 psi) will be used to place the protective cover over the geocomposite. A minimum of 1 foot of cover material is required between the geocomposite and the low ground pressure equipment. A minimum of 2 feet of cover is required between the geocomposite and all other tracked or flotation wheeled equipment. A minimum of 30 inches of cover soil is required between the geocomposite and all rubber-tired vehicles.

Any noncompliance with the above requirements will be recorded and reported by the RPR to the CQA Officer.

Table 18-1. Geocomposite Tests, Test Methods, and Acceptance Criteria

Property	Units	Acceptance Value	Test	Criterion
Geocomposite (1)				
Ply Adhesion	lb/in	0.5	ASTM D7005	Min. Average
Transmissivity(4)	m^2/sec	$1.19x10^{-3}$	ASTM D4716	Min. Average
Geonet Core(2)				
Thickness	mils	200	ASTM D5199	Min. Average
Density	g/cu cm	0.94	ASTM D1505	Min. Average
Carbon Black Content	Percent	2	ASTM D1603/4218	Min. Average
Geotextile(2)				
Mass per Unit Area	oz/yd^2	6	ASTM D5261	Min. Average
Grab Tensile	lb	160	ASTM D4632	Min. Average
Puncture Strength (Pin) (5)	lb	90	ASTM D4833	Min. Average
Puncture Strength (CBR) (5)	lb	435	ASTM D6241	Min. Average
AOS, US sieve	US Sieve No.	70	ASTM D4751	Max. Average
Permittivity	sec^{-2}	1.5	ASTM D4491	Min. Average
Flow Rate	gpm/ft^2	110	ASTM D4491	Min. Average
Gradient Ratio or Hydraulic Conductivity Ratio (6)	Ratio	(6)	ASTM D5101 or ASTM D5567	Approximate Range

Notes:
1. The geocomposite shall be manufactured by heat bonding the geotextile to the geonet on both sides. No burn through geotextiles nor glue or adhesive shall be permitted.
2. Component properties prior to the lamination.
3. Refer to **Section 3** for direct shear test requirements.
4. Conformance testing with a 100-hour test is required for the geocomposite drainage layer of the final cover to confirm the transmissivity of geocomposite sandwiched between textured LLDPE geomembrane and lightly tamped rooting zone material at a vertical pressure of 300 psf. A minimum transmissivity of 1.19×10^{-3} m^2/sec is required at a hydraulic gradient of 0.25. If the topsoil or rooting zone properties change, or if there is new, site-specific information, the required transmissivity may be re-evaluated and submitted with the final cover pre-construction report.
5. Geotextile to meet puncture strength (pin) or puncture strength (CBR) specification.
6. Gradient ratio or hydraulic conductivity ratio testing of the upper geotextile with rooting zone soil. Acceptable ratios are approximately 0.4 to 0.8 for hydraulic conductivity ratio or less than 3.0 for gradient ratio.

19.0 SOIL BARRIER LAYER

19.1 GENERAL

This section includes the quality assurance requirements for placing, backfilling, and compacting the barrier layer soil in the final cover system. The 24-inch-thick soil barrier layer will consist of on-site or imported soil.

19.2 SUBGRADE PREPARATION

The Contractor will be responsible for the preparation of the subgrade of the barrier layer. Subgrade preparation may include top-of-waste regrading, grading layer placement, or top of grading layer regrading, at the discretion of the Owner.

The subgrade will consist of a minimum 3-inch-thick soil grading layer placed on top of the waste. The soil grading layer will consist of general fill material obtained from on site or off site (see **Section 9**). If topsoil material was used as part of the grading layer placed during normal landfill operations, the Contractor will remove and salvage the temporary topsoil layer. The CQA Officer or RPR will inspect the subgrade, upon completion of the grading layer work and will verify, at a minimum, the following:

- Survey of verified lines and grades as described in **Subsection 9.3.**
- The grading layer soil meets the depth criteria in the project specifications and CQA plan.

The RPR will indicate to the Contractor any observed locations that are not adequate for the placement of the barrier layer during final cover construction. The Contractor will repair defects in the subgrade soil such that the properties of the repaired areas meet the minimum subgrade requirements.

19.3 PROCEDURES AND OBSERVATIONS

The RPR will observe and document barrier layer construction activities to support certification of the following requirements:

- The RPR will confirm the uniformity of the barrier layer soil and will monitor for segregation and removal of unsuitable material and for changes in soil type, color, texture, and moisture content. The Contractor will segregate and/or remove unsuitable materials, such as soil not meeting acceptance criteria, boulders, cobbles, and organic material.

- The RPR will observe the barrier layer placement and will measure field densities and moisture contents (see **Subsection 19.4**) to document that the barrier layer is in substantial conformance with the specifications and that soil placement has been conducted in a manner to achieve a uniform, homogeneous mass.

- The RPR will backfill with granular bentonite, or a bentonite-soil mixture, voids created by nuclear density gauge probes.

- The RPR will document areas of unacceptable density or moisture content, as defined by **Subsection 19.4**. The Contractor will perform corrective action that will consist of the moisture-conditioning of the soil and/or additional compactive effort, as necessary. The RPR will retest the area, following corrective actions.

- The Contractor will place each lift of barrier layer material in approximate 1-foot lifts.

- The RPR will verify that compaction equipment has a minimum static weight of 30,000 pounds or has a minimum static weight 15,000 pounds that is capable of vibrating to produce a minimum dynamic compaction force of 30,000 pounds.

- The RPR will verify that compaction equipment used to compact the barrier layer has compaction feet a minimum of 6 inches long.

- The Contractor will not use frozen soil in the barrier layer and will remove frozen soil from the compaction work area.

- The Contractor will remove stones and other penetrating objects 1 inch or larger protruding from the surface of the final lift of the barrier layer to avoid puncturing the overlying geosynthetics. The RPR will document the removal of the stones and other objects. The Contractor will fill with barrier layer soil or bentonite any voids made by the removal of stones, and the entire cover surface will be rolled with a smooth-drum compactor.

- Preconstruction planning will be undertaken to sequence construction activities to minimize the length of time a completed barrier layer surface will be exposed prior to receiving protective cover. Protective cover will be provided by the installation of the GCL and subsequently the geomembrane.

19.4 SAMPLING REQUIREMENTS AND ACCEPTANCE CRITERIA

This section describes the required analyses, methods, sample frequencies, and acceptance limits of the barrier layer. The RPR will collect soil samples for laboratory analysis. The RPR will record the field sample locations in the daily construction reports or field data sheets as record construction data, including locations and lift locations of the laboratory sample points.

19.4.1 Field Testing

The RPR will use the following field-testing methods during construction of the barrier layer:

Parameter	Test Method
Moisture content and Field density	ASTM D6938

Moisture content and field density tests will be performed in accordance with NR 516.07(2m)(b)(1) using a nuclear density gauge on a 100-foot grid pattern for each 1-foot thickness of barrier layer soil placed. The testing grid pattern will be offset on each subsequent layer of tests. In confined areas where compaction equipment is hindered or hand compaction is necessary, a minimum of two field density and moisture content tests will be performed for each 1-foot thickness of barrier layer soil placed.

19.4.2 Field Testing Acceptance Criteria

Acceptance criteria for field density will require soil compaction to a minimum of 90 percent of the Modified Proctor (ASTM D1557) maximum dry density or to a minimum of 95 percent of the Standard Proctor (ASTM D698) maximum dry density and at a moisture content wet of optimum moisture content.

19.4.3 Laboratory Testing

Routine laboratory testing of the barrier layer soil will be performed on samples from the borrow area or on-site stockpile (representative). Soil characteristics will be determined from the representative samples.

Representative Sample Analysis

Representative (grab) samples will be obtained on the basis of three criteria. First, an initial sample will be obtained from the borrow source (if not used in construction of a prior phase) and analyzed prior to construction. This will confirm soil characteristics and provide an initial maximum dry density and optimum moisture content for field moisture/density testing. Second, routine samples will be obtained for every 5,000 cubic yards placed. Third, in the event that changes in physical appearance or soil characteristics are observed, a sample will be obtained and analyzed. The maximum dry density and optimum moisture content values used for compaction testing may be adjusted during the course of cover construction based on the results of the above sampling.

The following laboratory analyses will be performed on the representative samples obtained:

Parameter	Test Method
Moisture-density relationship using Modified or Standard Proctor compaction	ASTM D1557 (1, 2)/ ASTM D698 (1, 2)
Atterberg limits (c)	ASTM D4318
Grain-size analysis	ASTM D6913 and D7928 (3)

Notes:
1. Five-point Proctor analysis required, except as described in Note 2, below.
2. One-point Proctor analysis may be utilized for representative samples collected for apparent changes in soil quality to verify applicability of previously analyzed moisture-density relationships. If the result does not verify applicability, then a five-point analysis will be performed in accordance with the first sampling criteria.
3. Distribution is to be reported through the 0.002 mm particle size.

19.4.4 Laboratory Testing Acceptance Criteria

The following acceptance criteria will apply to the barrier layer.

- The upper 1 foot of the barrier layer will have a maximum particle diameter of 2 inches and the lower 1 foot of the barrier layer will have a maximum particle diameter of 4 inches.

- Fine grained-soil or well-graded sandy soil with fines meeting the USCS soil types ML, CL, CH, SM, or SC, or dual-symbol classifications composed of those soil types, with at least 25 percent by weight passing the #200 sieve.

19.5 THICKNESS DOCUMENTATION

The bottom of the final cover barrier layer (top of grading layer) will be surveyed on a maximum 100-foot grid pattern (maximum 50-foot grid pattern if the final cover construction is less than 4 acres) and at key locations on the final cover. Key locations include breaks in grade, top of slopes, and limits of final cover construction. The barrier layer thickness will be determined at the top of grading layer surveyed locations and reported in a tabular fashion in the Construction Documentation Report. The minimum acceptable barrier layer thickness will be 2 feet.

Appendix E

Calculations

E.1 Geotechnical Calculations

Purpose: Evaluate the Module 12 and 13 landfill liner side slope drainage layer for static veneer slope stability. The following calculations evaluate the static veneer slope stability of the 3:1 slope.

References: 1. Koerner, Robert M. & Te-Yang Soong, Analysis and Design of Veneer Cover Soils, Geosynthetic Research Institute.
2. U.S. Department of Transportation - Federal Highway Administration Recycled Materials, Coal Bottom Ash User's Guide

Calculation:

$FS = (-b + (b^2 - 4 * a * c)^{1/2}) / (2 * a)$

$a = (W_A - N_A * \cos\beta) * \cos\beta$

$b = -((W_A - N_A * \cos\beta) * \sin\beta * \tan\phi + (N_A * \tan\delta + C_a) * \sin\beta * \cos\beta + (C + W_P * \tan\phi) * \sin\beta)$

$c = (N_A * \tan\delta + C_a) * (\sin\beta)^2 * \tan\phi$

$N_A = W_A * \cos\beta$

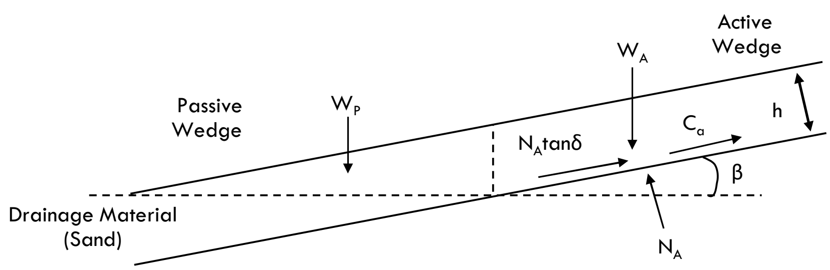
$W_A = \gamma * h^2 * (L / h - 1 / \sin\beta - \tan\beta / 2)$

$W_P = (\gamma * h^2) / \sin 2\beta$

$C_a = c_a (L - h / \sin\beta)$

<u>Where:</u>

FS	=	Factor of Safety						
a, b, & c	=	intermediate variables (calculated variable)						
N_A	=	Effective force normal to the failure plane of the active wedge (calculated variable)						
W_A	=	Total weight of active wedge (calculated variable)						
W_P	=	Total weight of passive wedge (calculated variable)						
β	=	Soil slope angle beneath the geomembrane	=	18.421	degrees	=	0.3215	radians
			based on liner slope of	3	to	1		
ϕ	=	Friction angle of the sand drainage layer material	=	30	degrees	=	0.5236	radians
			based on experience					
δ	=	Interface friction angle for liner system geosynthetics (to be determined)						
c_a	=	Adhesion for liner system geosynthetics at active wedge (to be determined), Variable						
γ	=	Unit weight of the drainage layer material	=	125	pcf			
			based on conservative wet density of sand					
C	=	Cohesive force along the failure plane of the passive wedge, assumed						
			=	0	for drainage layer material			
C_a	=	Adhesive force of the active wedge for the liner system geosynthetics						
h	=	Thickness of the drainage layer material	=	1	foot, based on base design			
L	=	Length of slope measured along the geomembrane	=	82	feet, based on base design			



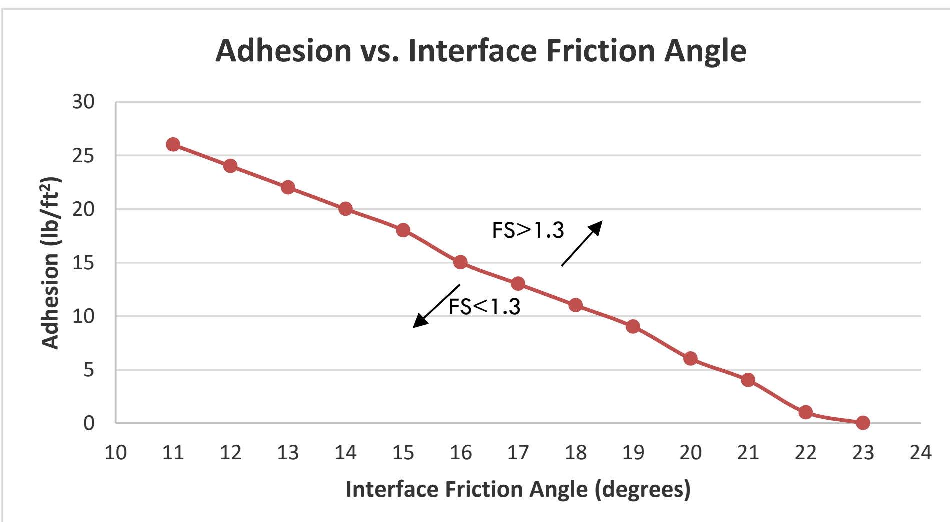
Job No. 25222260.00 | Job: Columbia Dry Ash Disposal Facility | By: MJT | Date: 08/04/23

Client: WPL | Subject: Liner Side Slope Drainage Layer Stability | Chk'd: DLN | Date: 08/10/23

Calculation:

(cont.)

δ		c_a	W_A	W_P	N_A	C_a	a	b	c	FS
(deg)	(rad)	(lb/ft^2)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	
11	0.192	26	9,834	208	9,330	2049.7	932	-1,375	223	1.3
12	0.2094	24	9,834	208	9,330	1,892	932	-1,379	223	1.3
13	0.2269	22	9,834	208	9,330	1,734	932	-1,383	224	1.3
14	0.2443	20	9,834	208	9,330	1,577	932	-1,387	225	1.3
15	0.2618	18	9,834	208	9,330	1,419	932	-1,392	226	1.3
16	0.2793	15	9,834	208	9,330	1,183	932	-1,374	222	1.3
17	0.2967	13	9,834	208	9,330	1,025	932	-1,380	224	1.3
18	0.3142	11	9,834	208	9,330	867	932	-1,386	225	1.3
19	0.3316	9	9,834	208	9,330	710	932	-1,393	226	1.3
20	0.3491	6	9,834	208	9,330	473	932	-1,377	223	1.3
21	0.3665	4	9,834	208	9,330	315	932	-1,385	225	1.3
22	0.384	1	9,834	208	9,330	79	932	-1,371	222	1.3
23	0.4014	0	9,834	208	9,330	0	932	-1,405	228	1.3



Conclusion: The landfill liner side slope drainage layer was evaluated for static veneer slope stability along its longest slope. Calculations were performed to determine the minimum adhesion necessary for a range of interface friction angles to reach a FS of 1.3 or greater. Each interface friction angle and the coinciding adhesion was graphed in order to easily determine if a material interface is acceptable along the side slope.

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the liner system.

Approach: Use maximum shear stress formula and assumed values.

References: Design of GCL Barrier for Final Cover Side Slope Applications, Gregory N. Richardson, Ph.D., P.E., Geosynthetics '97-541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin \beta$$

$$\beta = 18.4^\circ$$

$$W_T = \gamma \quad X \quad h$$

Where: γ = Sand Unit Weight = 125 pcf

h = Drainage Layer Thickness = 1 ft

$$W_T = 125 \text{ psf}$$

$$\tau_{act} = 39.5 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS \quad X \quad \tau_{act} = 1.5 \quad X \quad 39.5 = 59 \text{ psf}$$

Assumptions: Slope angle, β = 18.4° (3:1 horizontal / vertical liner side slope

Sand unit weight, γ = 125 pcf

Conclusion: For a total weight of the leachate drainage layer of 125 psf and a slope angle of 3:1, the maximum shear stress will be 39.46 psf. A minimum GCL internal shear strength of 59.19 psf is required to provide a slope stability safety factor of 1.5.

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		Calc. No.	
		Rev. No.	
Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 03/03/2022
Client: WPL	Subject: Pipe Filter Analysis	Chk'd: DLN	Date: 04/13/2022

Purpose: To demonstrate that the filter design criteria are met for the sand leachate drainage layer in relation to the head well piping perforation size. Also to demonstrate that the filter design criteria are met for the leachate collection and sump riser pipe bedding in relation to the pipe hole size. The hole or slot size of the pipes must be designed to limit pipe bedding material from entering the pipe.

Approach: Determine the pipe perforation and pipe hole relationship as specified in the Naval Facilities Engineering Command (NAVFAC) Design Manual (US Navy, 1986).

References: Naval Facilities Engineering Command, US Navy, Soil Mechanics, Design Manual 7.01, September 1986.

ASTM E11, Standard Specification for Wire Cloth and Sieves for testing purposes.

Assumptions: Assuming the head well piping slot size is No.10 or an approximate width of 0.01 inches.

Assuming the leachate collection and sump riser pipe hole size is 1/2" diameter

Calculation: **Pipe Perforation Relationship** (to avoid loss of filter material into collection and riser pipe perforations)

D_{85F}/Slot width > 1.2 to 1.4 D_{85F}/Hole Diameter > 1.0 to 1.2

Where D_{85F} = particle size at which 85% of total pipe bedding particles are finer by weight.

Headwell Piping

	Filter				Pipe Slot			
(for 1.2)	D_{85}	=	0.3	mm	Size	=	0.01	inches
(for 1.4)	D_{85}	=	0.36	mm	Size	=	0.254	mm

Pipe Perforation Relationship

(for 1.2)	D_{85F}/Slot width	=	1.2	OK
(for 1.4)	D_{85F}/Slot width	=	1.4	OK

From ASTM E11, No. 50 U.S. Standard sieve opening size is close to 0.30 mm.

Leachate Collection Piping

	Filter				Pipe Slot			
(for 1.2)	D_{85}	=	15	mm	Size	=	0.5	inches
(for 1.4)	D_{85}	=	12.7	mm	Size	=	12.7	mm

Pipe Hole Relationship

(for 1.2)	D_{85F}/Hole width	=	1.2	OK

Conclusion: To avoid movement of leachate drainage layer particles into No. 10 size pipe slots, no more than 85% of the sand particles should pass a No. 50 sieve. To avoid movement of the leachate collection and sump riser pipe bedding material into the piping holes, no more than 85% of the pipe bedding particles should pass a 1/2 inch sieve.

Purpose: Perform a puncture analysis on the geomembrane to determine the geotextile cushion requirements for the geotextile beneath the leachate collection pipe bedding.

Approach: Use the GRI-Method (Koerner 2008)

References: Modification to the "GRI-Method" for the RFCR-Factor used in the Design of Geotextiles for Puncture Protection of Geomembranes; Robert M. Koerner, Ph.D, P.E., NAE; November 28, 2008, GRI White Paper #14.

Calculation: The following geomembrane puncture analysis was completed to show which factors control the recommended geotextile mass per unit area.

$$FS = \frac{P_{allow}}{P_{act}} \qquad (1)$$

Where:

- FS = factor of safety
- P_{act} = actual pressure due to the applied normal stress, e.g., landfill contents
- P_{allow} = allowable pressure using different types of geotextiles and site-specific conditions

$$P_{allow} = \left(50 + 0.00045 \frac{M}{H^2} \right) \left[\frac{1}{MF_S \times MF_{PD} \times MF_A} \right] \left[\frac{1}{RF_{CBD} \times RF_{CR}} \right] \qquad (2)$$

Where:

- P_{allow} = allowable pressure (kPa)
- M = geotextile mass per unit area (g/m^2)
- H = protrusion height (m)
- MF_S = modification factor for protrusion shape
- MF_{PD} = modification factor for packing density
- MF_A = modification factor for arching in solids
- RF_{CBD} = reduction factor for long-term chemical/biological degradation, and
- RF_{CR} = reduction factor for long-term creep

Assumptions:

H	=	25mm (1inch)	=	0.025	m
MF_S	=	Sub Rounded	=	0.5	
MF_{PD}	=	Dense, 25mm (1inch)	=	0.67	
MF_A	=	Geostatic, deep	=	0.25	
RF_{CBD}	=	Mild leachate	=	1.1	
RF_{CR}	=	25mm (1inch) @ geotextile mass per unit area (gm/m^2) of 1,100	=	1.5	

Calculation: Calculate allowable waste fill height using a factor of safety of 3.0 Due to creep effects, a minimum geotextile mass per unit area of 1,100 g/m^2 will control the design.

$$FS = \frac{P_{allow}}{P_{act}}$$

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Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/04/2023
Client: WPL	Subject: Geomembrane Puncture Analysis	Chk'd: DLN	Date: 08/10/2023

Assumptions: Solid waste density = 135 pcf = 21.13 kN/m^3
Peak Height of Waste = 127 feet = 38.71 meters

Calculation:

$$P_{act} = \text{Solid Waste Density} \times \text{Peak Height of Waste}$$

$$P_{act} = \frac{P_{allow}}{FS} = \frac{P_{allow}}{3}$$

$$P_{allow} = \left(50 + 0.00045\frac{M}{H^2}\right)\left[\frac{1}{MF_S \times MF_{PD} \times MF_A}\right]\left[\frac{1}{RF_{CBD} \times RF_{CR}}\right]$$

P_{act}	FS	P_{allow}	M	Recommendation	Max. Allowable Fill Height (feet)
2,031	3	6,093	1,100	See Below	315

Available geotextile cushion thicknesses include:

M (g/m^2)	M (oz/yd^2)
406	12
542	16
675	20
812	24
950	28
1080	32

Conclusion: Due to creep effects, the minimum required geotextile mass per unit area of 1,100 g/m^2 controls the design. Based on the puncture analysis, 3 layers of a 12 oz/yd^2 geotextile, 2 layers of a 16 oz/yd^2 geotextile, or a 32 oz/yd^2 geotextile will be acceptable for use below the leachate pipe bedding.

The maximum allowable fill height is 315 feet which is higher than the maximum design height of 127 feet.

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		Sheet No.	
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/04/23
Client: WPL	Subject: Pipe Strength Calculations	Chk'd: DLN	Date: 08/11/23

Purpose: To evaluate the pipe strength of 6-in. dia., SDR 11 HDPE leachate collection piping in the base system of the Columbia Dry Ash Disposal Facility Modules 12 and 13 using designed properties and parameters.

Approach: Use referenced formulas to determine the maximum height waste can be placed above the leachate piping and the specific physical pipe properties necessary to perform adequately.

References:

1. Plastics Pipe Institute, 2nd Edition Handbook of PE Pipe, Buried PE Pipe Design (Attachment 1)
2. ISCO Industries, Typical Physical Properties and Dimension Charts, www.isco-pipe.com (Attachment 2)
3. "Soil Reaction for Buried Flexible Pipe", Amster K. Howard, U.S. Bureau of Reclamation
4. Plan of Operation, Metro Landfill Western Expansion, Appendix F - "Report on Metro Landfill - Pipe Design", Watkins, 1989
5. U.S. Department of Transportation, Federal Highway Administration, Recycled Materials, Coal Ash User's Guide
6. "HDPE Leachate Collection Pipe Design by Fundamentals of Mechanics", Harrison and Watkins, 1996, Nineteenth International Madison Waste Conference.
7. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Modules 12 and 13) Plan Sheet, August 2023

Assumptions:

1. Waste above the piping is assumed to be wet.
2. Wet waste unit weight is a conservative 135 pcf from research and typical project experience values.
3. Live loads are negligible above the piping. The maximum fill height over an 6-in SDR 11 HDPE pipe will be 127 feet for the current design.
4. Leachate collection pipes will be 6-in., SDR 11 HDPE in Modules 12 and 13.
5. Allowable compressive stress for HDPE pipe is 1,000 psi (Plastic Pipe Institute, Attachment 1).

Calculations: **Pipe Loading, P_y**

$$P_y = DL + LL$$

where,
P_y = Pipe Load, lb/in²
DL = Dead Load, lb/in²
LL = Live Load, lb/in²

Dead Load, *DL*

$$DL = \frac{\gamma \cdot H}{144}$$

where,

γ	=	Fill Unit Weight, lb/ft^3	=	**135**	(waste unit weight)
H	=	Height of cover, ft	=	**127**	(max. waste height)
DL	=	Dead Load, lb/in^2	=	**119**	

In our case the live load = 0, due to limited live loads above the piping after placement.

So, P_y = DL = 119 lb/in^2

Assuming, 6 inch SDR 11 HDPE for leachate collection piping

Outer Diameter of Pipe (OD) = 6.625 in. (From Attachment 2)

Min. Pipe wall thickness (t) = 0.602 in. (From Attachment 2)

Calculations: (cont.)

Deflection

A deflection of 5 to 7.5% has become the standard for limiting deflection in flexible pipes. Based on Figure 7.16 in Uni-Bell (1991) and Watkins (1989) a vertical strain of greater than 5% will never be reached for flexible pipe bedded in compacted gravel, independent of vertical soil pressure. At 90% compaction the vertical strain will always be less than 2%. The height of fill over the pipe is not a factor when the pipe is well bedded in gravel. These findings are consistent for HDPE piping with the Harrison and Watkins (1996) paper.

Wall Crushing

where,

σ = *Compressive Stress, lb/in²*
T = *Wall Thrust, lb/in*
A = *Area of Pipe Wall, in²/in*

$$\sigma = \frac{T}{A}$$

Wall Thrust, T

$$T = \frac{P_y \cdot D_0}{2}$$

SDR 11 HDPE Piping

where,

P_y	=	Vertical Fill Pressure lb/in^2	=	**119**	(Previously Calculated)
D_0	=	Outside Diameter, in	=	**6.625**	(SDR 11, 6-inch)
T	=	Wall Thrust, lb/in	=	**394**	
A	=	Area of Pipe Wall, in^2/in	=	**0.602**	(Solid=Thickness)

So, σ = *Compressive Stress, lb/in²* = **655**

Result: The allowable compressive strength of HDPE pipe is approximately 1,000 psi, so the calculated compressive stress values are acceptable and wall crushing of the pipe will be avoided when the pipe is at least SDR 11, 6-inch diameter for the leachate collection pipe.

Leachate Collection Piping Maximum Height - SDR 11 HDPE

For

P_y	=	Vertical Fill Pressure lb/in^2	=	**182**	
D_0	=	Outside Diameter, in	=	**6.625**	(SDR 11, 6-inch)
T	=	Wall Thrust, lb/in	=	**602**	
A	=	Area of Pipe Wall, in^2/in	=	**0.602**	(Solid=Thickness)

So, σ = *Compressive Stress, lb/in²* = **1,000**

Maximum Height (feet) = Py*(144)/ɣ = **194**

Result: The maximum height of fill above the 6-inch SDR 11 HDPE piping is 194 feet for a fill unit weight of 135 lb/ft^3 to maintain the required minimum factor of safety against wall crushing. Wall crushing controls the maximum fill height that can be placed above the leachate collection pipes. The maximum fill height above the 6-inch diameter piping when Modules 1-6 and Modules 10-13 are filled will be approximately 127 feet, which is lower than the maximum allowable fill height.

Attachment 1

From the Handbook of PE Pipe 2008, Second Edition by the Plastics Pipe Institute

TABLE C.1
Allowable Compressive Stress for 73°F (23°C)

	Pe Pipe Material Designation Code (1)					
	PE 2406		PE3408		PE 4710	
	PE 2708		PE 3608			
			PE 3708			
			PE 3710			
			PE 4708			
	psi	MPa	psi	MPa	psi	MPa
Allowable Compressive Stress	800	5.52	1000	6.90	1150	7.93

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code.

Attachment 2

From the ISCO Product Catalog dated Q4 2020

IPS ASTM ISCO

For reference only. Actual dimensions may vary.

PE4710 HDPE PIPE SIZES IPS AND LARGE DIAMETER METRIC

PE4710 Tamaños HDPE tuberías IPS y Diámetro Grande Métrico

ASTM MATERIALS Materiales ASTM

DR		11			13.5			15.5		
PE4710 Pressure Rating / Resistencia a la Presión		200 psi			160 psi			138 psi		
Nom. OD / OD Nominal (in)	Actual OD / OD Actual (in)	Min Wall / Espesor Mínimo de Pared (in)	Avg ID / DI Promedio (in)	Weight / Peso (lb/ft)	Min Wall / Espesor Mínimo de Pared (in)	Avg ID / DI Promedio (in)	Weight / Peso (lb/ft)	Min Wall / Espesor Mínimo de Pared (in)	Avg ID / DI Promedio (in)	Weight / Peso (lb/ft)
¾"	1.05	0.095	0.848	0.13	---	---	---	---	---	---
1"	1.315	0.12	1.062	0.2	---	---	---	---	---	---
1¼"	1.66	0.151	1.34	0.314	---	---	---	---	---	---
1½"	1.9	0.173	1.534	0.411	---	---	---	---	---	---
2"	2.375	0.216	1.917	0.642	0.176	2.002	0.534	0.153	2.05	0.47
3"	3.5	0.318	2.825	1.395	0.259	2.95	1.16	0.226	3.021	1.02
4"	4.5	0.409	3.633	2.31	0.333	3.793	1.92	0.29	3.885	1.687
5"	5.563	0.506	4.491	3.523	0.412	4.689	2.928	0.359	4.802	2.58
6"	6.625	0.602	5.348	4.93	0.491	5.585	4.152	0.427	5.719	3.656
8"	8.625	0.784	6.963	8.47	0.639	7.271	7.04	0.556	7.445	6.197
10"	10.75	0.977	8.678	13.16	0.796	9.062	10.932	0.694	9.28	9.626
12"	12.75	1.159	10.293	18.51	0.944	10.748	15.38	0.823	11.006	13.53
14"	14	1.273	11.302	22.32	1.037	11.801	18.54	0.903	12.085	16.31
16"	16	1.455	12.916	29.15	1.185	13.487	24.22	1.032	13.812	21.3
18"	18	1.636	14.531	36.89	1.333	15.173	30.651	1.161	15.538	26.95
20"	20	1.818	16.145	45.541	1.481	16.859	37.84	1.29	17.265	33.28
22"	22	2	17.76	55.105	1.63	18.545	45.79	1.419	18.991	39.712
24"	24	2.182	19.375	65.58	1.778	20.231	54.49	1.548	20.717	47.92
26"	26	2.364	20.989	77.44	1.926	21.917	64.261	1.677	22.444	56.532
28"	28	2.545	22.604	89.785	2.074	23.603	74.522	1.806	24.17	65.563
30"	30	2.727	24.218	103.076	2.222	25.289	85.543	1.935	25.897	75.264
32"	32	2.909	25.833	117.285	2.37	26.975	97.324	2.065	27.623	85.673
34"	34	3.091	27.447	132.411	2.519	28.661	109.905	2.194	29.35	96.714
36"	36	3.273	29.062	148.454	2.667	30.347	123.208	2.323	31.076	108.424
42"	42	3.818	33.906	202.039	3.111	35.404	167.675	2.71	36.255	147.568
48"	48	4.364	38.749	278.27	3.556	40.461	216.74	3.097	41.435	192.774
54"	54	4.909	43.59	352.14	4.00	45.75	286.94	3.484	46.614	243.921
1600mm/63"	62.99	---	---	---	4.667	53.107	390.58	4.065	54.383	340.15
1800mm	70.87	---	---	---	5.2*	60.1*	Call	---	---	---
2000mm	78.74	---	---	---	5.8*	66.8*	Call	---	---	---
2250mm	88.58	---	---	---	---	---	---	---	---	---
2500mm	98.43	---	---	---	---	---	---	---	---	---
2720mm	107.1	---	---	---	---	---	---	---	---	---
2800mm	110.2	---	---	---	---	---	---	---	---	---
3000mm	118.1	---	---	---	---	---	---	---	---	---
3500mm	137.8	---	---	---	---	---	---	---	---	---

1. Pressures are based on using water at 23°C (73°F)
2. Average inside diameter calculated using actual OD and minimum wall plus 6% for use in estimating fluid flows. Actual ID will vary.
3. Other piping sizes or DR's may be available upon request.
4. Standard Lengths
   - 40' for 2"-24"
   - 50' for 26" and larger
   - Coils available for ¾ - 4" (6" by special order)

*DR 13.6

Purpose: To evaluate the pipe strength of 18-in. dia., SDR 17 HDPE sump riser piping in the base system of the Columbia Dry Ash Disposal Facility Modules 12 and 13 using designed properties and parameters.

Approach: Use referenced formulas to determine the maximum height waste can be placed above the sump riser piping and the specific physical pipe properties necessary to perform adequately.

References:

1. Plastics Pipe Institute, 2nd Edition Handbook of PE Pipe, Buried PE Pipe Design (Attachment 1)

2. ISCO Industries, Typical Physical Properties and Dimension Charts, www.isco-pipe.com (Attachment 2)

3. "Soil Reaction for Buried Flexible Pipe", Amster K. Howard, U.S. Bureau of Reclamation

4. Plan of Operation, Metro Landfill Western Expansion, Appendix F - "Report on Metro Landfill - Pipe Design", Watkins, 1989

5. U.S. Department of Transportation, Federal Highway Administration, Recycled Materials, Coal Ash User's Guide

6. "HDPE Leachate Collection Pipe Design by Fundamentals of Mechanics", Harrison and Watkins, 1996, Nineteenth International Madison Waste Conference.

8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Base and Final Grades (Modules 12 and 13) Plan Sheets, August 2023

Assumptions:

1. Waste above the piping is assumed to be wet.

2. Wet waste unit weight is a conservative 135 pcf from research and typical project experience values.

3. Live loads are negligible above the piping. The maximum fill height over an 18-in SDR 17 HDPE pipe will be 55 feet for the current design.

4. Sump riser pipes will be 18-in., SDR 17 HDPE in Modules 12 and 13.

5. Allowable compressive stress for HDPE pipe is 1,000 psi (Plastic Pipe Institute, Attachment 1).

Calculations: **Pipe Loading, P_y**

$$P_y = DL + LL$$

where,
P_y = Pipe Load, lb/in^2
DL = Dead Load, lb/in^2
LL = Live Load, lb/in^2

Dead Load, *DL*

$$DL = \frac{\gamma \cdot H}{144}$$

where,

γ	=	Fill Unit Weight, lb/ft^3	=	**135**	(waste unit weight)
H	=	Height of cover, ft	=	**55**	(max. waste height)
DL	=	Dead Load, lb/in^2	=	**52**	

In our case the live load = 0, due to limited live loads above the piping after placement.

So, P_y = DL = 52 lb/in^2

Assuming, 18 inch SDR 17 HDPE for leachate sump riser piping

Outer Diameter of Pipe (OD) = 18 in. (From Attachment 2)

Min. Pipe wall thickness (t) = 1.059 in. (From Attachment 2)

Calculations: (cont.)

Deflection

A deflection of 5 to 7.5% has become the standard for limiting deflection in flexible pipes. Based on Figure 7.16 in Uni-Bell (1991) and Watkins (1989) a vertical strain of greater than 5% will never be reached for flexible pipe bedded in compacted gravel, independent of vertical soil pressure. At 90% compaction the vertical strain will always be less than 2%. The height of fill over the pipe is not a factor when the pipe is well bedded in gravel. These findings are consistent for HDPE piping with the Harrison and Watkins (1996) paper.

Wall Crushing

where,

σ = *Compressive Stress, lb/in²*
T = *Wall Thrust, lb/in*
A = *Area of Pipe Wall, in²/in*

$$\sigma = \frac{T}{A}$$

Wall Thrust, T

$$T = \frac{P_y \cdot D_o}{2}$$

SDR 17 HDPE Piping

where,

P_y	=	Vertical Fill Pressure lb/in^2	=	**52**	(Previously Calculated)
D_0	=	Outside Diameter, in	=	**18.000**	(SDR 17, 18-inch)
T	=	Wall Thrust, lb/in	=	**464**	
A	=	Area of Pipe Wall, in^2/in	=	**1.059**	(Solid=Thickness)

So, σ = *Compressive Stress, lb/in²* = **438**

Result: The allowable compressive strength of HDPE pipe is approximately 1,000 psi, so the calculated compressive stress values are acceptable and wall crushing of the pipe will be avoided when the pipe is at least SDR 17, 18-inch diameter for the sump riser pipe.

Sump Riser Piping Maximum Height - SDR 17 HDPE

For

P_y	=	Vertical Fill Pressure lb/in^2	=	**118**	
D_0	=	Outside Diameter, in	=	**18.000**	(SDR 17, 18-inch)
T	=	Wall Thrust, lb/in	=	**1,059**	
A	=	Area of Pipe Wall, in^2/in	=	**1.059**	(Solid=Thickness)

So, σ = *Compressive Stress, lb/in²* = **1,000**

Maximum Height (feet) = Py*(144)/ɣ = **126**

Result: The maximum height of fill above the 18-inch SDR 17 HDPE piping is 126 feet for a fill unit weight of 135 lb/ft^3 to maintain the required minimum factor of safety against wall crushing. Wall crushing controls the maximum fill height that can be placed above the sump riser pipes. The maximum fill height above the 18-inch diameter piping when Modules 12 and 13 are filled will be approximately 55 feet, which is lower than the maximum allowable fill height.

Attachment 1

From the Handbook of PE Pipe 2008, Second Edition by the Plastics Pipe Institute

TABLE C.1

Allowable Compressive Stress for 73°F (23°C)

	Pe Pipe Material Designation Code (1)					
	PE 2406, PE 2708		PE3408, PE 3608, PE 3708, PE 3710, PE 4708		PE 4710	
	psi	MPa	psi	MPa	psi	MPa
Allowable Compressive Stress	800	5.52	1000	6.90	1150	7.93

(1) See Chapter 5 for an explanation of the PE Pipe Material Designation Code.

Attachment 2

From the ISCO Product Catalog dated Q4 2020

ISCO ASTM IPS

For reference only. Actual dimensions may vary.

PE4710 HDPE PIPE SIZES IPS AND LARGE DIAMETER METRIC

PE4710 Tamaños HDPE tuberías IPS y Diámetro Grande Métrico

DR		17			19			21		
PE4710 Pressure Rating		125 psi			111 psi			100 psi		
Nom. OD (in)	Actual OD (in)	Min Wall (in)	Avg ID (in)	Weight (lb/ft)	Min Wall (in)	Avg ID (in)	Weight (lb/ft)	Min Wall (in)	Avg ID (in)	Weight (lb/ft)
¾"	1.05	---	---	---	---	---	---	---	---	---
1"	1.315	---	---	---	---	---	---	---	---	---
1¼"	1.66	---	---	---	---	---	---	---	---	---
1½"	1.9	---	---	---	---	---	---	---	---	---
2"	2.375	0.14	2.079	0.431	---	---	---	---	---	---
3"	3.5	0.206	3.064	0.94	---	---	---	0.167	3.147	0.757
4"	4.5	0.265	3.939	1.55	0.237	3.998	1.39	0.214	4.046	1.27
5"	5.563	0.327	4.869	2.36	0.293	4.942	2.12	0.265	5.001	1.94
6"	6.625	0.39	5.799	3.36	0.349	5.886	3.01	0.315	5.956	2.75
8"	8.625	0.507	7.549	5.69	0.454	7.663	5.1	0.411	7.754	4.662
10"	10.75	0.632	9.409	8.834	0.566	9.551	7.92	0.512	9.665	7.242
12"	12.75	0.75	11.16	12.43	0.671	11.327	11.14	0.607	11.463	10.19
14"	14	0.824	12.254	14.983	0.737	12.438	13.43	0.667	12.587	12.282
16"	16	0.941	14.005	19.57	0.842	14.215	17.54	0.762	14.385	16.042
18"	18	1.059	15.755	24.77	0.947	15.992	22.2	0.857	16.183	20.304
20"	20	1.176	17.506	30.58	1.053	17.768	27.41	0.952	17.981	25.07
22"	22	1.294	19.256	37	1.158	19.545	33.162	1.048	19.779	30.33
24"	24	1.412	21.007	44.031	1.263	21.322	39.47	1.143	21.577	36.1
26"	26	1.529	22.758	51.856	1.368	23.099	46.701	1.238	23.375	42.486
28"	28	1.647	24.508	60.154	1.474	24.876	54.189	1.333	25.173	49.266
30"	30	1.765	26.259	69.068	1.579	26.653	62.196	1.429	26.971	56.585
32"	32	1.882	28.009	78.557	1.684	28.429	70.755	1.524	28.77	64.37
34"	34	2	29.76	88.7	1.789	30.206	79.865	1.619	30.568	72.657
36"	36	2.118	31.511	99.457	1.895	31.983	89.571	1.714	32.366	81.446
42"	42	2.471	36.762	135.372	2.211	37.314	121.925	2	37.76	110.874
48"	48	2.824	42.014	176.813	2.526	42.644	159.198	2.286	43.154	144.833
54"	54	3.176	47.266	223.713	2.842	47.975	201.502	2.571	48.549	183.253
1600mm/63"	62.99	3.706	55.143	303.398	3.315	55.97	273.362	3	56.631	249.57
1800mm	70.87	4.169	62.029	Call	---	---	---	3.375	63.712	Call
2000mm	78.74	4.632	68.921	Call	---	---	---	3.75	70.791	Call
2250mm	88.58	5.211	77.536	Call	---	---	---	4.218	79.64	Call
2500mm	98.43	5.79	86.151	Call	---	---	---	4.687	88.489	Call
2720mm	107.1	---	---	---	---	---	---	5.1	96.6	Call
2800mm	110.2	---	---	---	---	---	---	5.3	99.4	Call
3000mm	118.1	---	---	---	---	---	---	5.6	106.5	Call
3500mm	137.8	---	---	---	---	---	---	6.6	124.3	Call

1. Pressures are based on using water at 23°C (73°F).
2. Average inside diameter calculated using actual OD and minimum wall plus 6% for use in estimating fluid flows. Actual ID will vary.
3. Other piping sizes or DR's may be available upon request.
4. Standard Lengths
   - 40' for 2"-24"
   - 50' for 26" and larger
   - Coils available for ¾ - 4" (6" by special order)

ASTM MATERIALS

August 31, 2023
File No. 25222260.00

TECHNICAL MEMORANDUM

ANALYSIS BY: Niko Villanueva

REVIEWED BY: Deb Nelson
Keith Gilkey
Phil Gearing

SUBJECT: Slope Stability Analyses
Plan of Operation 2023 Update
Columbia Dry Ash Disposal Facility

PURPOSE

The purposes of the slope stability analyses were to evaluate:

- The final 4H:1V final cover slope in Module 12/Module 13 at the highest final cover grade.
- The interim 3H:1V waste slope in Modules 12/13 at the highest waste grade.
- The access road over 4H:1V final cover slope through Module 6.

CONCLUSION

The attached results confirm that the interim waste slopes will be stable during the construction and operation of the disposal facility modules and that the final grade slope, as well as the overlying access road, will be stable post-closure of the disposal facility.

APPROACH

SCS Engineers (SCS) evaluated the waste mass slope stability of Modules 12/13 during interim waste filling conditions at the most critical/highest waste grades. The Modules 12/13 interim 3H:1V waste slope analyzed is the northern filling face with a maximum waste fill height of approximately 122 feet above the base grade corresponding to a peak elevation of approximately 912 feet above mean sea level. The interim waste slopes were evaluated for block failure and optimized circular failure.

SCS completed analysis for this waste slope by iteratively modifying the coal combustion residual (CCR) friction angle to determine the minimum friction angle required for a safety factor of 1.3. This calculated CCR friction angle was used in the other analyzed sections. The calculated CCR friction angle of 23.5 degrees is still conservative based on assumed published values of stabilized CCR in the range of 35 to 45 degrees (see Reference 7).

SCS evaluated the final grade slope stability of longest final cover slope at the most critical/highest final grade cross-section within the Modules 12/13 footprint. The critical cross-section analyzed is through the Modules 12/ 13 waste mass with slope of 4H:1V, a maximum waste fill height of approximately 130 feet above base grades, and a peak elevation of approximately 938 feet above mean sea level. The final grade slope was evaluated for block failure and optimized circular failure.

SCS evaluated the final grade slope stability of the final grade access road. The critical cross section analyzed is through Module 6 final cover with slope of 4H:1V, and 1% slope under the access road. The shoulder of the access road has a 3H:1V slope. The access road was evaluated for block failure and optimized circular failure.

RESULTS

The calculated safety factors for each slope section and failure type are shown in the attached summary table.

SCS recommends a minimum safety factor of 1.3 for the interim waste slopes and 1.5 for the final grade slopes and the access road. The results indicate that the interim waste slopes and final grade slopes have acceptable minimum safety factors.

REFERENCES

1. SCS Engineers, Columbia Dry Ash Disposal Facility, Module 3 Liner Construction, 2016, existing composite liner grades and material properties for geosynthetics.

2. SCS Engineers, Columbia Dry Ash Disposal Facility, 2018 Module 4 Liner Construction, 2018, existing composite liner grades and material properties for subbase, clay, and drainage layer.

3. SCS Engineers, Columbia Dry Ash Disposal Facility, Module 5-6 Liner Construction, 2021, existing composite liner grades and material properties for subbase, clay, and drainage layer.

4. SCS Engineers, Columbia Dry Ash Disposal Facility, Plan of Operation 2022 Update, 2022, Module 10-11 composite liner grades, interim waste filling stages, and final grades.

5. TRI/Environmental, Interface Friction Test Results, 2016, for 2016 Module 3 Liner Construction, and Modules 1 and 2 Cover Construction.

6. TRI/Environmental, Consolidated-Undrained Triaxial Compression Test Results for FGD Material, 2015, material properties for CCR (SCS Project No. 25214049.00).

7. U.S. Department of Transportation, Federal Highway Administration, Recycled Materials, User Guidelines for Waste and Byproduct Materials in Pavement Construction.

8. Stabilization of FGD By-Products by Using Fly Ash, Cement, and Sialite, 2009 WOCA Conference.

9. Geo-Slope International, Ltd., GeoStudio 2023.1.2, Version 23.1.2.11, Slope/W slope stability software.

10. SCS Engineers, Plan Modification Request/Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Base Grade and Final Grade Plan Sheets, August 2023.

ASSUMPTIONS

- Sand drainage layers in each of the existing and future modules have the same properties.

- Geosynthetics installed for each of the module composite liners have the same properties.

- Clay material for each of the module composite liners have the same properties.

- CCR waste material will be the same in each of the existing and future modules.

- A waste fill slope of 3H:1V is representative of the design interim waste slopes.

- The groundwater elevation will remain below the elevation at the base of the landfill liner system.

- The access road vehicle is a John Deere 410 off-road haul truck with a fully loaded weight capacity of approximately 152,000 pounds. The surcharge load on the road will be 630 pcf over the truck width.

- The disposal facility will be operated to prevent development of liquid pressures, or seepage forces, within the waste, and there will be no buildup of leachate above the top of the drainage layer.

- The disposal facility will be operated to prevent placement of weak layers of waste within the overall waste mass.

- Optimized circular and sliding block failure stability analyses are appropriate to evaluate the waste interim grade, final grade, and access road slope stability.

- Material properties are as shown in the table below, based on the indicated references and assumed values based on experience. Friction angles for soils are conservative assumed values based on soil type, published typical values, and SCS experience. The CCR friction angle is a calculated conservative value that is in line with assumed published values, and the CCR unit weight is based on 2015 triaxial compression test results by TRI/Environmental for CCR.

Table 1. Material Properties Summary Table

Material	Unit Weight (pcf)	Friction Angle (degrees)	Cohesion (psf)	Reference
Subbase	120	30	0	1, 2, and 3
Clay	125	28	0	1, 2, and 3
Geosynthetics	58	24.3	0	5, 10
Drainage Layer	115	30	0	2 and 3
CCR	86	23.5(1)	0	6, 7, 8, and Calculation
Soil Barrier Layer	125	28	0	10
Geotextile	58	30	0	5, 10
Rooting Zone/Sand	120	30	0	10
Road Aggregate	135	35	0	10

Notes:
(1) CCR friction angle iteratively calculated for minimum value for a safety factor of 1.3 for Module 12/13 interim 3H:1V analysis. Calculated CCR friction angle was used in the other analyzed sections.

Attachments: Calculations organized as follows:
- Factor of Safety Summary Table
- Cross Section Locations
- Slope/W Outputs

NV/jsn/DLN/KRG/PEG

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Slope Stability Analysis
Factor of Safety Results Summary
Columbia Dry Ash Disposal Facility / SCS Project No. 25222260.00

Scenario Analyzed	Calculated Safety Factor	Recommended Minimum Safety Factor
Interim Waste Conditions (Module 12-13 Interim 3H:1V Waste Slope)		
Optimized Circular (Rotational Failure)	1.306(1)	1.300
Block (Translational Failure)	1.61	1.300
Final Grade (Module 12-13 Final Cover 4H:1V Slope)		
Optimized Circular (Rotational Failure)	1.745	1.500
Block (Translational Failure)	2.073	1.500
Access Road (Overlying 4H:1V Final Cover Slope)		
Optimized Circular (Rotational Failure)	1.709	1.500
Block (Translational Failure)	1.724	1.500

Notes:
1. Coal combustion residual (CCR) friction angle iteratively calculated for minimum value for a safety factor of 1.3.

Updated by: NV, 08/02/2023
Checked by: DLN, 08/30/2023

I:\25222260.00\Data and Calculations\Geotech Calculations\Slope Stability\2023 Tech Memo and Attachments\[A1_Slope Stability_FS Results Summary Table_230802.xlsx]FS Results Summary

DRAWN BY:	KRG	
CHECKED BY:	XX	
APPROVED BY:	XXX	
PROJECT NO.	PROJECT	
DRAWN:	05/17/18	
REVISED:	08/28/23	

WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

Wisconsin Power and Light Company

CLIENT

SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

ENGINEER

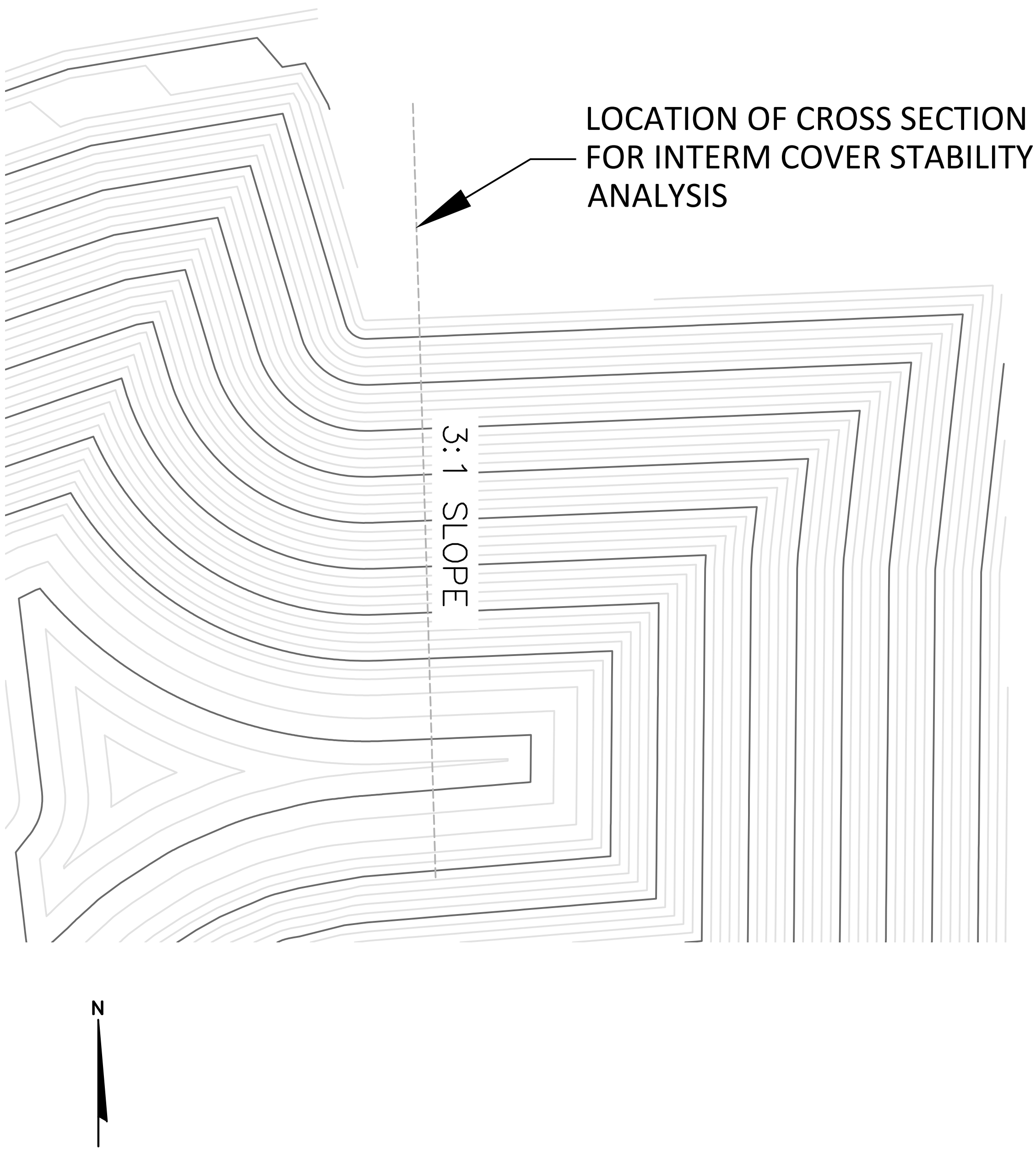
PLAN OF OPERATION UPDATE
COLUMBIA ENERGY CENTER
COLUMBIA DRY ASH DISPOSAL FACILITY
TOWN OF PACIFIC, WISCONSIN

SITE

STABILITY ANALYSIS CROSS SECTION LOCATIONS

STAMP

FIGURE
E1



CLIENT	WISCONSIN POWER AND LIGHT COMPANY COLUMBIA ENERGY CENTER W8375 MURRAY ROAD PARDEEVILLE, WI 53954	SITE	PLAN OF OPERATION UPDATE COLUMBIA DRY ASH DISPOSAL FACILITY TOWN OF PACIFIC, WISCONSIN

LOCATION OF INTERM
GRADES STABILITY ANALYSIS
CROSS SECTION

PROJECT NO.	25222260.00	DRAWN BY:	KRG
DRAWN:	08/02/2022	CHECKED BY:	DLN
REVISED:	08/28/2023	APPROVED BY:	PEG

ENGINEER
SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

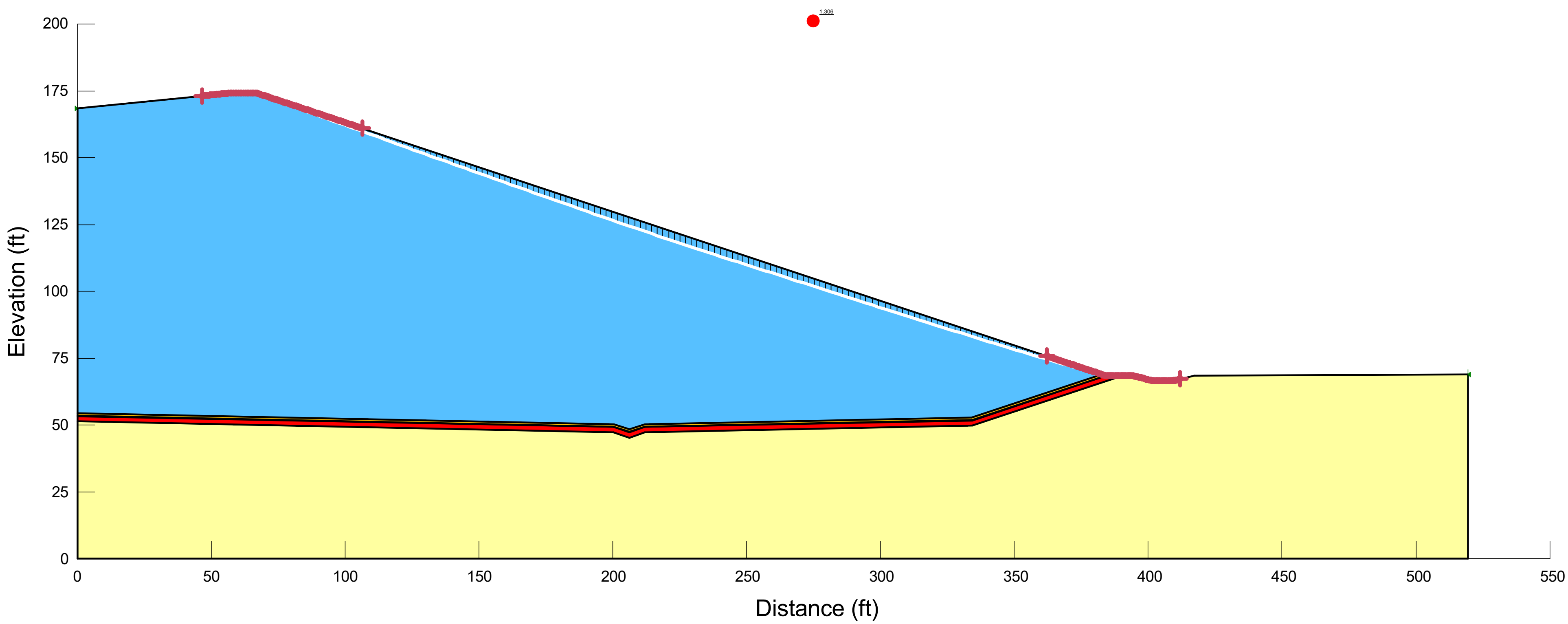
FIGURE
E2

I:\25222260.00\Data and Calculations\Geotech Calculations\Slope Stability\E2-Interim Slope Section.dwg, 8/28/2023 2:18:55 PM

Title: Columbia Mod 12-13 Interim Conditions
Name: Optimized Circular_FS=1.3
Method: Bishop
Last Edited By: Villanueva, Niko

F of S: 1.306
F of S Rank (Analysis): 1 of 51,006 slip surfaces
Last Solved Date: 8/2/2023, Last Solved Time: 3:30:24 PM

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Drainage Layer	Mohr-Coulomb	115	0	30
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Subbase	Mohr-Coulomb	120	0	30



Optimized Circular_FS=1.3

File Information

- File Version: 11.05
- Title: Columbia Mod 12-13 Interim Condi ons 3:1 Slope
- Created By: Villanueva, Niko
- Last Edited By: Gilkey, Keith
- Revision Number: 27
- Date: 08/07/2023
- Time: 09:58:32 AM
- Tool Version: 23.1.1.829
- File Name: COL_Mod12-13_Interim Condi ons.gsz
- Directory: I:\25222260.00\Data and Calcula ons\Geotech Calcula ons\Slope Stability\SlopeW\
- Last Solved Date: 08/28/2023
- Last Solved Time: 01:19:10 PM

Project Settings

- Unit System: U.S. Customary Units

Analysis Settings

Optimized Circular_FS=1.3

- Kind: SLOPE/W
- Analysis Type: Bishop
- Se ngs
  - PWP Condi ons from: (none)
  - Unit Weight of Water: 62.4 pcf
- Slip Surface
  - Direc on of movement: Le. to Right
  - Use Passive Mode: No
  - Slip Surface Op⍰on: Entry and Exit
  - Cri⍰cal slip surfaces saved: 10
  - Op⍰mize Cri⍰cal Slip Surface Loca⍰on: Yes
  - Op⍰miza⍰ons Se⍰ ngs
    - Maximum Itera⍰ons: 2,000
    - Star⍰ng Points: 8
    - Ending Points: 16
    - Driving Side Maximum Convex Angle: 5 °
    - Resis⍰ng Side Maximum Convex Angle: 1 °
  - Tension Crack Op⍰on: (none)
- Distribu⍰on
  - F of S Calcula⍰on Op⍰on: Constant
- Convergence
  - Geometry Se⍰ ngs
    - Minimum Slip Surface Depth: 0.1 ft
    - Number of Columns: 150
  - Factor of Safety Convergence Se⍰ ngs

Maximum Number of Itera⍰ons: 20,000
Tolerable difference in F of S: 0.001

Materials

CCR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 23.5 °
Phi-B: 0 °

Clay

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 28 °
Phi-B: 0 °

Drainage Layer

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Geosynthetics

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 24.3 °
Phi-B: 0 °

Subbase

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (46.59062, 173.12871) ft
Left-Zone Right Coordinate: (106.54318, 161) ft
Left-Zone Increment: 100
Right Type: Range
Right-Zone Left Coordinate: (362.19284, 75.78345) ft
Right-Zone Right Coordinate: (412, 67.22491) ft
Right-Zone Increment: 100
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 168.49196) ft
Right Coordinate: (519.45834, 68.88205) ft

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	0 ft	51.34809 ft
Point 2	200.19951 ft	47.31405 ft
Point 3	206.14741 ft	45.33145 ft
Point 4	212.095 ft	47.31198 ft
Point 5	334.29245 ft	49.73507 ft
Point 6	390.42013 ft	68.42378 ft
Point 7	390.59413 ft	68.42454 ft
Point 8	394.34772 ft	68.44017 ft
Point 9	401.75147 ft	66.62062 ft
Point 10	409.75552 ft	66.6544 ft
Point 11	417.15984 ft	68.53647 ft
Point 12	519.45834 ft	68.88205 ft
Point 13	519.45834 ft	0 ft
Point 14	0 ft	0 ft
Point 15	0 ft	54.44831 ft
Point 16	0 ft	53.44811 ft
Point 17	200.21671 ft	49.41372 ft
Point 18	206.14743 ft	47.43686 ft
Point 19	212.07782 ft	49.41166 ft
Point 20	334.27528 ft	51.83475 ft
Point 21	384.18447 ft	68.4529 ft
Point 22	382.60264 ft	68.98018 ft
Point 23	334.10353 ft	52.83154 ft
Point 24	211.90606 ft	50.40845 ft
Point 25	206.14759 ft	48.49089 ft
Point 26	200.38878 ft	50.41046 ft
Point 27	0 ft	53.34809 ft
Point 28	200.19951 ft	49.31405 ft
Point 29	206.14741 ft	47.33145 ft
Point 30	212.095 ft	49.31198 ft
Point 31	334.29245 ft	51.73507 ft
Point 32	384.34265 ft	68.40018 ft
Point 33	386.24265 ft	68.40557 ft
Point 34	386.24265 ft	67.50557 ft
Point 35	386.34265 ft	67.50557 ft

Point 36	386.34265 ft	68.40601 ft
Point 37	386.34265 ft	68.50557 ft
Point 38	384.34265 ft	68.50557 ft
Point 39	0 ft	168.49196 ft
Point 40	66.5815 ft	174.32056 ft
Point 41	58.24521 ft	174.28859 ft

Regions

	Material	Points	Area
Region 1	Subbase	1,2,3,4,5,6,7,8,9,10,11,12,13,14	28,504 ft^2
Region 2	Drainage Layer	15,16,17,18,19,20,21,22,23,24,25,26	386.75 ft^2
Region 3	Geosynthe⍰cs	16,27,28,29,30,31,32,33,34,35,36,37,38,21,20,19,18,17	39.07 ft^2
Region 4	Clay	27,1,2,3,4,5,6,36,35,34,33,32,31,30,29,28	774.67 ft^2
Region 5	CCR	39,15,26,25,24,23,22,40,41	29,542 ft^2

Slip Results

Slip Surfaces Analysed: 46903 of 51006 converged

Current Slip Surface

Slip Surface: 51,006
Factor of Safety: 1.306
Volume: 695.49644 ft^3
Weight: 59,812.727 lbf
Resis⍰ng Moment: 50,841,807 lbf·ft
Ac⍰va⍰ng Moment: 38,936,047 lbf·ft
Resis⍰ng Force: 23,408.102 lbf
Ac⍰va⍰ng Force: 17,938.848 lbf
Slip Rank: 1 of 51,006 slip surfaces
Exit: (382.78319, 68.919998) ft
Entry: (66.579471, 174.32055) ft
Radius: 153.07166 ft
Center: (885.3998, 2,069.3162) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Fric⍰onal Strength	Cohesive Strength	Suc⍰on Strength	Base Material
Column 1	66.58049 ft	174.32017 ft	0 psf	0.029738458 psf	0.01293065 psf	0 psf	0 psf	CCR
Column 2	67.73459 ft	173.88130 ft	0 psf	4.1901142 psf	1.8219135 psf	0 psf	0 psf	CCR
Column 3	70.04078 ft	173.00435 ft	0 psf	12.451389 psf	5.4140179 psf	0 psf	0 psf	CCR
Column 4	72.34697 ft	172.12740 ft	0 psf	20.712663 psf	9.0061223 psf	0 psf	0 psf	CCR
Column 5	74.65315 ft	171.25045 ft	0 psf	28.973938 psf	12.598227 psf	0 psf	0 psf	CCR
Column 6	76.95934 ft	170.37350 ft	0 psf	37.235212 psf	16.190331 psf	0 psf	0 psf	CCR
Column	79.20885	169.54584	0	43.500805	18.914688	0 psf	0 psf	CCR

7	ft	ft	psf	psf	psf			
Column 8	81.40169 ft	168.76748 ft	0 psf	47.147318 psf	20.500237 psf	0 psf	0 psf	CCR
Column 9	83.59454 ft	167.98912 ft	0 psf	50.793832 psf	22.085787 psf	0 psf	0 psf	CCR
Column 10	85.78738 ft	167.21076 ft	0 psf	54.440346 psf	23.671336 psf	0 psf	0 psf	CCR
Column 11	87.98022 ft	166.43240 ft	0 psf	58.086859 psf	25.256885 psf	0 psf	0 psf	CCR
Column 12	90.17307 ft	165.65404 ft	0 psf	61.733373 psf	26.842434 psf	0 psf	0 psf	CCR
Column 13	92.36591 ft	164.87568 ft	0 psf	65.379887 psf	28.427984 psf	0 psf	0 psf	CCR
Column 14	94.55875 ft	164.09732 ft	0 psf	69.0264 psf	30.013533 psf	0 psf	0 psf	CCR
Column 15	96.75159 ft	163.31896 ft	0 psf	72.672914 psf	31.599082 psf	0 psf	0 psf	CCR
Column 16	98.94444 ft	162.54060 ft	0 psf	76.319427 psf	33.184631 psf	0 psf	0 psf	CCR
Column 17	101.13728 ft	161.76224 ft	0 psf	79.965941 psf	34.770181 psf	0 psf	0 psf	CCR
Column 18	103.30055 ft	160.98728 ft	0 psf	83.94283 psf	36.499381 psf	0 psf	0 psf	CCR
Column 19	105.43426 ft	160.21572 ft	0 psf	88.573452 psf	38.512833 psf	0 psf	0 psf	CCR
Column 20	107.56797 ft	159.44415 ft	0 psf	93.204074 psf	40.526285 psf	0 psf	0 psf	CCR
Column 21	109.70168 ft	158.67259 ft	0 psf	97.834696 psf	42.539737 psf	0 psf	0 psf	CCR
Column 22	111.83538 ft	157.90103 ft	0 psf	102.46532 psf	44.553188 psf	0 psf	0 psf	CCR
Column 23	113.96909 ft	157.12946 ft	0 psf	107.09594 psf	46.56664 psf	0 psf	0 psf	CCR
Column 24	116.10280 ft	156.35790 ft	0 psf	111.72656 psf	48.580092 psf	0 psf	0 psf	CCR
Column 25	118.23651 ft	155.58634 ft	0 psf	116.35718 psf	50.593544 psf	0 psf	0 psf	CCR
Column 26	120.37022 ft	154.81477 ft	0 psf	120.98781 psf	52.606996 psf	0 psf	0 psf	CCR
Column 27	122.50392 ft	154.04321 ft	0 psf	125.61843 psf	54.620448 psf	0 psf	0 psf	CCR
Column 28	124.63763 ft	153.27165 ft	0 psf	130.24905 psf	56.633899 psf	0 psf	0 psf	CCR
Column 29	126.77134 ft	152.50008 ft	0 psf	134.87967 psf	58.647351 psf	0 psf	0 psf	CCR
Column 30	128.90505 ft	151.72852 ft	0 psf	139.5103 psf	60.660803 psf	0 psf	0 psf	CCR
Column 31	131.03527 ft	150.96444 ft	0 psf	143.90592 psf	62.572076 psf	0 psf	0 psf	CCR
Column 32	133.16201 ft	150.20785 ft	0 psf	147.57233 psf	64.166276 psf	0 psf	0 psf	CCR
Column 33	135.28874 ft	149.45125 ft	0 psf	151.23874 psf	65.760477 psf	0 psf	0 psf	CCR

Column 34	137.41548 ft	148.69466 ft	0 psf	154.90515 psf	67.354677 psf	0 psf	0 psf	CCR
Column 35	139.54222 ft	147.93806 ft	0 psf	158.57156 psf	68.948877 psf	0 psf	0 psf	CCR
Column 36	141.66895 ft	147.18147 ft	0 psf	162.23797 psf	70.543077 psf	0 psf	0 psf	CCR
Column 37	143.79569 ft	146.42487 ft	0 psf	165.90438 psf	72.137278 psf	0 psf	0 psf	CCR
Column 38	145.92243 ft	145.66828 ft	0 psf	169.57079 psf	73.731478 psf	0 psf	0 psf	CCR
Column 39	148.04916 ft	144.91168 ft	0 psf	173.2372 psf	75.325678 psf	0 psf	0 psf	CCR
Column 40	150.17590 ft	144.15509 ft	0 psf	176.90361 psf	76.919878 psf	0 psf	0 psf	CCR
Column 41	152.30264 ft	143.39850 ft	0 psf	180.57002 psf	78.514079 psf	0 psf	0 psf	CCR
Column 42	154.42937 ft	142.64190 ft	0 psf	184.23643 psf	80.108279 psf	0 psf	0 psf	CCR
Column 43	156.55611 ft	141.88531 ft	0 psf	187.90284 psf	81.702479 psf	0 psf	0 psf	CCR
Column 44	158.68285 ft	141.12871 ft	0 psf	191.56925 psf	83.29668 psf	0 psf	0 psf	CCR
Column 45	160.80958 ft	140.37212 ft	0 psf	195.23566 psf	84.89088 psf	0 psf	0 psf	CCR
Column 46	162.93632 ft	139.61552 ft	0 psf	198.90207 psf	86.48508 psf	0 psf	0 psf	CCR
Column 47	165.06306 ft	138.85893 ft	0 psf	202.56848 psf	88.07928 psf	0 psf	0 psf	CCR
Column 48	167.18979 ft	138.10233 ft	0 psf	206.23489 psf	89.673481 psf	0 psf	0 psf	CCR
Column 49	169.31653 ft	137.34574 ft	0 psf	209.9013 psf	91.267681 psf	0 psf	0 psf	CCR
Column 50	171.38820 ft	136.61143 ft	0 psf	213.43539 psf	92.804351 psf	0 psf	0 psf	CCR
Column 51	173.40481 ft	135.89940 ft	0 psf	216.50015 psf	94.136944 psf	0 psf	0 psf	CCR
Column 52	175.42142 ft	135.18737 ft	0 psf	219.5649 psf	95.469538 psf	0 psf	0 psf	CCR
Column 53	177.43802 ft	134.47534 ft	0 psf	222.62966 psf	96.802131 psf	0 psf	0 psf	CCR
Column 54	179.45463 ft	133.76331 ft	0 psf	225.69441 psf	98.134724 psf	0 psf	0 psf	CCR
Column 55	181.47124 ft	133.05128 ft	0 psf	228.75917 psf	99.467318 psf	0 psf	0 psf	CCR
Column 56	183.55171 ft	132.32028 ft	0 psf	231.87626 psf	100.82267 psf	0 psf	0 psf	CCR
Column 57	185.69605 ft	131.57029 ft	0 psf	234.58812 psf	102.00182 psf	0 psf	0 psf	CCR
Column 58	187.84039 ft	130.82031 ft	0 psf	237.29998 psf	103.18097 psf	0 psf	0 psf	CCR
Column 59	189.98473 ft	130.07032 ft	0 psf	240.01184 psf	104.36012 psf	0 psf	0 psf	CCR

Column 60	192.12907 ft	129.32034 ft	0 psf	242.72369 psf	105.53927 psf	0 psf	0 psf	CCR
Column 61	194.27341 ft	128.57035 ft	0 psf	245.43555 psf	106.71842 psf	0 psf	0 psf	CCR
Column 62	196.41774 ft	127.82037 ft	0 psf	248.14741 psf	107.89756 psf	0 psf	0 psf	CCR
Column 63	198.56208 ft	127.07038 ft	0 psf	250.85927 psf	109.07671 psf	0 psf	0 psf	CCR
Column 64	200.70642 ft	126.32040 ft	0 psf	253.57113 psf	110.25586 psf	0 psf	0 psf	CCR
Column 65	202.85076 ft	125.57041 ft	0 psf	256.28298 psf	111.43501 psf	0 psf	0 psf	CCR
Column 66	204.99510 ft	124.82043 ft	0 psf	258.99484 psf	112.61416 psf	0 psf	0 psf	CCR
Column 67	207.13944 ft	124.07044 ft	0 psf	261.7067 psf	113.79331 psf	0 psf	0 psf	CCR
Column 68	209.26771 ft	123.34386 ft	0 psf	264.3559 psf	114.94522 psf	0 psf	0 psf	CCR
Column 69	211.37990 ft	122.64068 ft	0 psf	264.28736 psf	114.91541 psf	0 psf	0 psf	CCR
Column 70	213.49209 ft	121.93750 ft	0 psf	264.21881 psf	114.88561 psf	0 psf	0 psf	CCR
Column 71	215.60428 ft	121.23433 ft	0 psf	264.15027 psf	114.85581 psf	0 psf	0 psf	CCR
Column 72	217.71647 ft	120.53115 ft	0 psf	264.08172 psf	114.826 psf	0 psf	0 psf	CCR
Column 73	219.82866 ft	119.82797 ft	0 psf	264.01318 psf	114.7962 psf	0 psf	0 psf	CCR
Column 74	221.94085 ft	119.12479 ft	0 psf	263.94463 psf	114.76639 psf	0 psf	0 psf	CCR
Column 75	224.05305 ft	118.42161 ft	0 psf	263.87609 psf	114.73659 psf	0 psf	0 psf	CCR
Column 76	226.16524 ft	117.71843 ft	0 psf	263.80754 psf	114.70678 psf	0 psf	0 psf	CCR
Column 77	228.27743 ft	117.01525 ft	0 psf	263.739 psf	114.67698 psf	0 psf	0 psf	CCR
Column 78	230.38962 ft	116.31208 ft	0 psf	263.67045 psf	114.64717 psf	0 psf	0 psf	CCR
Column 79	232.50181 ft	115.60890 ft	0 psf	263.60191 psf	114.61737 psf	0 psf	0 psf	CCR
Column 80	234.61400 ft	114.90572 ft	0 psf	263.53336 psf	114.58757 psf	0 psf	0 psf	CCR
Column 81	236.81778 ft	114.17639 ft	0 psf	263.42442 psf	114.5402 psf	0 psf	0 psf	CCR
Column 82	239.11312 ft	113.42092 ft	0 psf	262.677 psf	114.21521 psf	0 psf	0 psf	CCR
Column 83	241.40848 ft	112.66545 ft	0 psf	261.92958 psf	113.89022 psf	0 psf	0 psf	CCR
Column 84	243.57960 ft	111.96250 ft	0 psf	261.21188 psf	113.57816 psf	0 psf	0 psf	CCR
Column 85	245.62650 ft	111.31209 ft	0 psf	258.7319 psf	112.49983 psf	0 psf	0 psf	CCR

Column 86	247.67341 ft	110.66168 ft	0 psf	256.25192 psf	111.42151 psf	0 psf	0 psf	CCR
Column 87	249.72031 ft	110.01126 ft	0 psf	253.77194 psf	110.34318 psf	0 psf	0 psf	CCR
Column 88	251.76721 ft	109.36085 ft	0 psf	251.29196 psf	109.26485 psf	0 psf	0 psf	CCR
Column 89	253.81411 ft	108.71044 ft	0 psf	248.81198 psf	108.18653 psf	0 psf	0 psf	CCR
Column 90	255.86102 ft	108.06003 ft	0 psf	246.332 psf	107.1082 psf	0 psf	0 psf	CCR
Column 91	257.90792 ft	107.40961 ft	0 psf	243.85202 psf	106.02988 psf	0 psf	0 psf	CCR
Column 92	259.95482 ft	106.75920 ft	0 psf	241.37204 psf	104.95155 psf	0 psf	0 psf	CCR
Column 93	262.00172 ft	106.10879 ft	0 psf	238.89206 psf	103.87322 psf	0 psf	0 psf	CCR
Column 94	264.04862 ft	105.45837 ft	0 psf	236.41208 psf	102.7949 psf	0 psf	0 psf	CCR
Column 95	266.09553 ft	104.80796 ft	0 psf	233.9321 psf	101.71657 psf	0 psf	0 psf	CCR
Column 96	268.14243 ft	104.15755 ft	0 psf	231.45212 psf	100.63825 psf	0 psf	0 psf	CCR
Column 97	270.18933 ft	103.50714 ft	0 psf	228.97214 psf	99.559919 psf	0 psf	0 psf	CCR
Column 98	272.23623 ft	102.85672 ft	0 psf	226.49216 psf	98.481593 psf	0 psf	0 psf	CCR
Column 99	274.28314 ft	102.20631 ft	0 psf	224.01218 psf	97.403267 psf	0 psf	0 psf	CCR
Column 100	276.33004 ft	101.55590 ft	0 psf	221.5322 psf	96.324941 psf	0 psf	0 psf	CCR
Column 101	278.42490 ft	100.88613 ft	0 psf	219.06082 psf	95.250357 psf	0 psf	0 psf	CCR
Column 102	280.56772 ft	100.19701 ft	0 psf	217.10705 psf	94.400834 psf	0 psf	0 psf	CCR
Column 103	282.71054 ft	99.50788 ft	0 psf	215.15328 psf	93.55131 psf	0 psf	0 psf	CCR
Column 104	284.85336 ft	98.81876 ft	0 psf	213.19951 psf	92.701787 psf	0 psf	0 psf	CCR
Column 105	286.99618 ft	98.12964 ft	0 psf	211.24574 psf	91.852264 psf	0 psf	0 psf	CCR
Column 106	289.13900 ft	97.44052 ft	0 psf	209.29197 psf	91.00274 psf	0 psf	0 psf	CCR
Column 107	291.28182 ft	96.75139 ft	0 psf	207.3382 psf	90.153217 psf	0 psf	0 psf	CCR
Column 108	293.42464 ft	96.06227 ft	0 psf	205.38443 psf	89.303693 psf	0 psf	0 psf	CCR
Column 109	295.71917 ft	95.32194 ft	0 psf	203.35924 psf	88.423116 psf	0 psf	0 psf	CCR
Column 110	298.16540 ft	94.53041 ft	0 psf	201.50547 psf	87.617072 psf	0 psf	0 psf	CCR
Column 111	300.61163 ft	93.73888 ft	0 psf	199.6517 psf	86.811028 psf	0 psf	0 psf	CCR

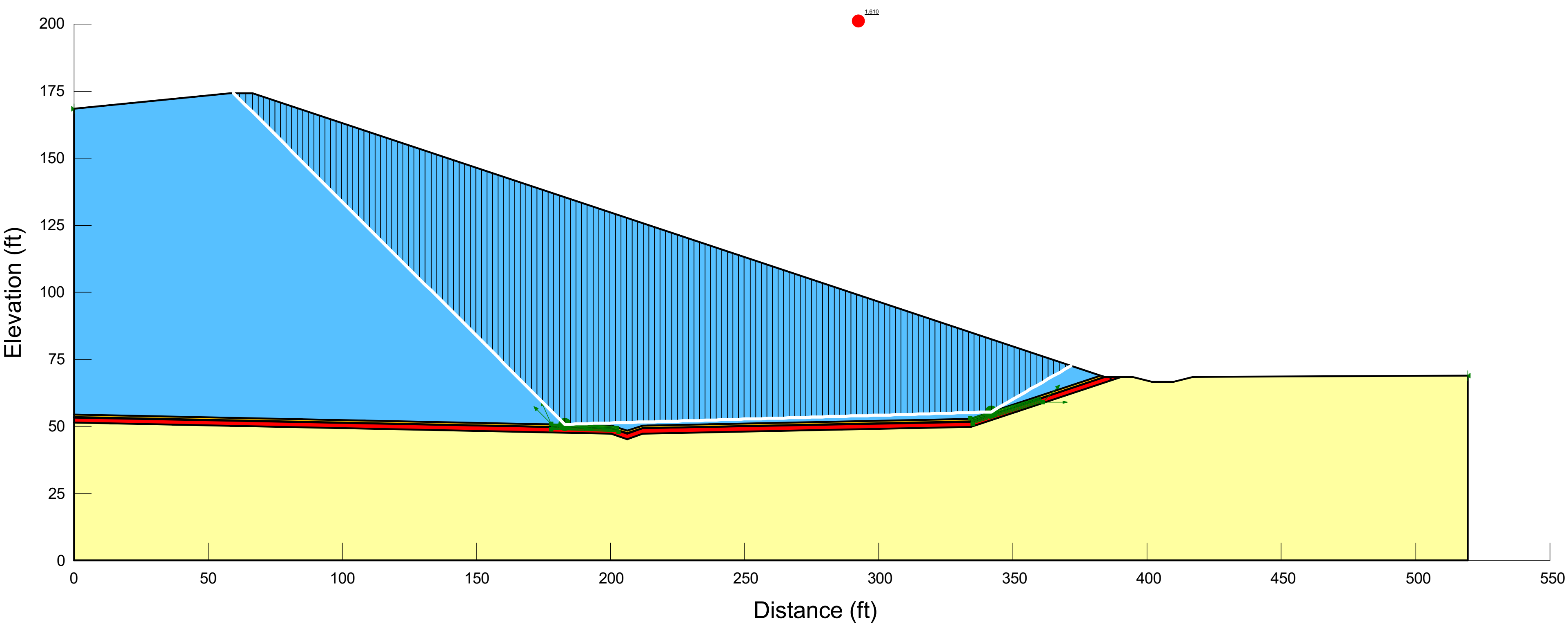
Column 112	302.91346 ft	93.00204 ft	0 psf	197.7276 psf	85.974406 psf	0 psf	0 psf	CCR
Column 113	305.07088 ft	92.31991 ft	0 psf	194.84809 psf	84.722359 psf	0 psf	0 psf	CCR
Column 114	307.22831 ft	91.63778 ft	0 psf	191.96857 psf	83.470312 psf	0 psf	0 psf	CCR
Column 115	309.38573 ft	90.95564 ft	0 psf	189.08906 psf	82.218264 psf	0 psf	0 psf	CCR
Column 116	311.54315 ft	90.27351 ft	0 psf	186.20955 psf	80.966217 psf	0 psf	0 psf	CCR
Column 117	313.70057 ft	89.59138 ft	0 psf	183.33004 psf	79.71417 psf	0 psf	0 psf	CCR
Column 118	315.85800 ft	88.90924 ft	0 psf	180.45053 psf	78.462122 psf	0 psf	0 psf	CCR
Column 119	318.01542 ft	88.22711 ft	0 psf	177.57102 psf	77.210075 psf	0 psf	0 psf	CCR
Column 120	320.17284 ft	87.54498 ft	0 psf	174.6915 psf	75.958028 psf	0 psf	0 psf	CCR
Column 121	322.33026 ft	86.86284 ft	0 psf	171.81199 psf	74.705981 psf	0 psf	0 psf	CCR
Column 122	324.48769 ft	86.18071 ft	0 psf	168.93248 psf	73.453933 psf	0 psf	0 psf	CCR
Column 123	326.64511 ft	85.49858 ft	0 psf	166.05297 psf	72.201886 psf	0 psf	0 psf	CCR
Column 124	328.77373 ft	84.83343 ft	0 psf	162.96735 psf	70.860218 psf	0 psf	0 psf	CCR
Column 125	330.87355 ft	84.18526 ft	0 psf	158.92995 psf	69.104708 psf	0 psf	0 psf	CCR
Column 126	332.97337 ft	83.53709 ft	0 psf	154.89255 psf	67.349198 psf	0 psf	0 psf	CCR
Column 127	335.07320 ft	82.88892 ft	0 psf	150.85516 psf	65.593688 psf	0 psf	0 psf	CCR
Column 128	337.17302 ft	82.24075 ft	0 psf	146.81776 psf	63.838178 psf	0 psf	0 psf	CCR
Column 129	339.27284 ft	81.59258 ft	0 psf	142.78036 psf	62.082668 psf	0 psf	0 psf	CCR
Column 130	341.37266 ft	80.94441 ft	0 psf	138.74297 psf	60.327158 psf	0 psf	0 psf	CCR
Column 131	343.47248 ft	80.29624 ft	0 psf	134.70557 psf	58.571648 psf	0 psf	0 psf	CCR
Column 132	345.57230 ft	79.64807 ft	0 psf	130.66817 psf	56.816138 psf	0 psf	0 psf	CCR
Column 133	347.67213 ft	78.99990 ft	0 psf	126.63078 psf	55.060628 psf	0 psf	0 psf	CCR
Column 134	349.77195 ft	78.35173 ft	0 psf	122.59338 psf	53.305118 psf	0 psf	0 psf	CCR
Column 135	351.87177 ft	77.70356 ft	0 psf	118.55598 psf	51.549608 psf	0 psf	0 psf	CCR
Column 136	353.98692 ft	77.06536 ft	0 psf	113.81717 psf	49.489113 psf	0 psf	0 psf	CCR
Column 137	356.11740 ft	76.43712 ft	0 psf	107.40211 psf	46.699767 psf	0 psf	0 psf	CCR

Column 138	358.24789 ft	75.80887 ft	0 psf	100.98706 psf	43.910421 psf	0 psf	0 psf	CCR
Column 139	360.37837 ft	75.18063 ft	0 psf	94.572 psf	41.121076 psf	0 psf	0 psf	CCR
Column 140	362.50885 ft	74.55239 ft	0 psf	88.156945 psf	38.33173 psf	0 psf	0 psf	CCR
Column 141	364.63933 ft	73.92414 ft	0 psf	81.741889 psf	35.542385 psf	0 psf	0 psf	CCR
Column 142	366.76981 ft	73.29590 ft	0 psf	75.326834 psf	32.753039 psf	0 psf	0 psf	CCR
Column 143	368.90030 ft	72.66765 ft	0 psf	68.911778 psf	29.963694 psf	0 psf	0 psf	CCR
Column 144	371.03078 ft	72.03941 ft	0 psf	62.496723 psf	27.174348 psf	0 psf	0 psf	CCR
Column 145	373.14453 ft	71.45006 ft	0 psf	54.002694 psf	23.48104 psf	0 psf	0 psf	CCR
Column 146	375.24156 ft	70.89961 ft	0 psf	42.253635 psf	18.372403 psf	0 psf	0 psf	CCR
Column 147	377.33859 ft	70.34916 ft	0 psf	30.504575 psf	13.263767 psf	0 psf	0 psf	CCR
Column 148	379.43562 ft	69.79871 ft	0 psf	18.755516 psf	8.1551303 psf	0 psf	0 psf	CCR
Column 149	381.54339 ft	69.24543 ft	0 psf	6.9462823 psf	3.0203295 psf	0 psf	0 psf	CCR
Column 150	382.69291 ft	68.94369 ft	0 psf	0.6589839 psf	0.38046453 psf	0 psf	0 psf	Drainage Layer

Title: Columbia Mod 12-13 Interim Conditions
Name: Block_FS=1.3
Method: Janbu
Last Edited By: Villanueva, Niko

F of S: 1.610
F of S Rank (Analysis): 1 of 234,256 slip surfaces
Last Solved Date: 8/2/2023, Last Solved Time: 3:33:10 PM

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Drainage Layer	Mohr-Coulomb	115	0	30
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Subbase	Mohr-Coulomb	120	0	30



Block_FS=1.3

File Information

File Version: 11.05
Title: Columbia Mod 12-13 Interim Condi ons 3:1 Slope
Created By: Villanueva, Niko
Last Edited By: Gilkey, Keith
Revision Number: 27
Date: 08/07/2023
Time: 09:58:32 AM
Tool Version: 23.1.1.829
File Name: COL_Mod12-13_Interim Condi ons.gsz
Directory: I:\25222260.00\Data and Calcula ons\Geotech Calcula ons\Slope Stability\SlopeW\
Last Solved Date: 08/28/2023
Last Solved Time: 01:23:04 PM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

Block_FS=1.3

Kind: SLOPE/W
Analysis Type: Janbu
Se ngs
PWP Condi ons from: (none)
Unit Weight of Water: 62.4 pcf
Slip Surface
Direc on of movement: Le. to Right
Use Passive Mode: No
Slip Surface Op⍰on: Block
Cri⍰cal slip surfaces saved: 10
Restrict Block Crossing: No
Op⍰mize Cri⍰cal Slip Surface Loca⍰on: No
Tension Crack Op⍰on: (none)
Distribu⍰on
F of S Calcula⍰on Op⍰on: Constant
Convergence
Geometry Se⍰ ngs
Minimum Slip Surface Depth: 0.1 ft
Number of Columns: 150
Factor of Safety Convergence Se⍰ ngs
Maximum Number of Itera⍰ons: 100
Tolerable difference in F of S: 0.001

Materials

CCR
Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 23.5 °
Phi-B: 0 °

Clay
Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 28 °
Phi-B: 0 °

Drainage Layer
Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 30 °
Phi-B: 0 °

Geosynthetics
Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 24.3 °
Phi-B: 0 °

Subbase
Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 30 °
Phi-B: 0 °

Slip Surface Limits
Left Coordinate: (0, 168.49196) ft
Right Coordinate: (519.45834, 68.88205) ft

Slip Surface Block
Left Grid
- Upper Left: (178, 51) ft
- Lower Left: (178, 49) ft
- Lower Right: (203, 48) ft
- X Increments: 10
- Y Increments: 10
- Starting Angle: 115 °
- Ending Angle: 135 °

Angle Increments: 3

Right Grid

Star�ng Angle: 0 °

Ending Angle: 45 °

Upper Left: (334, 53) ft

Lower Left: (335, 51) ft

Lower Right: (361, 59) ft

X Increments: 10

Y Increments: 10

Angle Increments: 3

Geometry

Name: Default Geometry

Settings

View: 2D

Element Thickness: 1 ft

Points

	X	Y
Point 1	0 ft	51.34809 ft
Point 2	200.19951 ft	47.31405 ft
Point 3	206.14741 ft	45.33145 ft
Point 4	212.095 ft	47.31198 ft
Point 5	334.29245 ft	49.73507 ft
Point 6	390.42013 ft	68.42378 ft
Point 7	390.59413 ft	68.42454 ft
Point 8	394.34772 ft	68.44017 ft
Point 9	401.75147 ft	66.62062 ft
Point 10	409.75552 ft	66.6544 ft
Point 11	417.15984 ft	68.53647 ft
Point 12	519.45834 ft	68.88205 ft
Point 13	519.45834 ft	0 ft
Point 14	0 ft	0 ft
Point 15	0 ft	54.44831 ft
Point 16	0 ft	53.44811 ft
Point 17	200.21671 ft	49.41372 ft
Point 18	206.14743 ft	47.43686 ft
Point 19	212.07782 ft	49.41166 ft
Point 20	334.27528 ft	51.83475 ft
Point 21	384.18447 ft	68.4529 ft
Point 22	382.60264 ft	68.98018 ft
Point 23	334.10353 ft	52.83154 ft
Point 24	211.90606 ft	50.40845 ft
Point 25	206.14759 ft	48.49089 ft
Point 26	200.38878 ft	50.41046 ft
Point 27	0 ft	53.34809 ft
Point 28	200.19951 ft	49.31405 ft
Point 29	206.14741 ft	47.33145 ft

Point 30	212.095 ft	49.31198 ft
Point 31	334.29245 ft	51.73507 ft
Point 32	384.34265 ft	68.40018 ft
Point 33	386.24265 ft	68.40557 ft
Point 34	386.24265 ft	67.50557 ft
Point 35	386.34265 ft	67.50557 ft
Point 36	386.34265 ft	68.40601 ft
Point 37	386.34265 ft	68.50557 ft
Point 38	384.34265 ft	68.50557 ft
Point 39	0 ft	168.49196 ft
Point 40	66.5815 ft	174.32056 ft
Point 41	58.24521 ft	174.28859 ft

Regions

	Material	Points	Area
Region 1	Subbase	1,2,3,4,5,6,7,8,9,10,11,12,13,14	28,504 ft²
Region 2	Drainage Layer	15,16,17,18,19,20,21,22,23,24,25,26	386.75 ft²
Region 3	Geosynthetics	16,27,28,29,30,31,32,33,34,35,36,37,38,21,20,19,18,17	39.07 ft²
Region 4	Clay	27,1,2,3,4,5,6,36,35,34,33,32,31,30,29,28	774.67 ft²
Region 5	CCR	39,15,26,25,24,23,22,40,41	29,542 ft²

Slip Results

Slip Surfaces Analysed: 175692 of 234256 converged

Current Slip Surface

Slip Surface: 218,739
Factor of Safety: 1.610
Volume: 14,659.824 ft³
Weight: 1,260,744.9 lbf
Resisting Moment: 71,899,110 lbf·ft
Activating Moment: 41,317,828 lbf·ft
Resisting Force: 510,914.88 lbf
Activating Force: 317,436.82 lbf
Slip Rank: 1 of 234,256 slip surfaces
Exit: (371.64688, 72.632102) ft
Entry: (59.506573, 174.29343) ft
Radius: 171.79774 ft
Center: (240.40937, 199.70876) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Column 1	60.68573 ft	173.11427 ft	0 psf	80.15187 psf	34.851025 psf	0 psf	0 psf	CCR
Column 2	63.04404 ft	170.75596 ft	0 psf	240.45561 psf	104.55307 psf	0 psf	0 psf	CCR
Column 3	65.40235 ft	168.39765 ft	0 psf	400.75935 psf	174.25512 psf	0 psf	0 psf	CCR

Column 4	67.62095 ft	166.17905 ft	0 psf	527.83503 psf	229.5092 psf	0 psf	0 psf	CCR
Column 5	69.69985 ft	164.10015 ft	0 psf	621.68266 psf	270.31531 psf	0 psf	0 psf	CCR
Column 6	71.77875 ft	162.02125 ft	0 psf	715.53028 psf	311.12142 psf	0 psf	0 psf	CCR
Column 7	73.85766 ft	159.94234 ft	0 psf	809.37791 psf	351.92753 psf	0 psf	0 psf	CCR
Column 8	75.93656 ft	157.86344 ft	0 psf	903.22553 psf	392.73364 psf	0 psf	0 psf	CCR
Column 9	78.01546 ft	155.78454 ft	0 psf	997.07316 psf	433.53975 psf	0 psf	0 psf	CCR
Column 10	80.09436 ft	153.70564 ft	0 psf	1,090.9208 psf	474.34586 psf	0 psf	0 psf	CCR
Column 11	82.17326 ft	151.62674 ft	0 psf	1,184.7684 psf	515.15196 psf	0 psf	0 psf	CCR
Column 12	84.25217 ft	149.54783 ft	0 psf	1,278.616 psf	555.95807 psf	0 psf	0 psf	CCR
Column 13	86.33107 ft	147.46893 ft	0 psf	1,372.4637 psf	596.76418 psf	0 psf	0 psf	CCR
Column 14	88.40997 ft	145.39003 ft	0 psf	1,466.3113 psf	637.57029 psf	0 psf	0 psf	CCR
Column 15	90.48887 ft	143.31113 ft	0 psf	1,560.1589 psf	678.3764 psf	0 psf	0 psf	CCR
Column 16	92.56777 ft	141.23223 ft	0 psf	1,654.0065 psf	719.18251 psf	0 psf	0 psf	CCR
Column 17	94.64667 ft	139.15333 ft	0 psf	1,747.8542 psf	759.98862 psf	0 psf	0 psf	CCR
Column 18	96.72558 ft	137.07442 ft	0 psf	1,841.7018 psf	800.79472 psf	0 psf	0 psf	CCR
Column 19	98.80448 ft	134.99552 ft	0 psf	1,935.5494 psf	841.60083 psf	0 psf	0 psf	CCR
Column 20	100.88338 ft	132.91662 ft	0 psf	2,029.397 psf	882.40694 psf	0 psf	0 psf	CCR
Column 21	102.96228 ft	130.83772 ft	0 psf	2,123.2447 psf	923.21305 psf	0 psf	0 psf	CCR
Column 22	105.04118 ft	128.75882 ft	0 psf	2,217.0923 psf	964.01916 psf	0 psf	0 psf	CCR
Column 23	107.12008 ft	126.67992 ft	0 psf	2,310.9399 psf	1,004.8253 psf	0 psf	0 psf	CCR
Column 24	109.19899 ft	124.60101 ft	0 psf	2,404.7875 psf	1,045.6314 psf	0 psf	0 psf	CCR
Column 25	111.27789 ft	122.52211 ft	0 psf	2,498.6352 psf	1,086.4375 psf	0 psf	0 psf	CCR
Column 26	113.35679 ft	120.44321 ft	0 psf	2,592.4828 psf	1,127.2436 psf	0 psf	0 psf	CCR
Column 27	115.43569 ft	118.36431 ft	0 psf	2,686.3304 psf	1,168.0497 psf	0 psf	0 psf	CCR
Column 28	117.51459 ft	116.28541 ft	0 psf	2,780.178 psf	1,208.8558 psf	0 psf	0 psf	CCR
Column 29	119.59350 ft	114.20650 ft	0 psf	2,874.0257 psf	1,249.6619 psf	0 psf	0 psf	CCR

Column 30	121.67240 ft	112.12760 ft	0 psf	2,967.8733 psf	1,290.468 psf	0 psf	0 psf	CCR
Column 31	123.75130 ft	110.04870 ft	0 psf	3,061.7209 psf	1,331.2741 psf	0 psf	0 psf	CCR
Column 32	125.83020 ft	107.96980 ft	0 psf	3,155.5685 psf	1,372.0802 psf	0 psf	0 psf	CCR
Column 33	127.90910 ft	105.89090 ft	0 psf	3,249.4162 psf	1,412.8864 psf	0 psf	0 psf	CCR
Column 34	129.98800 ft	103.81200 ft	0 psf	3,343.2638 psf	1,453.6925 psf	0 psf	0 psf	CCR
Column 35	132.06691 ft	101.73309 ft	0 psf	3,437.1114 psf	1,494.4986 psf	0 psf	0 psf	CCR
Column 36	134.14581 ft	99.65419 ft	0 psf	3,530.959 psf	1,535.3047 psf	0 psf	0 psf	CCR
Column 37	136.22471 ft	97.57529 ft	0 psf	3,624.8067 psf	1,576.1108 psf	0 psf	0 psf	CCR
Column 38	138.30361 ft	95.49639 ft	0 psf	3,718.6543 psf	1,616.9169 psf	0 psf	0 psf	CCR
Column 39	140.38251 ft	93.41749 ft	0 psf	3,812.5019 psf	1,657.723 psf	0 psf	0 psf	CCR
Column 40	142.46142 ft	91.33858 ft	0 psf	3,906.3495 psf	1,698.5291 psf	0 psf	0 psf	CCR
Column 41	144.54032 ft	89.25968 ft	0 psf	4,000.1972 psf	1,739.3352 psf	0 psf	0 psf	CCR
Column 42	146.61922 ft	87.18078 ft	0 psf	4,094.0448 psf	1,780.1413 psf	0 psf	0 psf	CCR
Column 43	148.69812 ft	85.10188 ft	0 psf	4,187.8924 psf	1,820.9474 psf	0 psf	0 psf	CCR
Column 44	150.77702 ft	83.02298 ft	0 psf	4,281.74 psf	1,861.7535 psf	0 psf	0 psf	CCR
Column 45	152.85592 ft	80.94408 ft	0 psf	4,375.5876 psf	1,902.5597 psf	0 psf	0 psf	CCR
Column 46	154.93483 ft	78.86517 ft	0 psf	4,469.4353 psf	1,943.3658 psf	0 psf	0 psf	CCR
Column 47	157.01373 ft	76.78627 ft	0 psf	4,563.2829 psf	1,984.1719 psf	0 psf	0 psf	CCR
Column 48	159.09263 ft	74.70737 ft	0 psf	4,657.1305 psf	2,024.978 psf	0 psf	0 psf	CCR
Column 49	161.17153 ft	72.62847 ft	0 psf	4,750.9781 psf	2,065.7841 psf	0 psf	0 psf	CCR
Column 50	163.25043 ft	70.54957 ft	0 psf	4,844.8258 psf	2,106.5902 psf	0 psf	0 psf	CCR
Column 51	165.32933 ft	68.47067 ft	0 psf	4,938.6734 psf	2,147.3963 psf	0 psf	0 psf	CCR
Column 52	167.40824 ft	66.39176 ft	0 psf	5,032.521 psf	2,188.2024 psf	0 psf	0 psf	CCR
Column 53	169.48714 ft	64.31286 ft	0 psf	5,126.3686 psf	2,229.0085 psf	0 psf	0 psf	CCR
Column 54	171.56604 ft	62.23396 ft	0 psf	5,220.2163 psf	2,269.8146 psf	0 psf	0 psf	CCR
Column 55	173.64494 ft	60.15506 ft	0 psf	5,314.0639 psf	2,310.6207 psf	0 psf	0 psf	CCR

Column 56	175.72384 ft	58.07616 ft	0 psf	5,407.9115 psf	2,351.4269 psf	0 psf	0 psf	CCR
Column 57	177.80275 ft	55.99725 ft	0 psf	5,501.7591 psf	2,392.233 psf	0 psf	0 psf	CCR
Column 58	179.88165 ft	53.91835 ft	0 psf	5,595.6068 psf	2,433.0391 psf	0 psf	0 psf	CCR
Column 59	181.96055 ft	51.83945 ft	0 psf	5,689.4544 psf	2,473.8452 psf	0 psf	0 psf	CCR
Column 60	184.04474 ft	50.83026 ft	0 psf	7,310.068 psf	3,178.508 psf	0 psf	0 psf	CCR
Column 61	186.13421 ft	50.89079 ft	0 psf	7,244.4513 psf	3,149.9771 psf	0 psf	0 psf	CCR
Column 62	188.22368 ft	50.95132 ft	0 psf	7,178.8345 psf	3,121.4461 psf	0 psf	0 psf	CCR
Column 63	190.31316 ft	51.01184 ft	0 psf	7,113.2177 psf	3,092.9151 psf	0 psf	0 psf	CCR
Column 64	192.40263 ft	51.07237 ft	0 psf	7,047.6009 psf	3,064.3841 psf	0 psf	0 psf	CCR
Column 65	194.49211 ft	51.13289 ft	0 psf	6,981.9841 psf	3,035.8531 psf	0 psf	0 psf	CCR
Column 66	196.58158 ft	51.19342 ft	0 psf	6,916.3673 psf	3,007.3221 psf	0 psf	0 psf	CCR
Column 67	198.67105 ft	51.25395 ft	0 psf	6,850.7505 psf	2,978.7911 psf	0 psf	0 psf	CCR
Column 68	200.76053 ft	51.31447 ft	0 psf	6,785.1337 psf	2,950.2601 psf	0 psf	0 psf	CCR
Column 69	202.85000 ft	51.37500 ft	0 psf	6,719.517 psf	2,921.7291 psf	0 psf	0 psf	CCR
Column 70	204.93947 ft	51.43553 ft	0 psf	6,653.9002 psf	2,893.1981 psf	0 psf	0 psf	CCR
Column 71	207.02895 ft	51.49605 ft	0 psf	6,588.2834 psf	2,864.6671 psf	0 psf	0 psf	CCR
Column 72	209.11842 ft	51.55658 ft	0 psf	6,522.6666 psf	2,836.1362 psf	0 psf	0 psf	CCR
Column 73	211.20789 ft	51.61711 ft	0 psf	6,457.0498 psf	2,807.6052 psf	0 psf	0 psf	CCR
Column 74	213.29737 ft	51.67763 ft	0 psf	6,391.433 psf	2,779.0742 psf	0 psf	0 psf	CCR
Column 75	215.38684 ft	51.73816 ft	0 psf	6,325.8162 psf	2,750.5432 psf	0 psf	0 psf	CCR
Column 76	217.47632 ft	51.79868 ft	0 psf	6,260.1995 psf	2,722.0122 psf	0 psf	0 psf	CCR
Column 77	219.56579 ft	51.85921 ft	0 psf	6,194.5827 psf	2,693.4812 psf	0 psf	0 psf	CCR
Column 78	221.65526 ft	51.91974 ft	0 psf	6,128.9659 psf	2,664.9502 psf	0 psf	0 psf	CCR
Column 79	223.74474 ft	51.98026 ft	0 psf	6,063.3491 psf	2,636.4192 psf	0 psf	0 psf	CCR
Column 80	225.83421 ft	52.04079 ft	0 psf	5,997.7323 psf	2,607.8882 psf	0 psf	0 psf	CCR
Column 81	227.92368 ft	52.10132 ft	0 psf	5,932.1155 psf	2,579.3572 psf	0 psf	0 psf	CCR

Column 82	230.01316 ft	52.16184 ft	0 psf	5,866.4987 psf	2,550.8262 psf	0 psf	0 psf	CCR
Column 83	232.10263 ft	52.22237 ft	0 psf	5,800.8819 psf	2,522.2953 psf	0 psf	0 psf	CCR
Column 84	234.19211 ft	52.28289 ft	0 psf	5,735.2652 psf	2,493.7643 psf	0 psf	0 psf	CCR
Column 85	236.28158 ft	52.34342 ft	0 psf	5,669.6484 psf	2,465.2333 psf	0 psf	0 psf	CCR
Column 86	238.37105 ft	52.40395 ft	0 psf	5,604.0316 psf	2,436.7023 psf	0 psf	0 psf	CCR
Column 87	240.46053 ft	52.46447 ft	0 psf	5,538.4148 psf	2,408.1713 psf	0 psf	0 psf	CCR
Column 88	242.55000 ft	52.52500 ft	0 psf	5,472.798 psf	2,379.6403 psf	0 psf	0 psf	CCR
Column 89	244.63947 ft	52.58553 ft	0 psf	5,407.1812 psf	2,351.1093 psf	0 psf	0 psf	CCR
Column 90	246.72895 ft	52.64605 ft	0 psf	5,341.5644 psf	2,322.5783 psf	0 psf	0 psf	CCR
Column 91	248.81842 ft	52.70658 ft	0 psf	5,275.9477 psf	2,294.0473 psf	0 psf	0 psf	CCR
Column 92	250.90789 ft	52.76711 ft	0 psf	5,210.3309 psf	2,265.5163 psf	0 psf	0 psf	CCR
Column 93	252.99737 ft	52.82763 ft	0 psf	5,144.7141 psf	2,236.9853 psf	0 psf	0 psf	CCR
Column 94	255.08684 ft	52.88816 ft	0 psf	5,079.0973 psf	2,208.4544 psf	0 psf	0 psf	CCR
Column 95	257.17632 ft	52.94868 ft	0 psf	5,013.4805 psf	2,179.9234 psf	0 psf	0 psf	CCR
Column 96	259.26579 ft	53.00921 ft	0 psf	4,947.8637 psf	2,151.3924 psf	0 psf	0 psf	CCR
Column 97	261.35526 ft	53.06974 ft	0 psf	4,882.2469 psf	2,122.8614 psf	0 psf	0 psf	CCR
Column 98	263.44474 ft	53.13026 ft	0 psf	4,816.6301 psf	2,094.3304 psf	0 psf	0 psf	CCR
Column 99	265.53421 ft	53.19079 ft	0 psf	4,751.0134 psf	2,065.7994 psf	0 psf	0 psf	CCR
Column 100	267.62368 ft	53.25132 ft	0 psf	4,685.3966 psf	2,037.2684 psf	0 psf	0 psf	CCR
Column 101	269.71316 ft	53.31184 ft	0 psf	4,619.7798 psf	2,008.7374 psf	0 psf	0 psf	CCR
Column 102	271.80263 ft	53.37237 ft	0 psf	4,554.163 psf	1,980.2064 psf	0 psf	0 psf	CCR
Column 103	273.89211 ft	53.43289 ft	0 psf	4,488.5462 psf	1,951.6754 psf	0 psf	0 psf	CCR
Column 104	275.98158 ft	53.49342 ft	0 psf	4,422.9294 psf	1,923.1444 psf	0 psf	0 psf	CCR
Column 105	278.07105 ft	53.55395 ft	0 psf	4,357.3126 psf	1,894.6135 psf	0 psf	0 psf	CCR
Column 106	280.16053 ft	53.61447 ft	0 psf	4,291.6959 psf	1,866.0825 psf	0 psf	0 psf	CCR
Column 107	282.25000 ft	53.67500 ft	0 psf	4,226.0791 psf	1,837.5515 psf	0 psf	0 psf	CCR

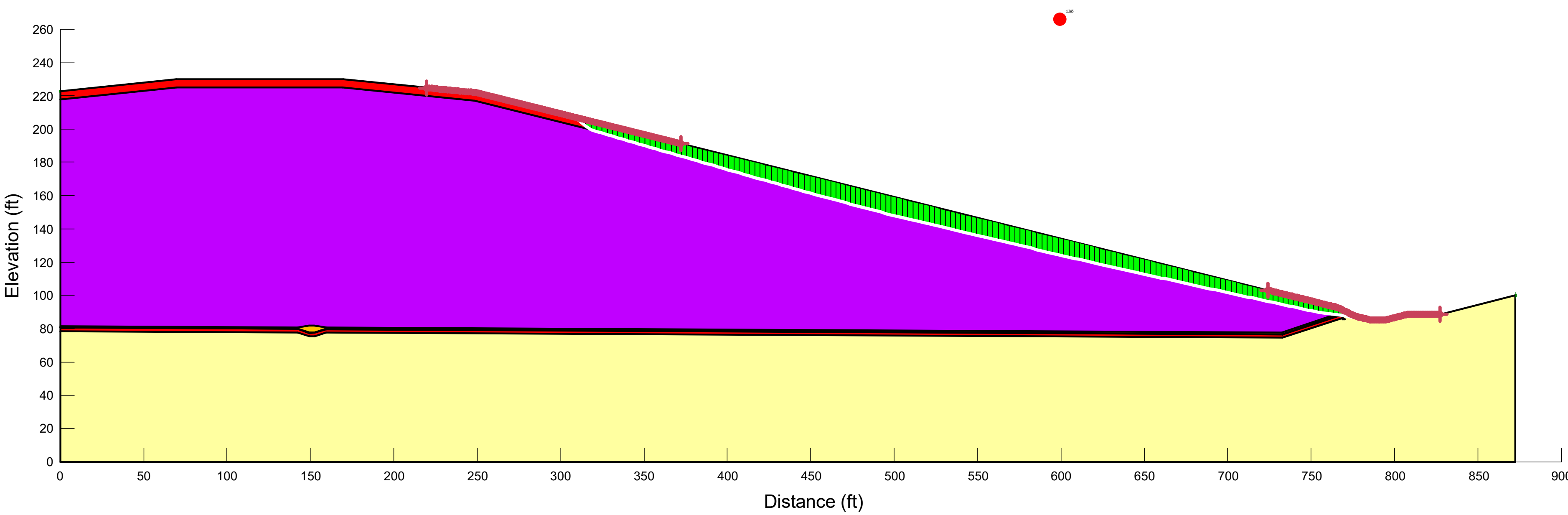
Column 108	284.33947 ft	53.73553 ft	0 psf	4,160.4623 psf	1,809.0205 psf	0 psf	0 psf	CCR
Column 109	286.42895 ft	53.79605 ft	0 psf	4,094.8455 psf	1,780.4895 psf	0 psf	0 psf	CCR
Column 110	288.51842 ft	53.85658 ft	0 psf	4,029.2287 psf	1,751.9585 psf	0 psf	0 psf	CCR
Column 111	290.60789 ft	53.91711 ft	0 psf	3,963.6119 psf	1,723.4275 psf	0 psf	0 psf	CCR
Column 112	292.69737 ft	53.97763 ft	0 psf	3,897.9951 psf	1,694.8965 psf	0 psf	0 psf	CCR
Column 113	294.78684 ft	54.03816 ft	0 psf	3,832.3783 psf	1,666.3655 psf	0 psf	0 psf	CCR
Column 114	296.87632 ft	54.09868 ft	0 psf	3,766.7616 psf	1,637.8345 psf	0 psf	0 psf	CCR
Column 115	298.96579 ft	54.15921 ft	0 psf	3,701.1448 psf	1,609.3035 psf	0 psf	0 psf	CCR
Column 116	301.05526 ft	54.21974 ft	0 psf	3,635.528 psf	1,580.7726 psf	0 psf	0 psf	CCR
Column 117	303.14474 ft	54.28026 ft	0 psf	3,569.9112 psf	1,552.2416 psf	0 psf	0 psf	CCR
Column 118	305.23421 ft	54.34079 ft	0 psf	3,504.2944 psf	1,523.7106 psf	0 psf	0 psf	CCR
Column 119	307.32368 ft	54.40132 ft	0 psf	3,438.6776 psf	1,495.1796 psf	0 psf	0 psf	CCR
Column 120	309.41316 ft	54.46184 ft	0 psf	3,373.0608 psf	1,466.6486 psf	0 psf	0 psf	CCR
Column 121	311.50263 ft	54.52237 ft	0 psf	3,307.444 psf	1,438.1176 psf	0 psf	0 psf	CCR
Column 122	313.59211 ft	54.58289 ft	0 psf	3,241.8273 psf	1,409.5866 psf	0 psf	0 psf	CCR
Column 123	315.68158 ft	54.64342 ft	0 psf	3,176.2105 psf	1,381.0556 psf	0 psf	0 psf	CCR
Column 124	317.77105 ft	54.70395 ft	0 psf	3,110.5937 psf	1,352.5246 psf	0 psf	0 psf	CCR
Column 125	319.86053 ft	54.76447 ft	0 psf	3,044.9769 psf	1,323.9936 psf	0 psf	0 psf	CCR
Column 126	321.95000 ft	54.82500 ft	0 psf	2,979.3601 psf	1,295.4626 psf	0 psf	0 psf	CCR
Column 127	324.03947 ft	54.88553 ft	0 psf	2,913.7433 psf	1,266.9317 psf	0 psf	0 psf	CCR
Column 128	326.12895 ft	54.94605 ft	0 psf	2,848.1265 psf	1,238.4007 psf	0 psf	0 psf	CCR
Column 129	328.21842 ft	55.00658 ft	0 psf	2,782.5098 psf	1,209.8697 psf	0 psf	0 psf	CCR
Column 130	330.30789 ft	55.06711 ft	0 psf	2,716.893 psf	1,181.3387 psf	0 psf	0 psf	CCR
Column 131	332.39737 ft	55.12763 ft	0 psf	2,651.2762 psf	1,152.8077 psf	0 psf	0 psf	CCR
Column 132	334.48684 ft	55.18816 ft	0 psf	2,585.6594 psf	1,124.2767 psf	0 psf	0 psf	CCR
Column 133	336.57632 ft	55.24868 ft	0 psf	2,520.0426 psf	1,095.7457 psf	0 psf	0 psf	CCR

Column 134	338.66579 ft	55.30921 ft	0 psf	2,454.4258 psf	1,067.2147 psf	0 psf	0 psf	CCR
Column 135	340.75526 ft	55.36974 ft	0 psf	2,388.809 psf	1,038.6837 psf	0 psf	0 psf	CCR
Column 136	342.86596 ft	56.01543 ft	0 psf	2,670.429 psf	1,161.1356 psf	0 psf	0 psf	CCR
Column 137	344.99788 ft	57.24630 ft	0 psf	2,472.6194 psf	1,075.1255 psf	0 psf	0 psf	CCR
Column 138	347.12980 ft	58.47716 ft	0 psf	2,274.8099 psf	989.11549 psf	0 psf	0 psf	CCR
Column 139	349.26172 ft	59.70803 ft	0 psf	2,077.0003 psf	903.10544 psf	0 psf	0 psf	CCR
Column 140	351.39364 ft	60.93889 ft	0 psf	1,879.1908 psf	817.0954 psf	0 psf	0 psf	CCR
Column 141	353.52556 ft	62.16975 ft	0 psf	1,681.3812 psf	731.08536 psf	0 psf	0 psf	CCR
Column 142	355.65748 ft	63.40062 ft	0 psf	1,483.5717 psf	645.07532 psf	0 psf	0 psf	CCR
Column 143	357.78940 ft	64.63148 ft	0 psf	1,285.7621 psf	559.06528 psf	0 psf	0 psf	CCR
Column 144	359.92132 ft	65.86235 ft	0 psf	1,087.9526 psf	473.05523 psf	0 psf	0 psf	CCR
Column 145	362.05324 ft	67.09321 ft	0 psf	890.143 psf	387.04519 psf	0 psf	0 psf	CCR
Column 146	364.18516 ft	68.32408 ft	0 psf	692.33344 psf	301.03515 psf	0 psf	0 psf	CCR
Column 147	366.31708 ft	69.55494 ft	0 psf	494.52389 psf	215.02511 psf	0 psf	0 psf	CCR
Column 148	368.44900 ft	70.78580 ft	0 psf	296.71433 psf	129.01506 psf	0 psf	0 psf	CCR
Column 149	370.58092 ft	72.01667 ft	0 psf	98.904777 psf	43.005021 psf	0 psf	0 psf	CCR

Title: Columbia Mod 12-13 Full Buildout
Name: Optimized Circular_FS=1.5
Method: Bishop
Last Edited By: Villanueva, Niko

F of S: 1.745
F of S Rank (Analysis): 1 of 51,006 slip surfaces
Last Solved Date: 08/30/2023, Last Solved Time: 07:35:34 AM

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Drainage Layer	Mohr-Coulomb	115	0	30
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Subbase	Mohr-Coulomb	120	0	30



Optimized Circular_FS=1.5

File Information

File Version: 11.05
Title: Columbia Mod 12-13 Full Buildout
Created By: Villanueva, Niko
Last Edited By: Villanueva, Niko
Revision Number: 56
Date: 08/30/2023
Time: 07:34:03 AM
Tool Version: 23.1.1.829
File Name: COL_Mod12-13_Full Buildout.gsz
Directory: I:\25222260.00\Data and Calcula ons\Geotech Calcula ons\Slope Stability\SlopeW\
Last Solved Date: 08/30/2023
Last Solved Time: 07:35:34 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

Optimized Circular_FS=1.5

Kind: SLOPE/W
Analysis Type: Bishop
Se ngs
PWP Condi ons from: (none)
Unit Weight of Water: 62.4 pcf
Slip Surface
Direc on of movement: Le. to Right
Use Passive Mode: No
Slip Surface Op�on: Entry and Exit
Cri�cal slip surfaces saved: 10
Op�mize Cri�cal Slip Surface Loca�on: Yes
Op�miza�ons Se� ngs
Maximum Itera�ons: 2,000
Star�ng Points: 8
Ending Points: 16
Driving Side Maximum Convex Angle: 5 °
Resis�ng Side Maximum Convex Angle: 1 °
Tension Crack Op�on: (none)
Distribu�on
F of S Calcula�on Op�on: Constant
Convergence
Geometry Se� ngs
Minimum Slip Surface Depth: 0.1 ft
Number of Columns: 150
Factor of Safety Convergence Se� ngs
Maximum Number of Itera�ons: 30,000
Tolerable difference in F of S: 0.001

Materials

CCR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effec�ve Cohesion: 0 psf

Effec⍰ve Fric⍰on Angle: 23.5 °
Phi-B: 0 °

Clay

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 28 °
Phi-B: 0 °

Drainage Layer

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Geosynthetics

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 24.3 °
Phi-B: 0 °

Subbase

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (219.68881, 224.73412) ft
Left-Zone Right Coordinate: (372.17498, 191.11662) ft
Left-Zone Increment: 100
Right Type: Range
Right-Zone Left Coordinate: (723.92456, 103.25913) ft
Right-Zone Right Coordinate: (827.14488, 88.78332) ft
Right-Zone Increment: 100
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 222.8) ft
Right Coordinate: (872.23081, 100) ft

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	768.91041 ft	87.74349 ft
Point 2	766.02664 ft	87.74317 ft
Point 3	732.66754 ft	76.62354 ft
Point 4	159.35647 ft	79.79909 ft

Point 5	152.46501 ft	77.58553 ft
Point 6	149.45787 ft	77.54639 ft
Point 7	142.29499 ft	79.95559 ft
Point 8	0 ft	80.72488 ft
Point 9	0 ft	78.63599 ft
Point 10	142.29493 ft	77.86789 ft
Point 11	149.45787 ft	75.41847 ft
Point 12	152.46501 ft	75.45626 ft
Point 13	159.35619 ft	77.75007 ft
Point 14	732.66724 ft	74.58984 ft
Point 15	768.91041 ft	86.64701 ft
Point 16	872.23081 ft	100 ft
Point 17	828.17946 ft	88.78332 ft
Point 18	808.17769 ft	88.78332 ft
Point 19	794.02935 ft	85.24543 ft
Point 20	786.03116 ft	85.24543 ft
Point 21	776.0289 ft	87.7443 ft
Point 22	769.01095 ft	87.8435 ft
Point 23	769.01041 ft	85.84317 ft
Point 24	770.01041 ft	85.84317 ft
Point 25	770.01041 ft	85.74351 ft
Point 26	768.91041 ft	85.74351 ft
Point 27	0 ft	0 ft
Point 28	872.23081 ft	0 ft
Point 29	764.03814 ft	88.23984 ft
Point 30	732.49201 ft	77.72453 ft
Point 31	159.6047 ft	80.8285 ft
Point 32	152.35619 ft	82.00202 ft
Point 33	148.97182 ft	82.00419 ft
Point 34	142.29493 ft	80.97938 ft
Point 35	0 ft	81.74787 ft
Point 36	0 ft	80.82487 ft
Point 37	142.31162 ft	80.0555 ft
Point 38	149.47361 ft	77.64661 ft
Point 39	152.44871 ft	77.68532 ft
Point 40	159.34108 ft	79.89918 ft
Point 41	732.65158 ft	76.72363 ft
Point 42	766.01041 ft	87.84317 ft
Point 43	249.53 ft	221.75 ft
Point 44	169.53 ft	229.75 ft
Point 45	69.53 ft	229.75 ft
Point 46	0 ft	222.8 ft
Point 47	0 ft	217.82 ft
Point 48	69.78 ft	224.75 ft
Point 49	169.28 ft	224.75 ft
Point 50	248.67 ft	216.81 ft
Point 51	769.01041 ft	87.84351 ft
Point 52	766.02664 ft	92.74317 ft
Point 53	766.02718 ft	87.74317 ft
Point 54	768.91095 ft	87.74349 ft
Point 55	768.91095 ft	85.7435 ft
Point 56	770.01095 ft	85.7435 ft
Point 57	770.01095 ft	85.84316 ft
Point 58	769.01095 ft	85.84316 ft
Point 59	766.01095 ft	87.84316 ft
Point 60	732.65213 ft	76.72363 ft
Point 61	159.34162 ft	79.89918 ft
Point 62	152.44925 ft	77.68532 ft

Point 63	149.47415 ft	77.6466 ft
Point 64	142.31216 ft	80.0555 ft
Point 65	142.29553 ft	79.95558 ft
Point 66	149.45841 ft	77.54639 ft
Point 67	152.46555 ft	77.58552 ft
Point 68	159.35701 ft	79.79909 ft
Point 69	732.66808 ft	76.62354 ft
Point 70	768.91095 ft	85.74351 ft
Point 71	770.01041 ft	85.84316 ft
Point 72	769.01095 ft	85.84317 ft
Point 73	732.65159 ft	76.72363 ft
Point 74	159.34161 ft	79.89918 ft
Point 75	149.4741 ft	77.64662 ft
Point 76	142.29501 ft	79.95558 ft
Point 77	149.45839 ft	77.5464 ft
Point 78	159.357 ft	79.79909 ft
Point 79	732.66755 ft	76.62354 ft

Regions

	Material	Points	Area
Region 1	Clay	1,53,69,79,3,68,78,67,66,77,6,76,8,9,10,11,12,13,14,15	1,576.1 ft²
Region 2	Subbase	16,17,18,19,20,21,22,72,24,71,57,56,55,70,26,15,14,13,12,11,10,9,27,28	68,366 ft²
Region 3	Drainage Layer	29,30,31,32,33,34,35,36,37,64,75,39,40,74,61,41,73,42	769.27 ft²
Region 4	Clay	43,44,45,46,47,48,49,50,29,42,51,22,21,52	3,896.4 ft²
Region 5	CCR	50,49,48,47,35,34,33,32,31,30,29	72,914 ft²
Region 6	Geosynthe�cs	53,1,54,70,55,56,57,71,58,72,22,59,60,73,41,61,74,62,63,75,64,37,36,8,76,65,77,66,67,78,68,3,79,69	77.457 ft²

Slip Results

Slip Surfaces Analysed: 39342 of 51006 converged

Current Slip Surface

Slip Surface: 51,006
Factor of Safety: 1.745
Volume: 4,009.1179 ft³
Weight: 435,365.84 lbf
Resis�ng Moment: 6.698018e+08 lbf·ft
Ac�va�ng Moment: 3.8392957e+08 lbf·ft
Resis�ng Force: 179,103.91 lbf
Ac�va�ng Force: 102,795.44 lbf
Slip Rank: 1 of 51,006 slip surfaces
Exit: (785.97288, 85.259989) ft
Entry: (308.50283, 207.02019) ft
Radius: 210.34059 ft
Center: (1,393.2702, 3,660.481) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Fric�onal Strength	Cohesive Strength	Suc�on Strength	Base Material
Column 1	310.14171 ft	205.75520 ft	0 psf	86.593136 psf	46.042387 psf	0 psf	0 psf	Clay
Column 2	313.41948 ft	203.22520 ft	0 psf	259.77941 psf	138.12716 psf	0 psf	0 psf	Clay

Column 3	316.70451 ft	200.68961 ft	0 psf	433.34934 psf	230.41593 psf	0 psf	0 psf	Clay
Column 4	319.95630 ft	198.94705 ft	0 psf	604.21909 psf	262.72194 psf	0 psf	0 psf	CCR
Column 5	323.16761 ft	198.00312 ft	0 psf	615.54908 psf	267.64836 psf	0 psf	0 psf	CCR
Column 6	326.37891 ft	197.05920 ft	0 psf	626.87907 psf	272.57478 psf	0 psf	0 psf	CCR
Column 7	329.59021 ft	196.11527 ft	0 psf	638.20907 psf	277.5012 psf	0 psf	0 psf	CCR
Column 8	332.80152 ft	195.17134 ft	0 psf	649.53906 psf	282.42762 psf	0 psf	0 psf	CCR
Column 9	336.01282 ft	194.22742 ft	0 psf	660.86906 psf	287.35404 psf	0 psf	0 psf	CCR
Column 10	339.22413 ft	193.28349 ft	0 psf	672.19905 psf	292.28046 psf	0 psf	0 psf	CCR
Column 11	342.43543 ft	192.33957 ft	0 psf	683.52904 psf	297.20689 psf	0 psf	0 psf	CCR
Column 12	345.64674 ft	191.39564 ft	0 psf	694.85904 psf	302.13331 psf	0 psf	0 psf	CCR
Column 13	348.85804 ft	190.45171 ft	0 psf	706.18903 psf	307.05973 psf	0 psf	0 psf	CCR
Column 14	352.06934 ft	189.50779 ft	0 psf	717.51902 psf	311.98615 psf	0 psf	0 psf	CCR
Column 15	355.28065 ft	188.56386 ft	0 psf	728.84902 psf	316.91257 psf	0 psf	0 psf	CCR
Column 16	358.45208 ft	187.63799 ft	0 psf	740.22605 psf	321.85945 psf	0 psf	0 psf	CCR
Column 17	361.58365 ft	186.73018 ft	0 psf	750.2683 psf	326.22594 psf	0 psf	0 psf	CCR
Column 18	364.71522 ft	185.82237 ft	0 psf	760.31055 psf	330.59243 psf	0 psf	0 psf	CCR
Column 19	367.84679 ft	184.91456 ft	0 psf	770.3528 psf	334.95893 psf	0 psf	0 psf	CCR
Column 20	370.97836 ft	184.00675 ft	0 psf	780.39504 psf	339.32542 psf	0 psf	0 psf	CCR
Column 21	374.10993 ft	183.09894 ft	0 psf	790.43729 psf	343.69192 psf	0 psf	0 psf	CCR
Column 22	377.24149 ft	182.19113 ft	0 psf	800.47954 psf	348.05841 psf	0 psf	0 psf	CCR
Column 23	380.37306 ft	181.28332 ft	0 psf	810.52179 psf	352.4249 psf	0 psf	0 psf	CCR
Column 24	383.50463 ft	180.37551 ft	0 psf	820.56404 psf	356.7914 psf	0 psf	0 psf	CCR
Column 25	386.63620 ft	179.46769 ft	0 psf	830.60629 psf	361.15789 psf	0 psf	0 psf	CCR
Column 26	389.76777 ft	178.55988 ft	0 psf	840.64854 psf	365.52439 psf	0 psf	0 psf	CCR
Column 27	392.89934 ft	177.65207 ft	0 psf	850.69079 psf	369.89088 psf	0 psf	0 psf	CCR
Column 28	396.03091 ft	176.74426 ft	0 psf	860.73303 psf	374.25737 psf	0 psf	0 psf	CCR
Column 29	399.16247 ft	175.83645 ft	0 psf	870.77528 psf	378.62387 psf	0 psf	0 psf	CCR
Column 30	402.29404 ft	174.92864 ft	0 psf	880.81753 psf	382.99036 psf	0 psf	0 psf	CCR
Column 31	405.42561 ft	174.02083 ft	0 psf	890.85978 psf	387.35686 psf	0 psf	0 psf	CCR
Column 32	408.55718 ft	173.11302 ft	0 psf	900.90203 psf	391.72335 psf	0 psf	0 psf	CCR
Column 33	411.68875 ft	172.20521 ft	0 psf	910.94428 psf	396.08985 psf	0 psf	0 psf	CCR

Column 34	414.82032 ft	171.29740 ft	0 psf	920.98653 psf	400.45634 psf	0 psf	0 psf	CCR
Column 35	418.04195 ft	170.37935 ft	0 psf	932.12055 psf	405.29755 psf	0 psf	0 psf	CCR
Column 36	421.35365 ft	169.45106 ft	0 psf	940.21248 psf	408.81602 psf	0 psf	0 psf	CCR
Column 37	424.66535 ft	168.52277 ft	0 psf	948.30441 psf	412.33449 psf	0 psf	0 psf	CCR
Column 38	427.97705 ft	167.59449 ft	0 psf	956.39634 psf	415.85296 psf	0 psf	0 psf	CCR
Column 39	431.28875 ft	166.66620 ft	0 psf	964.48827 psf	419.37143 psf	0 psf	0 psf	CCR
Column 40	434.60045 ft	165.73791 ft	0 psf	972.5802 psf	422.88991 psf	0 psf	0 psf	CCR
Column 41	437.91214 ft	164.80963 ft	0 psf	980.67213 psf	426.40838 psf	0 psf	0 psf	CCR
Column 42	441.22384 ft	163.88134 ft	0 psf	988.76406 psf	429.92685 psf	0 psf	0 psf	CCR
Column 43	444.53554 ft	162.95305 ft	0 psf	996.85599 psf	433.44532 psf	0 psf	0 psf	CCR
Column 44	447.84724 ft	162.02477 ft	0 psf	1,004.9479 psf	436.96379 psf	0 psf	0 psf	CCR
Column 45	451.15894 ft	161.09648 ft	0 psf	1,013.0398 psf	440.48226 psf	0 psf	0 psf	CCR
Column 46	454.47064 ft	160.16819 ft	0 psf	1,021.1318 psf	444.00073 psf	0 psf	0 psf	CCR
Column 47	457.59438 ft	159.30603 ft	0 psf	1,029.8793 psf	447.80426 psf	0 psf	0 psf	CCR
Column 48	460.53016 ft	158.50997 ft	0 psf	1,034.9039 psf	449.98902 psf	0 psf	0 psf	CCR
Column 49	463.46594 ft	157.71392 ft	0 psf	1,039.9285 psf	452.17378 psf	0 psf	0 psf	CCR
Column 50	466.40171 ft	156.91788 ft	0 psf	1,044.9531 psf	454.35853 psf	0 psf	0 psf	CCR
Column 51	469.33749 ft	156.12183 ft	0 psf	1,049.9777 psf	456.54329 psf	0 psf	0 psf	CCR
Column 52	472.31393 ft	155.31721 ft	0 psf	1,055.2757 psf	458.84693 psf	0 psf	0 psf	CCR
Column 53	475.33104 ft	154.50404 ft	0 psf	1,060.0442 psf	460.92034 psf	0 psf	0 psf	CCR
Column 54	478.34815 ft	153.69087 ft	0 psf	1,064.8127 psf	462.99375 psf	0 psf	0 psf	CCR
Column 55	481.36526 ft	152.87769 ft	0 psf	1,069.5812 psf	465.06716 psf	0 psf	0 psf	CCR
Column 56	484.38237 ft	152.06452 ft	0 psf	1,074.3497 psf	467.14056 psf	0 psf	0 psf	CCR
Column 57	487.39948 ft	151.25134 ft	0 psf	1,079.1182 psf	469.21397 psf	0 psf	0 psf	CCR
Column 58	490.41659 ft	150.43817 ft	0 psf	1,083.8868 psf	471.28738 psf	0 psf	0 psf	CCR
Column 59	493.43370 ft	149.62500 ft	0 psf	1,088.6553 psf	473.36078 psf	0 psf	0 psf	CCR
Column 60	496.57821 ft	148.82414 ft	0 psf	1,097.1704 psf	477.06329 psf	0 psf	0 psf	CCR
Column 61	499.85012 ft	148.03561 ft	0 psf	1,094.8056 psf	476.03503 psf	0 psf	0 psf	CCR
Column 62	503.12204 ft	147.24708 ft	0 psf	1,092.4408 psf	475.00677 psf	0 psf	0 psf	CCR
Column 63	506.39395 ft	146.45855 ft	0 psf	1,090.0759 psf	473.9785 psf	0 psf	0 psf	CCR
Column 64	509.66587 ft	145.67002 ft	0 psf	1,087.7111 psf	472.95024 psf	0 psf	0 psf	CCR

Column 65	512.93778 ft	144.88148 ft	0 psf	1,085.3463 psf	471.92198 psf	0 psf	0 psf	CCR
Column 66	516.20970 ft	144.09295 ft	0 psf	1,082.9814 psf	470.89372 psf	0 psf	0 psf	CCR
Column 67	519.48161 ft	143.30442 ft	0 psf	1,080.6166 psf	469.86546 psf	0 psf	0 psf	CCR
Column 68	522.75353 ft	142.51589 ft	0 psf	1,078.2517 psf	468.8372 psf	0 psf	0 psf	CCR
Column 69	526.02544 ft	141.72736 ft	0 psf	1,075.8869 psf	467.80894 psf	0 psf	0 psf	CCR
Column 70	529.18802 ft	140.96820 ft	0 psf	1,073.8558 psf	466.9258 psf	0 psf	0 psf	CCR
Column 71	532.24125 ft	140.23842 ft	0 psf	1,071.1569 psf	465.75226 psf	0 psf	0 psf	CCR
Column 72	535.29448 ft	139.50865 ft	0 psf	1,068.4579 psf	464.57871 psf	0 psf	0 psf	CCR
Column 73	538.34771 ft	138.77887 ft	0 psf	1,065.7589 psf	463.40516 psf	0 psf	0 psf	CCR
Column 74	541.40094 ft	138.04909 ft	0 psf	1,063.0599 psf	462.23161 psf	0 psf	0 psf	CCR
Column 75	544.55978 ft	137.29768 ft	0 psf	1,060.5259 psf	461.1298 psf	0 psf	0 psf	CCR
Column 76	547.82423 ft	136.52463 ft	0 psf	1,057.0528 psf	459.61963 psf	0 psf	0 psf	CCR
Column 77	551.08868 ft	135.75158 ft	0 psf	1,053.5796 psf	458.10945 psf	0 psf	0 psf	CCR
Column 78	554.35313 ft	134.97854 ft	0 psf	1,050.1064 psf	456.59927 psf	0 psf	0 psf	CCR
Column 79	557.61758 ft	134.20549 ft	0 psf	1,046.6333 psf	455.08909 psf	0 psf	0 psf	CCR
Column 80	560.88203 ft	133.43244 ft	0 psf	1,043.1601 psf	453.57892 psf	0 psf	0 psf	CCR
Column 81	564.14647 ft	132.65940 ft	0 psf	1,039.6869 psf	452.06874 psf	0 psf	0 psf	CCR
Column 82	567.41092 ft	131.88635 ft	0 psf	1,036.2138 psf	450.55856 psf	0 psf	0 psf	CCR
Column 83	570.67537 ft	131.11330 ft	0 psf	1,032.7406 psf	449.04839 psf	0 psf	0 psf	CCR
Column 84	573.93982 ft	130.34026 ft	0 psf	1,029.2674 psf	447.53821 psf	0 psf	0 psf	CCR
Column 85	577.20427 ft	129.56721 ft	0 psf	1,025.7942 psf	446.02803 psf	0 psf	0 psf	CCR
Column 86	580.46872 ft	128.79416 ft	0 psf	1,022.3211 psf	444.51785 psf	0 psf	0 psf	CCR
Column 87	583.73317 ft	128.02111 ft	0 psf	1,018.8479 psf	443.00768 psf	0 psf	0 psf	CCR
Column 88	586.99761 ft	127.24807 ft	0 psf	1,015.3747 psf	441.4975 psf	0 psf	0 psf	CCR
Column 89	590.26206 ft	126.47502 ft	0 psf	1,011.9016 psf	439.98732 psf	0 psf	0 psf	CCR
Column 90	593.52651 ft	125.70197 ft	0 psf	1,008.4284 psf	438.47714 psf	0 psf	0 psf	CCR
Column 91	596.79096 ft	124.92893 ft	0 psf	1,004.9552 psf	436.96697 psf	0 psf	0 psf	CCR
Column 92	600.05541 ft	124.15588 ft	0 psf	1,001.482 psf	435.45679 psf	0 psf	0 psf	CCR
Column 93	603.31986 ft	123.38283 ft	0 psf	998.00888 psf	433.94661 psf	0 psf	0 psf	CCR
Column 94	606.47852 ft	122.65026 ft	0 psf	995.76287 psf	432.97002 psf	0 psf	0 psf	CCR
Column 95	609.53141 ft	121.95816 ft	0 psf	989.99576 psf	430.46241 psf	0 psf	0 psf	CCR

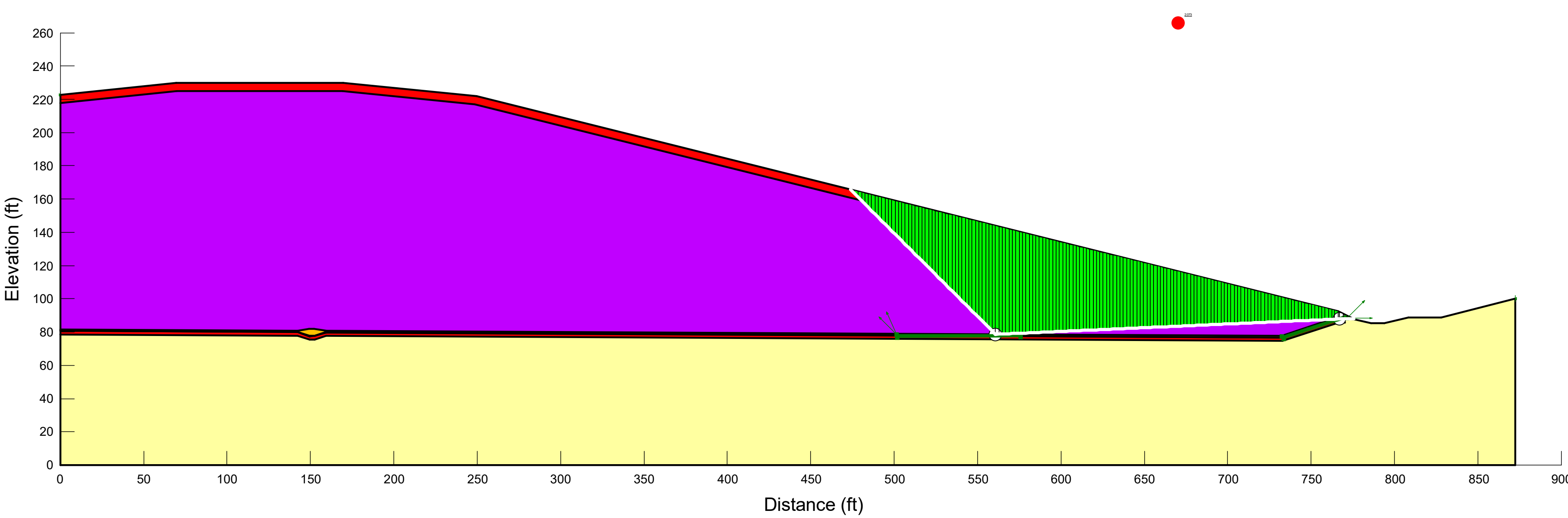
Column 96	612.58429 ft	121.26607 ft	0 psf	984.22865 psf	427.9548 psf	0 psf	0 psf	CCR
Column 97	615.63718 ft	120.57397 ft	0 psf	978.46154 psf	425.44719 psf	0 psf	0 psf	CCR
Column 98	618.69006 ft	119.88187 ft	0 psf	972.69443 psf	422.93958 psf	0 psf	0 psf	CCR
Column 99	621.74295 ft	119.18978 ft	0 psf	966.92732 psf	420.43197 psf	0 psf	0 psf	CCR
Column 100	624.98277 ft	118.45139 ft	0 psf	960.6082 psf	417.68433 psf	0 psf	0 psf	CCR
Column 101	628.40952 ft	117.66671 ft	0 psf	954.77523 psf	415.14809 psf	0 psf	0 psf	CCR
Column 102	631.83627 ft	116.88203 ft	0 psf	948.94226 psf	412.61184 psf	0 psf	0 psf	CCR
Column 103	635.26302 ft	116.09734 ft	0 psf	943.1093 psf	410.07559 psf	0 psf	0 psf	CCR
Column 104	638.68977 ft	115.31266 ft	0 psf	937.27633 psf	407.53935 psf	0 psf	0 psf	CCR
Column 105	642.11652 ft	114.52798 ft	0 psf	931.44336 psf	405.0031 psf	0 psf	0 psf	CCR
Column 106	645.45015 ft	113.77637 ft	0 psf	926.39638 psf	402.80861 psf	0 psf	0 psf	CCR
Column 107	648.69066 ft	113.05784 ft	0 psf	918.95572 psf	399.57332 psf	0 psf	0 psf	CCR
Column 108	651.93117 ft	112.33931 ft	0 psf	911.51506 psf	396.33803 psf	0 psf	0 psf	CCR
Column 109	655.17168 ft	111.62077 ft	0 psf	904.0744 psf	393.10274 psf	0 psf	0 psf	CCR
Column 110	658.41218 ft	110.90224 ft	0 psf	896.63374 psf	389.86745 psf	0 psf	0 psf	CCR
Column 111	661.65269 ft	110.18371 ft	0 psf	889.19308 psf	386.63216 psf	0 psf	0 psf	CCR
Column 112	664.89320 ft	109.46517 ft	0 psf	881.75242 psf	383.39687 psf	0 psf	0 psf	CCR
Column 113	668.13371 ft	108.74664 ft	0 psf	874.31176 psf	380.16157 psf	0 psf	0 psf	CCR
Column 114	671.37421 ft	108.02811 ft	0 psf	866.87111 psf	376.92628 psf	0 psf	0 psf	CCR
Column 115	674.61472 ft	107.30957 ft	0 psf	859.43045 psf	373.69099 psf	0 psf	0 psf	CCR
Column 116	677.85523 ft	106.59104 ft	0 psf	851.98979 psf	370.4557 psf	0 psf	0 psf	CCR
Column 117	681.09574 ft	105.87251 ft	0 psf	844.54913 psf	367.22041 psf	0 psf	0 psf	CCR
Column 118	684.32338 ft	105.16099 ft	0 psf	837.31073 psf	364.07307 psf	0 psf	0 psf	CCR
Column 119	687.53817 ft	104.45649 ft	0 psf	829.24559 psf	360.56625 psf	0 psf	0 psf	CCR
Column 120	690.75295 ft	103.75198 ft	0 psf	821.18046 psf	357.05942 psf	0 psf	0 psf	CCR
Column 121	693.96773 ft	103.04748 ft	0 psf	813.11532 psf	353.5526 psf	0 psf	0 psf	CCR
Column 122	697.18252 ft	102.34298 ft	0 psf	805.05019 psf	350.04578 psf	0 psf	0 psf	CCR
Column 123	700.39730 ft	101.63847 ft	0 psf	796.98505 psf	346.53896 psf	0 psf	0 psf	CCR
Column 124	703.61208 ft	100.93397 ft	0 psf	788.91991 psf	343.03214 psf	0 psf	0 psf	CCR
Column 125	706.82687 ft	100.22947 ft	0 psf	780.85478 psf	339.52532 psf	0 psf	0 psf	CCR
Column 126	710.04165 ft	99.52497 ft	0 psf	772.78964 psf	336.0185 psf	0 psf	0 psf	CCR

Column 127	713.25643 ft	98.82046 ft	0 psf	764.72451 psf	332.51168 psf	0 psf	0 psf	CCR
Column 128	716.47122 ft	98.11596 ft	0 psf	756.65937 psf	329.00486 psf	0 psf	0 psf	CCR
Column 129	719.59880 ft	97.43481 ft	0 psf	748.96071 psf	325.65738 psf	0 psf	0 psf	CCR
Column 130	722.63918 ft	96.77700 ft	0 psf	740.6362 psf	322.03779 psf	0 psf	0 psf	CCR
Column 131	725.67956 ft	96.11920 ft	0 psf	732.31169 psf	318.41819 psf	0 psf	0 psf	CCR
Column 132	728.71994 ft	95.46139 ft	0 psf	723.98719 psf	314.79859 psf	0 psf	0 psf	CCR
Column 133	731.76032 ft	94.80359 ft	0 psf	715.66268 psf	311.17899 psf	0 psf	0 psf	CCR
Column 134	734.80070 ft	94.14579 ft	0 psf	707.33817 psf	307.55939 psf	0 psf	0 psf	CCR
Column 135	737.84109 ft	93.48798 ft	0 psf	699.01366 psf	303.93979 psf	0 psf	0 psf	CCR
Column 136	740.88147 ft	92.83018 ft	0 psf	690.68915 psf	300.32019 psf	0 psf	0 psf	CCR
Column 137	743.92185 ft	92.17237 ft	0 psf	682.36465 psf	296.70059 psf	0 psf	0 psf	CCR
Column 138	746.96223 ft	91.51457 ft	0 psf	674.04014 psf	293.08099 psf	0 psf	0 psf	CCR
Column 139	750.00261 ft	90.85676 ft	0 psf	665.71563 psf	289.46139 psf	0 psf	0 psf	CCR
Column 140	752.96270 ft	90.30768 ft	0 psf	660.0558 psf	287.00043 psf	0 psf	0 psf	CCR
Column 141	755.84249 ft	89.86732 ft	0 psf	636.91515 psf	276.93859 psf	0 psf	0 psf	CCR
Column 142	758.72228 ft	89.42696 ft	0 psf	613.7745 psf	266.87675 psf	0 psf	0 psf	CCR
Column 143	761.62830 ft	88.98260 ft	0 psf	580.35843 psf	308.58205 psf	0 psf	0 psf	Clay
Column 144	764.56053 ft	88.53422 ft	0 psf	546.43685 psf	290.54563 psf	0 psf	0 psf	Clay
Column 145	767.55552 ft	88.07625 ft	0 psf	466.13834 psf	247.85015 psf	0 psf	0 psf	Clay
Column 146	770.82052 ft	87.57699 ft	0 psf	328.47082 psf	189.64272 psf	0 psf	0 psf	Subbase
Column 147	774.29277 ft	87.04603 ft	0 psf	182.87759 psf	105.58442 psf	0 psf	0 psf	Subbase
Column 148	777.68623 ft	86.52713 ft	0 psf	91.734141 psf	52.962731 psf	0 psf	0 psf	Subbase
Column 149	781.00089 ft	86.02027 ft	0 psf	55.040484 psf	31.777639 psf	0 psf	0 psf	Subbase
Column 150	784.31555 ft	85.51342 ft	0 psf	18.346828 psf	10.592546 psf	0 psf	0 psf	Subbase

Title: Columbia Mod 12-13 Full Buildout
Name: Block_FS=1.5
Method: Janbu
Last Edited By: Villanueva, Niko

F of S: 2.073
F of S Rank (Analysis): 1 of 234,256 slip surfaces
Last Solved Date: 08/30/2023, Last Solved Time: 07:51:00 AM

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Drainage Layer	Mohr-Coulomb	115	0	30
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Subbase	Mohr-Coulomb	120	0	30



Block_FS=1.5

File Information

File Version: 11.05
Title: Columbia Mod 12-13 Full Buildout
Created By: Villanueva, Niko
Last Edited By: Villanueva, Niko
Revision Number: 59
Date: 08/30/2023
Time: 07:48:22 AM
Tool Version: 23.1.1.829
File Name: COL_Mod12-13_Full Buildout.gsz
Directory: I:\25222260.00\Data and Calculations\Geotech Calculations\Slope Stability\SlopeW\
Last Solved Date: 08/30/2023
Last Solved Time: 07:51:00 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

Block_FS=1.5

- Kind: SLOPE/W
- Analysis Type: Janbu
- Settings
  - PWP Conditions from: (none)
  - Unit Weight of Water: 62.4 pcf
- Slip Surface
  - Direction of movement: Left to Right
  - Use Passive Mode: No
  - Slip Surface Option: Block
  - Critical slip surfaces saved: 10
  - Restrict Block Crossing: No
  - Optimize Critical Slip Surface Location: No
  - Tension Crack Option: (none)
- Distribution
  - F of S Calculation Option: Constant
- Convergence
  - Geometry Settings
    - Minimum Slip Surface Depth: 0.1 ft
    - Number of Columns: 150
  - Factor of Safety Convergence Settings
    - Maximum Number of Iterations: 30,000
    - Tolerable difference in F of S: 0.001

Materials

CCR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 23.5 °
Phi-B: 0 °

Clay

Slope Stability Material Model: Mohr-Coulomb

Unit Weight: 125 pcf
Effec?ve Cohesion: 0 psf
Effec?ve Fric?on Angle: 28 °
Phi-B: 0 °

Drainage Layer

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 115 pcf
Effec?ve Cohesion: 0 psf
Effec?ve Fric?on Angle: 30 °
Phi-B: 0 °

Geosynthetics

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effec?ve Cohesion: 0 psf
Effec?ve Fric?on Angle: 24.3 °
Phi-B: 0 °

Subbase

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effec?ve Cohesion: 0 psf
Effec?ve Fric?on Angle: 30 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (0, 222.8) ft
Right Coordinate: (872.23081, 100) ft

Slip Surface Block

Left Grid
- Upper Left: (501.66323, 78.59637) ft
- Lower Left: (501.71597, 76.77685) ft
- Lower Right: (575.63085, 76.85596) ft
- X Increments: 10
- Y Increments: 10
- Star?ng Angle: 115 °
- Ending Angle: 135 °
- Angle Increments: 3

Right Grid
- Upper Left: (732.31286, 77.23832) ft
- Lower Left: (733.52148, 75.77333) ft
- Lower Right: (771.48024, 88.43235) ft
- X Increments: 10
- Y Increments: 10
- Angle Increments: 3

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	768.91041 ft	87.74349 ft
Point 2	766.02664 ft	87.74317 ft
Point 3	732.66754 ft	76.62354 ft

Point 4	159.35647 ft	79.79909 ft
Point 5	152.46501 ft	77.58553 ft
Point 6	149.45787 ft	77.54639 ft
Point 7	142.29499 ft	79.95559 ft
Point 8	0 ft	80.72488 ft
Point 9	0 ft	78.63599 ft
Point 10	142.29493 ft	77.86789 ft
Point 11	149.45787 ft	75.41847 ft
Point 12	152.46501 ft	75.45626 ft
Point 13	159.35619 ft	77.75007 ft
Point 14	732.66724 ft	74.58984 ft
Point 15	768.91041 ft	86.64701 ft
Point 16	872.23081 ft	100 ft
Point 17	828.17946 ft	88.78332 ft
Point 18	808.17769 ft	88.78332 ft
Point 19	794.02935 ft	85.24543 ft
Point 20	786.03116 ft	85.24543 ft
Point 21	776.0289 ft	87.7443 ft
Point 22	769.01095 ft	87.8435 ft
Point 23	769.01041 ft	85.84317 ft
Point 24	770.01041 ft	85.84317 ft
Point 25	770.01041 ft	85.74351 ft
Point 26	768.91041 ft	85.74351 ft
Point 27	0 ft	0 ft
Point 28	872.23081 ft	0 ft
Point 29	764.03814 ft	88.23984 ft
Point 30	732.49201 ft	77.72453 ft
Point 31	159.6047 ft	80.8285 ft
Point 32	152.35619 ft	82.00202 ft
Point 33	148.97182 ft	82.00419 ft
Point 34	142.29493 ft	80.97938 ft
Point 35	0 ft	81.74787 ft
Point 36	0 ft	80.82487 ft
Point 37	142.31162 ft	80.0555 ft
Point 38	149.47361 ft	77.64661 ft
Point 39	152.44871 ft	77.68532 ft
Point 40	159.34108 ft	79.89918 ft
Point 41	732.65158 ft	76.72363 ft
Point 42	766.01041 ft	87.84317 ft
Point 43	249.53 ft	221.75 ft
Point 44	169.53 ft	229.75 ft
Point 45	69.53 ft	229.75 ft
Point 46	0 ft	222.8 ft
Point 47	0 ft	217.82 ft
Point 48	69.78 ft	224.75 ft
Point 49	169.28 ft	224.75 ft
Point 50	248.67 ft	216.81 ft
Point 51	769.01041 ft	87.84351 ft
Point 52	766.02664 ft	92.74317 ft
Point 53	766.02718 ft	87.74317 ft
Point 54	768.91095 ft	87.74349 ft
Point 55	768.91095 ft	85.7435 ft
Point 56	770.01095 ft	85.7435 ft
Point 57	770.01095 ft	85.84316 ft
Point 58	769.01095 ft	85.84316 ft
Point 59	766.01095 ft	87.84316 ft
Point 60	732.65213 ft	76.72363 ft
Point 61	159.34162 ft	79.89918 ft

Point 62	152.44925 ft	77.68532 ft
Point 63	149.47415 ft	77.6466 ft
Point 64	142.31216 ft	80.0555 ft
Point 65	142.29553 ft	79.95558 ft
Point 66	149.45841 ft	77.54639 ft
Point 67	152.46555 ft	77.58552 ft
Point 68	159.35701 ft	79.79909 ft
Point 69	732.66808 ft	76.62354 ft
Point 70	768.91095 ft	85.74351 ft
Point 71	770.01041 ft	85.84316 ft
Point 72	769.01095 ft	85.84317 ft
Point 73	732.65159 ft	76.72363 ft
Point 74	159.34161 ft	79.89918 ft
Point 75	149.4741 ft	77.64662 ft
Point 76	142.29501 ft	79.95558 ft
Point 77	149.45839 ft	77.5464 ft
Point 78	159.357 ft	79.79909 ft
Point 79	732.66755 ft	76.62354 ft

Regions

	Material	Points	Area
Region 1	Clay	1,53,69,79,3,68,78,67,66,77,6,76,8,9,10,11,12,13,14,15	1,576.1 ft²
Region 2	Subbase	16,17,18,19,20,21,22,72,24,71,57,56,55,70,26,15,14,13,12,11,10,9,27,28	68,366 ft²
Region 3	Drainage Layer	29,30,31,32,33,34,35,36,37,64,75,39,40,74,61,41,73,42	769.27 ft²
Region 4	Clay	43,44,45,46,47,48,49,50,29,42,51,22,21,52	3,896.4 ft²
Region 5	CCR	50,49,48,47,35,34,33,32,31,30,29	72,914 ft²
Region 6	Geosynthe�cs	53,1,54,70,55,56,57,71,58,72,22,59,60,73,41,61,74,62,63,75,64,37,36,8,76,65,77,66,67,78,68,3,79,69	77.457 ft²

Slip Results

Slip Surfaces Analysed: 70472 of 234256 converged

Current Slip Surface

Slip Surface: 230,157
Factor of Safety: 2.073
Volume: 10,076.604 ft³
Weight: 924,351.53 lbf
Resis�ng Moment: 40,261,081 lbf·ft
Ac�va�ng Moment: 21,196,838 lbf·ft
Resis�ng Force: 385,720.03 lbf
Ac�va�ng Force: 186,047.9 lbf
Slip Rank: 1 of 234,256 slip surfaces
Exit: (775.71947, 87.898943) ft
Entry: (473.69516, 165.75963) ft
Radius: 146.39865 ft
Center: (639.76145, 185.22481) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Fric�onal Strength	Cohesive Strength	Suc�on Strength	Base Material
Column 1	474.82486 ft	164.62994 ft	0 psf	84.31206 psf	44.829518 psf	0 psf	0 psf	Clay
Column 2	477.08425 ft	162.37054 ft	0 psf	252.93618 psf	134.48855 psf	0 psf	0 psf	Clay

Column 3	479.34365 ft	160.11115 ft	0 psf	421.5603 psf	224.14759 psf	0 psf	0 psf	Clay
Column 4	481.47737 ft	157.97743 ft	0 psf	578.95722 psf	251.73776 psf	0 psf	0 psf	CCR
Column 5	483.48541 ft	155.96938 ft	0 psf	686.02951 psf	298.29412 psf	0 psf	0 psf	CCR
Column 6	485.49346 ft	153.96134 ft	0 psf	793.1018 psf	344.85048 psf	0 psf	0 psf	CCR
Column 7	487.50150 ft	151.95329 ft	0 psf	900.1741 psf	391.40684 psf	0 psf	0 psf	CCR
Column 8	489.50954 ft	149.94525 ft	0 psf	1,007.2464 psf	437.96319 psf	0 psf	0 psf	CCR
Column 9	491.51759 ft	147.93720 ft	0 psf	1,114.3187 psf	484.51955 psf	0 psf	0 psf	CCR
Column 10	493.52563 ft	145.92916 ft	0 psf	1,221.391 psf	531.07591 psf	0 psf	0 psf	CCR
Column 11	495.53368 ft	143.92111 ft	0 psf	1,328.4633 psf	577.63227 psf	0 psf	0 psf	CCR
Column 12	497.54172 ft	141.91307 ft	0 psf	1,435.5356 psf	624.18863 psf	0 psf	0 psf	CCR
Column 13	499.54977 ft	139.90502 ft	0 psf	1,542.6079 psf	670.74498 psf	0 psf	0 psf	CCR
Column 14	501.55781 ft	137.89698 ft	0 psf	1,649.6801 psf	717.30134 psf	0 psf	0 psf	CCR
Column 15	503.56586 ft	135.88893 ft	0 psf	1,756.7524 psf	763.8577 psf	0 psf	0 psf	CCR
Column 16	505.57390 ft	133.88089 ft	0 psf	1,863.8247 psf	810.41406 psf	0 psf	0 psf	CCR
Column 17	507.58195 ft	131.87284 ft	0 psf	1,970.897 psf	856.97041 psf	0 psf	0 psf	CCR
Column 18	509.58999 ft	129.86480 ft	0 psf	2,077.9693 psf	903.52677 psf	0 psf	0 psf	CCR
Column 19	511.59804 ft	127.85675 ft	0 psf	2,185.0416 psf	950.08313 psf	0 psf	0 psf	CCR
Column 20	513.60608 ft	125.84871 ft	0 psf	2,292.1139 psf	996.63949 psf	0 psf	0 psf	CCR
Column 21	515.61413 ft	123.84067 ft	0 psf	2,399.1862 psf	1,043.1958 psf	0 psf	0 psf	CCR
Column 22	517.62217 ft	121.83262 ft	0 psf	2,506.2585 psf	1,089.7522 psf	0 psf	0 psf	CCR
Column 23	519.63022 ft	119.82458 ft	0 psf	2,613.3308 psf	1,136.3086 psf	0 psf	0 psf	CCR
Column 24	521.63826 ft	117.81653 ft	0 psf	2,720.4031 psf	1,182.8649 psf	0 psf	0 psf	CCR
Column 25	523.64631 ft	115.80849 ft	0 psf	2,827.4754 psf	1,229.4213 psf	0 psf	0 psf	CCR
Column 26	525.65435 ft	113.80044 ft	0 psf	2,934.5477 psf	1,275.9776 psf	0 psf	0 psf	CCR
Column 27	527.66240 ft	111.79240 ft	0 psf	3,041.6199 psf	1,322.534 psf	0 psf	0 psf	CCR
Column 28	529.67044 ft	109.78435 ft	0 psf	3,148.6922 psf	1,369.0904 psf	0 psf	0 psf	CCR
Column 29	531.67848 ft	107.77631 ft	0 psf	3,255.7645 psf	1,415.6467 psf	0 psf	0 psf	CCR
Column 30	533.68653 ft	105.76826 ft	0 psf	3,362.8368 psf	1,462.2031 psf	0 psf	0 psf	CCR
Column 31	535.69457 ft	103.76022 ft	0 psf	3,469.9091 psf	1,508.7594 psf	0 psf	0 psf	CCR
Column 32	537.70262 ft	101.75217 ft	0 psf	3,576.9814 psf	1,555.3158 psf	0 psf	0 psf	CCR
Column 33	539.71066 ft	99.74413 ft	0 psf	3,684.0537 psf	1,601.8721 psf	0 psf	0 psf	CCR

Column 34	541.71871 ft	97.73608 ft	0 psf	3,791.126 psf	1,648.4285 psf	0 psf	0 psf	CCR
Column 35	543.72675 ft	95.72804 ft	0 psf	3,898.1983 psf	1,694.9849 psf	0 psf	0 psf	CCR
Column 36	545.73480 ft	93.71999 ft	0 psf	4,005.2706 psf	1,741.5412 psf	0 psf	0 psf	CCR
Column 37	547.74284 ft	91.71195 ft	0 psf	4,112.3429 psf	1,788.0976 psf	0 psf	0 psf	CCR
Column 38	549.75089 ft	89.70390 ft	0 psf	4,219.4152 psf	1,834.6539 psf	0 psf	0 psf	CCR
Column 39	551.75893 ft	87.69586 ft	0 psf	4,326.4875 psf	1,881.2103 psf	0 psf	0 psf	CCR
Column 40	553.76698 ft	85.68781 ft	0 psf	4,433.5597 psf	1,927.7666 psf	0 psf	0 psf	CCR
Column 41	555.77502 ft	83.67977 ft	0 psf	4,540.632 psf	1,974.323 psf	0 psf	0 psf	CCR
Column 42	557.78307 ft	81.67173 ft	0 psf	4,647.7043 psf	2,020.8794 psf	0 psf	0 psf	CCR
Column 43	559.79111 ft	79.66368 ft	0 psf	4,754.7766 psf	2,067.4357 psf	0 psf	0 psf	CCR
Column 44	561.80308 ft	78.70480 ft	0 psf	5,846.4191 psf	2,542.0954 psf	0 psf	0 psf	CCR
Column 45	563.81897 ft	78.79509 ft	0 psf	5,794.8437 psf	2,519.6697 psf	0 psf	0 psf	CCR
Column 46	565.83487 ft	78.88538 ft	0 psf	5,743.2682 psf	2,497.2441 psf	0 psf	0 psf	CCR
Column 47	567.85076 ft	78.97567 ft	0 psf	5,691.6927 psf	2,474.8184 psf	0 psf	0 psf	CCR
Column 48	569.86666 ft	79.06596 ft	0 psf	5,640.1172 psf	2,452.3928 psf	0 psf	0 psf	CCR
Column 49	571.88255 ft	79.15625 ft	0 psf	5,588.5417 psf	2,429.9671 psf	0 psf	0 psf	CCR
Column 50	573.89844 ft	79.24654 ft	0 psf	5,536.9663 psf	2,407.5415 psf	0 psf	0 psf	CCR
Column 51	575.91434 ft	79.33683 ft	0 psf	5,485.3908 psf	2,385.1158 psf	0 psf	0 psf	CCR
Column 52	577.93023 ft	79.42712 ft	0 psf	5,433.8153 psf	2,362.6901 psf	0 psf	0 psf	CCR
Column 53	579.94613 ft	79.51741 ft	0 psf	5,382.2398 psf	2,340.2645 psf	0 psf	0 psf	CCR
Column 54	581.96202 ft	79.60770 ft	0 psf	5,330.6644 psf	2,317.8388 psf	0 psf	0 psf	CCR
Column 55	583.97791 ft	79.69799 ft	0 psf	5,279.0889 psf	2,295.4132 psf	0 psf	0 psf	CCR
Column 56	585.99381 ft	79.78828 ft	0 psf	5,227.5134 psf	2,272.9875 psf	0 psf	0 psf	CCR
Column 57	588.00970 ft	79.87857 ft	0 psf	5,175.9379 psf	2,250.5619 psf	0 psf	0 psf	CCR
Column 58	590.02559 ft	79.96886 ft	0 psf	5,124.3624 psf	2,228.1362 psf	0 psf	0 psf	CCR
Column 59	592.04149 ft	80.05915 ft	0 psf	5,072.787 psf	2,205.7105 psf	0 psf	0 psf	CCR
Column 60	594.05738 ft	80.14944 ft	0 psf	5,021.2115 psf	2,183.2849 psf	0 psf	0 psf	CCR
Column 61	596.07328 ft	80.23973 ft	0 psf	4,969.636 psf	2,160.8592 psf	0 psf	0 psf	CCR
Column 62	598.08917 ft	80.33002 ft	0 psf	4,918.0605 psf	2,138.4336 psf	0 psf	0 psf	CCR
Column 63	600.10506 ft	80.42031 ft	0 psf	4,866.4851 psf	2,116.0079 psf	0 psf	0 psf	CCR
Column 64	602.12096 ft	80.51060 ft	0 psf	4,814.9096 psf	2,093.5823 psf	0 psf	0 psf	CCR

Column 65	604.13685 ft	80.60089 ft	0 psf	4,763.3341 psf	2,071.1566 psf	0 psf	0 psf	CCR
Column 66	606.15274 ft	80.69118 ft	0 psf	4,711.7586 psf	2,048.731 psf	0 psf	0 psf	CCR
Column 67	608.16864 ft	80.78147 ft	0 psf	4,660.1831 psf	2,026.3053 psf	0 psf	0 psf	CCR
Column 68	610.18453 ft	80.87176 ft	0 psf	4,608.6077 psf	2,003.8796 psf	0 psf	0 psf	CCR
Column 69	612.20043 ft	80.96205 ft	0 psf	4,557.0322 psf	1,981.454 psf	0 psf	0 psf	CCR
Column 70	614.21632 ft	81.05234 ft	0 psf	4,505.4567 psf	1,959.0283 psf	0 psf	0 psf	CCR
Column 71	616.23221 ft	81.14263 ft	0 psf	4,453.8812 psf	1,936.6027 psf	0 psf	0 psf	CCR
Column 72	618.24811 ft	81.23292 ft	0 psf	4,402.3058 psf	1,914.177 psf	0 psf	0 psf	CCR
Column 73	620.26400 ft	81.32321 ft	0 psf	4,350.7303 psf	1,891.7514 psf	0 psf	0 psf	CCR
Column 74	622.27989 ft	81.41350 ft	0 psf	4,299.1548 psf	1,869.3257 psf	0 psf	0 psf	CCR
Column 75	624.29579 ft	81.50379 ft	0 psf	4,247.5793 psf	1,846.9001 psf	0 psf	0 psf	CCR
Column 76	626.31168 ft	81.59408 ft	0 psf	4,196.0039 psf	1,824.4744 psf	0 psf	0 psf	CCR
Column 77	628.32758 ft	81.68437 ft	0 psf	4,144.4284 psf	1,802.0487 psf	0 psf	0 psf	CCR
Column 78	630.34347 ft	81.77465 ft	0 psf	4,092.8529 psf	1,779.6231 psf	0 psf	0 psf	CCR
Column 79	632.35936 ft	81.86494 ft	0 psf	4,041.2774 psf	1,757.1974 psf	0 psf	0 psf	CCR
Column 80	634.37526 ft	81.95523 ft	0 psf	3,989.7019 psf	1,734.7718 psf	0 psf	0 psf	CCR
Column 81	636.39115 ft	82.04552 ft	0 psf	3,938.1265 psf	1,712.3461 psf	0 psf	0 psf	CCR
Column 82	638.40705 ft	82.13581 ft	0 psf	3,886.551 psf	1,689.9205 psf	0 psf	0 psf	CCR
Column 83	640.42294 ft	82.22610 ft	0 psf	3,834.9755 psf	1,667.4948 psf	0 psf	0 psf	CCR
Column 84	642.43883 ft	82.31639 ft	0 psf	3,783.4 psf	1,645.0692 psf	0 psf	0 psf	CCR
Column 85	644.45473 ft	82.40668 ft	0 psf	3,731.8246 psf	1,622.6435 psf	0 psf	0 psf	CCR
Column 86	646.47062 ft	82.49697 ft	0 psf	3,680.2491 psf	1,600.2178 psf	0 psf	0 psf	CCR
Column 87	648.48651 ft	82.58726 ft	0 psf	3,628.6736 psf	1,577.7922 psf	0 psf	0 psf	CCR
Column 88	650.50241 ft	82.67755 ft	0 psf	3,577.0981 psf	1,555.3665 psf	0 psf	0 psf	CCR
Column 89	652.51830 ft	82.76784 ft	0 psf	3,525.5226 psf	1,532.9409 psf	0 psf	0 psf	CCR
Column 90	654.53420 ft	82.85813 ft	0 psf	3,473.9472 psf	1,510.5152 psf	0 psf	0 psf	CCR
Column 91	656.55009 ft	82.94842 ft	0 psf	3,422.3717 psf	1,488.0896 psf	0 psf	0 psf	CCR
Column 92	658.56598 ft	83.03871 ft	0 psf	3,370.7962 psf	1,465.6639 psf	0 psf	0 psf	CCR
Column 93	660.58188 ft	83.12900 ft	0 psf	3,319.2207 psf	1,443.2382 psf	0 psf	0 psf	CCR
Column 94	662.59777 ft	83.21929 ft	0 psf	3,267.6453 psf	1,420.8126 psf	0 psf	0 psf	CCR
Column 95	664.61366 ft	83.30958 ft	0 psf	3,216.0698 psf	1,398.3869 psf	0 psf	0 psf	CCR

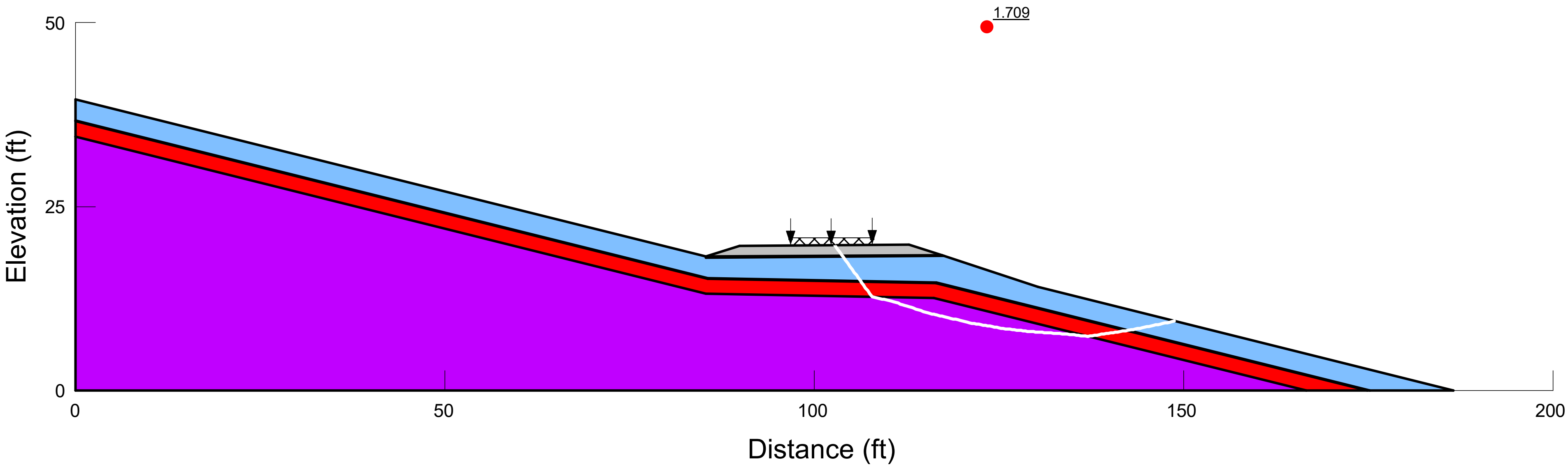
Column 96	666.62956 ft	83.39987 ft	0 psf	3,164.4943 psf	1,375.9613 psf	0 psf	0 psf	CCR
Column 97	668.64545 ft	83.49016 ft	0 psf	3,112.9188 psf	1,353.5356 psf	0 psf	0 psf	CCR
Column 98	670.66135 ft	83.58045 ft	0 psf	3,061.3433 psf	1,331.11 psf	0 psf	0 psf	CCR
Column 99	672.67724 ft	83.67074 ft	0 psf	3,009.7679 psf	1,308.6843 psf	0 psf	0 psf	CCR
Column 100	674.69313 ft	83.76103 ft	0 psf	2,958.1924 psf	1,286.2587 psf	0 psf	0 psf	CCR
Column 101	676.70903 ft	83.85132 ft	0 psf	2,906.6169 psf	1,263.833 psf	0 psf	0 psf	CCR
Column 102	678.72492 ft	83.94161 ft	0 psf	2,855.0414 psf	1,241.4073 psf	0 psf	0 psf	CCR
Column 103	680.74081 ft	84.03190 ft	0 psf	2,803.466 psf	1,218.9817 psf	0 psf	0 psf	CCR
Column 104	682.75671 ft	84.12219 ft	0 psf	2,751.8905 psf	1,196.556 psf	0 psf	0 psf	CCR
Column 105	684.77260 ft	84.21248 ft	0 psf	2,700.315 psf	1,174.1304 psf	0 psf	0 psf	CCR
Column 106	686.78850 ft	84.30277 ft	0 psf	2,648.7395 psf	1,151.7047 psf	0 psf	0 psf	CCR
Column 107	688.80439 ft	84.39306 ft	0 psf	2,597.164 psf	1,129.2791 psf	0 psf	0 psf	CCR
Column 108	690.82028 ft	84.48335 ft	0 psf	2,545.5886 psf	1,106.8534 psf	0 psf	0 psf	CCR
Column 109	692.83618 ft	84.57364 ft	0 psf	2,494.0131 psf	1,084.4278 psf	0 psf	0 psf	CCR
Column 110	694.85207 ft	84.66393 ft	0 psf	2,442.4376 psf	1,062.0021 psf	0 psf	0 psf	CCR
Column 111	696.86797 ft	84.75422 ft	0 psf	2,390.8621 psf	1,039.5764 psf	0 psf	0 psf	CCR
Column 112	698.88386 ft	84.84451 ft	0 psf	2,339.2867 psf	1,017.1508 psf	0 psf	0 psf	CCR
Column 113	700.89975 ft	84.93480 ft	0 psf	2,287.7112 psf	994.72513 psf	0 psf	0 psf	CCR
Column 114	702.91565 ft	85.02509 ft	0 psf	2,236.1357 psf	972.29948 psf	0 psf	0 psf	CCR
Column 115	704.93154 ft	85.11538 ft	0 psf	2,184.5602 psf	949.87382 psf	0 psf	0 psf	CCR
Column 116	706.94743 ft	85.20567 ft	0 psf	2,132.9847 psf	927.44816 psf	0 psf	0 psf	CCR
Column 117	708.96333 ft	85.29596 ft	0 psf	2,081.4093 psf	905.02251 psf	0 psf	0 psf	CCR
Column 118	710.97922 ft	85.38625 ft	0 psf	2,029.8338 psf	882.59685 psf	0 psf	0 psf	CCR
Column 119	712.99512 ft	85.47654 ft	0 psf	1,978.2583 psf	860.1712 psf	0 psf	0 psf	CCR
Column 120	715.01101 ft	85.56683 ft	0 psf	1,926.6828 psf	837.74554 psf	0 psf	0 psf	CCR
Column 121	717.02690 ft	85.65711 ft	0 psf	1,875.1074 psf	815.31989 psf	0 psf	0 psf	CCR
Column 122	719.04280 ft	85.74740 ft	0 psf	1,823.5319 psf	792.89423 psf	0 psf	0 psf	CCR
Column 123	721.05869 ft	85.83769 ft	0 psf	1,771.9564 psf	770.46857 psf	0 psf	0 psf	CCR
Column 124	723.07458 ft	85.92798 ft	0 psf	1,720.3809 psf	748.04292 psf	0 psf	0 psf	CCR
Column 125	725.09048 ft	86.01827 ft	0 psf	1,668.8055 psf	725.61726 psf	0 psf	0 psf	CCR
Column 126	727.10637 ft	86.10856 ft	0 psf	1,617.23 psf	703.19161 psf	0 psf	0 psf	CCR

Column 127	729.12227 ft	86.19885 ft	0 psf	1,565.6545 psf	680.76595 psf	0 psf	0 psf	CCR
Column 128	731.13816 ft	86.28914 ft	0 psf	1,514.079 psf	658.34029 psf	0 psf	0 psf	CCR
Column 129	733.15405 ft	86.37943 ft	0 psf	1,462.5035 psf	635.91464 psf	0 psf	0 psf	CCR
Column 130	735.16995 ft	86.46972 ft	0 psf	1,410.9281 psf	613.48898 psf	0 psf	0 psf	CCR
Column 131	737.18584 ft	86.56001 ft	0 psf	1,359.3526 psf	591.06333 psf	0 psf	0 psf	CCR
Column 132	739.20173 ft	86.65030 ft	0 psf	1,307.7771 psf	568.63767 psf	0 psf	0 psf	CCR
Column 133	741.21763 ft	86.74059 ft	0 psf	1,256.2016 psf	546.21201 psf	0 psf	0 psf	CCR
Column 134	743.23352 ft	86.83088 ft	0 psf	1,204.6262 psf	523.78636 psf	0 psf	0 psf	CCR
Column 135	745.24942 ft	86.92117 ft	0 psf	1,153.0507 psf	501.3607 psf	0 psf	0 psf	CCR
Column 136	747.26531 ft	87.01146 ft	0 psf	1,101.4752 psf	478.93505 psf	0 psf	0 psf	CCR
Column 137	749.28120 ft	87.10175 ft	0 psf	1,049.8997 psf	456.50939 psf	0 psf	0 psf	CCR
Column 138	751.29710 ft	87.19204 ft	0 psf	998.32424 psf	434.08374 psf	0 psf	0 psf	CCR
Column 139	753.31299 ft	87.28233 ft	0 psf	946.74877 psf	411.65808 psf	0 psf	0 psf	CCR
Column 140	755.32889 ft	87.37262 ft	0 psf	895.17329 psf	389.23242 psf	0 psf	0 psf	CCR
Column 141	757.34478 ft	87.46291 ft	0 psf	843.59781 psf	366.80677 psf	0 psf	0 psf	CCR
Column 142	759.36067 ft	87.55320 ft	0 psf	792.02233 psf	344.38111 psf	0 psf	0 psf	CCR
Column 143	761.37657 ft	87.64349 ft	0 psf	740.44686 psf	321.95546 psf	0 psf	0 psf	CCR
Column 144	763.21133 ft	87.72567 ft	0 psf	702.67465 psf	405.6894 psf	0 psf	0 psf	Drainage Layer
Column 145	765.03239 ft	87.80723 ft	0 psf	653.80591 psf	377.47502 psf	0 psf	0 psf	Drainage Layer
Column 146	766.55335 ft	87.87535 ft	0 psf	582.26311 psf	309.59478 psf	0 psf	0 psf	Clay
Column 147	768.15998 ft	87.89894 ft	0 psf	472.25478 psf	251.10232 psf	0 psf	0 psf	Clay
Column 148	770.31984 ft	87.89894 ft	0 psf	337.32485 psf	179.3588 psf	0 psf	0 psf	Clay
Column 149	772.47969 ft	87.89894 ft	0 psf	202.39491 psf	107.61528 psf	0 psf	0 psf	Clay
Column 150	774.63955 ft	87.89894 ft	0 psf	67.464969 psf	35.87176 psf	0 psf	0 psf	Clay

Title: Columbia Mod 12-13 Access Road
Name: Optimized Circular_FS=1.5
Method: Bishop
Last Edited By: Villanueva, Niko

F of S: 1.709
F of S Rank (Analysis): 1 of 10,572 slip surfaces
Surcharge (Unit Weight): 630 pcf
Last Solved Date: 08/23/2023, Last Solved Time: 09:55:54 AM

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Geotextile	Mohr-Coulomb	58	0	30
	Road Aggregate	Mohr-Coulomb	135	0	35
	Rooting Zone/Sand	Mohr-Coulomb	120	0	30



Optimized Circular_FS=1.5

File Information

- File Version: 11.05
- Title: Columbia Mod 12-13 Access Road
- Created By: Villanueva, Niko
- Last Edited By: Villanueva, Niko
- Revision Number: 122
- Date: 08/23/2023
- Time: 09:51:08 AM
- Tool Version: 23.1.1.829
- File Name: COL_Mod12-13_Access Road_3H1V.gsz
- Directory: I:\25222260.00\Data and Calcula ons\Geotech Calcula ons\Slope Stability\SlopeW\
- Last Solved Date: 08/23/2023
- Last Solved Time: 09:55:54 AM

Project Settings

- Unit System: U.S. Customary Units

Analysis Settings

Optimized Circular_FS=1.5

- Kind: SLOPE/W
- Analysis Type: Bishop
- Se   ngs
  - PWP Condi ons from: (none)
  - Unit Weight of Water: 62.4 pcf
- Slip Surface
  - Direc on of movement: Le. to Right
  - Use Passive Mode: No
  - Slip Surface Op⍰on: Entry and Exit
  - Cri⍰cal slip surfaces saved: 10
  - Op⍰mize Cri⍰cal Slip Surface Loca⍰on: Yes
  - Op⍰miza⍰ons Se⍰ ngs
    - Maximum Itera⍰ons: 2,000
    - Star⍰ng Points: 8
    - Ending Points: 16
    - Driving Side Maximum Convex Angle: 5 °
    - Resis⍰ng Side Maximum Convex Angle: 1 °
  - Tension Crack Op⍰on: (none)
- Distribu⍰on
  - F of S Calcula⍰on Op⍰on: Constant
- Convergence
  - Geometry Se⍰ ngs
    - Minimum Slip Surface Depth: 0.1 ft
    - Number of Columns: 150
  - Factor of Safety Convergence Se⍰ ngs

Maximum Number of Itera⍰ons: 30,000
Tolerable difference in F of S: 0.001

Materials

CCR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 23.5 °
Phi-B: 0 °

Clay

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 28 °
Phi-B: 0 °

Geosynthetics

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 24.3 °
Phi-B: 0 °

Rooting Zone/Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Road Aggregate

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 135 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 35 °
Phi-B: 0 °

Geotextile

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effec⍰ve Cohesion: 0 psf
Effec⍰ve Fric⍰on Angle: 30 °
Phi-B: 0 °

Slip Surface Entry and Exit

Left Type: Range
Left-Zone Left Coordinate: (78.91665, 19.808399) ft
Left-Zone Right Coordinate: (108.8813, 19.83983) ft

Left-Zone Increment: 30
Right Type: Range
Right-Zone Left Coordinate: (109.43572, 19.845042) ft
Right-Zone Right Coordinate: (150.00821, 9.142644) ft
Right-Zone Increment: 30
Radius Increments: 10

Slip Surface Limits

Left Coordinate: (0, 39.537491) ft
Right Coordinate: (186.5395, 0) ft

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 630 pcf
Direc�on: Ver�cal

Coordinates

	X	Y
	96.84206 ft	20.783361 ft
	107.8622 ft	20.783361 ft

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	112.87744 ft	19.877396 ft
Point 2	89.91043 ft	19.661493 ft
Point 3	85.31702 ft	18.208312 ft
Point 4	117.29 ft	18.41 ft
Point 5	85.31765 ft	18.108314 ft
Point 6	117.58 ft	18.31 ft
Point 7	130.28 ft	14.08 ft
Point 8	0 ft	39.537491 ft
Point 9	0 ft	36.702121 ft
Point 10	85.59619 ft	15.303152 ft
Point 11	116.51412 ft	14.68512 ft
Point 12	175.28247 ft	0 ft
Point 13	186.5395 ft	0 ft
Point 14	0 ft	36.599043 ft
Point 15	85.58289 ft	15.203397 ft
Point 16	116.50083 ft	14.585366 ft

Point 17	174.86997 ft	0 ft
Point 18	0 ft	34.537491 ft
Point 19	85.31702 ft	13.208312 ft
Point 20	116.23507 ft	12.590279 ft
Point 21	166.62008 ft	0 ft
Point 22	0 ft	0 ft

Regions

	Material	Points	Area
Region 1	Road Aggregate	1,2,3,4	40.095 ft²
Region 2	Geotex?le	4,3,5,6	3.241 ft²
Region 3	Roo?ng Zone/Sand	7,6,5,3,8,9,10,11,12,13	531.75 ft²
Region 4	Geosynthe?cs	10,9,14,15,16,17,12,11	17.952 ft²
Region 5	Clay	16,15,14,18,19,20,21,17	350.11 ft²
Region 6	CCR	20,19,18,22,21	2,752.8 ft²

Slip Results

Slip Surfaces Analysed: 8730 of 10572 converged

Current Slip Surface

Slip Surface: 10,572
Factor of Safety: 1.709
Volume: 257.46814 ft³
Weight: 29,861.711 lbf
Resis?ng Moment: 798,807.09 lbf·ft
Ac?va?ng Moment: 467,413.8 lbf·ft
Resis?ng Force: 14,053.471 lbf
Ac?va?ng Force: 8,738.6005 lbf
Slip Rank: 1 of 10,572 slip surfaces
Exit: (148.7607, 9.4548574) ft
Entry: (102.81763, 19.782828) ft
Radius: 21.246033 ft
Center: (135.55203, 58.237563) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Fric?onal Strength	Cohesive Strength	Suc?on Strength	Base Material
Column 1	102.98675 ft	19.539875 ft	0 psf	416.97639 psf	291.97001 psf	0 psf	0 psf	Road Aggregate
Column 2	103.32498 ft	19.053968 ft	0 psf	457.28021 psf	320.19105 psf	0 psf	0 psf	Road Aggregate
Column 3	103.66321 ft	18.568061 ft	0 psf	497.58404 psf	348.41209 psf	0 psf	0 psf	Road Aggregate
Column 4	103.86734 ft	18.274802 ft	0 psf	555.5742 psf	320.76091 psf	0 psf	0 psf	Geotex?le
Column 5	104.06699 ft	17.987985 ft	0 psf	575.9994 psf	332.55341 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column	104.39625	17.514966	0	613.16315	354.00991	0 psf	0 psf	Roo?ng

6	ft	ft	psf	psf	psf			Zone/Sand
Column 7	104.70699 ft	17.079336 ft	0 psf	658.41853 psf	380.13812 psf	0 psf	0 psf	Rooting Zone/Sand
Column 8	104.99922 ft	16.681095 ft	0 psf	690.19252 psf	398.48284 psf	0 psf	0 psf	Rooting Zone/Sand
Column 9	105.29144 ft	16.282854 ft	0 psf	721.96651 psf	416.82756 psf	0 psf	0 psf	Rooting Zone/Sand
Column 10	105.58366 ft	15.884613 ft	0 psf	753.7405 psf	435.17228 psf	0 psf	0 psf	Rooting Zone/Sand
Column 11	105.87589 ft	15.486372 ft	0 psf	785.51449 psf	453.517 psf	0 psf	0 psf	Rooting Zone/Sand
Column 12	106.16811 ft	15.088131 ft	0 psf	817.28848 psf	471.86172 psf	0 psf	0 psf	Rooting Zone/Sand
Column 13	106.35146 ft	14.838256 ft	0 psf	896.70745 psf	404.87894 psf	0 psf	0 psf	Geosynthetics
Column 14	106.53606 ft	14.586694 ft	0 psf	875.54461 psf	465.53533 psf	0 psf	0 psf	Clay
Column 15	106.83076 ft	14.185081 ft	0 psf	909.79611 psf	483.74717 psf	0 psf	0 psf	Clay
Column 16	107.12545 ft	13.783467 ft	0 psf	944.04761 psf	501.95902 psf	0 psf	0 psf	Clay
Column 17	107.42015 ft	13.381854 ft	0 psf	978.29912 psf	520.17087 psf	0 psf	0 psf	Clay
Column 18	107.71485 ft	12.980240 ft	0 psf	1,012.5506 psf	538.38271 psf	0 psf	0 psf	Clay
Column 19	107.86881 ft	12.770425 ft	0 psf	608.76308 psf	323.68507 psf	0 psf	0 psf	Clay
Column 20	107.88514 ft	12.759206 ft	0 psf	810.88297 psf	431.15412 psf	0 psf	0 psf	Clay
Column 21	108.05570 ft	12.720411 ft	0 psf	824.2937 psf	358.4131 psf	0 psf	0 psf	CCR
Column 22	108.37737 ft	12.647244 ft	0 psf	830.80461 psf	361.24412 psf	0 psf	0 psf	CCR
Column 23	108.69904 ft	12.574077 ft	0 psf	837.31551 psf	364.07515 psf	0 psf	0 psf	CCR
Column 24	109.02071 ft	12.500910 ft	0 psf	843.82642 psf	366.90617 psf	0 psf	0 psf	CCR
Column 25	109.34238 ft	12.427743 ft	0 psf	850.33732 psf	369.73719 psf	0 psf	0 psf	CCR
Column 26	109.66405 ft	12.354576 ft	0 psf	856.84823 psf	372.56821 psf	0 psf	0 psf	CCR
Column 27	109.98572 ft	12.281409 ft	0 psf	863.35913 psf	375.39923 psf	0 psf	0 psf	CCR
Column 28	110.30739 ft	12.208242 ft	0 psf	869.87004 psf	378.23026 psf	0 psf	0 psf	CCR
Column 29	110.61880 ft	12.123666 ft	0 psf	858.45061 psf	373.26495 psf	0 psf	0 psf	CCR
Column 30	110.91995 ft	12.027681 ft	0 psf	866.60168 psf	376.80914 psf	0 psf	0 psf	CCR
Column 31	111.22110 ft	11.931697 ft	0 psf	874.75276 psf	380.35332 psf	0 psf	0 psf	CCR
Column 32	111.52225 ft	11.835713 ft	0 psf	882.90384 psf	383.89751 psf	0 psf	0 psf	CCR

Column 33	111.82341 ft	11.739728 ft	0 psf	891.05491 psf	387.4417 psf	0 psf	0 psf	CCR
Column 34	112.12456 ft	11.643744 ft	0 psf	899.20599 psf	390.98589 psf	0 psf	0 psf	CCR
Column 35	112.42571 ft	11.547760 ft	0 psf	907.35706 psf	394.53008 psf	0 psf	0 psf	CCR
Column 36	112.72686 ft	11.451775 ft	0 psf	915.50814 psf	398.07427 psf	0 psf	0 psf	CCR
Column 37	113.02683 ft	11.356169 ft	0 psf	917.24799 psf	398.83078 psf	0 psf	0 psf	CCR
Column 38	113.32561 ft	11.260941 ft	0 psf	912.57661 psf	396.7996 psf	0 psf	0 psf	CCR
Column 39	113.63904 ft	11.158843 ft	0 psf	904.99296 psf	393.50214 psf	0 psf	0 psf	CCR
Column 40	113.96711 ft	11.049874 ft	0 psf	900.22892 psf	391.43067 psf	0 psf	0 psf	CCR
Column 41	114.29519 ft	10.940905 ft	0 psf	895.46487 psf	389.35921 psf	0 psf	0 psf	CCR
Column 42	114.62326 ft	10.831936 ft	0 psf	890.70083 psf	387.28774 psf	0 psf	0 psf	CCR
Column 43	114.95134 ft	10.722967 ft	0 psf	885.93679 psf	385.21628 psf	0 psf	0 psf	CCR
Column 44	115.27941 ft	10.613998 ft	0 psf	881.17275 psf	383.14482 psf	0 psf	0 psf	CCR
Column 45	115.57539 ft	10.528768 ft	0 psf	896.68343 psf	389.88905 psf	0 psf	0 psf	CCR
Column 46	115.83926 ft	10.467275 ft	0 psf	890.6373 psf	387.26012 psf	0 psf	0 psf	CCR
Column 47	116.10313 ft	10.405782 ft	0 psf	884.59117 psf	384.63119 psf	0 psf	0 psf	CCR
Column 48	116.36795 ft	10.344069 ft	0 psf	879.64813 psf	382.48189 psf	0 psf	0 psf	CCR
Column 49	116.50747 ft	10.311554 ft	0 psf	877.53551 psf	381.5633 psf	0 psf	0 psf	CCR
Column 50	116.64343 ft	10.279871 ft	0 psf	875.33411 psf	380.6061 psf	0 psf	0 psf	CCR
Column 51	116.90206 ft	10.219600 ft	0 psf	871.31658 psf	378.85923 psf	0 psf	0 psf	CCR
Column 52	117.16069 ft	10.159330 ft	0 psf	867.29905 psf	377.11236 psf	0 psf	0 psf	CCR
Column 53	117.43500 ft	10.095404 ft	0 psf	866.51197 psf	376.77013 psf	0 psf	0 psf	CCR
Column 54	117.73805 ft	10.024782 ft	0 psf	866.02807 psf	376.55972 psf	0 psf	0 psf	CCR
Column 55	118.05415 ft	9.951117 ft	0 psf	862.61689 psf	375.0765 psf	0 psf	0 psf	CCR
Column 56	118.37025 ft	9.877453 ft	0 psf	859.20571 psf	373.59327 psf	0 psf	0 psf	CCR
Column 57	118.68636 ft	9.803789 ft	0 psf	855.79453 psf	372.11005 psf	0 psf	0 psf	CCR
Column 58	119.00246 ft	9.730125 ft	0 psf	852.38334 psf	370.62683 psf	0 psf	0 psf	CCR

Column 59	119.31856 ft	9.656461 ft	0 psf	848.97216 psf	369.1436 psf	0 psf	0 psf	CCR
Column 60	119.63466 ft	9.582797 ft	0 psf	845.56098 psf	367.66038 psf	0 psf	0 psf	CCR
Column 61	119.95076 ft	9.509133 ft	0 psf	842.1498 psf	366.17715 psf	0 psf	0 psf	CCR
Column 62	120.26686 ft	9.435468 ft	0 psf	838.73862 psf	364.69393 psf	0 psf	0 psf	CCR
Column 63	120.58297 ft	9.361804 ft	0 psf	835.32744 psf	363.21071 psf	0 psf	0 psf	CCR
Column 64	120.89907 ft	9.288140 ft	0 psf	831.91625 psf	361.72748 psf	0 psf	0 psf	CCR
Column 65	121.21517 ft	9.214476 ft	0 psf	828.50507 psf	360.24426 psf	0 psf	0 psf	CCR
Column 66	121.52489 ft	9.151643 ft	0 psf	836.78531 psf	363.84461 psf	0 psf	0 psf	CCR
Column 67	121.82824 ft	9.099642 ft	0 psf	831.92249 psf	361.73019 psf	0 psf	0 psf	CCR
Column 68	122.13158 ft	9.047640 ft	0 psf	827.05966 psf	359.61578 psf	0 psf	0 psf	CCR
Column 69	122.43493 ft	8.995639 ft	0 psf	822.19684 psf	357.50136 psf	0 psf	0 psf	CCR
Column 70	122.73827 ft	8.943637 ft	0 psf	817.33402 psf	355.38695 psf	0 psf	0 psf	CCR
Column 71	123.04161 ft	8.891636 ft	0 psf	812.4712 psf	353.27253 psf	0 psf	0 psf	CCR
Column 72	123.34496 ft	8.839634 ft	0 psf	807.60838 psf	351.15812 psf	0 psf	0 psf	CCR
Column 73	123.64830 ft	8.787633 ft	0 psf	802.74556 psf	349.0437 psf	0 psf	0 psf	CCR
Column 74	123.95165 ft	8.735631 ft	0 psf	797.88273 psf	346.92929 psf	0 psf	0 psf	CCR
Column 75	124.25499 ft	8.683630 ft	0 psf	793.01991 psf	344.81487 psf	0 psf	0 psf	CCR
Column 76	124.55833 ft	8.631628 ft	0 psf	788.15709 psf	342.70046 psf	0 psf	0 psf	CCR
Column 77	124.86168 ft	8.579627 ft	0 psf	783.29427 psf	340.58604 psf	0 psf	0 psf	CCR
Column 78	125.16502 ft	8.527625 ft	0 psf	778.43145 psf	338.47163 psf	0 psf	0 psf	CCR
Column 79	125.46837 ft	8.475624 ft	0 psf	773.56862 psf	336.35721 psf	0 psf	0 psf	CCR
Column 80	125.76779 ft	8.432283 ft	0 psf	778.36888 psf	338.44442 psf	0 psf	0 psf	CCR
Column 81	126.06330 ft	8.397603 ft	0 psf	772.23426 psf	335.77701 psf	0 psf	0 psf	CCR
Column 82	126.35880 ft	8.362923 ft	0 psf	766.09963 psf	333.1096 psf	0 psf	0 psf	CCR
Column 83	126.65430 ft	8.328243 ft	0 psf	759.96501 psf	330.44219 psf	0 psf	0 psf	CCR
Column 84	126.94981 ft	8.293563 ft	0 psf	753.83039 psf	327.77478 psf	0 psf	0 psf	CCR

Column 85	127.24531 ft	8.258882 ft	0 psf	747.69576 psf	325.10737 psf	0 psf	0 psf	CCR
Column 86	127.54082 ft	8.224202 ft	0 psf	741.56114 psf	322.43996 psf	0 psf	0 psf	CCR
Column 87	127.83632 ft	8.189522 ft	0 psf	735.42652 psf	319.77255 psf	0 psf	0 psf	CCR
Column 88	128.13182 ft	8.154842 ft	0 psf	729.29189 psf	317.10514 psf	0 psf	0 psf	CCR
Column 89	128.42733 ft	8.120162 ft	0 psf	723.15727 psf	314.43773 psf	0 psf	0 psf	CCR
Column 90	128.71716 ft	8.092523 ft	0 psf	724.6398 psf	315.08235 psf	0 psf	0 psf	CCR
Column 91	129.00131 ft	8.071925 ft	0 psf	717.59804 psf	312.02051 psf	0 psf	0 psf	CCR
Column 92	129.28546 ft	8.051328 ft	0 psf	710.55627 psf	308.95866 psf	0 psf	0 psf	CCR
Column 93	129.56962 ft	8.030730 ft	0 psf	703.51451 psf	305.89681 psf	0 psf	0 psf	CCR
Column 94	129.85377 ft	8.010132 ft	0 psf	696.47274 psf	302.83497 psf	0 psf	0 psf	CCR
Column 95	130.13792 ft	7.989534 ft	0 psf	689.43098 psf	299.77312 psf	0 psf	0 psf	CCR
Column 96	130.43024 ft	7.968345 ft	0 psf	683.65272 psf	297.26066 psf	0 psf	0 psf	CCR
Column 97	130.73072 ft	7.946564 ft	0 psf	679.13796 psf	295.29759 psf	0 psf	0 psf	CCR
Column 98	131.03119 ft	7.924782 ft	0 psf	674.62321 psf	293.33452 psf	0 psf	0 psf	CCR
Column 99	131.33167 ft	7.903001 ft	0 psf	670.10846 psf	291.37145 psf	0 psf	0 psf	CCR
Column 100	131.63215 ft	7.881220 ft	0 psf	665.59371 psf	289.40838 psf	0 psf	0 psf	CCR
Column 101	131.93263 ft	7.859439 ft	0 psf	661.07895 psf	287.44531 psf	0 psf	0 psf	CCR
Column 102	132.23311 ft	7.837658 ft	0 psf	656.5642 psf	285.48224 psf	0 psf	0 psf	CCR
Column 103	132.53358 ft	7.815877 ft	0 psf	652.04945 psf	283.51917 psf	0 psf	0 psf	CCR
Column 104	132.83406 ft	7.794096 ft	0 psf	647.5347 psf	281.5561 psf	0 psf	0 psf	CCR
Column 105	133.13454 ft	7.772315 ft	0 psf	643.01994 psf	279.59303 psf	0 psf	0 psf	CCR
Column 106	133.44519 ft	7.746577 ft	0 psf	635.43867 psf	276.2966 psf	0 psf	0 psf	CCR
Column 107	133.76601 ft	7.716882 ft	0 psf	631.18338 psf	274.44634 psf	0 psf	0 psf	CCR
Column 108	134.08682 ft	7.687188 ft	0 psf	626.92808 psf	272.59609 psf	0 psf	0 psf	CCR
Column 109	134.40764 ft	7.657494 ft	0 psf	622.67279 psf	270.74583 psf	0 psf	0 psf	CCR
Column 110	134.72845 ft	7.627800 ft	0 psf	618.41749 psf	268.89558 psf	0 psf	0 psf	CCR

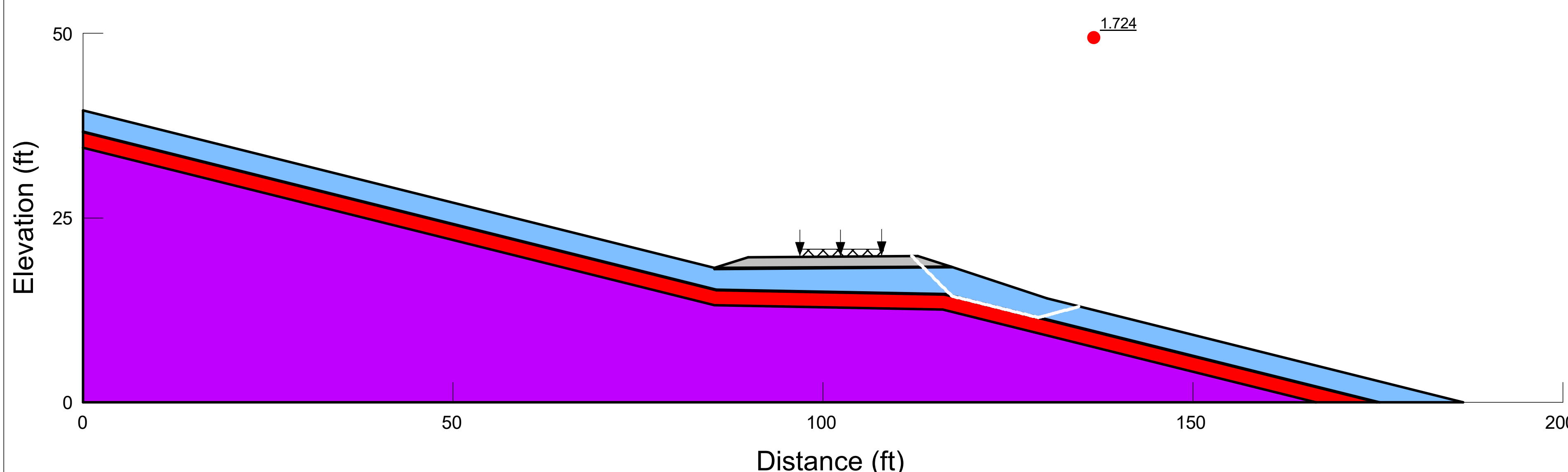
Column 111	135.04927 ft	7.598105 ft	0 psf	614.1622 psf	267.04532 psf	0 psf	0 psf	CCR
Column 112	135.36119 ft	7.566917 ft	0 psf	607.90836 psf	264.32608 psf	0 psf	0 psf	CCR
Column 113	135.66421 ft	7.534234 ft	0 psf	604.29235 psf	262.75379 psf	0 psf	0 psf	CCR
Column 114	135.96723 ft	7.501551 ft	0 psf	600.67635 psf	261.18151 psf	0 psf	0 psf	CCR
Column 115	136.27025 ft	7.468869 ft	0 psf	597.06034 psf	259.60923 psf	0 psf	0 psf	CCR
Column 116	136.57327 ft	7.436186 ft	0 psf	593.44434 psf	258.03694 psf	0 psf	0 psf	CCR
Column 117	136.87629 ft	7.403503 ft	0 psf	589.82833 psf	256.46466 psf	0 psf	0 psf	CCR
Column 118	137.03706 ft	7.388548 ft	0 psf	627.74274 psf	272.95031 psf	0 psf	0 psf	CCR
Column 119	137.20234 ft	7.413293 ft	0 psf	624.81493 psf	332.21999 psf	0 psf	0 psf	Clay
Column 120	137.51439 ft	7.460010 ft	0 psf	608.45182 psf	323.51957 psf	0 psf	0 psf	Clay
Column 121	137.82644 ft	7.506727 ft	0 psf	592.08872 psf	314.81916 psf	0 psf	0 psf	Clay
Column 122	138.13849 ft	7.553444 ft	0 psf	575.72561 psf	306.11874 psf	0 psf	0 psf	Clay
Column 123	138.45054 ft	7.600161 ft	0 psf	559.36251 psf	297.41832 psf	0 psf	0 psf	Clay
Column 124	138.76259 ft	7.646878 ft	0 psf	542.9994 psf	288.7179 psf	0 psf	0 psf	Clay
Column 125	139.07464 ft	7.693595 ft	0 psf	526.63629 psf	280.01748 psf	0 psf	0 psf	Clay
Column 126	139.38669 ft	7.740312 ft	0 psf	510.27319 psf	271.31707 psf	0 psf	0 psf	Clay
Column 127	139.69874 ft	7.787029 ft	0 psf	493.91008 psf	262.61665 psf	0 psf	0 psf	Clay
Column 128	140.01079 ft	7.833746 ft	0 psf	477.54698 psf	253.91623 psf	0 psf	0 psf	Clay
Column 129	140.32284 ft	7.880463 ft	0 psf	461.18387 psf	245.21581 psf	0 psf	0 psf	Clay
Column 130	140.63489 ft	7.927180 ft	0 psf	444.82076 psf	236.5154 psf	0 psf	0 psf	Clay
Column 131	140.94694 ft	7.973897 ft	0 psf	428.45766 psf	227.81498 psf	0 psf	0 psf	Clay
Column 132	141.25899 ft	8.020614 ft	0 psf	412.09455 psf	219.11456 psf	0 psf	0 psf	Clay
Column 133	141.57104 ft	8.067331 ft	0 psf	395.73145 psf	210.41414 psf	0 psf	0 psf	Clay
Column 134	141.84910 ft	8.107971 ft	0 psf	380.27546 psf	202.19605 psf	0 psf	0 psf	Clay
Column 135	142.09318 ft	8.142536 ft	0 psf	367.7688 psf	195.54614 psf	0 psf	0 psf	Clay
Column 136	142.34686 ft	8.178461 ft	0 psf	355.90849 psf	160.69885 psf	0 psf	0 psf	Geosynthe�cs

Column 137	142.69826 ft	8.228224 ft	0 psf	345.80605 psf	199.65121 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 138	143.05551 ft	8.285168 ft	0 psf	332.81623 psf	192.15154 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 139	143.33049 ft	8.336813 ft	0 psf	317.38137 psf	183.24022 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 140	143.62365 ft	8.394759 ft	0 psf	302.58048 psf	174.69492 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 141	143.93498 ft	8.459008 ft	0 psf	284.24227 psf	164.10735 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 142	144.24632 ft	8.523256 ft	0 psf	265.90406 psf	153.51978 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 143	144.55766 ft	8.587504 ft	0 psf	247.56585 psf	142.93221 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 144	144.86899 ft	8.651753 ft	0 psf	229.22764 psf	132.34464 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 145	145.18033 ft	8.716001 ft	0 psf	210.88943 psf	121.75707 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 146	145.49167 ft	8.780249 ft	0 psf	192.55122 psf	111.1695 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 147	145.80300 ft	8.844498 ft	0 psf	174.213 psf	100.58192 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 148	146.11434 ft	8.908746 ft	0 psf	155.87479 psf	89.994354 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 149	146.42567 ft	8.972995 ft	0 psf	137.53658 psf	79.406783 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 150	146.73701 ft	9.037243 ft	0 psf	119.19837 psf	68.819212 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 151	147.04835 ft	9.101491 ft	0 psf	100.86016 psf	58.231641 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 152	147.35968 ft	9.165740 ft	0 psf	82.521949 psf	47.64407 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 153	147.67102 ft	9.229988 ft	0 psf	64.183738 psf	37.056499 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 154	147.98236 ft	9.294236 ft	0 psf	45.845527 psf	26.468928 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 155	148.29369 ft	9.358485 ft	0 psf	27.507316 psf	15.881357 psf	0 psf	0 psf	Roo�ng Zone/Sand
Column 156	148.60503 ft	9.422733 ft	0 psf	9.1691055 psf	5.2937855 psf	0 psf	0 psf	Roo�ng Zone/Sand

Title: Columbia Mod 12-13 Access Road
Name: Block_FS=1.5
Method: Janbu
Last Edited By: Villanueva, Niko

F of S: 1.724
F of S Rank (Analysis): 1 of 234,256 slip surfaces
Surcharge (Unit Weight): 630 pcf
Last Solved Date: 08/23/2023, Last Solved Time: 10:14:59 AM

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)
	CCR	Mohr-Coulomb	86	0	23.5
	Clay	Mohr-Coulomb	125	0	28
	Geosynthetics	Mohr-Coulomb	58	0	24.3
	Geotextile	Mohr-Coulomb	58	0	30
	Road Aggregate	Mohr-Coulomb	135	0	35
	Rooting Zone/Sand	Mohr-Coulomb	120	0	30



Block_FS=1.5

File Information

File Version: 11.05
Title: Columbia Mod 12-13 Access Road
Created By: Villanueva, Niko
Last Edited By: Villanueva, Niko
Revision Number: 124
Date: 08/23/2023
Time: 10:14:01 AM
Tool Version: 23.1.1.829
File Name: COL_Mod12-13_Access Road_3H1V.gsz
Directory: I:\25222260.00\Data and Calcula ons\Geotech Calcula ons\Slope Stability\SlopeW\
Last Solved Date: 08/23/2023
Last Solved Time: 10:14:58 AM

Project Settings

Unit System: U.S. Customary Units

Analysis Settings

Block_FS=1.5

- Kind: SLOPE/W
- Analysis Type: Janbu
- Se ngs
  - PWP Condi ons from: (none)
  - Unit Weight of Water: 62.4 pcf
- Slip Surface
  - Direc on of movement: Le. to Right
  - Use Passive Mode: No
  - Slip Surface Op⍰on: Block
  - Cri⍰cal slip surfaces saved: 10
  - Restrict Block Crossing: No
  - Op⍰mize Cri⍰cal Slip Surface Loca⍰on: No
  - Tension Crack Op⍰on: (none)
- Distribu⍰on
  - F of S Calcula⍰on Op⍰on: Constant
- Convergence
  - Geometry Se⍰ ngs
    - Minimum Slip Surface Depth: 0.1 ft
    - Number of Columns: 150
  - Factor of Safety Convergence Se⍰ ngs
    - Maximum Number of Itera⍰ons: 100
    - Tolerable difference in F of S: 0.001

Materials

CCR

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 86 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 23.5 °
Phi-B: 0 °

Clay

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 125 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 28 °
Phi-B: 0 °

Geosynthetics

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 24.3 °
Phi-B: 0 °

Rooting Zone/Sand

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 120 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 30 °
Phi-B: 0 °

Road Aggregate

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 135 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 35 °
Phi-B: 0 °

Geotextile

Slope Stability Material Model: Mohr-Coulomb
Unit Weight: 58 pcf
Effective Cohesion: 0 psf
Effective Friction Angle: 30 °
Phi-B: 0 °

Slip Surface Limits

Left Coordinate: (0, 39.537491) ft
Right Coordinate: (186.5395, 0) ft

Slip Surface Block

Left Grid

Upper Left: (105.31355, 15.853234) ft
Lower Left: (105.22097, 14.202143) ft
Lower Right: (120.46655, 13.230005) ft
X Increments: 10
Y Increments: 10
Star�ng Angle: 115 °
Ending Angle: 135 °
Angle Increments: 3

Right Grid

Upper Left: (122.69352, 13.67688) ft
Lower Left: (122.4491, 12.521425) ft
Lower Right: (155.15737, 4.611001) ft
X Increments: 10
Y Increments: 10
Angle Increments: 3

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 630 pcf
Direc�on: Ver�cal

Coordinates

	X	Y
	96.9402 ft	20.742933 ft
	107.91703 ft	20.742933 ft

Geometry

Name: Default Geometry

Settings

View: 2D
Element Thickness: 1 ft

Points

	X	Y
Point 1	112.87744 ft	19.877396 ft
Point 2	89.91043 ft	19.661493 ft
Point 3	85.31702 ft	18.208312 ft
Point 4	117.29 ft	18.41 ft
Point 5	85.31765 ft	18.108314 ft
Point 6	117.58 ft	18.31 ft
Point 7	130.28 ft	14.08 ft
Point 8	0 ft	39.537491 ft
Point 9	0 ft	36.702121 ft
Point 10	85.59619 ft	15.303152 ft
Point 11	116.51412 ft	14.68512 ft
Point 12	175.28247 ft	0 ft
Point 13	186.5395 ft	0 ft

Point 14	0 ft	36.599043 ft
Point 15	85.58289 ft	15.203397 ft
Point 16	116.50083 ft	14.585366 ft
Point 17	174.86997 ft	0 ft
Point 18	0 ft	34.537491 ft
Point 19	85.31702 ft	13.208312 ft
Point 20	116.23507 ft	12.590279 ft
Point 21	166.62008 ft	0 ft
Point 22	0 ft	0 ft

Regions

	Material	Points	Area
Region 1	Road Aggregate	1,2,3,4	40.095 ft²
Region 2	Geotextile	4,3,5,6	3.241 ft²
Region 3	Rooting Zone/Sand	7,6,5,3,8,9,10,11,12,13	531.75 ft²
Region 4	Geosynthetics	10,9,14,15,16,17,12,11	17.952 ft²
Region 5	Clay	16,15,14,18,19,20,21,17	350.11 ft²
Region 6	CCR	20,19,18,22,21	2,752.8 ft²

Slip Results

Slip Surfaces Analysed: 233976 of 234256 converged

Current Slip Surface

Slip Surface: 144,946
Factor of Safety: 1.724
Volume: 59.378416 ft³
Weight: 7,134.8484 lbf
Resisting Moment: 30,069.202 lbf·ft
Activating Moment: 17,647.289 lbf·ft
Resisting Force: 3,242.053 lbf
Activating Force: 1,880.6689 lbf
Slip Rank: 1 of 234,256 slip surfaces
Exit: (134.62224, 12.993273) ft
Entry: (112.01875, 19.869324) ft
Radius: 11.580067 ft
Center: (124.88928, 21.588336) ft

Slip Columns

	X	Y	PWP	Base Normal Stress	Frictional Strength	Cohesive Strength	Suction Strength	Base Material
Column 1	112.09030 ft	19.797766 ft	0 psf	6.9339626 psf	4.8552129 psf	0 psf	0 psf	Road Aggregate
Column 2	112.23342 ft	19.654650 ft	0 psf	20.801888 psf	14.565639 psf	0 psf	0 psf	Road Aggregate
Column 3	112.37653 ft	19.511534 ft	0 psf	34.669813 psf	24.276064 psf	0 psf	0 psf	Road Aggregate
Column 4	112.51965 ft	19.368419 ft	0 psf	48.537738 psf	33.98649 psf	0 psf	0 psf	Road Aggregate

Column 5	112.66277 ft	19.225303 ft	0 psf	62.405663 psf	43.696916 psf	0 psf	0 psf	Road Aggregate
Column 6	112.80588 ft	19.082187 ft	0 psf	76.273589 psf	53.407342 psf	0 psf	0 psf	Road Aggregate
Column 7	112.95551 ft	18.932564 ft	0 psf	88.209495 psf	61.764953 psf	0 psf	0 psf	Road Aggregate
Column 8	113.11164 ft	18.776433 ft	0 psf	98.213381 psf	68.76975 psf	0 psf	0 psf	Road Aggregate
Column 9	113.26777 ft	18.620301 ft	0 psf	108.21727 psf	75.774547 psf	0 psf	0 psf	Road Aggregate
Column 10	113.42390 ft	18.464170 ft	0 psf	118.22115 psf	82.779344 psf	0 psf	0 psf	Road Aggregate
Column 11	113.55245 ft	18.335621 ft	0 psf	130.28018 psf	75.217297 psf	0 psf	0 psf	Geotextile
Column 12	113.67975 ft	18.208324 ft	0 psf	135.07325 psf	77.984575 psf	0 psf	0 psf	Rooting Zone/Sand
Column 13	113.83337 ft	18.054696 ft	0 psf	143.70491 psf	82.96807 psf	0 psf	0 psf	Rooting Zone/Sand
Column 14	113.98700 ft	17.901068 ft	0 psf	152.33658 psf	87.951564 psf	0 psf	0 psf	Rooting Zone/Sand
Column 15	114.14063 ft	17.747440 ft	0 psf	160.96824 psf	92.935058 psf	0 psf	0 psf	Rooting Zone/Sand
Column 16	114.29426 ft	17.593812 ft	0 psf	169.59991 psf	97.918553 psf	0 psf	0 psf	Rooting Zone/Sand
Column 17	114.44788 ft	17.440184 ft	0 psf	178.23157 psf	102.90205 psf	0 psf	0 psf	Rooting Zone/Sand
Column 18	114.60151 ft	17.286557 ft	0 psf	186.86324 psf	107.88554 psf	0 psf	0 psf	Rooting Zone/Sand
Column 19	114.75514 ft	17.132929 ft	0 psf	195.49491 psf	112.86904 psf	0 psf	0 psf	Rooting Zone/Sand
Column 20	114.90877 ft	16.979301 ft	0 psf	204.12657 psf	117.85253 psf	0 psf	0 psf	Rooting Zone/Sand
Column 21	115.06240 ft	16.825673 ft	0 psf	212.75824 psf	122.83603 psf	0 psf	0 psf	Rooting Zone/Sand
Column 22	115.21602 ft	16.672045 ft	0 psf	221.3899 psf	127.81952 psf	0 psf	0 psf	Rooting Zone/Sand
Column 23	115.36965 ft	16.518417 ft	0 psf	230.02157 psf	132.80301 psf	0 psf	0 psf	Rooting Zone/Sand
Column 24	115.52328 ft	16.364789 ft	0 psf	238.65323 psf	137.78651 psf	0 psf	0 psf	Rooting Zone/Sand
Column 25	115.67691 ft	16.211162 ft	0 psf	247.2849 psf	142.77 psf	0 psf	0 psf	Rooting Zone/Sand
Column 26	115.83054 ft	16.057534 ft	0 psf	255.91656 psf	147.7535 psf	0 psf	0 psf	Rooting Zone/Sand
Column 27	115.98416 ft	15.903906 ft	0 psf	264.54823 psf	152.73699 psf	0 psf	0 psf	Rooting Zone/Sand
Column 28	116.13779 ft	15.750278 ft	0 psf	273.1799 psf	157.72049 psf	0 psf	0 psf	Rooting Zone/Sand
Column 29	116.29142 ft	15.596650 ft	0 psf	281.81156 psf	162.70398 psf	0 psf	0 psf	Rooting Zone/Sand
Column 30	116.44505 ft	15.443022 ft	0 psf	290.44323 psf	167.68748 psf	0 psf	0 psf	Rooting Zone/Sand

Column 31	116.59867 ft	15.289395 ft	0 psf	299.07489 psf	172.67097 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 32	116.75230 ft	15.135767 ft	0 psf	307.70656 psf	177.65446 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 33	116.90593 ft	14.982139 ft	0 psf	316.33822 psf	182.63796 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 34	117.05956 ft	14.828511 ft	0 psf	324.96989 psf	187.62145 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 35	117.21319 ft	14.674883 ft	0 psf	333.60155 psf	192.60495 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 36	117.36121 ft	14.526862 ft	0 psf	343.27191 psf	198.18813 psf	0 psf	0 psf	Roo?ng Zone/Sand
Column 37	117.45270 ft	14.435371 ft	0 psf	369.66238 psf	166.90896 psf	0 psf	0 psf	Geosynthe?cs
Column 38	117.52649 ft	14.401765 ft	0 psf	439.4875 psf	198.43621 psf	0 psf	0 psf	Geosynthe?cs
Column 39	117.65489 ft	14.369798 ft	0 psf	439.30039 psf	198.35173 psf	0 psf	0 psf	Geosynthe?cs
Column 40	117.80467 ft	14.332507 ft	0 psf	437.88932 psf	197.71461 psf	0 psf	0 psf	Geosynthe?cs
Column 41	117.95445 ft	14.295216 ft	0 psf	436.47825 psf	197.07749 psf	0 psf	0 psf	Geosynthe?cs
Column 42	118.10423 ft	14.257926 ft	0 psf	435.06718 psf	196.44037 psf	0 psf	0 psf	Geosynthe?cs
Column 43	118.25400 ft	14.220635 ft	0 psf	433.65612 psf	195.80324 psf	0 psf	0 psf	Geosynthe?cs
Column 44	118.40378 ft	14.183345 ft	0 psf	432.24505 psf	195.16612 psf	0 psf	0 psf	Geosynthe?cs
Column 45	118.55356 ft	14.146054 ft	0 psf	430.83398 psf	194.529 psf	0 psf	0 psf	Geosynthe?cs
Column 46	118.70334 ft	14.108763 ft	0 psf	429.42291 psf	193.89188 psf	0 psf	0 psf	Geosynthe?cs
Column 47	118.85312 ft	14.071473 ft	0 psf	428.01184 psf	193.25476 psf	0 psf	0 psf	Geosynthe?cs
Column 48	119.00290 ft	14.034182 ft	0 psf	426.60077 psf	192.61763 psf	0 psf	0 psf	Geosynthe?cs
Column 49	119.15268 ft	13.996892 ft	0 psf	425.1897 psf	191.98051 psf	0 psf	0 psf	Geosynthe?cs
Column 50	119.30246 ft	13.959601 ft	0 psf	423.77863 psf	191.34339 psf	0 psf	0 psf	Geosynthe?cs
Column 51	119.45223 ft	13.922310 ft	0 psf	422.36756 psf	190.70627 psf	0 psf	0 psf	Geosynthe?cs
Column 52	119.60201 ft	13.885020 ft	0 psf	420.95649 psf	190.06914 psf	0 psf	0 psf	Geosynthe?cs
Column 53	119.75179 ft	13.847729 ft	0 psf	419.54542 psf	189.43202 psf	0 psf	0 psf	Geosynthe?cs
Column 54	119.90157 ft	13.810439 ft	0 psf	418.13435 psf	188.7949 psf	0 psf	0 psf	Geosynthe?cs
Column 55	120.05135 ft	13.773148 ft	0 psf	416.72328 psf	188.15778 psf	0 psf	0 psf	Geosynthe?cs
Column 56	120.20113 ft	13.735858 ft	0 psf	415.31222 psf	187.52066 psf	0 psf	0 psf	Geosynthe?cs

Column 57	120.35091 ft	13.698567 ft	0 psf	413.90115 psf	186.88353 psf	0 psf	0 psf	Geosynthe�cs
Column 58	120.50069 ft	13.661276 ft	0 psf	412.49008 psf	186.24641 psf	0 psf	0 psf	Geosynthe�cs
Column 59	120.65046 ft	13.623986 ft	0 psf	411.07901 psf	185.60929 psf	0 psf	0 psf	Geosynthe�cs
Column 60	120.80024 ft	13.586695 ft	0 psf	409.66794 psf	184.97217 psf	0 psf	0 psf	Geosynthe�cs
Column 61	120.95002 ft	13.549405 ft	0 psf	408.25687 psf	184.33504 psf	0 psf	0 psf	Geosynthe�cs
Column 62	121.09980 ft	13.512114 ft	0 psf	406.8458 psf	183.69792 psf	0 psf	0 psf	Geosynthe�cs
Column 63	121.24958 ft	13.474823 ft	0 psf	405.43473 psf	183.0608 psf	0 psf	0 psf	Geosynthe�cs
Column 64	121.39936 ft	13.437533 ft	0 psf	404.02366 psf	182.42368 psf	0 psf	0 psf	Geosynthe�cs
Column 65	121.54914 ft	13.400242 ft	0 psf	402.61259 psf	181.78656 psf	0 psf	0 psf	Geosynthe�cs
Column 66	121.69892 ft	13.362952 ft	0 psf	401.20152 psf	181.14943 psf	0 psf	0 psf	Geosynthe�cs
Column 67	121.84869 ft	13.325661 ft	0 psf	399.79045 psf	180.51231 psf	0 psf	0 psf	Geosynthe�cs
Column 68	121.99847 ft	13.288371 ft	0 psf	398.37938 psf	179.87519 psf	0 psf	0 psf	Geosynthe�cs
Column 69	122.14825 ft	13.251080 ft	0 psf	396.96832 psf	179.23807 psf	0 psf	0 psf	Geosynthe�cs
Column 70	122.29803 ft	13.213789 ft	0 psf	395.55725 psf	178.60094 psf	0 psf	0 psf	Geosynthe�cs
Column 71	122.44781 ft	13.176499 ft	0 psf	394.14618 psf	177.96382 psf	0 psf	0 psf	Geosynthe�cs
Column 72	122.59759 ft	13.139208 ft	0 psf	392.73511 psf	177.3267 psf	0 psf	0 psf	Geosynthe�cs
Column 73	122.74737 ft	13.101918 ft	0 psf	391.32404 psf	176.68958 psf	0 psf	0 psf	Geosynthe�cs
Column 74	122.89715 ft	13.064627 ft	0 psf	389.91297 psf	176.05246 psf	0 psf	0 psf	Geosynthe�cs
Column 75	123.04692 ft	13.027336 ft	0 psf	388.5019 psf	175.41533 psf	0 psf	0 psf	Geosynthe�cs
Column 76	123.19670 ft	12.990046 ft	0 psf	387.09083 psf	174.77821 psf	0 psf	0 psf	Geosynthe�cs
Column 77	123.34648 ft	12.952755 ft	0 psf	385.67976 psf	174.14109 psf	0 psf	0 psf	Geosynthe�cs
Column 78	123.49626 ft	12.915465 ft	0 psf	384.26869 psf	173.50397 psf	0 psf	0 psf	Geosynthe�cs
Column 79	123.64604 ft	12.878174 ft	0 psf	382.85762 psf	172.86685 psf	0 psf	0 psf	Geosynthe�cs
Column 80	123.79582 ft	12.840883 ft	0 psf	381.44655 psf	172.22972 psf	0 psf	0 psf	Geosynthe�cs
Column 81	123.94560 ft	12.803593 ft	0 psf	380.03548 psf	171.5926 psf	0 psf	0 psf	Geosynthe�cs
Column 82	124.09538 ft	12.766302 ft	0 psf	378.62442 psf	170.95548 psf	0 psf	0 psf	Geosynthe�cs

Column 83	124.24515 ft	12.729012 ft	0 psf	377.21335 psf	170.31836 psf	0 psf	0 psf	Geosynthe�cs
Column 84	124.39493 ft	12.691721 ft	0 psf	375.80228 psf	169.68123 psf	0 psf	0 psf	Geosynthe�cs
Column 85	124.54471 ft	12.654431 ft	0 psf	374.39121 psf	169.04411 psf	0 psf	0 psf	Geosynthe�cs
Column 86	124.69449 ft	12.617140 ft	0 psf	372.98014 psf	168.40699 psf	0 psf	0 psf	Geosynthe�cs
Column 87	124.84427 ft	12.579849 ft	0 psf	371.56907 psf	167.76987 psf	0 psf	0 psf	Geosynthe�cs
Column 88	124.99405 ft	12.542559 ft	0 psf	370.158 psf	167.13275 psf	0 psf	0 psf	Geosynthe�cs
Column 89	125.14383 ft	12.505268 ft	0 psf	368.74693 psf	166.49562 psf	0 psf	0 psf	Geosynthe�cs
Column 90	125.29361 ft	12.467978 ft	0 psf	367.33586 psf	165.8585 psf	0 psf	0 psf	Geosynthe�cs
Column 91	125.44338 ft	12.430687 ft	0 psf	365.92479 psf	165.22138 psf	0 psf	0 psf	Geosynthe�cs
Column 92	125.59316 ft	12.393396 ft	0 psf	364.51372 psf	164.58426 psf	0 psf	0 psf	Geosynthe�cs
Column 93	125.74294 ft	12.356106 ft	0 psf	363.10265 psf	163.94713 psf	0 psf	0 psf	Geosynthe�cs
Column 94	125.89272 ft	12.318815 ft	0 psf	361.69158 psf	163.31001 psf	0 psf	0 psf	Geosynthe�cs
Column 95	126.04250 ft	12.281525 ft	0 psf	360.28052 psf	162.67289 psf	0 psf	0 psf	Geosynthe�cs
Column 96	126.19228 ft	12.244234 ft	0 psf	358.86945 psf	162.03577 psf	0 psf	0 psf	Geosynthe�cs
Column 97	126.34206 ft	12.206944 ft	0 psf	357.45838 psf	161.39865 psf	0 psf	0 psf	Geosynthe�cs
Column 98	126.49184 ft	12.169653 ft	0 psf	356.04731 psf	160.76152 psf	0 psf	0 psf	Geosynthe�cs
Column 99	126.64161 ft	12.132362 ft	0 psf	354.63624 psf	160.1244 psf	0 psf	0 psf	Geosynthe�cs
Column 100	126.79139 ft	12.095072 ft	0 psf	353.22517 psf	159.48728 psf	0 psf	0 psf	Geosynthe�cs
Column 101	126.94117 ft	12.057781 ft	0 psf	351.8141 psf	158.85016 psf	0 psf	0 psf	Geosynthe�cs
Column 102	127.09095 ft	12.020491 ft	0 psf	350.40303 psf	158.21303 psf	0 psf	0 psf	Geosynthe�cs
Column 103	127.24073 ft	11.983200 ft	0 psf	348.99196 psf	157.57591 psf	0 psf	0 psf	Geosynthe�cs
Column 104	127.39051 ft	11.945909 ft	0 psf	347.58089 psf	156.93879 psf	0 psf	0 psf	Geosynthe�cs
Column 105	127.54029 ft	11.908619 ft	0 psf	346.16982 psf	156.30167 psf	0 psf	0 psf	Geosynthe�cs
Column 106	127.69007 ft	11.871328 ft	0 psf	344.75875 psf	155.66455 psf	0 psf	0 psf	Geosynthe�cs
Column 107	127.83984 ft	11.834038 ft	0 psf	343.34768 psf	155.02742 psf	0 psf	0 psf	Geosynthe�cs
Column 108	127.98962 ft	11.796747 ft	0 psf	341.93662 psf	154.3903 psf	0 psf	0 psf	Geosynthe�cs

Column 109	128.13940 ft	11.759457 ft	0 psf	340.52555 psf	153.75318 psf	0 psf	0 psf	Geosynthe▯cs
Column 110	128.28918 ft	11.722166 ft	0 psf	339.11448 psf	153.11606 psf	0 psf	0 psf	Geosynthe▯cs
Column 111	128.43896 ft	11.684875 ft	0 psf	337.70341 psf	152.47894 psf	0 psf	0 psf	Geosynthe▯cs
Column 112	128.58874 ft	11.647585 ft	0 psf	336.29234 psf	151.84181 psf	0 psf	0 psf	Geosynthe▯cs
Column 113	128.73852 ft	11.610294 ft	0 psf	334.88127 psf	151.20469 psf	0 psf	0 psf	Geosynthe▯cs
Column 114	128.88830 ft	11.573004 ft	0 psf	333.4702 psf	150.56757 psf	0 psf	0 psf	Geosynthe▯cs
Column 115	129.03807 ft	11.535713 ft	0 psf	332.05913 psf	149.93045 psf	0 psf	0 psf	Geosynthe▯cs
Column 116	129.13212 ft	11.522199 ft	0 psf	378.79113 psf	171.03075 psf	0 psf	0 psf	Geosynthe▯cs
Column 117	129.23189 ft	11.548934 ft	0 psf	379.70229 psf	219.22122 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 118	129.39314 ft	11.592140 ft	0 psf	366.92589 psf	211.84476 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 119	129.55439 ft	11.635347 ft	0 psf	354.1495 psf	204.46831 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 120	129.71563 ft	11.678553 ft	0 psf	341.3731 psf	197.09185 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 121	129.87688 ft	11.721759 ft	0 psf	328.59671 psf	189.7154 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 122	130.03813 ft	11.764965 ft	0 psf	315.82031 psf	182.33894 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 123	130.19938 ft	11.808171 ft	0 psf	303.04391 psf	174.96249 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 124	130.35487 ft	11.849834 ft	0 psf	291.54096 psf	168.32125 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 125	130.50460 ft	11.889955 ft	0 psf	281.31146 psf	162.41524 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 126	130.65433 ft	11.930076 ft	0 psf	271.08195 psf	156.50924 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 127	130.80406 ft	11.970196 ft	0 psf	260.85244 psf	150.60323 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 128	130.95380 ft	12.010317 ft	0 psf	250.62293 psf	144.69722 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 129	131.10353 ft	12.050438 ft	0 psf	240.39343 psf	138.79121 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 130	131.25326 ft	12.090558 ft	0 psf	230.16392 psf	132.8852 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 131	131.40299 ft	12.130679 ft	0 psf	219.93441 psf	126.97919 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 132	131.55272 ft	12.170800 ft	0 psf	209.7049 psf	121.07318 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 133	131.70246 ft	12.210920 ft	0 psf	199.4754 psf	115.16717 psf	0 psf	0 psf	Roo▯ng Zone/Sand
Column 134	131.85219 ft	12.251041 ft	0 psf	189.24589 psf	109.26116 psf	0 psf	0 psf	Roo▯ng Zone/Sand

Column 135	132.00192 ft	12.291162 ft	0 psf	179.01638 psf	103.35516 psf	0 psf	0 psf	Rooting Zone/Sand
Column 136	132.15165 ft	12.331282 ft	0 psf	168.78687 psf	97.449147 psf	0 psf	0 psf	Rooting Zone/Sand
Column 137	132.30139 ft	12.371403 ft	0 psf	158.55737 psf	91.543138 psf	0 psf	0 psf	Rooting Zone/Sand
Column 138	132.45112 ft	12.411524 ft	0 psf	148.32786 psf	85.637129 psf	0 psf	0 psf	Rooting Zone/Sand
Column 139	132.60085 ft	12.451644 ft	0 psf	138.09835 psf	79.73112 psf	0 psf	0 psf	Rooting Zone/Sand
Column 140	132.75058 ft	12.491765 ft	0 psf	127.86884 psf	73.825111 psf	0 psf	0 psf	Rooting Zone/Sand
Column 141	132.90032 ft	12.531886 ft	0 psf	117.63934 psf	67.919102 psf	0 psf	0 psf	Rooting Zone/Sand
Column 142	133.05005 ft	12.572006 ft	0 psf	107.40983 psf	62.013093 psf	0 psf	0 psf	Rooting Zone/Sand
Column 143	133.19978 ft	12.612127 ft	0 psf	97.180321 psf	56.107084 psf	0 psf	0 psf	Rooting Zone/Sand
Column 144	133.34951 ft	12.652248 ft	0 psf	86.950813 psf	50.201076 psf	0 psf	0 psf	Rooting Zone/Sand
Column 145	133.49925 ft	12.692368 ft	0 psf	76.721306 psf	44.295067 psf	0 psf	0 psf	Rooting Zone/Sand
Column 146	133.64898 ft	12.732489 ft	0 psf	66.491799 psf	38.389058 psf	0 psf	0 psf	Rooting Zone/Sand
Column 147	133.79871 ft	12.772610 ft	0 psf	56.262291 psf	32.483049 psf	0 psf	0 psf	Rooting Zone/Sand
Column 148	133.94844 ft	12.812730 ft	0 psf	46.032784 psf	26.57704 psf	0 psf	0 psf	Rooting Zone/Sand
Column 149	134.09817 ft	12.852851 ft	0 psf	35.803276 psf	20.671031 psf	0 psf	0 psf	Rooting Zone/Sand
Column 150	134.24791 ft	12.892972 ft	0 psf	25.573769 psf	14.765022 psf	0 psf	0 psf	Rooting Zone/Sand
Column 151	134.39764 ft	12.933092 ft	0 psf	15.344261 psf	8.8590133 psf	0 psf	0 psf	Rooting Zone/Sand
Column 152	134.54737 ft	12.973213 ft	0 psf	5.1147537 psf	2.9530044 psf	0 psf	0 psf	Rooting Zone/Sand

Purpose: To evaluate the possible sliding of the access road on the final cover of the landfill.

Approach: Use assumed parameters from the 2023 Columbia Dry Ash Disposal Facility Plan of Operation to determine the factor of safety for the access road design.

References: **1.** Landfill Design.com

2. "Designing with Geosynthetics," R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

3. "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments," G.N. Richardson and R.M. Koerner, 1987.

4. SCS Engineers, Plan Modification Request/Plan of Operation Update, Dry Ash Disposal Facility, COL Energy Center, Final Grades Plan Sheet, August 2023.

Calculation:

The factor of safety is given as follows:

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

The advised minimum FS:

FS	Type of Load
3	Static
2	Dynamic

Static Factor of Safety (FS_{STATIC}) :

$$FS_{STATIC} = \frac{F_{shear}}{(W_s + W_v) \cdot \sin\beta}$$

Dynamic Factor of Safety ($FS_{DYNAMIC}$) :

$$FS_{DYNAMIC} = \frac{F_{shear}}{(W_s + W_v) \cdot \sin\beta + F_{deceleration}}$$

Where:

W_s = Weight of Roadway = $\gamma * w * L * t$

W_v = Weight of Vehicle (metric tons)

$F_{deceleration}$ = Vehicle braking force = $0.3 * W_v$

F_{shear} = $(W_s + W_v) \cdot \cos\beta \cdot \tan\delta$

And:

γ = Unit weight of the base layer

w = Ramp width

L = Ramp length

t = Ramp thickness

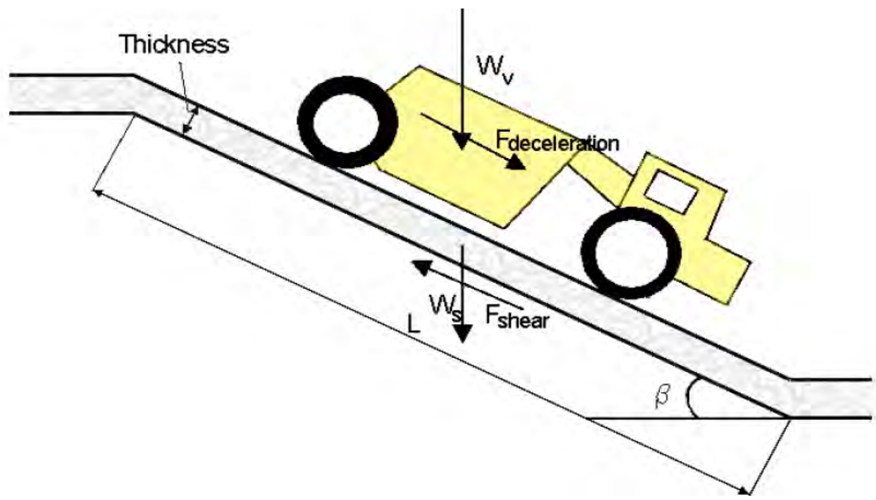
β = Slope

δ = Friction interface angle

The lowest shear force will be used in the calculations resulting from different interfaces.

Calculation:

(cont.)



Vehicle Weight (W_v)	=	68,966	kg	or	152,000	lbs
Base Layer Unit Weight (γ)	=	2,160	kg/m^3	or	135	pcf
$F_{acceleration}$	=	20,690	kg			
Friction Angles (δ)						
Soil to Geocomposite	=	21	degrees			
Geomembrane to Geocomposite	=	21	degrees			
GCL to Geomembrane	=	30	degrees			
Soil to GCL	=	21	degrees			
Base Layer (Clay)	=	28	degrees			
Base Layer (Ash)	=	23.5	degrees			
Road Thickness	=	1.22	meters	or	4	ft
Road Centerline Sliding						
Road Width (W)	=	6.1	meters	or	20	ft
Road Length (L)	=	103.7	meters	or	340	ft
Slope (β)	=	5.7	degrees	or	10	%
Weight of Roadway (W_s)	=	1,664,950	kg			
F_{shear}	=	661,932	kg			

FS_{static}	**=**	3.96	**> 3.0**	OK
$FS_{dynamic}$	**=**	3.52	**> 2.0**	OK

Assumptions: 1. Columbia currently uses a John Deere 410 off-road truck for hauling CCR. The fully loaded weight capacity is approximately 152,000 pounds.

2. A conservative minimum interface friction angle of 21 degrees is assumed for the final cover geosynthetics based on the final cover slope stability analyses.
3. Road thickness is depth from top of road to geomembrane.
4. Unit weight of the base layer is based on road building material.
5. A final cover interface friction angle of 30 degrees for the GCL to geomembrane interface is based on 2016 testing for the Modules 1 and 2 cover construction documentation.

Conclusions: The service road design is acceptable and will be stable under assumed loading conditions.

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Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/02/2023
Client: WPL	Subject: Pipe Sizing - Sand Drainage Layer	Chk'd: DLN	Date: 08/10/23

Purpose: To size the toe drain and intermediate drain corrugated HDPE piping to accommodate the final cover sand subsurface drainage.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (3 inches) for the given flow rate is acceptable.

Calculation: **Toe Drain (Outlet Pipes)**

Darcy's Equation, Q=KiA

Where:
- i = hydraulic gradient, for 4:1 slope = 0.25
- A = X-Section of flow area (200ft x 1ft), for 200 ft pipe spacing and 1 ft thick drainage layer = 200 ft^2
- k = Permeability of drainage material = 0.01 cm/s

so, Q = flow rate = k X i X A = 0.016 cfs

Manning's Equation

$$Q = \frac{1.49}{n} \times 3.14 \times r^2 \times \left(\frac{r}{2}\right)^{2/3} \times slope^{1/2}$$

Where:
- n = Manning's Number for corrugated HDPE pipe = 0.015
- r = Radius of pipe = 1.5 inches = 0.125 feet
- slope = 0.005

so, Q = 0.0543 cfs

Result: 0.054 is greater than 0.016 cfs, so a 3-inch outlet pipe at the toe is acceptable.

Intermediate Drain (Collection Pipes, including toe)

Darcy's Equation $Q_{in}=K_{veg} \times i \times A = K_{veg} \times 1 \times L \times 1 \times FS$

Inflow of water in 1-ft thick drainage sand (unit gradient)

- k_{veg} = Permeability of the vegetative supporting soil = 0.000042 cm/sec
- L_h = Drainage pipe spacing or length of slope measured horizontally = 371 ft
- FS = Overall factor of safety for drainage = 2.0

so, Q_{in} = 28.952 cm^3/s

Q_{in} = 0.0010 cfs

Mannings Equation

Where:
- n = Manning's Number for corrugated HDPE pipe = 0.015
- r = Radius of pipe = 1.5 inches = 0.125 feet
- slope = 0.005

so, Q = 0.0543 cfs

Result: 0.054 is greater than 0.001 cfs, so a 3-inch collection pipe is acceptable.

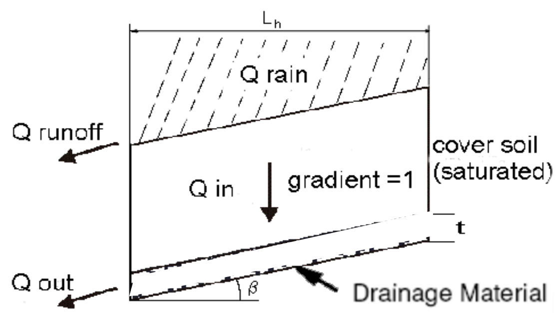
Conclusion: Based on the flow for the intermediate and toe piping, a 3" pipe is adequate.

Purpose: To determine the maximum length of slope that the final cover drainage layer (sand) can carry infiltrating water and remain stable.

Approach: Use the unit gradient method to determine the maximum slope length.

References:

1. Landfilldesign.com
2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001
3. "Beyond a factor-of-safety value, i.e., the probability of failure". GRI Newsletter/Report, Vol. 15, no. 3
4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5
6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002
7. HELP Model "User's Guide", Table 4: Default Soil, Waste, and Geosynthetic Characteristics
8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Modules 12 and 13) Plan Sheet, August 2023



With Darcy's Law:

$$Q = k \times i \times A$$

Inflow of water in the Drainage Material

$$Q_{in} = k_{veg} \times i \times A = k_{veg} \times 1 \times L_h \times 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{drain} \times i \times A = k_{drain} \times t \times \sin\beta$$

This results in a required k_{drain} of:

$$k_{drain} = \frac{k_{veg} \times L_h}{t \times \sin\beta} \times FS$$

Assumptions: 1. Soil hydraulic gradient *i* = 1.0.

2. Top soil will be clay. Soil permeability is 4.2×10^{-5} cm/sec for a CL clay from HELP model user's guide.
3. Drainage Layer hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Maximum horizontal final cover slope length from crest to toe drain is 371 feet as shown in Module 1 on the final grades plan sheet.
5. The minimum hydraulic conductivity ($k_{drain,ave}$) is 1.0×10^{-2} cm/s for the sand.
6. Cover drainage layer thickness t = 1 foot.

Calculation: Constants

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **b**	=	25%	b = 14°
FS_{slope}	=	Minimum factor of safety against sliding, for drainage layer/geomembrane interface	=	1.5	
$\delta_{req'd}$	=	Minimum interface friction angle = $\tan^{-1}(FS*\tan(b))$	=	20.6	degrees

Determine the maximum slope length for the given minimum required drainage layer permeability

L_h (feet)	L_h (meter)	$k_{drain, req}$ (cm/s)	
30	9.1	7.69E-03	Design

Conclusions: The design has an intermediate pipe every 30 feet spaced evenly up the slope. The intermediate pipe spacing design with the sand material has a factor of safety of 1.95.

Purpose: To determine the maximum length of slope that the final cover drainage geocomposite can carry infiltrating water and remain stable. Also determine the recommended minimum friction angle for final cover side slope stability. Note: This calculation does not include the flow convergence areas where a separate calculation is required.

Approach: Use the unit gradient method to determine the maximum slope length.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.

3. "Beyond a factor-of-safety value, i.e., the probability of failure". GRI Newsletter/Report, Vol. 15, no. 3.

4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

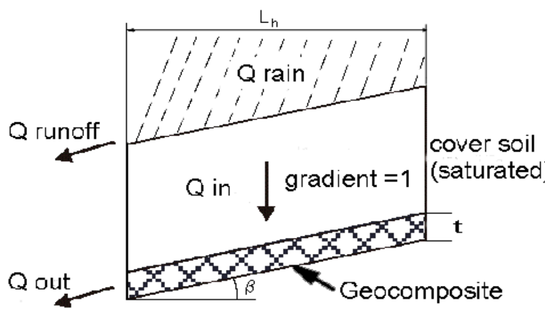
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.

6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.

7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International

8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Modules 12 and 13) Plan Sheet, August 2023

9. HELP Model "User's Guide" in conjunction with GRI report #19, pages 34-37 (Leachate Collection System)



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin\beta$$ = θ*i*1 where $\theta = k_{comp} * t$

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin\beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

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		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/04/23
Client: WPL	Subject: Geocomposite Unit Gradient	Chk'd: DLN	Date: 08/11/23

Assumptions: 1. Soil hydraulic gradient *i* = 1.0.

2. Top soil will be clay. Soil permeability is 4.2 x 10^{-5} cm/sec for a CL clay from HELP model user's guide.
3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"
5. Maximum horizontal final cover slope length from crest to toe drain is 570 feet as shown on Final Grades (Modules 12 and 13) plan sheet. This includes 128' of 10:1 slope length at the peak.

Calculation: Constants

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **b**	=	25%	b = 14 °
FS_{slope}	=	Minimum factor of safety against sliding, for soil/geocomposite or geocomposite/geomembrane interfaces	=	1.5	
$\delta_{req'd}$	=	Minimum interface friction angle = $\tan^{-1}$(FS*tan(b))	=	20.6	degrees
FS_d	=	Overall factor of safety for drainage	=	2.0	
RF_{in}	=	Intrusion Reduction Factor	=	1.1	
RF_{cr}	=	Creep Reduction Factor	=	1.2	
RF_{cc}	=	Chemical Clogging Reduction Factor	=	1.1	
RF_{bc}	=	Biological Clogging Reduction Factor	=	1.4	

Determine the maximum slope length for a given ultimate transmissivity

Θ_{ult} (m^2/sec)	L_h (meter)	L_h (feet)
1.00E-03	146.5	481

Determine the ultimate transmissivity based on a given slope length

L_h (feet)	L_h (meter)	Θ_{ult} (m^2/sec)	
570	173.7	1.19E-03	~ Total slope length
285	86.9	5.93E-04	~ 1/2 of total slope length
190	57.9	3.96E-04	~ 1/3 of total slope length

Conclusions: If no intermediate drainage outlets were constructed on the final cover, a minimum transmissivity of 1.19 x 10^{-3} m^2/sec would need to be obtained.

A minimum interface friction angle of 20.6 degrees between cover soil and geocomposite is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.

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Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/04/23
Client: WPL	Subject: Cover Geocomposite Toe Drain Pipe Sizing Calc.	Chk'd: DLN	Date: 08/11/23

Purpose: To size the collection piping toe drain and space the outlet piping to accommodate the final cover geocomposite drainage.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (4 inches) for the given flow rate is acceptable. Also determine what would be acceptable bedding material based on pipe hole / perforation size.

References:
1. SCS Engineers, Plan of Operation, Columbia Dry Ash Disposal Facility, Cover Unit Gradient Calculation, August 2023
2. NAVFAC DM 7, Design Criteria for Protective Filters
3. Advanced Drainage Systems (ADS), Inc. Drainage Handbook, Section 3-0 Hydraulics, July 2010
4. Advanced Drainage Systems (ADS), Inc. Technical Note (TN 1.01) Dual Wall HDPE Perforation Patterns, January 2015

Calculation:

Infiltration Flow / Collection Pipe Flow Capacity

Darcy's Equation, $Q_{in}=K_{veg} \times i \times A = K_{veg} \times 1 \times L_h \times 1 \times FS$

Inflow of water into geocomposite from surface = Inflow of water into collection pipe

K_{veg} = 4.2E-05 cm/s , [permeability of topsoil]
L_h = 570 ft , [longest horizontal length between collection pipes]
L_h = 173.7 m , (longest horizontal length between collection pipes)
FS (drainage) = 2.0 [Factor of safety, to account for variation in cover soil]
Q_{in}= 44.48 cm^3/s , [per linear foot of pipe]
→ Q_{in}= **0.0016** cfs [required collection pipe capacity]

Required geocomposite transmissivity (from Cover Unit Gradient Calculation)

$\Theta_{req} = (K_{veg} \times L_{h}) / i * FS$ where, i = 0.25
Θ_{req} = 5.84E-04 m^2/sec

Geocomposite Flow Capacity / Outlet Pipe Flow Capacity

Darcy's Equation,
$Q = k \times i \times A$ Q = flow rate
$A = L \times t$ t = thickness
$\Theta = k \times t$ k = permeability
so, $Q = \Theta \times i \times L$ Θ = transmissivity

i = 0.25 [hydraulic gradient, for 4:1 slope]
L = 293 ft [length of collection pipe (i.e. spacing between outlet pipe)]
Θ_{req} = 6.28E-03 ft^2/s [required transmissivity of geocomposite]

→ Q = **0.460** cfs [required outlet pipe capacity]

Design Pipe Flow

Manning's Equation,
$Q= (1.49/n) \times (3.14 \times r^2) \times (r / 2)^{2/3} \times (slope)^{1/2}$

Where,
n = 0.012 [Manning's Number for corrugated HDPE pipe with smooth interior]
r = 2.0 in , [Radius of 4" pipe]
r = 0.167 ft , (Radius of 4" pipe)

Q = **0.146** cfs [Collection Pipe at 0.5% slope]
Q = **0.292** cfs [Collection Pipe at 2% slope]
Q = **0.462** cfs [Outlet Pipe at 5% slope, 'min. design slope']
Q = **1.461** cfs [Outlet Pipe at 50% (2:1) slope]

Bedding Stone Diameter Sizing

Perforation design of 4" pipe (from ADS)

Maximum slot length =	0.875	inch
Maximum slot width =	0.125	inch

*Slot width will control the size of bedding stone

D_{85F} / Slot Width > (1.2 to 1.4) , [From the NAVFAC DM 7 Manual]

D_{85F} = (0.125 inch) * 1.2 =	0.150	inch
D_{85F} = (0.125 inch) * 1.4 =	0.175	inch

so, a bedding stone with a D_{85F} between 0.150 and 0.175 inch or larger would be acceptable.

Conclusion: Based on the outlet pipe estimated flow, a 4-inch pipe spaced at 293 ft or less would be adequate.

The design outlet pipe spacing is a maximum of 200 ft.

A 4" diameter collection pipe (toe drain) at a 2% slope (typical), and a minimum of 0.5% slope, is suitable to collect the expected drainage layer flow.

For a 0.125 inch perforated pipe slot width, bedding stone diameter should be between 0.150 and 0.175 inch (equivalent to the No. 4 sieve) or larger.

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Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/28/23
Client: WPL	Subject: Cover Geocomposite Pipe (Toe Drain) Sizing Calc.	Chk'd: DLN	Date: 08/28/23

Purpose: To size the final cover geocomposite collection piping (toe drain) and space the outlet piping to accommodate the final cover geocomposite drainage in the southernmost corner, near Module 1, 2, and 3.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (4-in collection piping and 8-in outlet piping) for the given flow rate is acceptable. Also determine what would be acceptable bedding material based on pipe hole / perforation size.

References:

1. SCS Engineers, Plan of Operation, Columbia Dry Ash Disposal Facility, Cover Unit Gradient Calculation, August 2023

2. NAVFAC DM 7, Design Criteria for Protective Filters

3. Advanced Drainage Systems (ADS), Inc. Drainage Handbook, Section 3-0 Hydraulics, July 2010

4. Advanced Drainage Systems (ADS), Inc. Technical Note (TN 1.01) Dual Wall HDPE Perforation Patterns, January 2015

Calculation:

Infiltration Flow / Collection Pipe Flow Capacity

Darcy's Equation, $Q_{in}=K_{veg} \times i \times A = K_{veg} \times 1 \times L_h \times 1 \times FS$

Inflow of water into geocomposite from surface = Inflow of water into collection pipe

K_{veg} = 4.2E-05 cm/s , [permeability of topsoil]

L_h = 570 ft , [longest horizontal length between collection pipes]

L_h = 173.7 m , (longest horizontal length between collection pipes)

FS (drainage) = 2.0 [Factor of safety, to account for variation in cover soil]

Q_{in} = 44.48 cm^3/s , [per linear foot of pipe]

→ Q_{in} = **0.0016** cfs [required collection pipe capacity]

Required geocomposite transmissivity (from Cover Unit Gradient Calculation)

$\Theta_{req} = (K_{veg} \times L_{h}) / i * FS$ where, i = 0.25

Θ_{req} = 5.84E-04 m^2/sec

Geocomposite Flow Capacity / Outlet Pipe Flow Capacity

Darcy's Equation,

$Q = k \times i \times A$	Q = flow rate
$A = L \times t$	t = thickness
$\Theta = k \times t$	k = permeability
so, $Q = \Theta \times i \times L$	Θ = transmissivity

i = 0.25 [hydraulic gradient, for 4:1 slope]

L = 417 ft [length of collection pipe (i.e. spacing between outlet pipe)]

Θ_{req} = 6.28E-03 ft^2/s [required transmissivity of geocomposite]

→ Q = **0.655** cfs [required outlet pipe capacity]

Design Pipe Flow

Manning's Equation,

$Q= (1.49/n) \times (3.14 \times r^2) \times (r / 2)^{2/3} \times (slope)^{1/2}$

Where,

n = 0.012 [Manning's Number for corrugated HDPE pipe with smooth interior]

r = 2.0	in , [Radius of 4" pipe]	r = 4.0	in , [Radius of 8" pipe]
r = 0.167	ft , (Radius of 4" pipe)	r = 0.333	ft , (Radius of 8" pipe)

Q = **0.146** cfs [4" Collection Pipe at 0.5% slope, 'min. design slope']

Q = **0.292** cfs [4" Collection Pipe at 2% slope]

Q = **0.656** cfs [8" Outlet Pipe at 0.25% slope]

Q = **9.277** cfs [8" Outlet Pipe at 50% (2:1) slope]

Bedding Stone Diameter Sizing

Perforation design of 4" pipe (from ADS)

Maximum slot length =	0.875	inch
Maximum slot width =	0.125	inch

*Slot width will control the size of bedding stone

D_{85F} / Slot Width > (1.2 to 1.4) , [From the NAVFAC DM 7 Manual]

D_{85F} = (0.125 inch) * 1.2 =	0.150	inch
D_{85F} = (0.125 inch) * 1.4 =	0.175	inch

so, a bedding stone with a D_{85F} between 0.150 and 0.175 inch or larger would be acceptable.

Conclusion: Based on the outlet pipe estimated flow, an 8-inch pipe spaced at 417 ft or less would be adequate.
The design outlet pipe spacing is 335 ft at the south end, near Module 1.
A 4" diameter collection pipe (toe drain) at a 2% slope (typical), and a minimum of 0.5% slope, is suitable to collect the expected drainage layer flow.
For a 0.125 inch perforated pipe slot width, bedding stone diameter should be between 0.150 and 0.175 inch (equivalent to the No. 4 sieve) or larger.

SCS ENGINEERS

		Sheet No.	1 of 2
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/11/2023
Client: WPL	Subject: Geocomposite Unit Gradient - Final Cover Access Road	Chk'd: DLN	Date: 08/15/2023

Purpose: To determine the maximum length of slopes that the final cover drainage geocomposite can carry infiltrating water and remain stable above the Final Cover Access Road.

Approach: Use the unit gradient method to determine the maximum slope length.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.

3. "Beyond a factor-of-safety value, i.e., the probability of failure". GRI Newsletter/Report, Vol. 15, no. 3.

4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.

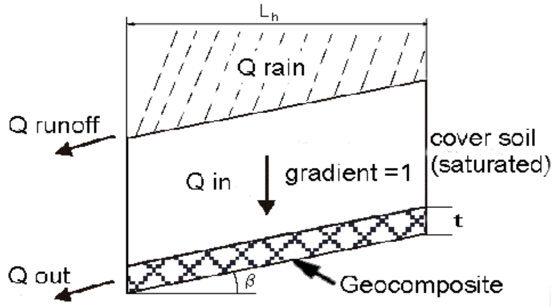
6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.

7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International

8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Module 12 and 13) Plan Sheet, August 2023

9. HELP Model "User's Guide", Table 1 - Default Low Density Soil Characteristics

10. Soong, T.Y. and Koerner, R.M. (1997), "The Design of Drainage Systems over Geosynthetically Lined Slopes", Geosynthetics Research Institute, Report #19.



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin\beta$$ = θ*i*1 where $\theta = k_{comp} * t$

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin\beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

4:1 final cover geocomposite slope above access road

Assumptions: 1. Soil hydraulic gradient *i* = 1.0.

2. Top soil will be clay. Soil permeability is 4.2 x 10 $^{-5}$ cm/sec for a CL clay from HELP model user's guide.
3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"
5. Maximum horizontal final cover slope length at 4:1 slope above the road is 495 feet as shown on Final Grades (Module 12 and 13) plan sheet. This includes 95' of 10:1 slope length at the peak.

Calculation: Constants

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **b**	=	25%	b = 14 °
FS_d	=	Overall factor of safety for drainage	=	2.0	
RF_{in}	=	Intrusion Reduction Factor	=	1.1	
RF_{cr}	=	Creep Reduction Factor	=	1.2	
RF_{cc}	=	Chemical Clogging Reduction Factor	=	1.1	
RF_{bc}	=	Biological Clogging Reduction Factor	=	1.4	

Determine the ultimate transmissivity based on a given slope length

L_h (feet)	L_h (meter)	Θ_{ult} (m^2/sec)
495	150.9	1.03E-03

~ Total slope length (4:1 slope above access road only)

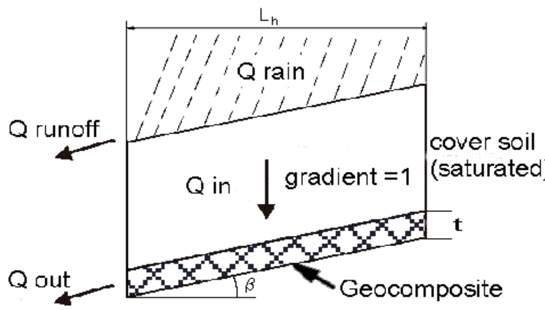
Conclusion: If no intermediate drainage outlets were constructed on the final cover, above the Final Cover Access Road, a minimum transmissivity of 1.03 x 10 $^{-3}$ m^2/sec would need to be obtained.

Purpose: To determine the geocomposite drainage requirements in the final cover where flow converges in the final cover corner including Modules 3, 4, 10, and 11 and the final cover corner including Modules 5, 6, 11, and 12 so the final cover drainage geocomposite can carry infiltrating water and remain stable. Also to determine the recommended minimum interface friction angle for final cover stability.

Approach: Use the unit gradient method and flow path geometry to determine the geocomposite transmissivity required at locations within the converging flow area.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method
2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.
3. "Beyond a factor-of-safety value, i.e., the probability of failure". GRI Newsletter/Report, Vol. 15, no. 3.
4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.
6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.
7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International
8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Module 12) Plan Sheet, August 2023
9. HELP Model "User's Guide" in conjunction with GRI report #19, pages 34-37 (Leachate Collection System)



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin\beta$$

= θ*i*1 where θ = k_{comp} * t (minimum allowable outflow to keep head within geocomposite)

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin\beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

Assumptions: 1. Soil hydraulic gradient *i* = 1.0.

2. Top soil will be clay. Soil permeability is 4.2×10^{-5} cm/sec for a CL clay from HELP model user's guide.

3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).

4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"

5. Flow paths A-E and F-J are as shown on attached drawing. Assume circular arc with radius measured from the corner of the toe drain.

6. Intermediate drainage piping will be used along the slope to divert flow from the drainage layer to the diversion berms and downslope flume.

Calculation: Constants

L_h = Drainage pipe spacing or length of slope measured horizontally = See Below

k_{veg} = Permeability of the vegetative supporting soil = 0.000042 cm/sec

S = The liner's slope, **S** = tan **b** = 25% b = 14°

FS_{slope} = Minimum factor of safety against sliding, for soil/geocomposite or geocomposite/geomembrane interfaces = 1.5

$\delta_{req'd}$ = Minimum interface friction angle = $\tan^{-1}$(FS*tan(b)) = 20.6 degrees

FS_d = Overall factor of safety for drainage = 2.0

RF_{in} = Intrusion Reduction Factor = 1.1

RF_{cr} = Creep Reduction Factor = 1.2

RF_{cc} = Chemical Clogging Reduction Factor = 1.1

RF_{bc} = Biological Clogging Reduction Factor = 1.4

w = Geocomposite width at drainage outlet

A = Final cover plan area upslope of geocomposite drainage outlet

Determine the maximum slope length for a given ultimate transmissivity

Min. Θ_{req} = A X k_{veg} / (w X sinβ)

For the outlet at the corner, use minimum 5 foot width and 2 foot width of geocomposite to connect the toe drain to drain the converging flow area:

Area	A (sq. feet)	w (feet)	w (meter)	Min. Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 1 Toe Drain	468	5	1.52	2.01E-04	1.00E-03
Area 4 Toe Drain	181	2	0.61	1.95E-04	1.00E-03

The toe drainage areas, Area 1 and Area 4, include only converging flow below the lowest intermediate drainage piping, as flow above this area is diverted. There are intermediate drainage pipes in Areas 1 and 4 which divert flow from the outlet corner to the downslope flume.

For converging flow in a circular arc, from radius R-top to radius R-bottom:

L = R-top - R-bottom

w-bot = w-top * (R-bot/R-top)

A = L* (1+ (R-bot/R-top))/2 (assuming unit width at top and trapezoid vs arc to simplify)

Θult-bot = (Θult calculated for L) * R-top/R-bot * (1+ (R-bot/R-top))/2

Calculation: (Cont.) For the southern convergence area, flow paths A-E, calculate Θult for selected R-bot values to determine appropriate geocomposite products as flow converges down the slope:

Flow Path	R-top (feet)	R-bot (feet)	L_h (feet)	L_h (meters)	Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 1						
A1	138	26	112	34	7.57E-04	1.00E-03
B1	136	27	109	33	7.03E-04	1.00E-03
C1	133	27	106	32	6.70E-04	1.00E-03
D1	129	25	104	31	6.74E-04	1.00E-03
E1	125	23	102	31	7.04E-04	1.00E-03
Area 2						
A2	298	138	160	48	5.35E-04	1.00E-03
B2	291	136	155	47	5.21E-04	1.00E-03
C2	284	133	151	46	5.09E-04	1.00E-03
D2	277	129	148	45	5.00E-04	1.00E-03
E2	269	125	144	43	4.79E-04	1.00E-03
Area 3						
A3	353	298	55	16	1.23E-04	1.00E-03
B3	393	291	102	31	2.57E-04	1.00E-03
C3	460	284	176	53	4.90E-04	1.00E-03
D3	481	277	204	62	5.99E-04	1.00E-03
E3	447	269	178	54	5.08E-04	1.00E-03

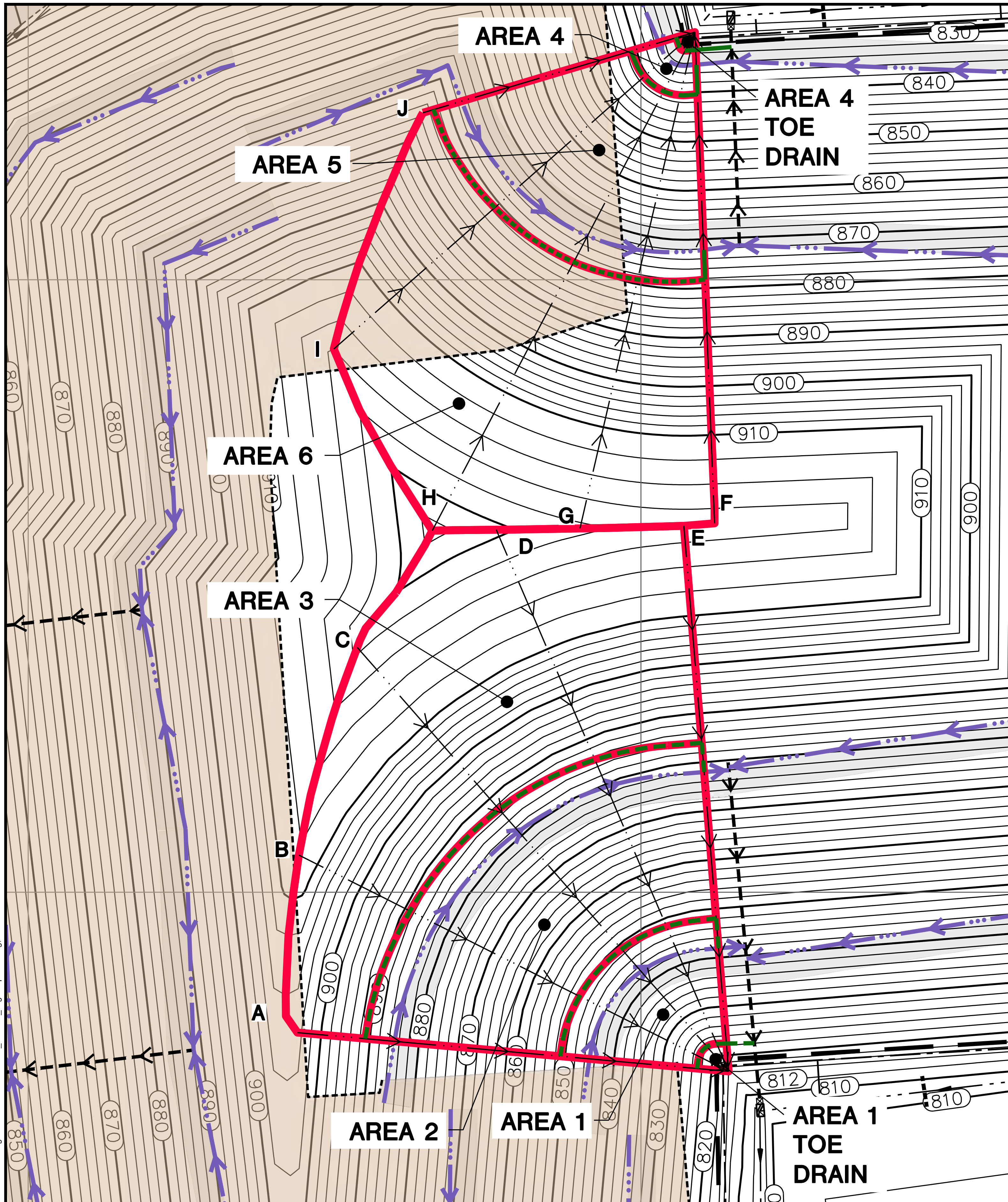
Conclusions: For the southern final cover corner including Modules 3, 4, 10, and 11 proposed design with intermediate slope outlets and a toe-of-slope drainage outlet, placement of geocomposite with the required transmissivities to the minimum lengths/areas shown in the table above and on the attached drawing will provide adequate drainage for the converging flow.
A minimum interface friction angle of 20.6 degrees for the geocomposite, geomembrane, and GCL interfaces is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.

Calculation: (Cont.) For the northern convergence area, flow paths F-J, calculate Θult for selected R-bot values to determine appropriate geocomposite products as flow converges down the slope:

Flow Path	R-top (feet)	R-bot (feet)	L_h (feet)	L_h (meters)	Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 4						
F4	51	15	36	10	1.55E-04	1.00E-03
G4	53	15	38	11	1.76E-04	1.00E-03
H4	55	17	38	11	1.64E-04	1.00E-03
I4	55	17	38	11	1.64E-04	1.00E-03
J4	55	16	39	11	1.72E-04	1.00E-03
Area 5						
F5	202	51	151	46	8.06E-04	1.00E-03
G5	207	53	154	46	7.97E-04	1.00E-03
H5	212	55	157	47	8.06E-04	1.00E-03
I5	217	55	162	49	8.56E-04	1.00E-03
J5	223	55	168	51	9.10E-04	1.00E-03
Area 6						
F6	401	202	199	60	6.32E-04	1.00E-03
G6	416	207	209	63	6.69E-04	1.00E-03
H6	460	212	248	75	8.39E-04	1.00E-03
I6	392	217	175	53	5.25E-04	1.00E-03
J6	232	223	9	2	1.44E-05	1.00E-03

Conclusions: For the northern final cover corner including Modules 5, 6, 11, and 12 area proposed design with intermediate slope outlets and a toe-of-slope drainage outlet, placement of geocomposite with the required transmissivities to the minimum lengths/areas shown in the table above and on the attached drawing will provide adequate drainage for the converging flow.

A minimum interface friction angle of 20.6 degrees for the geocomposite, geomembrane, and GCL interfaces is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.



LEGEND

	LIMITS OF WASTE
	LINER PHASE/MODULE LIMIT
840	PROPOSED GRADE (10' INTERVAL)
	PROPOSED GRADE (2' INTERVAL)
	PROPOSED SWALE
	PROPOSED DIVERSION BERM
	PROPOSED DOWNSLOPE FLUME
	PROPOSED ENERGY DISSIPATOR
	PROPOSED RIPRAP
	CONVERGENCE FLOW PATH
	PERFORATED SUBSURFACE PIPING
	SOLID SUBSURFACE PIPING

N

100 0 100

SCALE: 1" = 100'

DRAFT

GEOTECHNICAL CALCULATION – FLOW CONVERGENCE
FINAL GRADES (MODULE 12)

FIGURE 1

SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

ENGINEER

COLUMBIA ENERGY CENTER
PLAN OF OPERATION UPDATE
TOWN OF PACIFIC, WISCONSIN
COLUMBIA DRY ASH DISPOSAL FACILITY

SITE

WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

CLIENT

DRAWN BY:	KP/MJT
CHECKED BY:	DN/BSS
APPROVED BY:	
PROJECT NO.	25222260.00
DRAWN:	08/03/2023
REVISED:	08/17/2023

Purpose: To size the collection piping (Toe Drain and Final Cover Road Intermediate Drain) and space the outlet piping to accommodate the final cover geocomposite drainage.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (4 inches) for the given flow rate is acceptable. Also determine what would be acceptable bedding material based on pipe hole / perforation size.

References:

1. SCS Engineers, Plan of Operation, Columbia Dry Ash Disposal Facility, Cover Unit Gradient Calculation, August 2023

2. NAVFAC DM 7, Design Criteria for Protective Filters

3. Advanced Drainage Systems (ADS), Inc. Drainage Handbook, Section 3-0 Hydraulics, July 2010

4. Advanced Drainage Systems (ADS), Inc. Technical Note (TN 1.01) Dual Wall HDPE Perforation Patterns, January 2015

Calculation:

Infiltration Flow / Collection Pipe Flow Capacity

Darcy's Equation, $Q_{in}=K_{veg} \times i \times A = K_{veg} \times 1 \times L_h \times 1 \times FS$

Inflow of water into geocomposite from surface = Inflow of water into collection pipe

K_{veg} = 4.2E-05 cm/s , [permeability of topsoil]

L_h = 495 ft , [longest horizontal length between collection pipes]

L_h = 150.9 m , (longest horizontal length between collection pipes)

FS (drainage) = 2.0 [Factor of safety, to account for variation in cover soil]

Q_{in}= 38.63 cm^3/s , [per linear foot of pipe]

Q_{in}= **0.0014** cfs [required collection pipe capacity]

Required geocomposite transmissivity (from Cover Unit Gradient Calculation)

$\Theta_{req} = (K_{veg} \times L_h) / i * FS$ where, i = 0.25

Θ_{req} = 5.07E-04 m^2/sec

Geocomposite Flow Capacity / Outlet Pipe Flow Capacity

Darcy's Equation,

$Q = k \times i \times A$ — Q = flow rate

$A = L \times t$ — t = thickness

$\Theta = k \times t$ — k = permeability

so, $Q = \Theta \times i \times L$ — Θ = transmissivity

i = 0.25 [hydraulic gradient, for 4:1 slope]

L = 338 ft [length of collection pipe (i.e. spacing between outlet pipe)]

Θ_{req} = 5.45E-03 ft^2/s [required transmissivity of geocomposite]

Q = **0.461** cfs [required outlet pipe capacity]

Design Pipe Flow

Manning's Equation,

$Q= (1.49/n) \times (3.14 \times r^2) \times (r / 2)^{2/3} \times (slope)^{1/2}$

Where,

n = 0.012 [Manning's Number for corrugated HDPE pipe with smooth interior]

r = 2.0 in , [Radius of 4" pipe]

r = 0.167 ft , (Radius of 4" pipe)

Q = **0.146** cfs [Collection Pipe at 0.5% slope]

Q = **0.292** cfs [Collection Pipe at 2% slope]

Q = **0.462** cfs [Outlet Pipe at 5% slope, 'min. design slope']

Q = **1.461** cfs [Outlet Pipe at 50% (2:1) slope]

Bedding Stone Diameter Sizing

Perforation design of 4" pipe (from ADS)

Maximum slot length =	0.875	inch
Maximum slot width =	0.125	inch

*Slot width will control the size of bedding stone

D_{85F} / Slot Width > (1.2 to 1.4) , [From the NAVFAC DM 7 Manual]

D_{85F} = (0.125 inch) * 1.2 =	0.150	inch
D_{85F} = (0.125 inch) * 1.4 =	0.175	inch

so, a bedding stone with a D_{85F} between 0.150 and 0.175 inch or larger would be acceptable.

Conclusion: Based on the outlet pipe estimated flow, a 4-inch pipe spaced at 338 ft or less would be adequate.
The design outlet pipe spacing is a maximum of 200 ft.
A 4" diameter collection pipe (toe drain and final cover access road intermediate drain) at a 2% slope (typical), and a minimum of 0.5% slope, is suitable to collect the expected drainage layer flow.
For a 0.125 inch perforated pipe slot width, bedding stone diameter should be between 0.150 and 0.175 inch (equivalent to the No. 4 sieve) or larger.

Purpose: To size the collection piping and space the outlet piping to accommodate the final cover subsurface drainage in the flow convergence areas.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (4 inches) for the given flow rate is acceptable. Also determine what would be acceptable bedding material based on pipe hole / perforation size.

References:

1. SCS Engineers, Plan of Operation,Columbia Dry Ash Disposal Facility, Cover Unit Gradient Calculation, August 2023
2. NAVFAC DM 7, Design Criteria for Protective Filters
3. Advanced Drainage Systems (ADS), Inc. Drainage Handbook, Section 3-0 Hydraulics, July 2010
4. Advanced Drainage Systems (ADS), Inc. Technical Note (TN 1.01) Dual Wall HDPE Perforation Patterns, January 2015

Calculation: **Infiltration Flow / Collection Pipe Flow Capacity**

Darcy's Equation: $Q_{in} = K_{veg} \times i \times A = K_{veg} \times 1 \times L_h \times 1 \times FS$

Inflow of water into geocomposite from surface = Inflow of water into collection pipe

K_{veg} = Permeability of topsoil (cm/s)

L_h = Longest horizontal length between collection pipes

FS (drainage) = Factor of safety, to account for variation in cover soil

Q_{in} = Required collection pipe capacity, per linear foot of pipe

Required geocomposite transmissivity (from Cover Unit Gradient Calculation)

$\Theta_{req} = (K_{veg} \times L_h) / i * FS$ where, $i = 0.25$

Geocomposite Flow Capacity / Outlet Pipe Flow Capacity

Darcy's Equation:

$Q = k \times i \times A$	Q = flow rate
$A = L \times t$	t = thickness
$\Theta = k \times t$	k = permeability
so, $Q = \Theta \times i \times L$	Θ = transmissivity

i = hydraulic gradient, for 4:1 slope

L_{out} = length of collection pipe (i.e. spacing between outlet pipe) (ft)

Θ_{req} = Required transmissivity of geocomposite (ft^2/s)

Q_{out} = Required collection pipe capacity, per linear foot of pipe

Design Pipe Flow

Manning's Equation: $Q = (1.49/n) \times (3.14 \times r^2) \times (r / 2)^{2/3} \times (slope)^{1/2}$

Where,	n	=	0.012	=	Manning's Number for corrugated HDPE pipe with smooth interior
	r	=	2.0	=	Radius of 4" pipe (in)
	r	=	0.1667	=	Radius of 4" pipe (ft)
So,	Q	=	**0.2922**	=	Collection Pipe at 2% slope (cfs)
	Q	=	**0.462**	=	Outlet Pipe at 5% slope, 'min. design slope' (cfs)
	Q	=	**1.461**	=	Outlet Pipe at 50% (2:1) slope (cfs)

Calculation:
(cont.)

					Collection Pipe Flow Capacity			Outlet Pipe Flow Capacity	
	K_{veg} (cm/s)	L_h (ft)	L_h (m)	FS	Q_{in} (cm^3/s)	Q_{in} (cfs)	Θ_{req} (m^2/s)	L_{out} (ft)	Q_{out} (cfs)
Area 1	4.2E-05	112	34.1	2.0	8.74	**0.0003**	1.1E-04	40	**0.012**
Area 2	4.2E-05	160	48.8	2.0	12.49	**0.0004**	1.6E-04	190	**0.084**
Area 3	4.2E-05	204	62.2	2.0	15.92	**0.0006**	2.1E-04	400	**0.225**
Area 4	4.2E-05	39	11.9	2.0	3.04	**0.0001**	4.0E-05	25	**0.003**
Area 5	4.2E-05	168	51.2	2.0	13.11	**0.0005**	1.7E-04	75	**0.035**
Area 6	4.2E-05	248	75.6	2.0	19.35	**0.0007**	2.5E-04	285	**0.195**
Area 1 Toe Drain	4.2E-05	27	8.2	2.0	2.11	**0.0001**	2.8E-05	10	**0.001**
Area 4 Toe Drain	4.2E-05	17	5.2	2.0	1.33	**0.00005**	1.7E-05	10	**0.0005**

See the Figure in the Unit Gradient - Converging Flow Area calculation for Area locations.

Design Pipe Flow

(from Sheet 1)

Q = **0.292** = Collection Pipe at 2% slope (cfs)

Q = **0.462** = Outlet Pipe at 5% slope, 'min. design slope' (cfs)

Q = **1.461** = Outlet Pipe at 50% (2:1) slope (cfs)

Bedding Stone Diameter Sizing

Perforation design of 4" pipe (from ADS)

Maximum slot length = 0.875 inch

Maximum slot width = 0.125 inch

*Slot width will control the size of bedding stone

D_{85F} / Slot Width > (1.2 to 1.4) , [From the NAVFAC DM 7 Manual]

D_{85F} = (0.125 inch) * 1.2 = 0.150 inch

D_{85F} = (0.125 inch) * 1.4 = 0.175 inch

So, a bedding stone with a D_{85F} between 0.150 and 0.175 inch or larger would be acceptable.

Conclusion: Based on the outlet pipe estimated flow, one 4" outlet pipe in each flow convergence area would be adequate.

A 4" diameter collection pipe at a 2% slope is suitable to collect the expected drainage layer flow.

For a 0.125 inch perforated pipe slot width, bedding stone diameter should be between 0.150 and 0.175 inch (equivalent to a No. 4 sieve) or larger.

A 4" diameter outlet pipe at a 5% slope is suitable to handle the expected drainage layer flow.

Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/03/2023
Client: WPL	Subject: Unit Gradient - Converging Flow Area	Chk'd: BSS	Date: 08/16/2023

Purpose: To determine the geocomposite drainage requirements in the final cover where flow converges in the final cover corner including Modules 3, 4, 10, and 11 so the final cover drainage geocomposite can carry infiltrating water and remain stable. Also to determine the recommended minimum interface friction angle for final cover stability.

Approach: Use the unit gradient method and flow path geometry to determine the geocomposite transmissivity required at locations within the converging flow area.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.

3. "Beyond a factor-of-safety value, i.e., the probability of failure". GRI Newsletter/Report, Vol. 15, no. 3.

4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

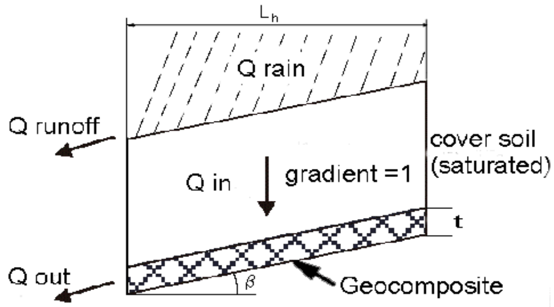
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.

6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.

7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International

8. SCS Engineers, Plan of Operation Update, Dry Ash Disposal Facility, Columbia Energy Center, Final Grades (Modules 12 and 13) Plan Sheet, August 2023

9. HELP Model "User's Guide" in conjunction with GRI report #19, pages 34-37 (Leachate Collection System)



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin \beta$$

= θ*i*1 where $\theta = k_{comp} * t$ (minimum allowable outflow to keep head within geocomposite)

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin \beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

Assumptions: 1. Soil hydraulic gradient i = 1.0.

2. Top soil will be clay. Soil permeability is 4.2 x 10^{-5} cm/sec for a CL clay from HELP model user's guide.
3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"
5. Flow paths A-E are as shown on attached drawing. Assume circular arc with radius measured from the corner of the toe drain.
6. Intermediate drainage piping will be used along the slope to divert flow from the drainage layer to the diversion berms and downslope flume.

Calculation: <u>Constants</u>

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **β**	=	25%	β = 14°
FS_{slope}	=	Minimum factor of safety against sliding, for soil/geocomposite or geocomposite/geomembrane interfaces	=	1.5	
$\delta_{req'd}$	=	Minimum interface friction angle = $\tan^{-1}(FS_{slope}*\tan(b))$	=	20.6	degrees
FS_d	=	Overall factor of safety for drainage	=	2.0	
RF_{in}	=	Intrusion Reduction Factor	=	1.1	
RF_{cr}	=	Creep Reduction Factor	=	1.2	
RF_{cc}	=	Chemical Clogging Reduction Factor	=	1.1	
RF_{bc}	=	Biological Clogging Reduction Factor	=	1.4	
w	=	Geocomposite width at drainage outlet			
A	=	Final cover plan area upslope of geocomposite drainage outlet			

Determine the maximum slope length for a given ultimate transmissivity

Min. Θ_{req} = A X k_{veg} / (w X sinβ)

For the outlet at the corner, use minimum 5 foot width of geocomposite to connect the toe drain to drain the converging flow area:

Area	A (sq. feet)	w (feet)	w (meter)	Min. Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 1 Toe Drain	519	5	1.52	2.23E-04	1.00E-03

The toe drainage area, Area 1 Toe Drain, includes only converging flow below the lowest intermediate drainage piping, as flow above this area is diverted. There are intermediate drainage pipes in Area 1 which diverts flow from the outlet corner to the downslope flume.

For converging flow in a circular arc, from radius R-top to radius R-bottom:

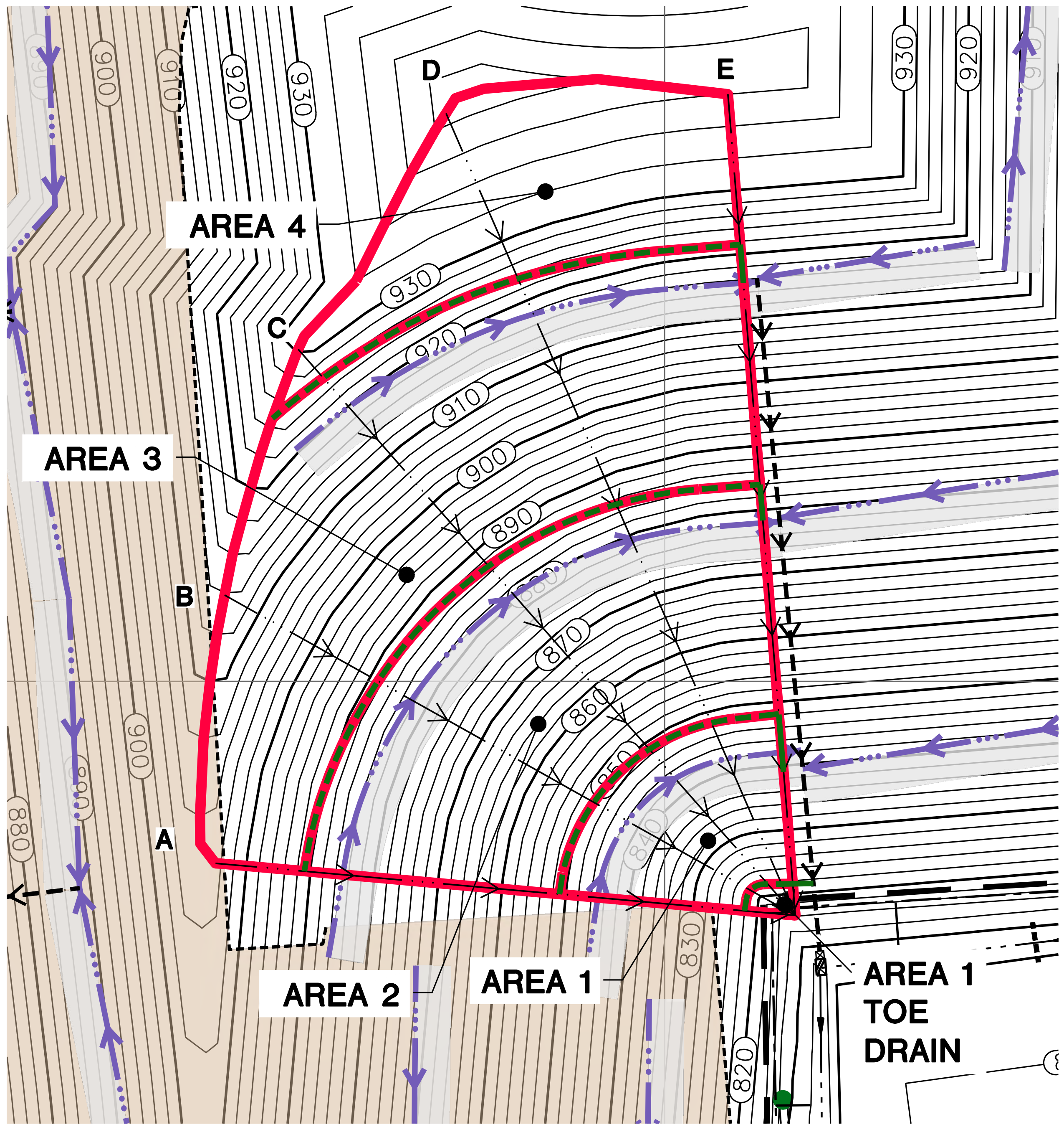
L	=	R-top - R-bottom
w-bot	=	w-top * (R-bot/R-top)
A	=	L* (1+ (R-bot/R-top))/2 (assuming unit width at top and trapezoid vs arc to simplify)
Θult-bot	=	(Θult calculated for L) * R-top/R-bot * (1+ (R-bot/R-top))/2

Calculation: (Cont.) For the southern convergence area, flow paths A-E, calculate Θult for selected R-bot values to determine appropriate geocomposite products as flow converges down the slope:

Flow Path	R-top (feet)	R-bot (feet)	L_h (feet)	L_h (meters)	Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 1						
A1	148	32	116	35	6.95E-04	1.00E-03
B1	144	32	112	34	6.60E-04	1.00E-03
C1	138	26	112	34	7.57E-04	1.00E-03
D1	131	21	110	33	8.43E-04	1.00E-03
E1	126	20	106	32	8.25E-04	1.00E-03
Area 2						
A2	308	148	160	48	5.22E-04	1.00E-03
B2	299	144	155	47	5.11E-04	1.00E-03
C2	290	138	152	46	5.04E-04	1.00E-03
D2	280	131	149	45	4.99E-04	1.00E-03
E2	270	126	144	43	4.77E-04	1.00E-03
Area 3						
A3	363	308	55	16	1.23E-04	1.00E-03
B3	408	299	109	33	2.76E-04	1.00E-03
C3	446	290	156	47	4.21E-04	1.00E-03
D3	433	280	153	46	4.14E-04	1.00E-03
E3	420	270	150	45	4.06E-04	1.00E-03
Area 4						
C4	470	446	24	7	5.08E-05	1.00E-03
D4	545	433	112	34	2.71E-04	1.00E-03
E4	514	420	94	28	2.20E-04	1.00E-03

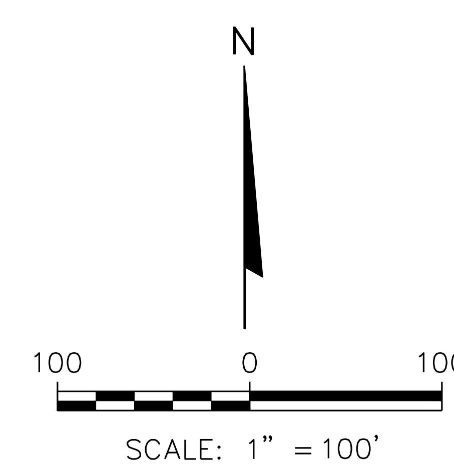
Conclusions: For the proposed convergence area design with intermediate slope outlets and a toe-of-slope drainage outlet, placement of geocomposite with the required transmissivities to the minimum lengths/areas shown in the table above and on the attached drawing will provide adequate drainage for the converging flow.

A minimum interface friction angle of 20.6 degrees for the geocomposite, geomembrane, and GCL interfaces is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.



LEGEND

	LIMITS OF WASTE
	LINER PHASE/MODULE LIMIT
840	PROPOSED GRADE (10' INTERVAL)
	PROPOSED GRADE (2' INTERVAL)
	PROPOSED SWALE
	PROPOSED DIVERSION BERM
	PROPOSED DOWNSLOPE FLUME
	PROPOSED ENERGY DISSIPATOR
	PROPOSED RIPRAP
	CONVERGENCE FLOW PATH
	PERFORATED SUBSURFACE PIPING
	SOLID SUBSURFACE PIPING



DRAFT

GEOTECHNICAL CALCULATION – FLOW CONVERGENCE
FINAL GRADES (MODULES 12 AND 13)

FIGURE 1

SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

ENGINEER

COLUMBIA ENERGY CENTER
PLAN OF OPERATION UPDATE
TOWN OF PACIFIC, WISCONSIN
COLUMBIA DRY ASH DISPOSAL FACILITY

SITE

WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

CLIENT

PROJECT NO.	25222260.00	DRAWN BY:	KP/MJT
DRAWN:	08/03/2023	CHECKED BY:	DN/BSS
REVISED:	08/17/2023	APPROVED BY:	

I:\25222260.00\Drawings\Geotech\Mod 12-13 Final_230816_HighCapGeo.dwg, 8/18/2023 8:53:05 AM

Purpose: To size the collection piping and space the outlet piping to accommodate the final cover subsurface drainage in the flow convergence areas.

Approach: Use the Darcy equation to determine the worst case flow rate to the pipe. Use Manning's equation to determine if the designed pipe size (4 inches) for the given flow rate is acceptable. Also determine what would be acceptable bedding material based on pipe hole / perforation size.

References:
1. SCS Engineers, Plan of Operation, Columbia Dry Ash Disposal Facility, Cover Unit Gradient Calculation, August 2023
2. NAVFAC DM 7, Design Criteria for Protective Filters
3. Advanced Drainage Systems (ADS), Inc. Drainage Handbook, Section 3-0 Hydraulics, July 2010
4. Advanced Drainage Systems (ADS), Inc. Technical Note (TN 1.01) Dual Wall HDPE Perforation Patterns, January 2015

Calculation: **Infiltration Flow / Collection Pipe Flow Capacity**

Darcy's Equation: $Q_{in} = K_{veg} \times i \times A = K_{veg} \times 1 \times L_h \times 1 \times FS$

Inflow of water into geocomposite from surface = Inflow of water into collection pipe

K_{veg} = Permeability of topsoil (cm/s)

L_h = Longest horizontal length between collection pipes

FS (drainage) = Factor of safety, to account for variation in cover soil

Q_{in} = Required collection pipe capacity, per linear foot of pipe

Required geocomposite transmissivity (from Cover Unit Gradient Calculation)

$\Theta_{req} = (K_{veg} \times L_h) / i * FS$ where, i = 0.25

Geocomposite Flow Capacity / Outlet Pipe Flow Capacity

Darcy's Equation:

	Q = k x i x A	Q = flow rate
	A = L x t	t = thickness
	Θ = k x t	k = permeability
so,	Q = Θ x i x L	Θ = transmissivity

i = hydraulic gradient, for 4:1 slope

L_{out} = length of collection pipe (i.e. spacing between outlet pipe) (ft)

Θ_{req} = Required transmissivity of geocomposite (ft^2/s)

Q_{out} = Required collection pipe capacity, per linear foot of pipe

Design Pipe Flow

Manning's Equation: $Q = (1.49/n) \times (3.14 \times r^2) \times (r / 2)^{2/3} \times (slope)^{1/2}$

Where,	n	=	0.012	=	Manning's Number for corrugated HDPE pipe with smooth interior
	r	=	2.0	=	Radius of 4" pipe (in)
	r	=	0.1667	=	Radius of 4" pipe (ft)
So,	Q	=	**0.292**	=	Collection Pipe at 2% slope (cfs)
	Q	=	**0.462**	=	Outlet Pipe at 5% slope, 'min. design slope' (cfs)
	Q	=	**1.461**	=	Outlet Pipe at 50% (2:1) slope (cfs)

Calculation:
(cont.)

					Collection Pipe Flow Capacity			Outlet Pipe Flow Capacity	
	K_{veg} (cm/s)	L_h (ft)	L_h (m)	FS	Q_{in} (cm^3/s)	Q_{in} (cfs)	Θ_{req} (m^2/s)	L_{out} (ft)	Q_{out} (cfs)
Area 1	4.2E-05	116	35.4	2.0	9.05	**0.0003**	1.2E-04	45	**0.014**
Area 2	4.2E-05	160	48.8	2.0	12.49	**0.0004**	1.6E-04	200	**0.088**
Area 3	4.2E-05	156	47.5	2.0	12.17	**0.0004**	1.6E-04	410	**0.176**
Area 4	4.2E-05	112	34.1	2.0	8.74	**0.0003**	1.1E-04	320	**0.099**
Area 1 Toe Drain	4.2E-05	32	9.8	2.0	2.50	**0.0001**	3.3E-05	10	**0.001**

See the Figure in the Unit Gradient - Converging Flow Area calculation for Area locations.

Design Pipe Flow

(from Sheet 1)

Q = **0.292** = Collection Pipe at 2% slope (cfs)

Q = **0.462** = Outlet Pipe at 5% slope, 'min. design slope' (cfs)

Q = **1.461** = Outlet Pipe at 50% (2:1) slope (cfs)

Bedding Stone Diameter Sizing

Perforation design of 4" pipe (from ADS)

Maximum slot length = 0.875 inch

Maximum slot width = 0.125 inch

*Slot width will control the size of bedding stone

D_{85F} / Slot Width > (1.2 to 1.4) , [From the NAVFAC DM 7 Manual]

D_{85F} = (0.125 inch) * 1.2 = 0.150 inch

D_{85F} = (0.125 inch) * 1.4 = 0.175 inch

So, a bedding stone with a D_{85F} between 0.150 and 0.175 inch or larger would be acceptable.

Conclusion: Based on the outlet pipe estimated flow, one 4" outlet pipe in each flow convergence area would be adequate.

A 4" diameter collection pipe at a 2% slope is suitable to collect the expected drainage layer flow.

For a 0.125 inch perforated pipe slot width, bedding stone diameter should be between 0.150 and 0.175 inch (equivalent to a No. 4 sieve) or larger.

A 4" diameter outlet pipe at a 5% slope is suitable to collect the expected drainage layer flow.

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the final cover.

Approach: Use maximum shear stress formula and assumed values.

References: Design of GCL Barrier for Final Cover Side Slope Applications, Gregory N. Richardson, Ph.D., P.E., Geosynthetics '97-541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin \beta$$

$$\beta = 14^\circ$$

$$W_T = \gamma \times h$$

Where:

γ	=	Soil Unit Weight	=	120	pcf
h	=	Cover Thickness	=	3.0	ft

$$W_T = 360 \text{ psf}$$

$$\tau_{act} = 87.1 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS \times \tau_{act} = 1.5 \times 87.1 = 131 \text{ psf}$$

Assumptions: Slope angle, β = 14° (4:1 horizontal / vertical final cover slope)

Soil unit weight, γ = 120 pcf

Conclusion: For a total weight of the final cover system of 360 psf and a slope angle of 4:1, the maximum shear stress will be 87.1 psf. A minimum GCL internal shear strength of 131 psf is required to provide a slope stability safety factor of 1.5.

E.2 Clay Borrow Calculations

SCS ENGINEERS

		Sheet No.	1
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/18/23
Client: WPL	Subject: Clay Volume Calculation	Chk'd: PEG	Date: 08/18/23

Purpose: Determine the volume of liner-quality and cover-quality clay material available at the Town of New Haven clay borrow source.

References:
1. Clay Volume Calculation (Town of New Haven clay borrow site) by SCS Engineers dated 9/17/2015, Appendix D of the Plan of Operations Modification - Addendum #1 dated 11/2/2015.
2. Survey of clay stockpile location at the Columbia Ash Disposal Facility (ADF) dated 06/23/2021.
3. Survey of clay stockpile at the ADF as of 06/27/23 and Civil 3D volume calculation by SCS Engineers.
4. Figure 1, Clay Borrow Site Proposed Excavation by SCS Engineers dated 08/01/2023.
5. Final Grades (Modules 12 and 13) drawing by SCS Engineers dated August 2023.
6. Existing Conditions drawing and Base Grades (Modules 12 and 13) drawing by SCS Engineers dated August 2023.

Assumptions:
1. Base of clay stockpile on site is estimated based on a June 23, 2021 topo, prior to clay stockpile placement. Clay base elevation range from 819.02' to 834.55'.
2. Thickness of clay required for the liner is 2'.
3. Thickness of clay required for the final cover is 1'.
4. 20% additional volume is assumed for clay shrinkage contingency.

Calculations:

Clay stockpiled on site: 14,122 cy (Based on volume calculations)

Clay remaining at clay borrow site: 99,181 cy

Phase	Module	Limits of Waste (ft^2)	Limits of Waste (acres)	Existing Final Cover (ft^2)	Proposed Final Cover, Sand (ft^2)	Proposed Final Cover, Geocomposite (ft^2)
1	1	360,848	8.28	246,985	23,565	90,297
1	2	176,456	4.05	5,185	791	170,481
1	3	173,290	3.98	N/A	N/A	173,290
1	4	176,240	4.05	N/A	N/A	176,240
1	5	179,251	4.12	N/A	N/A	179,251
1	6	165,253	3.79	N/A	N/A	165,253
2	10	149,157	3.42	N/A	N/A	149,157
2	11	151,628	3.48	N/A	N/A	151,628
2	12	202,610	4.65	N/A	N/A	202,610
2	13	108,151	2.48	N/A	N/A	108,151

SCS ENGINEERS

		Sheet No. 2	
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 08/18/23
Client: WPL	Subject: Clay Volume Calculation	Chk'd: PEG	Date: 08/18/23

Calculations (cont.):

Clay Required = Module Area (ft^2) X Clay depth (ft) X 1 cy / 27 ft^3

Liner Clay Depth = 2 ft

Cover Clay Depth = 1 ft

Clay required:	Liner Clay Layer		Final Cover Clay	
Module 1	Existing		3,344	cy
Module 2	Existing		6,314	cy
Module 3	Existing		6,418	cy
Module 4	Existing		6,527	cy
Module 5	Existing		6,639	cy
Module 6	Existing		6,120	cy
Module 10	Existing		5,524	cy
Module 11	Existing		5,616	cy
Module 12	15,008	cy	7,504	cy
Module 13	8,011	cy	4,006	cy
TOTAL	23,019	cy	58,013	cy

Total with 20% additional volume for clay shrinkage contingency =

	27,623	cy	69,616	cy

Total Clay Required = 97,239 cy

Clay stockpiled on site = 14,122 cy

Clay needed from clay borrow site = 83,117 cy

Clay remaining in Area 3 at clay borrow site = 99,181 cy

Conclusion:

Based on clay borrow calculations, there is sufficient liner-quality and cover-quality clay material available at the Town of New Haven clay borrow source.

SCS Engineers

2830 Dairy Drive

Madison, WI 53718-6751

Surface Report
Project Name:
I:\25222260.00\Drawings\Civil\Area 3 Pond Grading Full Area to 819.dwg
Report Date: 4/6/2023 10:06:04 AM

Client: WPL

Project Description:
Prepared by: Kirk Peterson

Linear Units: USSurveyFoot	**Area Units:** squareFoot	**Volume Units:** cubicYard

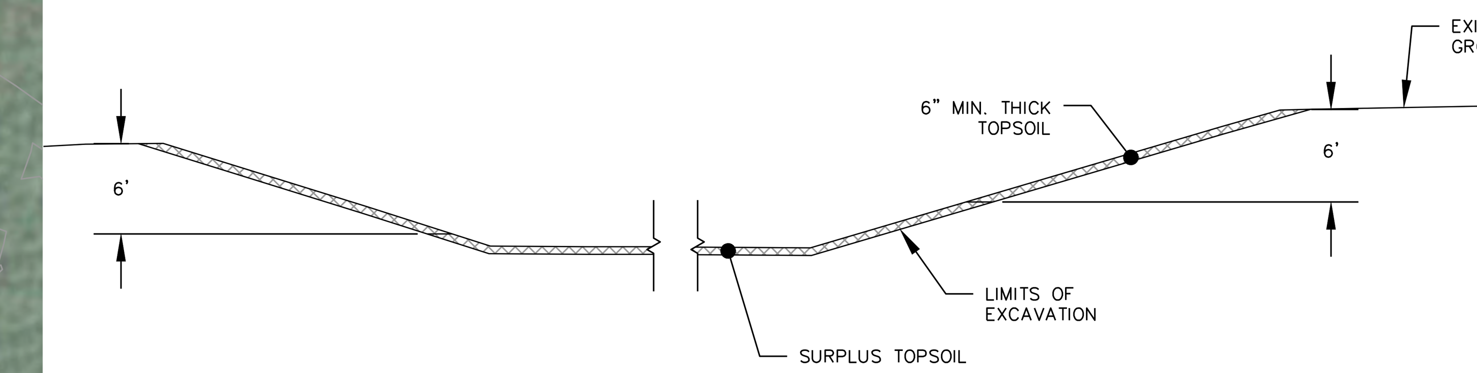
---

Surface: Vol -Area 3 Full to Elev 819
Description: Graded full pond area from existing grade to elevation 819, compared to top of clay surface (1.4' below existing) for clay volume. Ignore fill volume.

Area 2D: 208204.526	Area 3D: 212986.736
Elevation Max: 1.403	Elevation Min: -19.648
Number of Points: 19422	Number of Triangles: 38400

Volume Surface: Vol -Area 3 Full to Elev 819
Description: Graded full pond area from existing grade to elevation 819, compared to top of clay surface (1.4' below existing) for clay volume. Ignore fill volume.

Volume Cut: 99181.425	Volume Fill: 190.109	Volume Total: -98991.316
Compare Surface: Area 3 Full		
Base Surface: AIM_Existing_Ground (bottom of topsoil)		



TYPICAL POND RESTORATION SECTION

(SCALE: 1" = 10')

LEGEND

- 838 EXISTING GRADE (2' CONTOUR)
- 840 EXISTING GRADE (10' CONTOUR)
- 834 PROPOSED EXCAVATION GRADE (1' CONTOUR)
- 845 PROPOSED EXCAVATION GRADE (5' CONTOUR)
- EXISTING POND OUTLET
- PROPOSED POND OUTLET
- PROPERTY LINE
- ROAD RIGHT-OF-WAY
- ROAD CENTER LINE
- QUARTER SECTION LINE
- WETLAND
- 25' WETLAND SETBACK FOR CLAY EXCAVATION
- EXISTING MONITORING WELL
- EXISTING PIEZOMETER
- EXISTING ACCESS ROAD
- PROPOSED ACCESS ROAD

NOTES:

1. TOPOGRAPHIC BASE MAP WAS COMPILED FROM ADAMS COUNTY, WISCONSIN, 2010 LIDAR DATA AND SCS ENGINEERS SURVEY ON NOVEMBER 10, 2015 AND JULY 1, 2016, AND JULY 30, 2018, AS WELL AS, A CQM, INC. SURVEY ON NOVEMBER 9, 2017.
2. MAY 18, 2018 AERIAL PHOTOGRAPH SOURCES: ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, USDA FSA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY.
3. RESTORED 2021 CLAY BORROW EXCAVATION AREA CONTOURS FROM SURVEY PERFORMED BY SCS ENGINEERS IN OCTOBER AND NOVEMBER 2021.
4. WETLAND LIMITS BASED ON WETLAND DELINEATION PERFORMED BY HDR, INC. ON OCTOBER 9, 2014.
5. PROPERTY, RIGHT-OF-WAY, CENTER LINE, QUARTER SECTION, AND FENCING LOCATIONS BASED ON SENGLAUB PARCEL MAP PROVIDED BY ALLIANT ON JANUARY 5, 2015.
6. 25-FOOT CLAY EXCAVATION SETBACK FROM WETLAND LIMITS IS BASED ON THE TOWN OF NEW HAVEN CLAY BORROW SITE INITIAL SITE INSPECTION LETTER FROM THE WISCONSIN DEPARTMENT OF NATURAL RESOURCES DATED NOVEMBER 25, 2014.
7. CLAY BORROW SITE IS LOCATED NORTH OF GOLDEN AVENUE, TOWN OF NEW HAVEN, ADAMS COUNTY, WISCONSIN

N

60 0 60

SCALE: 1" = 60'

PROJECT NO.	25222260.00	DRAWN BY:	KP
DRAWN:	04/06/2023	CHECKED BY:	
REVISED:	08/01/2023	APPROVED BY:	

CLIENT: Wisconsin Power and Light Company
WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

ENGINEER: SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

SITE: COLUMBIA DRY ASH DISPOSAL FACILITY
TOWN OF PACIFIC, WISCONSIN

CLAY BORROW SITE
PROPOSED EXCAVATION

SHEET
1 OF 1

E.3 Closure Cost Estimates

E.3.1 Module 12 Closure Cost Estimates

Table 1. Closure Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 Scenario
Permit #3025
SCS Project #25222260.00

Total Area of Closure (acres): 34.0
Date of Estimate: 8/31/23

Major Cost Item	Unit	2023 Unit Cost	Quantity	Total Estimated Cost[1]
Closure and Post Closure Document Revisions				
Pre-closure Construction Documents	Lump Sum	$50,000	1	$50,000
Site Preparation, Earthwork, and Final Grading				
Mobilization	Lump Sum	$500,000	1	$500,000
Subgrade Preparation - Grading Top 1 foot	Acre	$5,500	34.0	$187,165
Erosion Control				
Silt Fence	Linear Foot	$3.60	5,400	$19,440
Final Cap Construction (Final Cover System, Sand Drainage Layer, Portions of Modules 1 and 2)				
Remove Temporary Intermediate Cover (2.5 feet)	Cubic Yards	$6.30	2,300	$14,490
Grading Layer Placement - Place from Onsite (0.25 feet)	Cubic Yards	$23.00	300	$6,900
Lower Barrier Layer (Onsite Sand) (1.0 foot)	Cubic Yards	$7.70	1,000	$7,700
Upper Barrier Layer (Clay) (1.0 foot)	Cubic Yards	$18.00	1,000	$18,000
GCL Installation - Purchase and Install	Square Feet	$1.05	25,000	$26,250
40-mil LLDPE Geomembrane - Purchase and Install	Square Feet	$0.90	25,000	$22,500
Drainage Layer (1.0 foot)	Cubic Yards	$54.00	1,000	$54,000
Rooting Zone - Place from Onsite (1.0 foot)	Cubic Yards	$9.60	1,000	$9,600
Topsoil - Purchase, Import, and Place (0.5 feet)	Cubic Yards	$38.00	500	$19,000
Intermediate Drainage Piping	Linear Foot	$6.00	500	$3,000
Seed, Fertilizer, Mulch	Acre	$9,400	0.6	$5,264
Erosion Mat	Acre	$13,500	0.6	$7,560
Final Cap Construction (Final Cover System, Geocomposite, North of Module 1)				
Remove Temporary Intermediate Cover (2.5 feet)	Cubic Yards	$6.30	72,800	$458,640
Grading Layer Placement - Place from Onsite (0.25 feet)	Cubic Yards	$23.00	13,500	$310,500
Lower Barrier Layer (Onsite Sand) (1 foot)	Cubic Yards	$7.70	54,000	$415,800
Upper Barrier Layer (Clay) (1 foot)	Cubic Yards	$18.00	54,000	$972,000
GCL Installation - Purchase and Install	Square Feet	$1.05	1,460,000	$1,533,000
40-mil LLDPE Geomembrane - Purchase and Install	Square Feet	$0.90	1,460,000	$1,314,000
Geocomposite drainage layer	Square Feet	$1.65	1,460,000	$2,409,000
Rooting Zone - Place from Onsite (2.5 feet)	Cubic Yards	$9.60	135,000	$1,296,000
Topsoil - Purchase, Import, and Place (0.5 feet)	Cubic Yards	$38.00	27,000	$1,026,000
Intermediate Drainage Piping	Linear Foot	$19.00	2,200	$41,800
Seed, Fertilizer, Mulch	Acre	$9,400	33.5	$314,618
Erosion Mat	Acre	$13,500	33.5	$451,845
Access Road over Final Cover				
Geotextile Separator	Square Feet	$0.50	25,000	$12,500
Breaker Run (1 foot)	Cubic Yards	$42.00	1,000	$42,000
Base Aggregate (0.5 feet)	Cubic Yards	$48.00	500	$24,000

Table 1. Closure Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 Scenario
Permit #3025
SCS Project #25222260.00

Total Area of Closure (acres): 34.0
Date of Estimate: 8/31/23

Major Cost Item	Unit	2023 Unit Cost	Quantity	Total Estimated Cost[1]
Storm Water Management				
Diversion Berms	Linear Foot	$12.30	7,900	$97,170
Down Slope Flumes	Linear Foot	$208.00	1,600	$332,800
Energy Dissipators	Each	$13,300.00	6	$79,800
Drop Structure Manhole	Each	$5,000.00	1	$5,000
Perimeter Toe Drain Collection Pipe, Outlet Pipe, and Stone	Linear Foot	$19.00	5,800	$110,200
Probable Construction Cost				***$12,197,542***
Engineering and Technical Services				
Final Cover Construction Documentation and Administration and Compliance Certifications (Assumed 15% of Construction, Large Closure Area)	Lump Sum	$1,822,200	1	$1,822,200
Legal, Financial, and Administrative Services				
All legal, financial, and administrative services (Assumed 2.5% of Construction, Large Closure Area)	Lump Sum	$303,700	1	$303,700
			Subtotal:	$14,323,400
			Contingency (10%):	$1,432,300
			Total Estimated Closure Cost:	**$15,755,700**

Notes:
1. Costs are based on experience with similar projects.
2. The total worst-case closure cost applies to Phase 1 and Modules 10, 11, and 12.
Closure of Phase 1 includes the remaining portions of Modules 1-6, which do not have final cover.

Updated By: MJT, 8/23/2023, PEG, 8/24/2023
Checked/Revised by: BSS, 08/30/2023

I:\25222260.00\Data and Calculations\Cost Estimates\[COL_Financial Responsibility_Estimate_Tables_2023 POO Update - Mod 12.xlsx]Table 1 - Closure Costs

Table 2. Long-Term Care Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 Scenario
Permit #3025
SCS Project #25222260.00

Date of Estimate: 8/31/23
Inflation Factor: Not Used – Estimates were prepared in current dollars

Major Cost Item	Unit	2023 Unit Cost	Quantity	Average Cost per Year[1]	Cost Source and Quantity Notes
General Care					
Repair erosion/reseed	Acre	$10,400	2.0	$20,800	Assumes 5% of the total closure area
Mowing	Acre	$200	79.6	$16,000	39.8 acres per event, and two events per year.
Maintenance of Drainage Features - Annually	Lump Sum	$5,000	1	$5,000	Assumes 1 discharge location is repaired per year and Sedimentation Basin Cleaning 1 per 10 years
Perimeter Roads - Annually	Lump Sum	$2,000	1	$2,000	Allowance
Leachate Management System Operation and Maintenance					
Leachate Line Cleaning and Televising	Linear Feet	$0.38	5,900	$2,300	Estimated unit cost from experience; quantity from existing and proposed piping in Phase 1 and 2; cleaning performed every year and televising every 5 years. Unit rate has been annualized.
Operation and Maintenance	Lump Sum	$5,000	1	$5,000	Estimated cost
Inspections					
Annual Inspection by PE	Lump Sum	$5,000	1	$5,000	Assumes one site visit and PE-certified Inspection Report per year.
Environmental Monitoring					
Groundwater Monitoring - Sampling and Expenses	Lump Sum	$17,000	1	$17,000	Assumes two rounds of groundwater sampling at CCR and non-CCR monitoring points under approved state monitoring program.
Groundwater Monitoring - Laboratory	Lump Sum	$9,600	1	$9,600	Assumes two rounds of groundwater sampling at CCR and non-CCR monitoring points under approved state monitoring program.
Well Maintenance, Repair, and Replacement	Lump Sum	$14,000	1	$14,000	Assumes replacement of one well every other year during the post-closure care period plus annual maintenance and repairs (minor).
Annual Reporting					
Data Management and Reporting to WDNR	Lump Sum	$48,100	1	$48,100	Assumes semiannual reporting and annual for CCR and non-CCR wells
Legal, Financial, and Administrative Services					
All legal, financial, and administrative services (Assumed 10% of Annual Costs)	%	10%	1	$14,480	
Annual Long-Term Care Subtotal:				$159,300	
Contingency (10%):				$16,000	
Annual Long-Term Care Cost:				$175,300	
40-Year Post-Closure Cost (40 x Annual Long-Term Care Cost):				**$7,012,000**	

Assumptions/Notes:
1. Costs are based on experience with similar projects or RSMeans construction cost data.

Updated By: MJT, 8/23/2023, PEG, 8/24/2023
Checked by: BSS, 08/30/2023

I:\25222260.00\Data and Calculations\Cost Estimates\[COL_Financial Responsibility_Estimate_Tables_2023 POO Update - Mod 12.xlsx]Table 2 - Long Term Care Costs

E.3.2 Modules 12 and 13 Closure Cost Estimates

Table 1. Closure Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 and 13 Scenario
Permit #3025
SCS Project #25222260.00

Total Area of Closure (acres): 36.5
Date of Estimate: 8/31/23

Major Cost Item	Unit	2023 Unit Cost	Quantity	Total Estimated Cost[1]
Closure and Post Closure Document Revisions				
Pre-closure Construction Documents	Lump Sum	$50,000	1	$50,000
Site Preparation, Earthwork, and Final Grading				
Mobilization	Lump Sum	$500,000	1	$500,000
Subgrade Preparation - Grading Top 1 foot	Acre	$5,500	36.5	$200,805
Erosion Control				
Silt Fence	Linear Foot	$3.60	5,400	$19,440
Final Cap Construction (Final Cover System, Sand Drainage Layer, Portions of Modules 1 and 2)				
Remove Temporary Intermediate Cover (2.5 feet)	Cubic Yards	$6.30	2,300	$14,490
Grading Layer Placement - Place from Onsite (0.25 feet)	Cubic Yards	$23.00	300	$6,900
Lower Barrier Layer (Onsite Sand) (1.0 foot)	Cubic Yards	$7.70	1,000	$7,700
Upper Barrier Layer (Clay) (1.0 foot)	Cubic Yards	$18.00	1,000	$18,000
GCL Installation - Purchase and Install	Square Feet	$1.05	25,000	$26,250
40-mil LLDPE Geomembrane - Purchase and Install	Square Feet	$0.90	25,000	$22,500
Drainage Layer (1.0 foot)	Cubic Yards	$54.00	1,000	$54,000
Rooting Zone - Place from Onsite (1.0 foot)	Cubic Yards	$9.60	1,000	$9,600
Topsoil - Purchase, Import, and Place (0.5 feet)	Cubic Yards	$38.00	500	$19,000
Intermediate Drainage Piping	Linear Foot	$6.00	500	$3,000
Seed, Fertilizer, Mulch	Acre	$9,400	0.6	$5,264
Erosion Mat	Acre	$13,500	0.6	$7,560
Final Cap Construction (Final Cover System, Geocomposite, North of Module 1)				
Remove Temporary Intermediate Cover (2.5 feet)	Cubic Yards	$6.30	72,800	$458,640
Grading Layer Placement - Place from Onsite (0.25 feet)	Cubic Yards	$23.00	14,500	$333,500
Lower Barrier Layer (Onsite Sand) (1 foot)	Cubic Yards	$7.70	58,000	$446,600
Upper Barrier Layer (Clay) (1 foot)	Cubic Yards	$18.00	58,000	$1,044,000
GCL Installation - Purchase and Install	Square Feet	$1.05	1,570,000	$1,648,500
40-mil LLDPE Geomembrane - Purchase and Install	Square Feet	$0.90	1,570,000	$1,413,000
Geocomposite drainage layer	Square Feet	$1.65	1,570,000	$2,590,500
Rooting Zone - Place from Onsite (2.5 feet)	Cubic Yards	$9.60	145,000	$1,392,000
Topsoil - Purchase, Import, and Place (0.5 feet)	Cubic Yards	$38.00	29,000	$1,102,000
Intermediate Drainage Piping	Linear Foot	$19.00	2,200	$41,800
Seed, Fertilizer, Mulch	Acre	$9,400	36.0	$337,930
Erosion Mat	Acre	$13,500	36.0	$485,325
Access Road over Final Cover				
Geotextile Separator	Square Feet	$0.50	25,000	$12,500
Breaker Run (1 foot)	Cubic Yards	$42.00	1,000	$42,000
Base Aggregate (0.5 feet)	Cubic Yards	$48.00	500	$24,000

Table 1. Closure Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 and 13 Scenario
Permit #3025
SCS Project #25222260.00

Total Area of Closure (acres): 36.5
Date of Estimate: 8/31/23

Major Cost Item	Unit	2023 Unit Cost	Quantity	Total Estimated Cost[1]
Storm Water Management				
Diversion Berms	Linear Foot	$12.30	9,700	$119,310
Down Slope Flumes	Linear Foot	$208.00	2,000	$416,000
Energy Dissipators	Each	$13,300.00	6	$79,800
Drop Structure Manhole	Each	$5,000.00	1	$5,000
Perimeter Toe Drain Collection Pipe, Outlet Pipe, and Stone	Linear Foot	$19.00	5,700	$108,300
Probable Construction Cost				***$13,065,214***
Engineering and Technical Services				
Final Cover Construction Documentation and Administration and Compliance Certifications (Assumed 15% of Construction, Large Closure Area)	Lump Sum	$1,952,300	1	$1,952,300
Legal, Financial, and Administrative Services				
All legal, financial, and administrative services (Assumed 2.5% of Construction, Large Closure Area)	Lump Sum	$325,400	1	$325,400
			Subtotal:	$15,342,900
			Contingency (10%):	$1,534,300
			Total Estimated Closure Cost:	**$16,877,200**

Notes:
1. Costs are based on experience with similar projects.
2. The total worst-case closure cost applies to Phase 1 and Modules 10, 11, 12 and 13.
Closure of Phase 1 includes the remaining portions of Modules 1-6, which do not have final cover.

Updated By: MJT, 8/23/2023, PEG, 8/24/2023
Checked/Revised by: BSS, 08/30/2023

I:\25222260.00\Data and Calculations\Cost Estimates\[COL_Financial Responsibility_Estimate_Tables_2023 POO Update - Mod 12 and 13.xlsx]Table 1 - Closure Cos

Table 2. Long-Term Care Cost Estimate
Alliant Energy - Columbia Energy Center - Ash Disposal Facility
Plan of Operation Modification Addendum, Module 12 and 13 Scenario
Permit #3025
SCS Project #25222260.00

Date of Estimate: 8/31/23
Inflation Factor: Not Used – Estimates were prepared in current dollars

Major Cost Item	Unit	2023 Unit Cost	Quantity	Average Cost per Year[1]	Cost Source and Quantity Notes
General Care					
Repair erosion/reseed[2]	Acre	$10,400	2.1	$22,000	Assumes 5% of the total closure area
Mowing	Acre	$200	84.6	$17,000	42.3 acres per event, and two events per year.
Maintenance of Drainage Features - Annually	Lump Sum	$5,000	1	$5,000	Assumes 1 discharge location is repaired per year and Sedimentation Basin Cleaning 1 per 10 years
Perimeter Roads - Annually	Lump Sum	$2,000	1	$2,000	Allowance
Leachate Management System Operation and Maintenance					
Leachate Line Cleaning and Televising	Linear Feet	$0.38	5,900	$2,300	Estimated unit cost from experience; quantity from existing and proposed piping in Phase 1 and 2; cleaning performed every year and televising every 5 years. Unit rate has been annualized.
Operation and Maintenance	Lump Sum	$5,000	1	$5,000	Estimated cost
Inspections					
Annual Inspection by PE	Lump Sum	$5,000	1	$5,000	Assumes one site visit and PE-certified Inspection Report per year.
Environmental Monitoring					
Groundwater Monitoring - Sampling and Expenses	Lump Sum	$17,000	1	$17,000	Assumes two rounds of groundwater sampling under approved state monitoring program.
Groundwater Monitoring - Laboratory	Lump Sum	$9,600	1	$9,600	Assumes two rounds of groundwater sampling under approved state monitoring program.
Well Maintenance, Repair, and Replacement	Lump Sum	$14,000	1	$14,000	Assumes replacement of one well every other year during the post-closure care period plus annual maintenance and repairs (minor).
Annual Reporting					
Data Management and Reporting to WDNR	Lump Sum	$48,100	1	$48,100	Assumes semiannual reporting and biennial
Legal, Financial, and Administrative Services					
All legal, financial, and administrative services (Assumed 10% of Annual Costs)	%	10%	1	$14,700	
			Annual Long-Term Care Subtotal:	$161,700	
			Contingency (10%):	$16,200	
			Annual Long-Term Care Cost:	$177,900	
			40-Year Post-Closure Cost (40 x Annual Long-Term Care Cost):	**$7,116,000**	

Assumptions/Notes:
1. Costs are based on experience with similar projects or RSMeans construction cost data.

Updated By: MJT, 8/23/2023, PEG, 8/24/2023
Checked by: BSS, 08/30/2023

I:\25222260.00\Data and Calculations\Cost Estimates\[COL_Financial Responsibility_Estimate_Tables_2023 POO Update - Mod 12 and 13.xlsx]Table 2 - Long Term Care Costs

E.4 Leachate Calculations

Hydraulic Capacity Calculations for Leachate Drainage Layer

Purpose:

To determine whether the maximum head in the leachate drainage blanket exceeds 1 foot during active and post-closure conditions, per NR 504.06(5)(a).

Approach:

The maximum head is calculated for 2 cases: active life (Case 1) and post-closure conditions (Case 2).

To estimate the maximum head in the leachate collection system drainage layer (Moore, 1982):

h_{max} = (L/2n) [sqrt(e/k + $\tan^2$ a) - tan a]

where: h_{max} = hydraulic head build up

e = infiltration rate

k = permeability of the drainage layer

L = length of the flow path to the leachate piping (maximum)

a = slope of the base liner in direction of flow

n = porosity of the drainage layer

References:

Moore, C.A., 1982, Landfill and Surface Impoundment Performance Evaluation, Revised Ed., USEPA Publication SW-869A.

Assumptions:

For both Cases:

a = 2% min. = 1.146 degrees (required by NR 504.06(2)(d))

L = 130 feet (required by NR 504.06(5)(a))

For Case 1, active life:

k =0.01 cm/sec (CQA plan)

e = 6 in/year (per NR 512.12(3)(a))

n = 0.4 (typical for stone)

For Case 2, post-closure, reduced hydraulic conductivity

k = 0.001 cm/sec (required by NR 514.07(8)(c)3.c.), post-closure assume K is 10% of original 1 cm/sec)

e = 1 in/year (per NR 512.12(3)(a))

n = 0.2 (assume porosity is also reduced due to clogging post-closure)

Hydraulic Capacity Calculations (continued)

Calculations:

h_{max} = (L/2n) [sqrt(e/k + tan^2 α) - tan α]

For Case 1, active life w/o leachate recirculation:

tan α	=	0.02					
L	=	130	ft				
k	=	0.01	cm/sec				
e	=	6	inches/year	x	2.54 cm/inch	/	((86400 sec/day)(365 day/year))
		4.8E-07	cm/sec				
n	=	0.4					
h_{max}	=	0.19	ft				

For Case 2, post-closure, reduced hydraulic conductivity

tan α	=	0.02					
L	=	130	ft				
k	=	0.001	cm/sec				
e	=	1	inches/year	x	2.54 cm/inch	/	((86400 sec/day)(365 day/year))
		8.1E-08	cm/sec				
n	=	0.2					
h_{max}	=	0.62	ft				

Conclusion:

The hydraulic capacity of the leachate drainage layer is adequate to convey the leachate to the collection pipe under active conditions and post-closure conditions.

SCS ENGINEERS

		Sheet No. 1 of 10	
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 8/21/23
Client: Wisconsin Power & Light	Subject: Leachate Pump Design, Pond	Chk'd: KRG	Date: 8/29/23

Purpose:

To size the leachate sump pumps during filling to pump from the leachate sumps to the Leachate Pond under the following scenarios:

1. Pumping from the Sump in Module 13 to the leachate pond, with all pumps operating at the same time.
2. Pumping from the Sump in Module 13 to the leachate pond, with only that pump operating.
3. Pumping from the Sump in Module 12 to the leachate pond, with all pumps operating at the same time.
4. Pumping from the Sump in Module 12 to the leachate pond, with only that pump operating.

Approach:

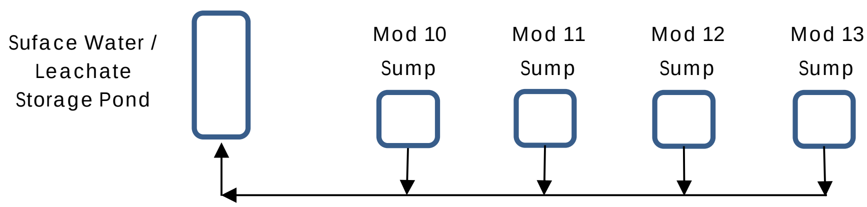
Determine the total dynamic head that the pump will operate against under various pumping rates.

The total dynamic head is a combination of the static head and friction losses from fittings and flow through the pipe.

Plot the resulting system curve on a representative pump curve to determine the suitability of a pump.

Calculations:

Pump System Layout



Pipe Header Lengths	Pipe Length		Pipe Material
Mod 10 Vault to Leachate Pond	280	ft	6" HDPE
Mod 11 Vault to Mod 10 Vault	246	ft	4" HDPE
Mod 12 Vault to Mod 11 Vault	268	ft	4" HDPE
Mod 13 Vault to Mod 12 Vault	347	ft	4" HDPE
Sump to Vault (Modules 10, 11, and 12)	64	ft	4" HDPE
Sump to Vault (Module13)	90	ft	4" HDPE

Results:

For the time period when Modules 10, 11, 12 and 13 are still open and the leachate storage pond is in operation: For Module 12, a EPG model 61-1 5.0 HP pump will pump at 123 GPM when all pumps in Modules 10, 11, 12, and 13 are operating at the same time and at 190 GPM when only the Module 12 pump is running. For Module 13, a EPG model 61-1 5.0 HP pump will pump at 95 GPM when all pumps in Modules 10, 11, 12, and 13 are operating at the same time and at 160 GPM when only the Module 13 pump is running.

Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 8/21/23
Client: Wisconsin Power & Light	Subject: Leachate Pump Design, Pond	Chk'd: KRG	Date: 8/29/23

Calculations (cont.):

Static Heads Elevations:

Mod 10 Sump	797.0
Mod 11 Sump	799.0
Mod 12 Sump	800.0
Mod 12 High Point*	820.5
Mod 13 Sump	801.0
Mod 13 High Point*	830.5
Leachate Pond Oultet	798.0

* Assumed to be 3.5' above base ground surface elevation

Static Heads:

Mod 12 Vault to Leachate Pond	=	20.5	ft.
Mod 13 Vault to Leachate Pond	=	29.5	ft.

Fittings and Equivalent Length (see Sheet 8)

Mod 13 Sump to Mod 13 Vault	Eq. Length (ft)				Total Eq. Length (ft)
Vacuum Relief Valve, 4"	1	X	110	=	110
Gate Valve, 4"	1	X	275	=	275
Flow Meter, 4"	1	X	110	=	110
Check Valve, 4"	1	X	25	=	25
Ball Valve, 4"	1	X	110	=	110
Tee, 4"	2	X	23	=	46
90° Elbow, 4"	2	X	11	=	22
			Total:		698

Mod 13 Sump to Mod 12 Vault

Actual Length (4" HDPE)		437
	Equivalent Length =	1135

From Mod 10/11/12 Sump to Vault	Eq. Length (ft)				Total Eq. Length (ft)
Vacuum Relief Valve, 4"	1	X	110	=	110
Gate Valve, 4"	1	X	275	=	275
Flow Meter, 4"	1	X	110	=	110
Check Valve, 4"	1	X	25	=	25
Ball Valve, 4"	1	X	110	=	110
Tee, 4"	3	X	23	=	69
90° Elbow, 4"	1	X	11	=	11
			Total:		710
Actual Length (4" HDPE)					64
			Equivalent Length =		774

Mod 10 Vault to Leachate Pond	Eq. Length (ft)				Total Eq. Length (ft)
4" to 6" enlargement	1	X	3.5	=	3.5
45˚ Elbow, 6"	1	X	10	=	10
			Total:		13.5
Actual Length (6" HDPE)					280
			Equivalent Length =		293.5

Calculations (cont.):

Scenario 1A - All System Pumps (4) Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 50 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
50	29.5	1,135	0.15	1.70	31.2
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
100	0	268	0.55	1.47	1.5
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
150	0	246	1.17	2.88	2.9
6" Pipe (Mod 10 Vault to Leachate Pond)					
200	0	294	0.30	0.88	0.9
			Total Dynamic Head (ft):		**36.4**

Scenario 1B - All System Pumps (4) Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 150 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
150	29.5	1,135	1.17	13.28	42.8
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
300	0	268	4.23	11.34	11.3
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
450	0	246	8.97	22.07	22.1
6" Pipe (Mod 10 Vault to Leachate Pond)					
600	0	294	2.40	7.06	7.1
			Total Dynamic Head (ft):		**83.2**

Scenario 1C - All System Pumps (4) Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 200 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
200	29.5	1,135	2.00	22.70	52.2
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
400	0	268	7.21	19.32	19.3
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
600	0	246	14.25	35.06	35.1
6" Pipe (Mod 10 Vault to Leachate Pond)					
800	0	294	3.89	11.42	11.4
			Total Dynamic Head (ft):		**118.0**

Calculations (cont.):

Scenario 2A - Only Module 13 Pump Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 100 gpm at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
100	29.5	1,135	0.55	6.24	35.7
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
100	0	268	0.55	1.47	1.5
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
100	0	246	0.55	1.35	1.4
6" Pipe (Mod 10 Vault to Leachate Pond)					
100	0	294	0.08	0.23	0.2
			Total Dynamic Head (ft):		**38.8**

Scenario 2B - Only Module 13 Pump Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 150 gpm at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
150	29.5	1,135	1.17	13.28	42.8
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
150	0	268	1.17	3.14	3.1
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
150	0	246	1.17	2.88	2.9
6" Pipe (Mod 10 Vault to Leachate Pond)					
150	0	294	0.18	0.53	0.5
			Total Dynamic Head (ft):		**49.3**

Scenario 2C - Only Module 13 Pump Operating, Pumping from Mod 13 to Leachate Pond

Assuming: 250 gpm at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 12 Vault)					
250	29.5	1,135	3.02	34.28	63.8
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
250	0	268	3.02	8.09	8.1
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
250	0	246	3.02	7.43	7.4
6" Pipe (Mod 10 Vault to Leachate Pond)					
250	0	294	0.46	1.35	1.4
			Total Dynamic Head (ft):		**80.6**

Calculations (cont.):

Scenario 3A - All System Pumps (4) Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 100 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
100	20.5	774	0.55	4.26	24.8
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
200	0	268	2.00	5.36	5.4
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
300	0	246	4.23	10.41	10.4
6" Pipe (Mod 10 Vault to Leachate Pond)					
400	0	294	1.10	3.23	3.2
				Total Dynamic Head (ft):	**43.8**

Scenario 3B - All System Pumps (4) Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 150 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
150	20.5	774	1.17	9.06	29.6
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
300	0	268	4.23	11.34	11.3
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
450	0	246	8.97	22.07	22.1
6" Pipe (Mod 10 Vault to Leachate Pond)					
600	0	294	2.40	7.06	7.1
				Total Dynamic Head (ft):	**70.0**

Scenario 3C - All System Pumps (4) Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 200 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
200	20.5	774	2.00	15.48	36.0
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
400	0	268	7.21	19.32	19.3
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
600	0	246	14.25	35.06	35.1
6" Pipe (Mod 10 Vault to Leachate Pond)					
800	0	294	3.89	11.42	11.4
				Total Dynamic Head (ft):	**101.8**

Calculations (cont.):

Scenario 4A - Only Module 12 Pump Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 100 gpm at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
100	20.5	774	0.55	4.26	24.8
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
100	0	268	0.55	1.47	1.5
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
100	0	246	0.55	1.35	1.4
6" Pipe (Mod 10 Vault to Leachate Pond)					
100	0	294	0.08	0.23	0.2
			Total Dynamic Head (ft):		**27.8**

Scenario 4B - Only Module 12 Pump Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 150 gpm at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
150	20.5	774	1.17	9.06	29.6
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
150	0	268	1.17	3.14	3.1
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
150	0	246	1.17	2.88	2.9
6" Pipe (Mod 10 Vault to Leachate Pond)					
150	0	294	0.18	0.53	0.5
			Total Dynamic Head (ft):		**36.1**

Scenario 4C - Only Module 12 Pump Operating, Pumping from Mod 12 to Leachate Pond

Assuming: 350 gpm at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
350	20.5	774	5.63	43.58	64.1
4" Pipe (Mod 12 Vault to Mod 11 Vault)					
350	0	268	5.63	15.09	15.1
4" Pipe (Mod 11 Vault to Mod 10 Vault)					
350	0	246	5.63	13.85	13.8
6" Pipe (Mod 10 Vault to Leachate Pond)					
350	0	294	0.86	2.52	2.5
			Total Dynamic Head (ft):		**95.5**

SPEARS

Engineering & Design Data

FLOW VELOCITY & FRICTION LOSS

SDR 21

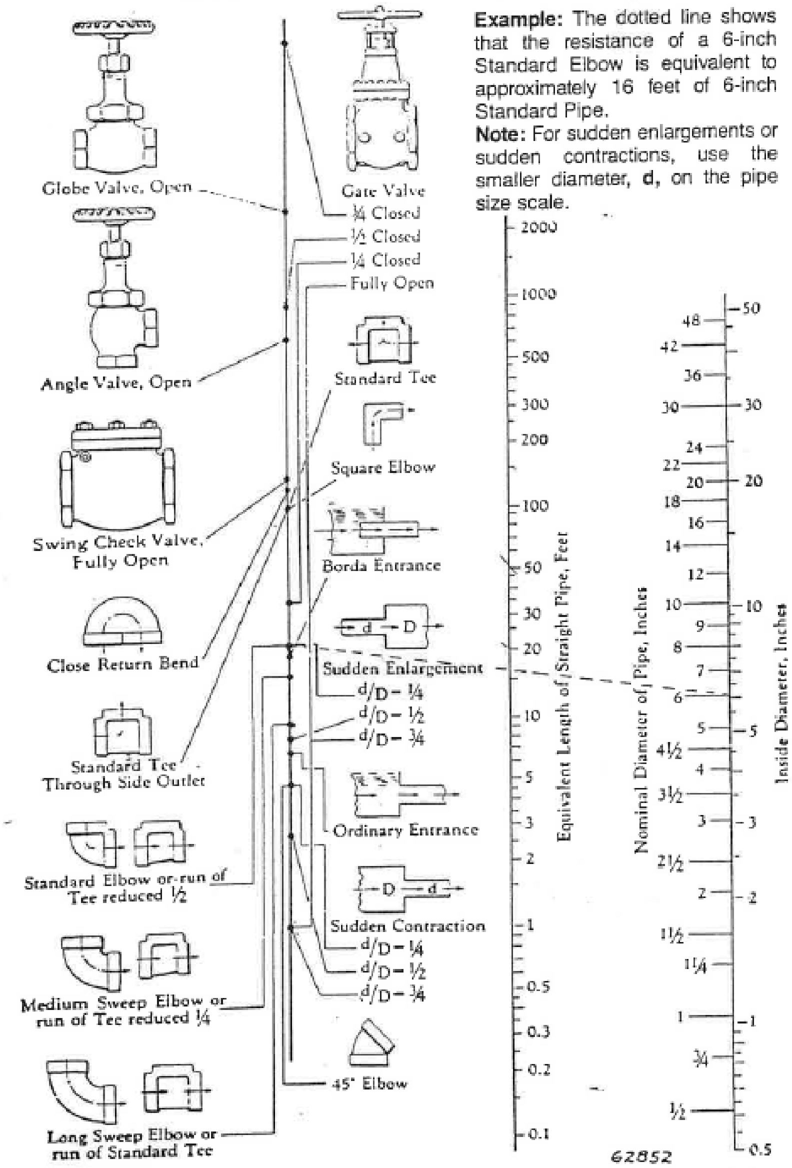
Flow Rate (Gallons per Minute)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Velocity (ft/sec.)	Friction Loss (Ft. Water/ 100ft)	Friction Loss (psi/ 100ft)	Flow Rate (Gallons per Minute)
GPM	1/2"			3/4"			1"			1-1/4"			1-1/2"			2"			2-1/2"			3"			GPM
1				0.49	0.16	0.07	0.30	0.05	0.02	0.19	0.01	0.01	0.14	0.01	0.00	0.09	0.00	0.00	0.06	0.00	0.00	0.04	0.00	0.00	1
2				0.98	0.56	0.24	0.60	0.17	0.07	0.37	0.05	0.02	0.26	0.03	0.01	0.18	0.01	0.00	0.12	0.00	0.00	0.08	0.00	0.00	2
5				2.46	3.06	1.23	1.49	0.91	0.39	0.93	0.29	0.12	0.71	0.15	0.06	0.45	0.05	0.02	0.31	0.02	0.01	0.21	0.01	0.00	5
7				3.45	5.71	2.48	2.09	1.66	0.73	1.30	0.53	0.23	0.99	0.27	0.12	0.63	0.09	0.04	0.43	0.04	0.02	0.29	0.01	0.01	7
10				4.93	11.06	4.80	2.99	3.27	1.42	1.86	1.03	0.45	1.41	0.53	0.23	0.90	0.18	0.08	0.61	0.07	0.03	0.41	0.03	0.01	10
15	4"			7.39	23.44	10.16	4.48	6.93	3.00	2.79	2.18	0.95	2.12	1.12	0.49	1.35	0.37	0.16	0.92	0.15	0.06	0.62	0.06	0.02	15
20	0.50	0.03	0.01	9.86	39.94	17.31	5.97	11.81	5.12	3.72	3.72	1.61	2.83	1.91	0.83	1.80	0.64	0.28	1.23	0.26	0.11	0.83	0.10	0.04	20
25	0.62	0.04	0.02	5"			7.47	17.86	7.74	4.65	5.63	2.44	3.53	2.89	1.25	2.25	0.97	0.42	1.53	0.38	0.16	1.03	0.14	0.06	25
30	0.75	0.06	0.03	0.49	0.02	0.01	8.96	25.02	10.85	5.58	7.89	3.42	4.24	4.05	1.75	2.70	1.35	0.59	1.84	0.53	0.23	1.24	0.20	0.09	30
35	0.87	0.08	0.03	0.57	0.03	0.01	10.45	33.28	14.43	6.51	10.49	4.55	4.94	5.38	2.33	3.15	1.80	0.78	2.15	0.71	0.31	1.44	0.27	0.12	35
40	1.00	0.10	0.04	0.65	0.04	0.02				7.43	13.44	5.83	5.65	6.89	2.99	3.60	2.31	1.00	2.45	0.90	0.39	1.65	0.34	0.15	40
45	1.12	0.13	0.05	0.73	0.04	0.02	6"			8.36	16.71	7.25	6.36	8.57	3.72	4.05	2.87	1.24	2.76	1.12	0.49	1.86	0.43	0.19	45
50	1.25	0.15	0.07	0.82	0.05	0.02	0.58	0.02	0.01	9.29	20.31	8.81	7.06	10.42	4.52	4.50	3.49	1.51	3.06	1.37	0.59	2.06	0.52	0.23	50
60	1.50	0.21	0.09	0.98	0.08	0.03	0.69	0.03	0.01				8.48	14.60	6.33	5.41	4.89	2.12	3.68	1.91	0.83	2.48	0.73	0.32	60
70	1.75	0.28	0.12	1.14	0.10	0.04	0.81	0.04	0.02				9.89	19.42	8.42	6.31	6.50	2.82	4.29	2.55	1.10	2.89	0.97	0.42	70
75	1.87	0.32	0.14	1.22	0.12	0.05	0.86	0.05	0.02				10.59	22.08	9.57	6.76	7.39	3.20	4.60	2.89	1.25	3.09	1.10	0.48	75
80	2.00	0.37	0.16	1.31	0.13	0.06	0.92	0.05	0.02							7.21	8.32	3.61	4.90	3.26	1.41	3.30	1.25	0.54	80
90	2.24	0.46	0.20	1.47	0.16	0.07	1.04	0.07	0.03	8"						8.11	10.35	4.49	5.52	4.06	1.76	3.71	1.55	0.67	90
100	2.49	0.55	0.24	1.63	0.20	0.09	1.15	0.08	0.04	0.68	0.02	0.01				9.01	12.58	5.46	6.13	4.93	2.14	4.13	1.88	0.82	100
125	3.12	0.84	0.36	2.04	0.30	0.13	1.44	0.12	0.05	0.85	0.04	0.02							7.66	7.46	3.23	5.16	2.85	1.23	125
150	3.74	1.17	0.51	2.45	0.42	0.18	1.73	0.16	0.08	1.02	0.05	0.02							9.19	10.45	4.53	6.19	3.99	1.73	150
175	4.36	1.56	0.68	2.86	0.56	0.24	2.01	0.24	0.10	1.19	0.07	0.03							10.73	13.90	6.03	7.22	5.31	2.30	175
200	4.99	2.00	0.87	3.26	0.71	0.31	2.30	0.30	0.13	1.36	0.08	0.04										8.25	6.80	2.95	200
250	6.24	3.02	1.31	4.08	1.08	0.47	2.88	0.46	0.20	1.70	0.13	0.06										10.31	10.27	4.45	250
300	7.48	4.23	1.84	4.90	1.51	0.65	3.45	0.65	0.28	2.04	0.18	0.08													300
350	8.73	5.63	2.44	5.71	2.01	0.87	4.03	0.86	0.37	2.38	0.24	0.10													350
400	9.98	7.21	3.13	6.53	2.57	1.12	4.61	1.10	0.48	2.71	0.30	0.13													400
450	11.22	8.97	3.89	7.35	3.20	1.39	5.18	1.37	0.59	3.06	0.38	0.16													450
500				8.16	3.89	1.69	5.76	1.66	0.72	3.39	0.46	0.20													500
750							8.64	3.52	1.53	5.09	0.97	0.42													750
1000										6.79	1.66	0.72													1000
1250										8.48	2.51	1.09													1250

NOTE: Spears® recommends that Flow Velocities be maintained at or below 5 feet per second in large diameter piping systems (i.e. 6" diameter and larger) to minimize the potential for hydraulic shock. Refer to Spears® engineering section entitled "Hydraulic Shock" for additional information. Friction loss data based on utilizing mean wall dimensions to determine average ID, actual ID may vary.

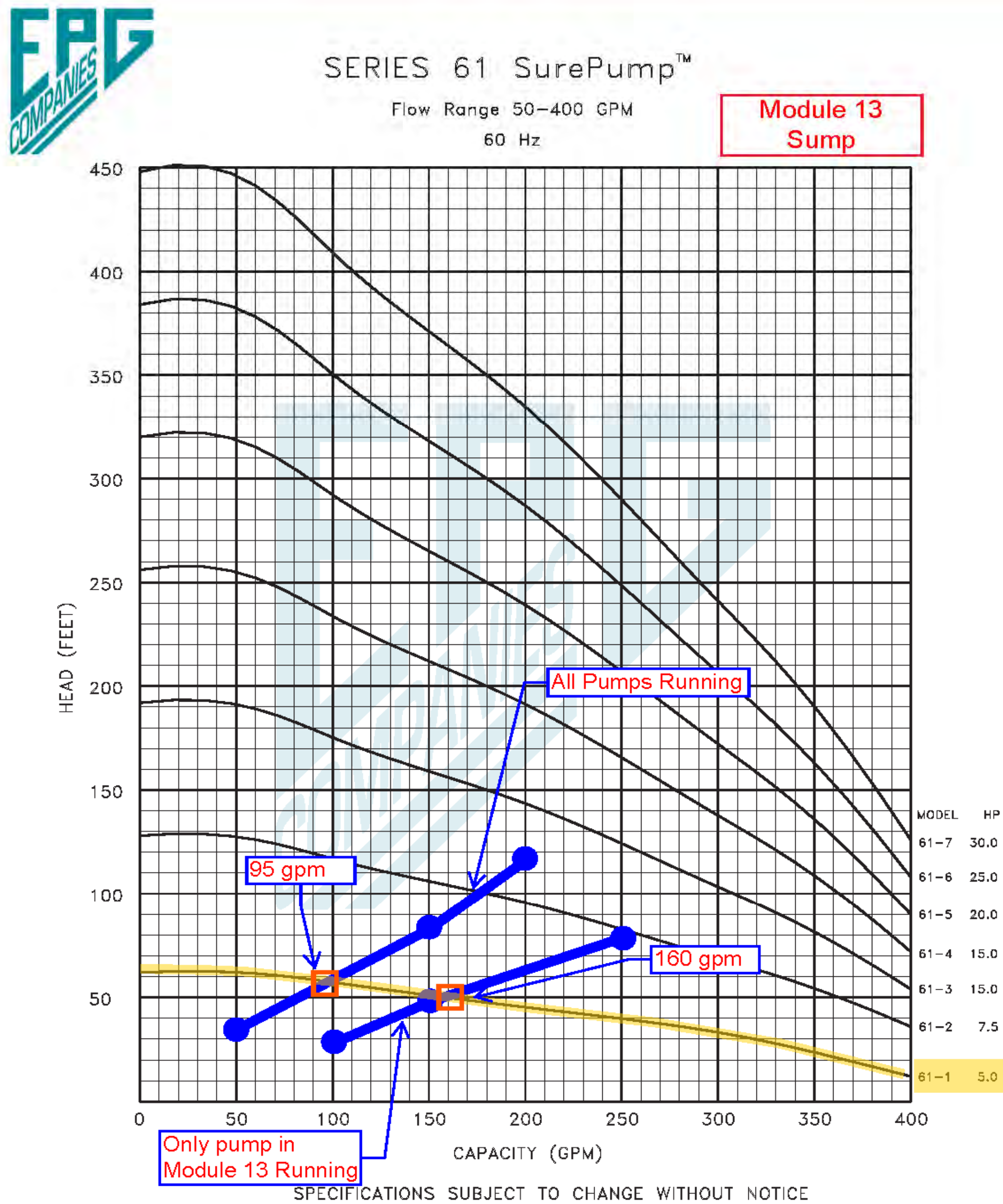
FRICTION-WATER-PIPE FITTINGS

Friction of Water *(Continued)*
Resistance of Valves and Fittings to Flow of Fluids in Equivalent Length of Pipe

Example: The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.
Note: For sudden enlargements or sudden contractions, use the smaller diameter, **d**, on the pipe size scale.

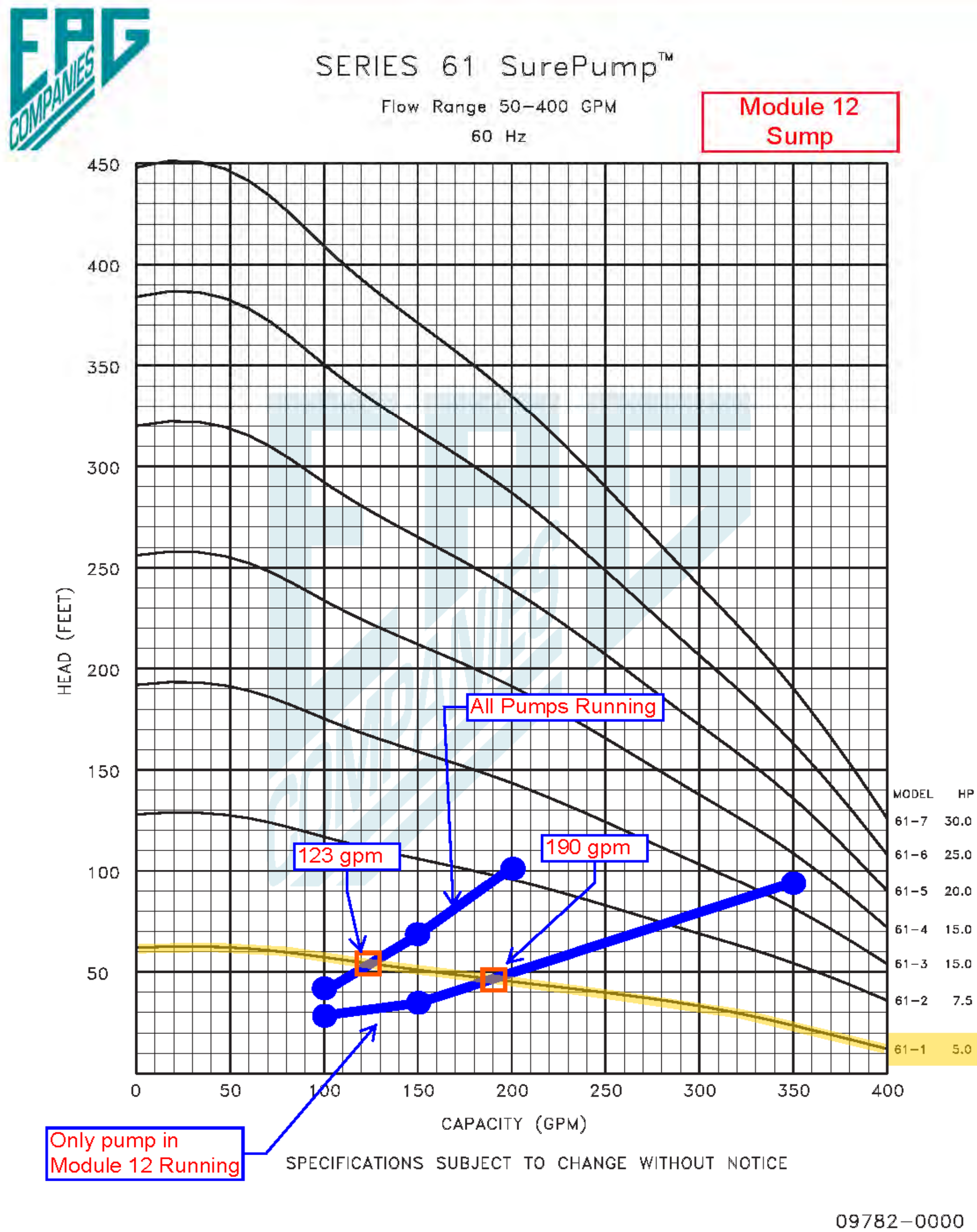


From Crane Co. Technical Paper No. 409. Data based on the above chart are satisfactory for most applications; for more detailed data and information refer to pages 3-110 to page 3-120 which are based on Crane Co. Technical Paper No. 410.



SERIES 61 SurePump™
Flow Range 50–400 GPM
60 Hz
Module 13 Sump
HEAD (FEET)
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
300
350
400
CAPACITY (GPM)
All Pumps Running
95 gpm
160 gpm
Only pump in Module 13 Running
MODEL HP
61–7 30.0
61–6 25.0
61–5 20.0
61–4 15.0
61–3 15.0
61–2 7.5
61–1 5.0
SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

09782–0000



EPG COMPANIES
SERIES 61 SurePump™
Flow Range 50–400 GPM
60 Hz
Module 12 Sump
All Pumps Running
123 gpm
190 gpm
Only pump in Module 12 Running
HEAD (FEET)
CAPACITY (GPM)
MODEL HP
61–7 30.0
61–6 25.0
61–5 20.0
61–4 15.0
61–3 15.0
61–2 7.5
61–1 5.0
SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE
09782–0000

SCS ENGINEERS

		Sheet No. 1 of 4	
		Calc. No.	
		Rev. No.	
Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 8/28/23
Client: Wisconsin Power & Light	Subject: Sump Volume and Pump Capacity	Chk'd: KRG	Date: 8/29/23

Leachate Sump Volume and Pump Capacity Calculations

Purpose:

To demonstrate that the volume in the leachate sumps and the capacity of the sump pump in Module 12 will adequately control the leachate to maintain accumulation within the sump and intersecting collection trenches, in accordance with NR 504.06(5)(j)1.

Approach:

Estimate the leachate generation rate to each sump assuming an annual leachate collection rate of 6 inches specified by NR 504.06(5)(j)1.

Calculate the sump volume based on the sump geometry shown in the Plan Mod/Plan of Operation plan set. The available volume is determined by calculating the overall sump volume between the pump on and off levels, minus the volume occupied by the granular bedding.

Determine the pumping intervals by dividing the available volume of the sump by the daily leachate generation rate. (This is the number of times the sump will fill and be required to be pumped on a daily basis.)

Identify commercially available pumps that can meet the required pumping interval calculated above.

Assumptions:

The sump in Module 12 will collect leachate from Modules 5, 6, and 12.

The leachate sumps will be filled with a granular material with a porosity of 40 percent.

Leachate generation is estimated assuming the entire area is open.

The annual leachate collection rate during open/active conditions is 6 inches per month, per NR 504.06(5)(j)1.

The pump on liquid level will occur below the bottom of the incoming leachate trenches. The pump off level will occur at 1 foot above the sump bottom.

Results:

The leachate generation rate for the sump during open/active conditions is 5,606 gal/day.
Refer to Sheet 2 for the generation rates for the sump.

The functional capacity in the sump, accounting for the stone porosity and solids buildup is 3,427 gallons.
Refer to Sheet 3 for the sump volume calculation.

The leachate sump pump is adequately sized to handle the estimated worst-case leachate volume at Module 12 with estimated filling times of 14.7 hours (Sheet 4)

Calculations:

Estimate an annual leachate collection volume based on a 6 inch per year generation rate for open conditions and an 1 inch per year generation rate for closed conditions.

Area	Sq. Ft.	Acre
Mod 1	360,841	8.28
Mod 2	171,313	3.93
Mod 3	173,212	3.98
Mod 4	176,240	4.05
Mod 5	179,251	4.12
Mod 6	165,253	3.79
Mod 10	149,157	3.42
Mod 11	151,628	3.48
Mod 12	202,610	4.65
	Total:	39.70

The sump in Module 12 will contain leachate from Module 5, 6, and 12, total area = 12.56 ac.

Open Conditions

6 inches per year for leachate collection:

Infiltration from precip=(6 in/yr)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 days)= 446.3 gal/acre/day

Closed Conditions

1 inches per year for precipitation:

Infiltration from precip=(1 in/yr)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 days)= 74.4 gal/acre/day

Calculate the maximum leachate generation rate to the sump under open/active conditions and closed conditions.

Sump Location	Average Leachate Collection Rate (gal/acre/day)	Area to Sump (acres)	Leachate Generation Rate (gal/day)
Open/Active Condition			
Module 12	446.3	12.56	5,606
Closed Condition			
Module 12	74.4	12.56	934

Sump Volumes

Module 12 (Base dimensions 15 ft. x 15 ft.)

Module 12	EL	Area (sf)	Volume (cf)	Cum Vol (cf)
Base	799	229	0	0
Pump Off	800	447	0	0
	801	737	592	592
Pump On	802	1133	935	1,527
	803	2407	1,770	3,297

Notes: Sump dimensions assumes 4:1 side slopes.
Areas of sump obtained from AutoCAD drawings of base grades.

Calculations:

Calculate the sump volume:

The sump has the dimensions and slopes as indicated on the sump detail in the Plan of Operation addendum plan set.

The general sump configuration is summarized below:

Module 12 operating volume = 1,527 cf x 7.48 gal/cf = 11,424 gal

Assuming 40% porosity for the coarse aggregate in the sump, the available capacity for leachate is as follows:

Module 12 Available Volume = 0.40 x sump operating vol. = 4,569 gal

Estimate sump filling time based on the leachate generation rates and sump volumes:

For Open/Active Conditions with leachate recirculation:

Fill Time = Operating Volume (gal)/(Leachate Generation Rate (gal/day) x 24 hrs/day)

Phase	Available Volume (gals)	25% Reduced Available Volume to Account for Solids Buildup	Leachate Generation Rate (gal/day)	Fill Time (hours)
Module 12	4,569	3,427	5,606	14.7

For Closed Conditions

Phase	Available Volume (gals)	25% Reduced Available Volume to Account for Solids Buildup	Leachate Generation Rate (gal/day)	Fill Time (hours)
Module 12	4,569	3,427	934	88.0

Sump filling times provide adequate pump rest time during active conditions with open and closed conditions.

Calculations:

Determine preliminary pumping rates and times based on assumed sump filling rate plus 50% margin for higher flows.

Filling rate (gpm) = Sump Volume (gal) / Sump Fill Time (hr) / 60 min/hr

Dewatering Time (hr) = Sump Volume (gal) / (Pumping Rate - Filling Rate (gpm)) / 60 min/hr

Pump Rest Time (hr) = Sump Fill Time (hr)

Open Conditions (pump will pump at 123 gpm with all pumps running, see pump sizing calculation)

Phase	Available Sump Volume, gal	Sump Fill Time, hrs	Filling Rate, gpm	Pumping Rate, gpm	Dewatering Time, hrs	Pump Rest Time, hrs
Mod 12	3,427	14.7	3.9	123	0.5	14.2

Closed Conditions (pump will pump at 15.5 gpm with all pumps running, see pump sizing calculation)

Phase	Operating Sump Volume, gal	Sump Fill Time, hrs	Filling Rate, gpm	Pumping Rate, gpm	Dewatering Time, hrs	Pump Rest Time, hrs
Mod 12	3,427	88.0	0.6	15	4.0	84.0

The required pumping rates are readily achievable with available pumps, such as EPG Model 61 series.

Conclusion:

The required pumping rates for dewatering are achievable with available pumps. The sumps are adequately sized to maintain liquid level within the sump based on peak generation rate of 6" of leachate collection per year.

Leachate Sump Volume and Pump Capacity Calculations

Purpose:

To demonstrate that the volume in the leachate sumps and the capacity of the sump pumps in Modules 12 and 13 will adequately control the leachate to maintain accumulation within the sump and intersecting collection trenches, in accordance with NR 504.06(5)(j)1.

Approach:

Estimate the leachate generation rate to each sump assuming an annual leachate collection rate of 6 inches specified by NR 504.06(5)(j)1.

Calculate the sump volume based on the sump geometry shown in the Plan Mod/Plan of Operation plan set. The available volume is determined by calculating the overall sump volume between the pump on and off levels, minus the volume occupied by the granular bedding.

Determine the pumping intervals by dividing the available volume of the sump by the daily leachate generation rate. (This is the number of times the sump will fill and be required to be pumped on a daily basis.)

Identify commercially available pumps that can meet the required pumping interval calculated above.

Assumptions:

The sump in Module 12 will collect leachate from Modules 5 and 12. The sump in Module 13 will collect leachate from Modules 6 and 13.

The leachate sumps will be filled with a granular material with a porosity of 40 percent.

Leachate generation is estimated assuming the entire area is open.

The annual leachate collection rate during open/active conditions is 6 inches per month, per NR 504.06(5)(j)1.

The pump on liquid level will occur below the bottom of the incoming leachate trenches. The pump off level will occur at 1 foot above the sump bottom.

Results:

The leachate generation rate for each sump during open/active conditions ranges from 2,801 to 3,913 gal/day. with the highest generation rate occurring in Module 12. Refer to Sheet 2 for the generation rates for each sump.

The functional capacity in the sumps, accounting for the stone porosity and solids buildup ranges from 3,427 to 3,434 gallons. Refer to Sheet 3 for the sump volume calculation.

The leachate sump pumps are adequately sized to handle the estimated worst-case leachate volume at Modules 12 and 13 with estimated filling times ranging from 21.0 hours to 29.4 hours (Sheet 4).

Calculations:

Estimate an annual leachate collection volume based on a 6 inch per year generation rate for open conditions and an 1 inch per year generation rate for closed conditions.

Area	Sq. Ft.	Acre
Mod 1	360,841	8.28
Mod 2	171,313	3.93
Mod 3	173,212	3.98
Mod 4	176,240	4.05
Mod 5	179,251	4.12
Mod 6	165,253	3.79
Mod 10	149,157	3.42
Mod 11	151,628	3.48
Mod 12	202,610	4.65
Mod 13	108,151	2.48
	Total:	42.19

The sump in Module 12 will contain leachate from Module 5 and 12, total area = 8.77 ac.

The sump in Module 13 will contain leachate from Module 6 and 13, total area = 6.28 ac.

Open Conditions

6 inches per year for leachate collection:

Infiltration from precip=(6 in/yr)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 days)= 446.3 gal/acre/day

Closed Conditions

1 inches per year for precipitation:

Infiltration from precip=(1 in/yr)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 days)= 74.4 gal/acre/day

Calculate the maximum leachate generation rate to each sump under open/active conditions and closed conditions.

Sump Location	Average Leachate Collection Rate (gal/acre/day)	Area to Sump (acres)	Leachate Generation Rate (gal/day)
Open/Active Condition			
Module 12	446.3	8.77	3,913
Module 13	446.3	6.28	2,801
Closed Condition			
Module 12	74.4	8.77	652
Module 13	74.4	6.28	467

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Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 8/28/23
Client: Wisconsin Power & Light	Subject: Sump Volume and Pump Capacity	Chk'd: KRG	Date: 8/29/23

Sump Volumes

Module 12 (Base dimensions 15 ft. x 15 ft.)

Module 12	EL	Area (sf)	Volume (cf)	Cum Vol (cf)
Base	799	229	0	0
Pump Off	800	447	0	0
	801	737	592	592
Pump On	802	1133	935	1,527
	803	2407	1,770	3,297

Notes: Sump dimensions assumes 4:1 side slopes.
Areas of sump obtained from AutoCAD drawings of base grades.

Module 13 (Base dimensions 15 ft. x 15 ft.)

Module 13	EL	Area (sf)	Volume (cf)	Cum Vol (cf)
Base	800	236	0	0
Pump Off	801	456	0	0
	802	747	602	602
Pump On	803	1110	929	1,530
	804	1757	1,434	2,964

Note: Sump dimensions assumes 4:1 side slopes.
Areas of sump obtained from AutoCAD drawings of base grades.

Calculations:

Calculate the sump volume:

The sumps have the dimensions and slopes as indicated on the sump detail in the Plan of Operation addendum plan set.

The general sump configuration is summarized below:

Module 12 operating volume =	1,527 cf	x	7.48	gal/cf	=	11,424	gal
Module 13 operating volume =	1,530 cf	x	7.48	gal/cf	=	11,448	gal

Assuming 40% porosity for the coarse aggregate in the sump, the available capacity for leachate is as follows:

Module 12 Available Volume = 0.40 x sump operating vol. =	4,569	gal
Module 13 Available Volume = 0.40 x sump operating vol. =	4,579	gal

Estimate sump filling time based on the leachate generation rates and sump volumes:

For Open/Active Conditions with leachate recirculation:

Fill Time = Operating Volume (gal)/(Leachate Generation Rate (gal/day) x 24 hrs/day)

Phase	Available Volume (gals)	25% Reduced Available Volume to Account for Solids Buildup	Leachate Generation Rate (gal/day)	Fill Time (hours)
Module 12	4,569	3,427	3,913	21.0
Module 13	4,579	3,434	2,801	29.4

For Closed Conditions

Phase	Available Volume (gals)	25% Reduced Available Volume to Account for Solids Buildup	Leachate Generation Rate (gal/day)	Fill Time (hours)
Module 12	4,569	3,427	652	126.1
Module 13	4,579	3,434	467	176.5

Sump filling times provide adequate pump rest time during active conditions with open and closed conditions.

Calculations:

Determine preliminary pumping rates and times based on assumed sump filling rate plus 50% margin for higher flows.

Filling rate (gpm) = Sump Volume (gal) / Sump Fill Time (hr) / 60 min/hr

Dewatering Time (hr) = Sump Volume (gal) / (Pumping Rate - Filling Rate (gpm)) / 60 min/hr

Pump Rest Time (hr) = Sump Fill Time (hr)

Open Conditions (pumps will pump at 123 and 95 gpm with all pumps running, see pump sizing calculation)

Phase	Available Sump Volume, gal	Sump Fill Time, hrs	Filling Rate, gpm	Pumping Rate, gpm	Dewatering Time, hrs	Pump Rest Time, hrs
Mod 12	3,427	21.0	2.7	123	0.5	20.5
Mod 13	3,434	29.4	1.9	95	0.6	28.8

Closed Conditions (pumps will pump at 15.5 gpm with all pumps running, see pump sizing calculation)

Phase	Operating Sump Volume, gal	Sump Fill Time, hrs	Filling Rate, gpm	Pumping Rate, gpm	Dewatering Time, hrs	Pump Rest Time, hrs
Mod 12	3,427	126.1	0.5	15	3.9	122.2
Mod 13	3,434	176.5	0.3	15	3.9	172.6

The required pumping rates are readily achievable with available pumps, such as EPG Model 61 series.

Conclusion:

The required pumping rates for dewatering are achievable with available pumps. The sumps are adequately sized to maintain liquid level within the sump based on peak generation rate of 6" of leachate collection per year.

Purpose:

To size the leachate sump pumps under the following scenarios:

1. Pumping from the Sump in Module 13 (furthest sump from leachate tank) to the leachate tank, with all pumps operating at the same time.
2. Pumping from the Sump in Module 13 (furthest sump from leachate tank) to the leachate tank, with only that pump operating.
3. Pumping from the Sump in Module 12 to the leachate tank, with only that pump operating.
4. Pumping from the Sump in Module 11 to the leachate tank, with only that pump operating.
5. Pumping from the Sump in Module 10 to the leachate tank, with only that pump operating.
6. Pumping from the Sump in Module 2 to the leachate tank, with only that pump operating.
7. Pumping from the Sump in Module 2 to the leachate tank, with all pumps operating.

Approach:

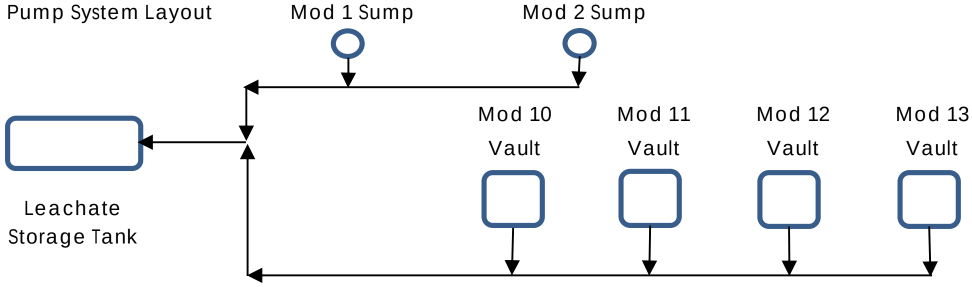
Determine the total dynamic head that the pump will operate against under various pumping rates.

The total dynamic head is a combination of the static head and friction losses from fittings and flow through the pipe.

Plot the resulting system curve on a representative pump curve to determine the suitability of a pump.

Calculations:

Pump System Layout



Pipe Header Lengths	Pipe Length		Pipe Material
Mod 2 Sump to Mod 1 Sump	164	ft	2" HDPE
Mod 1 Sump to Leachate Tank Tee	110	ft	2" HDPE
Leachate Tank Tee to Leachate Tank	49	ft	2" HDPE
Mod 10 Vault to Leachate Tank Tee	861	ft	2" HDPE
Mod 11 Vault to Mod 10 Vault	246	ft	2" HDPE
Mod 12 Vault to Mod 11 Vault	268	ft	2" HDPE
Mod 13 Vault to Mod 12 Vault	347	ft	2" HDPE
Sump to Vault (Modules 10, 11, and 12)	64	ft	4" HDPE
Sump to Vault (Module13)	90	ft	4" HDPE

Results:

For Mod 1 and Mod 2, the EPG Series 7, Model 7-1, 0.5 hp pump will pump 17 gpm when all pumps are operating and 29 gpm when only one pump is running. (See pump curve on Page 19)

For the sumps in Mods 10 through 13, the EPG Series 7, Model 7-4, 1.0 hp pump will pump 15 gpm when all pumps are running and 37.5 gpm when only one pump is running. (See Page 15)

Calculations (cont.):

Static Heads Elevations:

Mod 1:	Pump Off Elevation	=	791.0
Mod 2:	Pump Off Elevation	=	794.0
Mod 2 High Point*			810.0
Mod 10 Sump			797.0
Mod 10 High Point			815.7
Mod 11 Sump			799.0
Mod 11 High Point			817.0
Mod 12 Sump			800.0
Mod 12 High Point**			820.5
Mod 13 Sump			801.0
Mod 13 High Point**			830.5
Leachate Tank***			807.0

* Assumed to be 1.0' below ground surface elevation

** Assumed to be 3.5' above base ground surface elevation

*** Assumed to be 5' below ground surface elevation

Static Heads:

Mod 2 Sump to Leachate Tank	=	16.0	ft.
Mod 10 Sump to Leachate Tank	=	18.7	ft.
Mod 11 Sump to Leachate Tank	=	18.0	ft.
Mod 12 Sump to Leachate Tank	=	20.5	ft.
Mod 13 Sump to Leachate Tank	=	29.5	ft.

Fittings and Equivalent Length (see Sheet 15)

From Mod 2 Sump to Mod 1 Tee	Eq. Length (ft)				Total Eq. Length (ft)
90° Elbows, 2"	3	X	5.5	=	16.5
Union Fitting, 2"	1	X	2	=	2
Flow Meter, 2"	1	X	55	=	55
Check Valve, 2"	1	X	15	=	15
45˚ Elbows, 2"	1	X	2.5	=	2.5
Tee, 2"	1	X	13	=	13
			Total:		104
Actual Length (2" HDPE)					164
	Equivalent Length =				268

From Leachate FM Tee to Leachate Tank	Eq. Length (ft)				Total Eq. Length (ft)
Tee, 2"	1	X	13	=	13
90° Elbows, 2" (at Tank)	3	X	5.5	=	16.5
			Total:		29.5
Actual Length (2" HDPE)					49
	Equivalent Length =				78.5

Calculations (cont.):

Fittings and Equivalent Length, cont. (see Sheet 15)

Mod 13 Sump to Mod 13 Vault	Eq. Length (ft)				Total Eq. Length (ft)
Vacuum Relief Valve, 4"	1	X	110	=	110
Gate Valve, 4"	1	X	275	=	275
Flow Meter, 4"	1	X	110	=	110
Check Valve, 4"	1	X	25	=	25
Ball Valve, 4"	1	X	110	=	110
Tee, 4"	2	X	23	=	46
4" to 2" reduction	1	X	4	=	4
Actual Length (4" HDPE)					90
	Equivalent Length =				770

Mod 13 Vault to Mod 12 Vault					
90° Elbow, 2"	2	X	5.5	=	11
Actual Length (2" HDPE)					347
	Equivalent Length =				358

From Mod 10/11/12 Sump to Vault	Eq. Length (ft)				Total Eq. Length (ft)
Vacuum Relief Valve, 4"	1	X	110	=	110
Gate Valve, 4"	1	X	275	=	275
Flow Meter, 4"	1	X	110	=	110
Check Valve, 4"	1	X	25	=	25
Ball Valve, 4"	1	X	110	=	110
Tee, 4"	3	X	23	=	69
4" to 2" reduction	1	X	4	=	4
Actual Length (4" HDPE)					64
	Equivalent Length =				767

From Mod 12 Vault to Mod 11 Vault					
90° Elbow, 2"	1	X	5.5	=	5.5
Actual Length (2" HDPE)					268
	Equivalent Length =				273.5

From Mod 11 Vault to Mod 10 Vault					
90° Elbow, 2"	1	X	5.5	=	5.5
Actual Length (2" HDPE)					246
	Equivalent Length =				251.5

From Mod 10 Vault to Leachate FM Tee					
Tee, 2"	5	X	13	=	65
45˚ Elbows, 2"	4	X	2.5	=	10
Actual Length (2" HDPE)					861
	Equivalent Length =				936

Calculations (cont.):

Scenario 1A - All System Pumps (6) Operating, Pumping from Mod 13 to Leachate Tank

Assuming: 5 gpm pumping rate at Mod 1, Mod 2
5 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
5	29.5	770	0.01	0.08	29.6
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
5	0	358	0.08	0.27	0.3
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
10	0	274	0.24	0.66	0.7
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
15	0	252	0.50	1.26	1.3
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
20	0	936	0.85	7.96	8.0
2" Pipe (Leachate Tank Tee to Leachate Tank)					
30	0	79	1.8	1.41	1.4
			Total Dynamic Head (ft):		**41.1**

Scenario 1B - All System Pumps (6) Operating, Pumping from Mod 13 to Leachate Tank

Assuming: 5 gpm pumping rate at Mod 1, Mod 2
15 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
15	29.5	770	0.02	0.15	29.7
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
15	0	358	0.50	1.79	1.8
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
30	0	274	1.80	4.92	4.9
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
45	0	252	3.82	9.61	9.6
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
60	0	936	6.50	60.84	60.8
2" Pipe (Leachate Tank Tee to Leachate Tank)					
70	0	79	8.65	6.79	6.8
			Total Dynamic Head (ft):		**113.6**

Calculations (cont.):

Scenario 1C - All System Pumps (6) Operating, Pumping from Mod 13 to Leachate Tank

Assuming: 5 gpm pumping rate at Mod 1, Mod 2

20 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
20	29.5	770	0.04	0.31	29.8
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
20	0	358	0.85	3.04	3.0
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
40	0	274	3.07	8.40	8.4
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
60	0	252	6.50	16.35	16.3
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
80	0	936	11.08	103.71	103.7
2" Pipe (Leachate Tank Tee to Leachate Tank)					
90	0	79	13.78	10.82	10.8
			Total Dynamic Head (ft):		**172.1**

Calculations (cont.):

Scenario 2A - Pump at Module 13 Sump Operating, Pumping from Mod 13 to Leachate Tank, all other pumps off

Assuming: 20 gpm pumping rate at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
20	29.5	770	0.04	0.31	29.8
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
20	0	358	0.85	3.04	3.0
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
20	0	274	0.85	2.32	2.3
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
20	0	252	0.85	2.14	2.1
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
20	0	936	0.85	7.96	8.0
2" Pipe (Leachate Tank Tee to Leachate Tank)					
20	0	79	0.85	0.67	0.7
			Total Dynamic Head (ft):		**45.9**

Scenario 2B - Pump at Module 13 Sump Operating, Pumping from Mod 13 to Leachate Tank, all other pumps off

Assuming: 35 gpm pumping rate at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
35	29.5	770	0.11	0.85	30.3
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
35	0	358	2.40	8.59	8.6
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
35	0	274	2.40	6.56	6.6
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
35	0	252	2.40	6.04	6.0
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
35	0	936	2.40	22.46	22.5
2" Pipe (Leachate Tank Tee to Leachate Tank)					
35	0	79	2.4	1.88	1.9
			Total Dynamic Head (ft):		**75.9**

Calculations (cont.):

Scenario 2C - Pump at Module 13 Sump Operating, Pumping from Mod 13 to Leachate Tank, all other pumps off

Assuming: 45 gpm pumping rate at Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 13 Sump to Mod 13 Vault)					
45	29.5	770	0.17	1.31	30.8
2" Pipe (Mod 13 Vault to Mod 12 Vault)					
45	0	358	3.82	13.68	13.7
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
45	0	274	3.82	10.45	10.4
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
45	0	252	3.82	9.61	9.6
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
45	0	936	3.82	35.76	35.8
2" Pipe (Leachate Tank Tee to Leachate Tank)					
45	0	79	3.82	3.00	3.0
			Total Dynamic Head (ft):		**103.3**

Calculations (cont.):

Scenario 3A - Pump at Module 12 Sump Operating, Pumping from Mod 12 to Leachate Tank, all other pumps off

Assuming: 25 gpm pumping rate at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
25	20.5	767	0.06	0.46	21.0
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
25	0	274	1.29	3.53	3.5
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
25	0	252	1.29	3.24	3.2
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
25	0	936	1.29	12.07	12.1
2" Pipe (Leachate Tank Tee to Leachate Tank)					
25	0	79	1.29	1.01	1.0
				Total Dynamic Head (ft):	**40.8**

Scenario 3B - Pump at Module 12 Sump Operating, Pumping from Mod 12 to Leachate Tank, all other pumps off

Assuming: 35 gpm pumping rate at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
35	20.5	767	0.11	0.84	21.3
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
35	0	274	2.40	6.56	6.6
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
35	0	252	2.40	6.04	6.0
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
35	0	936	2.40	22.46	22.5
2" Pipe (Leachate Tank Tee to Leachate Tank)					
35	0	79	2.40	1.88	1.9
				Total Dynamic Head (ft):	**58.3**

Scenario 3C - Pump at Module 12 Sump Operating, Pumping from Mod 12 to Leachate Tank, all other pumps off

Assuming: 45 gpm pumping rate at Mod 12 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 12 Sump to Mod 12 Vault)					
45	20.5	767	0.17	1.30	21.8
2" Pipe (Mod 12 Vault to Mod 11 Vault)					
45	0	274	3.82	10.45	10.4
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
45	0	252	3.82	9.61	9.6
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
45	0	936	3.82	35.76	35.8
2" Pipe (Leachate Tank Tee to Leachate Tank)					
45	0	79	3.82	3.00	3.0
				Total Dynamic Head (ft):	**80.6**

Calculations (cont.):

Scenario 4A - Pump at Module 11 Sump Operating, Pumping from Mod 11 to Leachate Tank, all other pumps off

Assuming: 30 gpm pumping rate at Mod 11 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 11 Sump to Mod 11 Vault)					
30	18.0	767	0.08	0.61	18.6
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
30	0.0	252	1.80	4.53	4.5
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
30	0	936	1.80	16.85	16.8
2" Pipe (Leachate Tank Tee to Leachate Tank)					
30	0	79	1.80	1.41	1.4
				Total Dynamic Head (ft):	**41.4**

Scenario 4B - Pump at Module 11 Sump Operating, Pumping from Mod 11 to Leachate Tank, all other pumps off

Assuming: 40 gpm pumping rate at Mod 11 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 11 Sump to Mod 11 Vault)					
40	18.0	767	0.14	1.07	19.1
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
40	0.0	252	3.07	7.72	7.7
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
40	0	936	3.07	28.74	28.7
2" Pipe (Leachate Tank Tee to Leachate Tank)					
40	0	79	3.07	2.41	2.4
				Total Dynamic Head (ft):	**57.9**

Scenario 4C - Pump at Module 11 Sump Operating, Pumping from Mod 11 to Leachate Tank, all other pumps off

Assuming: 50 gpm pumping rate at Mod 11 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 11 Sump to Mod 11 Vault)					
50	18.0	767	0.21	1.61	19.6
2" Pipe (Mod 11 Vault to Mod 10 Vault)					
50	0.0	252	4.64	11.67	11.7
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
50	0	936	4.64	43.43	43.4
2" Pipe (Leachate Tank Tee to Leachate Tank)					
50	0	79	4.64	3.64	3.6
				Total Dynamic Head (ft):	**78.4**

Calculations (cont.):

Scenario 5A - Pump at Module 10 Sump Operating, Pumping from Mod 10 to Leachate Tank, all other pumps off

Assuming: 30 gpm pumping rate at Mod 10 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 10 Sump to Mod 10 Vault)					
30	18.7	767	0.08	0.61	19.3
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
30	0	936	1.80	16.85	16.8
2" Pipe (Leachate Tank Tee to Leachate Tank)					
30	0	79	1.80	1.41	1.4
			Total Dynamic Head (ft):		**37.6**

Scenario 5B - Pump at Module 10 Sump Operating, Pumping from Mod 10 to Leachate Tank, all other pumps off

Assuming: 40 gpm pumping rate at Mod 10 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 10 Sump to Mod 10 Vault)					
40	18.7	767	0.14	1.07	19.8
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
40	0	936	3.07	28.74	28.7
2" Pipe (Leachate Tank Tee to Leachate Tank)					
40	0	79	3.07	2.41	2.4
			Total Dynamic Head (ft):		**50.9**

Scenario 5C - Pump at Module 10 Sump Operating, Pumping from Mod 10 to Leachate Tank, all other pumps off

Assuming: 50 gpm pumping rate at Mod 10 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
4" Pipe (Mod 10 Sump to Mod 10 Vault)					
50	18.7	767	0.21	1.61	20.3
2" Pipe (Mod 10 Vault to Leachate Tank Tee)					
50	0	936	4.64	43.43	43.4
2" Pipe (Leachate Tank Tee to Leachate Tank)					
50	0	79	4.64	3.64	3.6
			Total Dynamic Head (ft):		**67.4**

Calculations (cont.):

Scenario 6A - Pump at Module 2 Sump Operating, Pumping from Mod 2 to Leachate Tank, all other pumps off

Assuming: 5 gpm pumping rate at Mod 2 Sump

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
5	16.0	268	0.08	0.20	16.2
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
5	0	110	0.08	0.08	0.1
2" Pipe (Leachate Tank Tee to Leachate Tank)					
5	0	79	0.08	0.06	0.1
			Total Dynamic Head (ft):		**16.3**

Scenario 6B - Pump at Module 2 Sump Operating, Pumping from Mod 2 to Leachate Tank, all other pumps off

Assuming: 25 gpm pumping rate at Mod 2 Sump

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
25	16.0	268	1.29	3.46	19.5
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
25	0	110	1.29	1.42	1.4
2" Pipe (Leachate Tank Tee to Leachate Tank)					
25	0	79	1.29	1.01	1.0
			Total Dynamic Head (ft):		**21.9**

Scenario 6C - Pump at Module 2 Sump Operating, Pumping from Mod 2 to Leachate Tank, all other pumps off

Assuming: 40 gpm pumping rate at Mod 2 Sump

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
40	16.0	268	3.07	8.23	24.2
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
40	0	110	3.07	3.38	3.4
2" Pipe (Leachate Tank Tee to Leachate Tank)					
40	0	79	3.07	2.41	2.4
			Total Dynamic Head (ft):		**30.0**

Calculations (cont.):

Scenario 7A - All System Pumps (6) Operating, Pumping from Mod 2 Sump to Leachate Tank

Assuming: 5 gpm pumping rate at Mod 1, Mod 2
10 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
5	16.0	268	0.075	0.20	16.2
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
10	0	110	0.24	0.26	0.3
2" Pipe (Leachate Tank Tee to Leachate Tank)					
50	0	79	4.64	3.64	3.6
			Total Dynamic Head (ft):		**20.1**

Scenario 7B - All System Pumps (6) Operating, Pumping from Mod 2 Sump to Leachate Tank

Assuming: 15 gpm pumping rate at Mod 1, Mod 2
10 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
15	16.0	268	0.5	1.34	17.3
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
30	0	110	1.8	1.98	2.0
2" Pipe (Leachate Tank Tee to Leachate Tank)					
70	0	79	8.65	6.79	6.8
			Total Dynamic Head (ft):		**26.1**

Scenario 7C - All System Pumps (6) Operating, Pumping from Mod 2 Sump to Leachate Tank

Assuming: 30 gpm pumping rate at Mod 1, Mod 2
10 gpm at Mod 10 Vault, Mod 11 Vault, Mod 12 Vault, and Mod 13 Vault

Flowrate (GPM)	Static Head (Ft)	Equivalent Length (Ft)	Head Loss Per 100 Ft.	Head Loss (Ft)	Total Dynamic Head (Ft)
2" Pipe (Mod 2 Sump to Mod 1 Sump Tee)					
30	16.0	268	1.8	4.82	20.8
2" Pipe (Mod 1 Sump Tee to Leachate Tank Tee)					
60	0	110	6.5	7.15	7.2
2" Pipe (Leachate Tank Tee to Leachate Tank)					
100	0	79	16.75	13.15	13.1
			Total Dynamic Head (ft):		**41.1**

Engineering & Design Data

SPEARS

FLOW VELOCITY & FRICTION LOSS

SDR 13.5

Flow Rate (Gallons/ Minute)	cubic ft/sec	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Velocity (ft/s)	Friction Head Loss (ft water/ 100ft)	Friction Pressure (psi/ 100ft)	Flow Rate (Gallons/ Minute)
GPM		1/2"			3/4"			1"			1-1/4"			1-1/2"			2"			2-1/2"			3"			GPM
1	0.002	0.85	1.03	0.45	0.54	0.34	0.15																			1
2	0.004	1.69	2.05	0.89	1.07	0.68	0.29	0.68	0.40	0.17	0.42	0.13	0.06	0.32	0.065	0.028	0.20	0.03	0.013							2
5	0.011	4.22	11.58	5.01	2.68	3.82	1.65	1.69	1.24	0.54	1.05	0.39	0.17	0.80	0.20	0.088	0.51	0.075	0.033	0.35	0.038	0.016	0.24	0.02	0.009	5
7	0.016	5.91	21.24	9.20	3.75	7.01	3.03	2.36	2.28	0.99	1.47	0.72	0.31	1.12	0.37	0.16	0.72	0.125	0.054	0.49	0.53	0.023	0.33	0.03	0.012	7
10	0.022	8.44	40.46	17.52	5.35	13.34	5.78	3.37	4.33	1.87	2.10	1.37	0.59	1.60	0.71	0.31	1.02	0.24	0.10	0.70	0.09	0.039	0.47	0.04	0.017	10
15	0.033	4"			8.03	28.27	12.24	5.06	9.18	3.97	3.15	2.91	1.26	2.40	1.50	0.65	1.53	0.50	0.22	1.04	0.20	0.087	0.70	0.08	0.035	15
20	0.045	0.57	0.04	0.017	10.70	48.17	20.86	6.74	15.64	6.77	4.21	4.96	2.91	3.20	2.55	1.10	2.04	0.85	0.37	1.39	0.34	0.15	0.94	0.13	0.056	20
25	0.056	0.71	0.06	0.026	5"			8.43	23.65	10.24	5.26	7.49	3.24	4.00	3.85	1.67	2.55	1.29	0.56	1.74	0.51	0.22	1.17	0.19 0.	082	25
30	0.067	0.85	0.08	0.035	0.56	0.03	0.013	10.11	33.15	14.35	6.31	10.50	4.55	4.80	5.40	2.34	3.05	1.80	0.78	2.09	0.71	0.31	1.41	0.27	0.12	30
35	0.078	0.99	0.11	0.048	0.65	0.04	0.017				7.36	13.97	6.05	5.60	7.19	3.11	3.57	2.40	1.04	2.44	0.95	0.41	1.64	0.36	0.16	35
40	0.089	1.14	0.14	0.060	0.74	0.05	0.022				8.41	17.90	7.75	6.40	9.20	3.98	4.08	3.07	1.33	2.78	1.21	0.52	1.88	0.46	0.20	40
45	0.100	1.28	0.17	0.074	0.84	0.06	0.026	6"			9.46	22.26	9.64	7.20	11.44	4.95	4.59	3.82	1.65	3.13	1.51	0.65	2.11	0.58	0.25	45
50	0.111	1.42	0.21	0.091	0.93	0.07	0.030	0.66	0.03	0.013	10.52	27.05	11.71	8.00	13.91	6.02	5.10	4.64	2.01	3.48	1.83	0.79	2.35	0.70	0.30	50
60	0.134	1.70	0.29	0.13	1.12	0.10	0.043	0.79	0.04	0.017				9.60	19.50	8.44	6.12	6.50	2.81	4.18	2.57	1.11	2.82	0.98	0.42	60
70	0.156	1.99	0.38	0.16	1.30	0.14	0.061	0.92	0.06	0.026							7.14	8.65	3.75	4.87	3.42	1.48	3.29	1.31	0.57	70
75	0.167	2.13	0.44	0.19	1.40	0.16	0.069	0.98	0.07	0.030							7.65	9.83	4.26	5.22	3.88	1.68	3.52	1.49	0.65	75
80	0.178	2.27	0.49	0.21	1.49	0.18	0.078	1.05	0.08	0.035							8.16	11.08	4.80	5.57	4.37	1.89	3.76	1.68	0.73	80
90	0.201	2.56	0.61	0.26	1.67	0.22	0.095	1.18	0.09	0.039							9.18	13.78	5.97	6.27	5.44	2.36	4.23	2.09	0.90	90
100	0.223	2.84	0.74	0.32	1.86	0.27	0.12	1.31	0.11	0.048							10.20	16.75	7.25	6.96	6.61	2.86	4.70	2.54	1.10	100
125	0.279	3.55	1.13	0.49	2.33	0.40	0.18	1.64	0.17	0.074										8.70	10.01	4.33	5.88	3.84	1.66	125
150	0.334	4.26	1.58	0.68	2.79	0.56	0.24	1.97	0.24	0.10										10.44	14.01	6.07	7.04	5.37	2.33	150
175	0.390	4.97	2.10	0.91	3.26	0.75	0.33	2.30	0.32	0.14													8.22	7.15	3.10	175
200	0.446	5.68	2.69	1.16	3.72	0.96	0.42	2.62	0.41	0.18													9.39	9.15	3.96	200
250	0.557	7.10	4.07	1.76	4.66	1.46	0.63	3.28	0.62	0.27													11.74	13.86	6.00	250
300	0.668	8.52	5.69	2.46	5.58	2.03	0.88	3.93	0.87	0.38																300
350	0.780	9.94	7.58	3.29	6.52	2.70	1.17	4.59	1.16	0.50																350
400	0.891	11.36	9.70	4.20	7.44	3.46	1.50	5.24	1.48	0.64																400
450	1.003				8.37	4.31	1.87	5.90	1.84	0.80																450
500	1.114				9.30	5.24	2.27	6.66	2.25	0.97																500
750								9.83	4.73	2.05																750
1000	2.228							13.11	8.06	3.49																1000

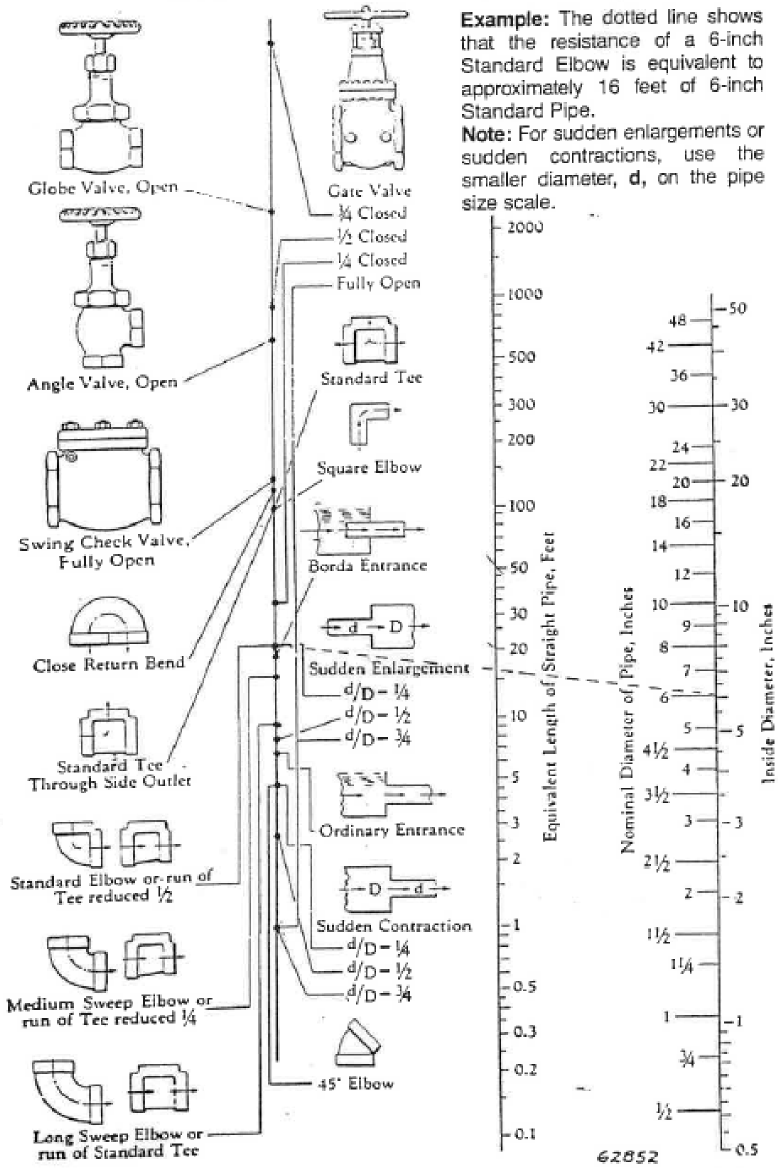
NOTE: Spears® recommends that Flow Velocities be maintained at or below 5 feet per second in large diameter piping systems (i.e. 8" diameter and larger) to minimize the potential for hydraulic shock. Refer to Spears® engineering section entitled "Hydraulic Shock" for additional information. Friction loss data based on utilizing mean wall dimensions to determine average ID; actual ID may vary.

FRICTION-WATER-PIPE FITTINGS

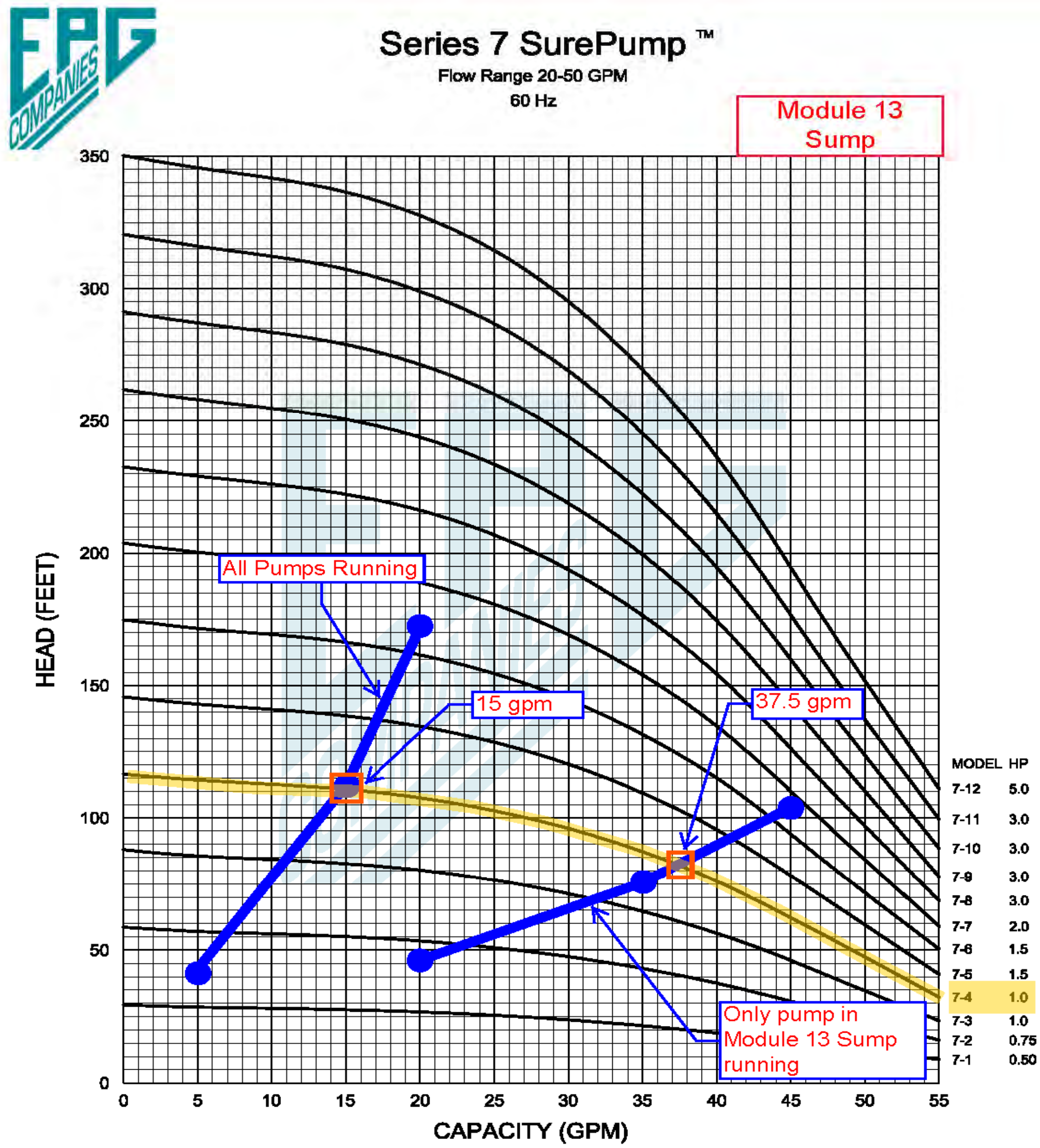
Friction of Water *(Continued)*
Resistance of Valves and Fittings to Flow of Fluids in Equivalent Length of Pipe

Example: The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note: For sudden enlargements or sudden contractions, use the smaller diameter, **d**, on the pipe size scale.

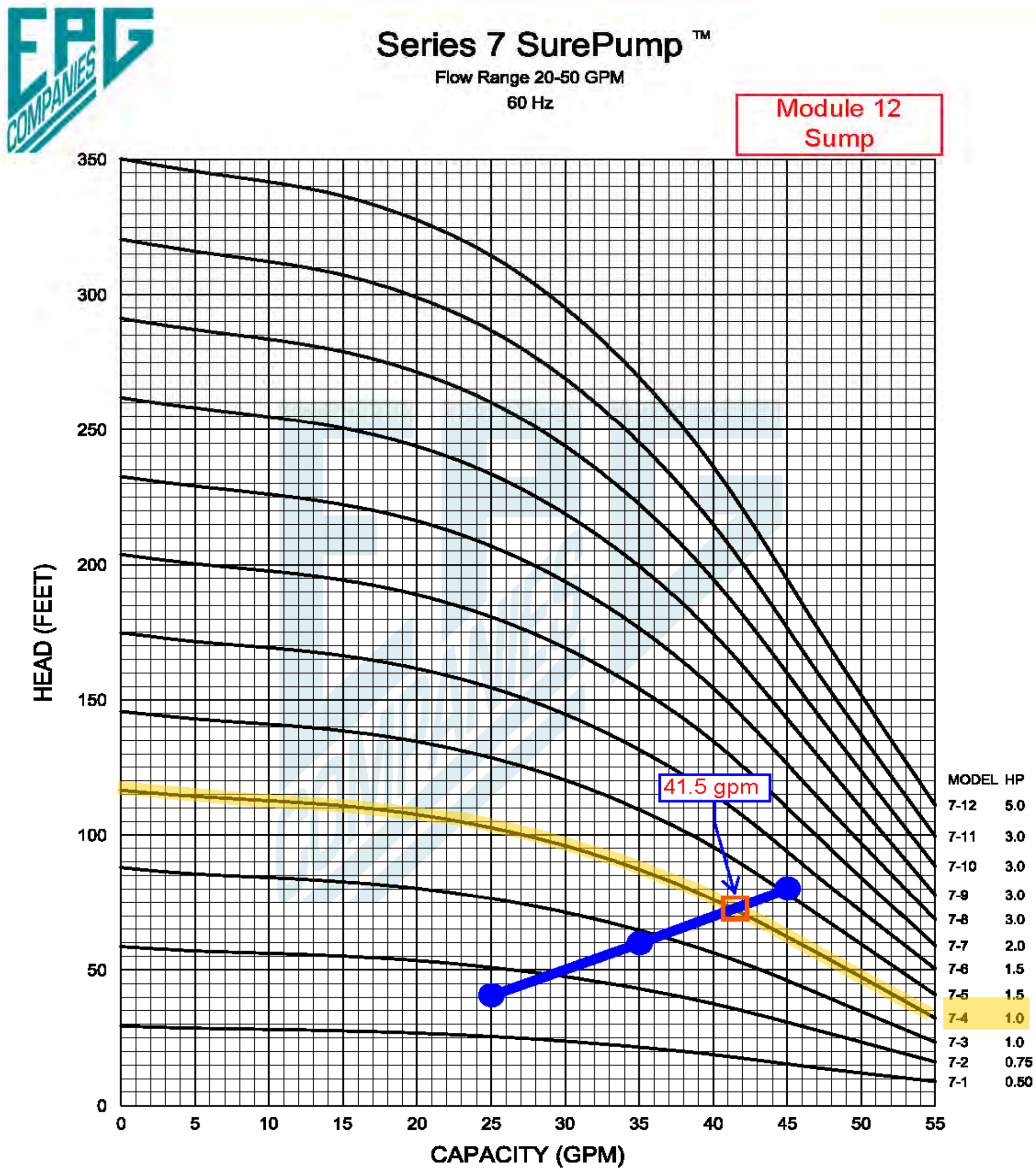


From Crane Co. Technical Paper No. 409. Data based on the above chart are satisfactory for most applications; for more detailed data and information refer to pages 3-110 to page 3-120 which are based on Crane Co. Technical Paper No. 410.



SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

09948-0000



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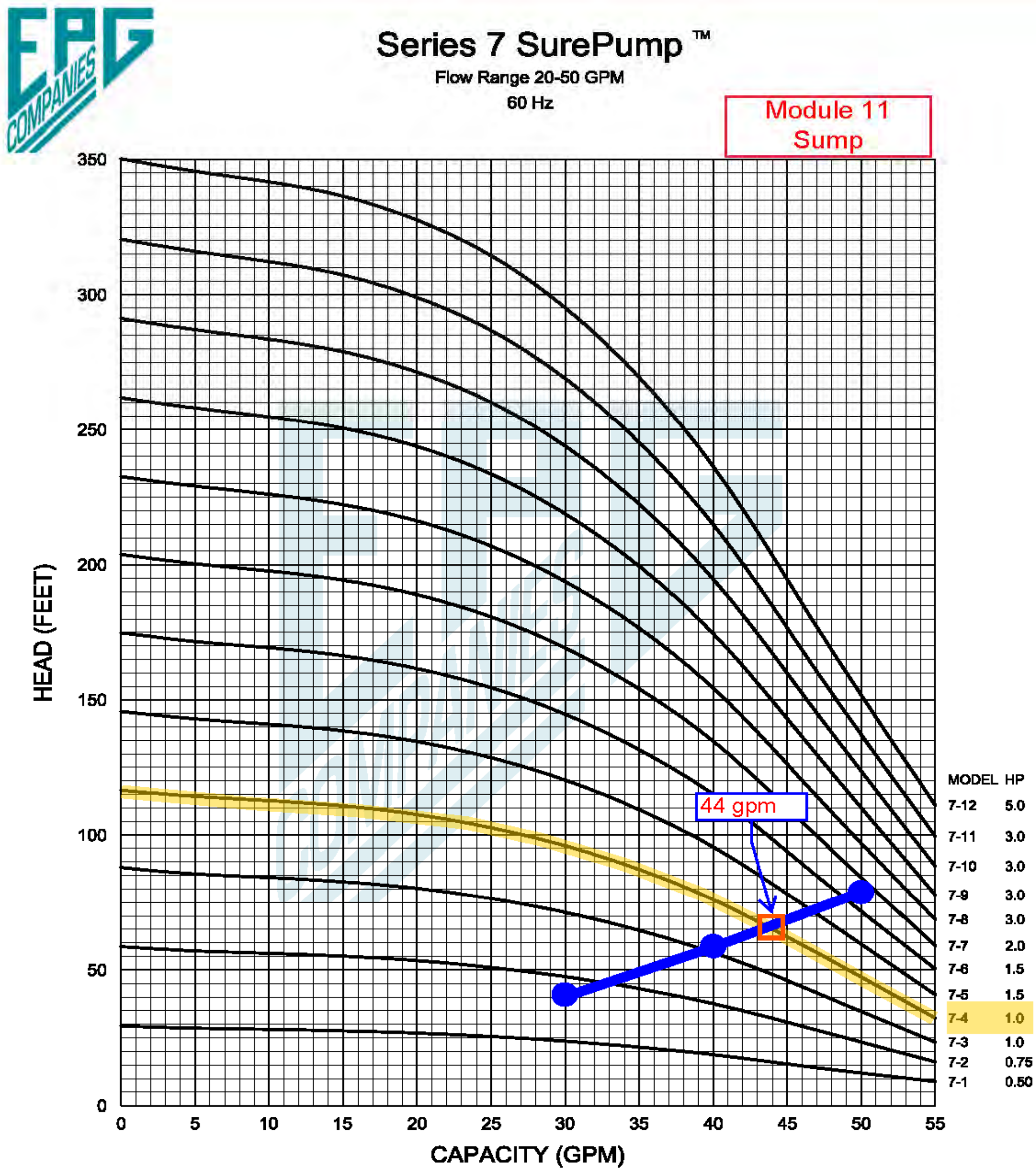

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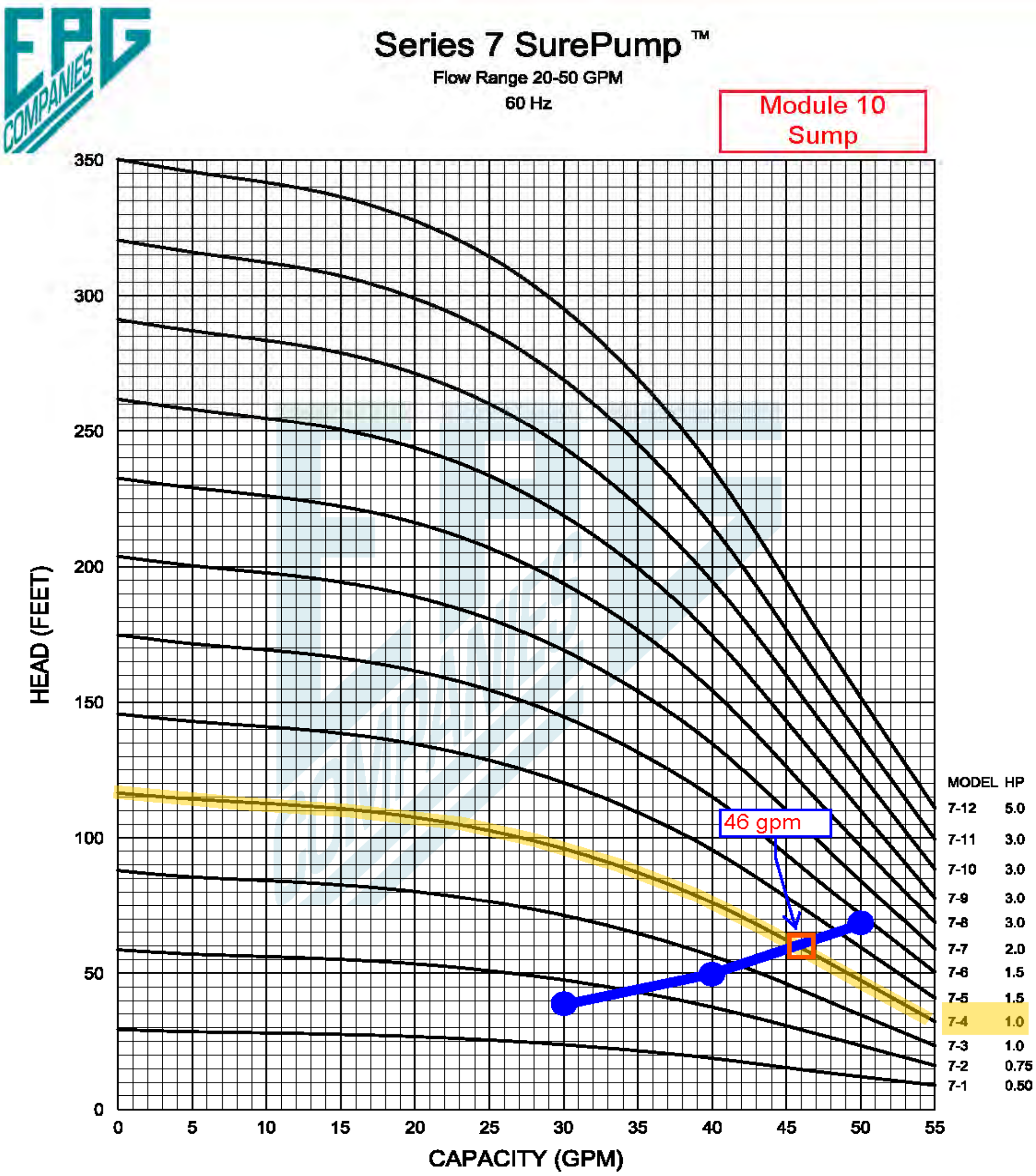

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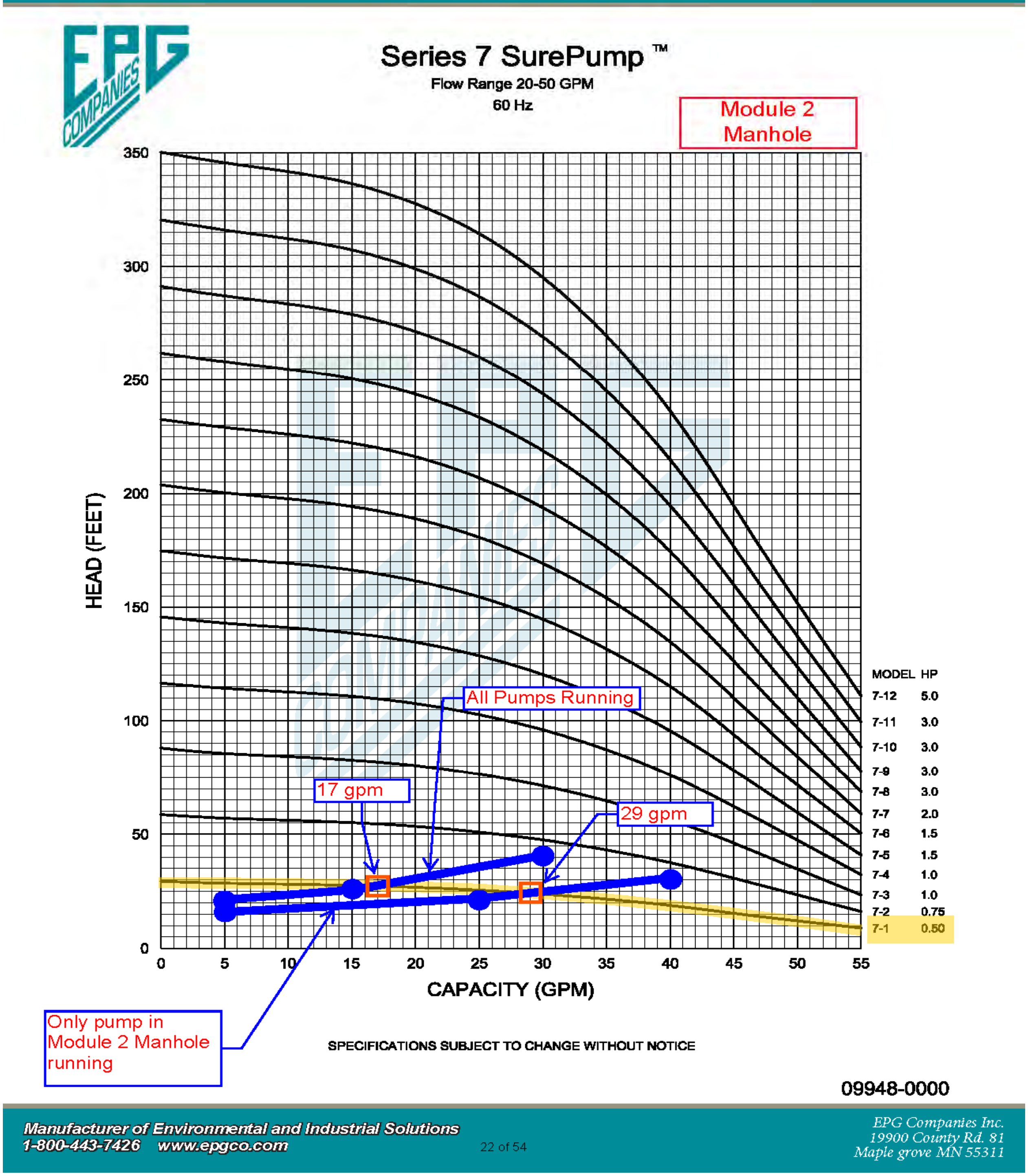
SCS ENGINEERS

Sheet No.	19 of 19
Calc. No.	
Rev. No.	

Job No. 25222260.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 8/15/23
Client: Wisconsin Power & Light	Subject: Leachate Pump Design	Chk'd: KRG	Date: 8/31/23



Modules 1 and 2 Sump Volume and Pump Capacity Calculations

Purpose:

To demonstrate that the volume in the leachate sumps and the capacity of the sump pumps in Modules 1 and 2 will adequately control the leachate to maintain accumulation within the sump and intersecting collection trenches, in accordance with NR 512.12(3).

Approach:

Estimate the leachate generation rate to each sump assuming leachate collection rates specified by NR 512.12(3).

Calculate the sump volume based on the sump dimensions shown in the Plan of Operation plan set. The available volume is determined by calculating the volume between the pump on and off levels.

Determine the pumping intervals by dividing the available volume of the sump by the daily leachate generation rate. (This is the number of times the sump will fill and be required to be pumped on a daily basis.)

Identify commercially available pumps that can meet the required pumping interval calculated above.

Assumptions:

The sump for Module 1 will collect leachate from Module 1. The sump for Module 2 will collect leachate from Module 2.

Module 1 and 2 are covered with Final Cover and Intermediate Cover

	Module 1	Module 2
Final Cover (Acres)	5.67	0.12
Interm Cover (Acres)	2.61	3.81

The leachate generation rate during Interm Cover conditions is 6 inches per year, per NR NR 512.12(3)(a).

The leachate generation rate for Final Cover conditions is 1 inch per year per NR NR 512.12(3)(b).

Results:

The leachate generation rate for each sump during open/active conditions ranges from 293 to 1,711 gal/day. with the highest generation rate occurring in Module 2. Refer to Sheet 2 for the generation rates for each sump.

The functional capacity in the sumps, accounting for the pumping levels is 587 gallons.

Refer to Sheet 3 and 4 for the sump volume calculation.

The leachate sumps are adequately sized to handle the estimated worst-case leachate volume at Modules 1 and 2, with estimated filling times ranging from 10.3 hours to 60.2 hours (Sheet 3).

Calculations:

Estimate an annual leachate collection volume based on a 6 inch per year generation rate for open conditions and an 1 inch per year generation rate for closed conditions.

Open Conditions

6 inches per year leachate collection rate:

Infiltration from precip=(6 in/year)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 day)= 446.3 gal/acre/day

Closed Conditions

1 inches per year leachate collection rate:

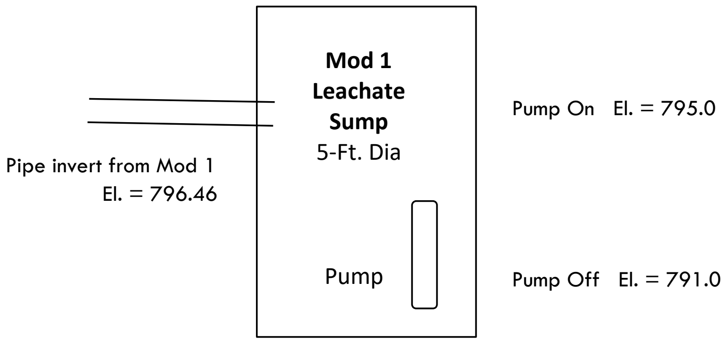
Infiltration from precip=(1 in/yr)x(1 ft/12 in)x(43,560 sf/ac)x(7.48 gal/cf)x(1 yr/365 day)= 74.4 gal/acre/day

Calculate the maximum leachate generation rate to each sump under open/active conditions and closed conditions.

Location	Average Leachate Collection Rate (gal/acre/day)	Area (acres)	Leachate Generation Rate (gal/day)
Current Condition			
Module 1 (Final Cover)	74.4	5.67	422
Module 1 (Interm Cover)	446.3	2.61	1,167
Module 1 Total			1,588
Module 2 (Final Cover)	74.4	0.12	9
Module 2 (Interm Cover)	446.3	3.81	1,702
Module 2 Total			1,711
Closed Condition			
Module 1	74.4	8.28	616
Module 2	74.4	3.93	293

Sump Volumes

Sump (For Module 1)



5 Ft. Diameter Sump Volume = $\pi \times r^2 \times 7.48$ gal/cf

= $3.14 \times 2.5^2 \times 7.48$

= 147 gal/ft

Mod 1 Sump volume = 376 gal.ft x 4 ft

= 587 gal

Calculations:

	Available Volume in Mod 1 Sump (gals)	Leachate Generation Rate (gal/day)	Fill Time (hours)
Module 1 (Current Conditions)	587	1,588	8.9
Module 1 (Final Conditions)	587	616	22.9

Sump filling times provide adequate pump rest time during active conditions with open and closed conditions.