# SUPPLEMENT
# LANDFILL REPORT FOR TRENCH 12

USEcology Nevada

an *American Ecology* company

**Hazardous Waste Management Facility**
**Beatty, Nevada**
**Nevada Hazardous Waste Treatment, Storage and Disposal Permit**
**NEV HW0019, USEPA ID #NVT330010000**

Prepared by:

AquAeTer
**7340 East Caley Avenue**
**Centennial, CO 80111**

**October 2007**

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## US Ecology Nevada, Inc.

## Hazardous Waste Management Facility

## Beatty, Nevada

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**October 8, 2007**

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- LCRS Infiltration Rate
- LCRS Flow Capacity and Pump Sizing
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- Appendix A - Above-Grade Facility Design Drawings
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- Appendix C - Construction Methods Specifications

## CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

**US Ecology Nevada Representative:** _____ **Date:** _____

**Printed name:** _____

**Title:** _____

**Nevada Professional Engineer** _____ **Date:** _____

# 1. PURPOSE OF THIS SUPPLEMENT

This Supplement to the Trench 12 Landfill Report (Supplement) and attachments present the Final Design for the Trench 12 landfill at the US Ecology Nevada, Inc. (USEN) hazardous waste management facility located near Beatty, Nevada (see Figure 1). This is a supplement to the 1994 "Section IV.D, Landfill Report, US Ecology, Inc., Beatty, Nevada" (Landfill Report) (USE, 1994) that was provided to the Nevada Division of Environmental Protection (NDEP). Another component of the previous Landfill Report was the March 1996 "Cell 12 Design Report" (TRC Environmental Solutions, 1996), as specifically cited in the 2005 RCRA Permit. The 1996 Design Report was provided in response to an NDEP letter dated September 22, 1995 (NDEP, 1995) that requested certain additional information with regard to the Trench 12 design. The 1994 Landfill Report, 1996 Design Report, and the resolution of Nevada Division of Environmental Protection (NDEP) design-related comments and questions (as cited in the 2005 RCRA Permit) comprise the 1996 Trench 12 Design (1996 Design) referenced in this Supplement.

The 1996 Design was given conditional approval by NDEP in the 1998 RCRA Permit and the renewed 2005 RCRA Permit. That approval was subject to satisfactory completion of the design-related conditions contained in Section 7.12 of the RCRA Permit. In general, the conditions under which approval was granted include finalization of certain design drawings and plans, completion of certain materials tests, and completion of a geophysical survey of the Trench 12 location.

USEN has completed the Final Design for disposal Trench 12 and presents the final design in this Supplement, which includes the attached "Construction Quality Assurance Plan for Trench 12" (CQA Plan). This Final Design differs from the conditionally approved 1996 Design as needed to satisfy the design-related conditions contained in the RCRA Permit and to accommodate minor changes in the USEN plan for the relationship between disposal Trenches 11 and 12. Also, during 2007, USEN renewed its lease agreement with the State of Nevada for the property that is occupied by the Beatty facility, including the location of Trench 12. The Trench 12 site area is referred to as Area C in the lease agreement. The terms of the renewed lease allow USEN to more effectively utilize the portion of its leased property

between the southern limit of waste disposal in new Trench 12 and the northern limit of the adjoining closed low-level radioactive waste (LLRW) disposal area.

This Supplement consists of the following components:

- Supplement – Trench 12 Landfill Report;
- Attachment 1 - Trench 12 Soil Testing Results;
- Attachment 2 - Results of Geophysical Survey of Trench 12 Area;
- Attachment 3 - Supplemental Engineering Calculations;
- Attachment 4 – Construction Quality Assurance Plan for Trench 12.

Attachment 4, the CQA Plan, also includes the following appendices:

- Appendix A - Above-Grade Facility Design Drawings;
- Appendix B -Construction Materials Specifications; and
- Appendix C - Construction Methods Specifications.

The Supplement and its various attachments present the Final Design for Trench 12 and address in detail the differences between the conditionally approved 1996 Design and the Final Design. The specific types of design refinements made are:

- The Final Design incorporates additional design refinements developed through the process of review and comment by NDEP;
- The Final Design addresses the specific conditions of NDEP approval of the 1996 Design (as presented in Section 7.12 of the RCRA Permit); and
- The Final Design accommodates changes in USEN planning to make more effective use of its leased property for development of Trench 12 and to facilitate the waste disposal transition from Trench 11 to Trench 12.

The Supplement is organized to address these areas of design refinement and to present appropriate supporting documentation. Aspects of Trench 12 design that are not modified in the Final Design remain in the Design Drawings (CQA Plan Appendix A), Construction Materials Specifications (CQA Appendix B), and Construction Methods Specifications (CQA Plan Appendix C). These unchanged design aspects are not specifically addressed in this

Supplement, and the supporting documentation (including calculations) provided in the 1996 Design, as previously reviewed and approved by NDEP, are not included in the Supplement.

Design details that either are clarified or changed between the 1996 Design and Final Design, and the location where the additional information is provided in this Supplement, are summarized below.

| Changed Design Details | | How Addressed | Information Location |
|---|---|---|---|
| **Design details developed in compliance with RCRA Permit conditions** | | | |
| 7.12.2 | Subgrade hydraulic conductivity requirement | Laboratory testing for site soil materials. | Section 5.2.2, and<br>Attachment 1<br>Additional test results to be provided as indicated herein. |
| 7.12.3 | Stress-strain testing for liner materials | On June 28, 2007, NDEP confirmed that this requirement would be satisfactorily addressed by providing the manufacture's quality control results for liner materials used. | Section 5.2.1,<br>CQA Plan, Appendix B, and<br>Attachment 3 |
| 7.12.4 | Submit complete set of final design drawings | The final design, including drawings and specifications, is provided in the CQA Plan. | CQA Plan, Appendix A |
| 7.12.5 | Submit QA/QC Plan for Trench 12 construction | QA/QC requirements for Trench 12 construction are provided in the CQA Plan. | Section 5.1, and<br>CQA Plan, Appendices A, B and C |
| 7.12.7 | Demonstrate capacity to store runoff from design storm | On June 28, 2007, NDEP confirmed that this requirement would be satisfactorily addressed by Response Action Plan (RAP) language. | (RAP to be provided separately) |

| Changed Design Details | | How Addressed | Information Location |
|---|---|---|---|
| 7.12.8 | Sump gravel hydraulic conductivity requirement | Laboratory testing for site soil materials. | Section 5.2.3,<br>Attachment 1, and<br>Attachment 3<br>Additional test results to be provided as indicated herein. |
| 7.12.11 | Magnetic survey of Trench 12 area | A geophysical survey of the Trench 12 area was conducted during July 2007. | Section 9.1, and<br>Attachment 2 |
| **Other design changes** | | | |
| Trench 11 – 12 relationship | | The 1996 Design merged the disposed waste footprints and final covers of the two trenches; the Final Design merges a small portion of the final covers, but not the waste footprints. | Section 4, and<br>CQA Plan, Appendix A |
| Separation between Trench 12 waste disposal and cover footprints and the closed LLRW area | | The 2007 lease agreement with Nevada allows Trench 12 to more closely approach the closed LLRW area in the Final Design. | Section 4, and<br>CQA Plan, Appendix A |
| Trench 12 LCRS and LDS areas | | The Final Design provides a larger total trench area, and increases the leachate volume to be managed by the LCRS/LDS. The Final Design accommodates the leachate volume increase. | Section 6,<br>Attachment 3, and<br>CQA Plan, Appendix A |

Note: Compliance schedule items 7.12.1, 7.12.6, 7.12.9, 7.12.10, and 7.12.12 in the RCRA Permit either require no design-related response or will be addressed in later submittals to NDEP.

In addition to these areas of design refinement, this Supplement also addresses questions related to landfill design and operations posed by the Nevada State Health Division, the agency responsible for long-term custodial care of the closed LLRW disposal facility that adjoins leased Area C and Trench 12. These questions pertain to the following topics.

- Excavation stability –Trench 12 excavation stability, as an influence on the long-term stability of the closed LLRW disposal cells. (Section 7)

- Surface-water management - Management of surface-water originating within Area C from the presence of operating or closed Trench 12, as an influence on the long-term stability of the closed LLRW disposal cells. (Section 8)

- Health and safety – Health and safety issues for Trench 12 construction and operations personnel as related to the presence the closed LLRW disposal cells, including known and unknown disposed materials. (Section 9)

- Accessibility – Access to the closed LLRW facility for inspection and custodial care, as affected by Trench 12 construction, disposal operations, and post-closure configuration. (Section 10)

## 2. FACILITY INFORMATION

The USEN Beatty, Nevada Hazardous Waste Management Facility is located approximately 100 miles northwest of Las Vegas in a remote and arid desert region. The facility is operated by USEN under Hazardous Waste Management Permit NEV HW0019 (2005 RCRA Permit) and is permitted to manage wastes regulated under the Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA). At the time of preparation of this Supplement to the Landfill Report, the active waste disposal trench is Trench 11. Trench 12 is planned as the next waste disposal trench on the property leased by USEN from the State of Nevada. The adjacent low-level radioactive waste (LLRW) management units, south of the Trench 12 location (as shown in Drawing NV12-07-002, CQA Plan Appendix A) has closed. The closed LLRW facility is owned and managed by the State of Nevada. Post-closure care for the LLRW facility is provided by the State.

The lease agreement between USEN and the State of Nevada (land owner) for the property occupied by the Beatty hazardous waste disposal facility was modified in April 2007 with regard to the requirements for waste disposal in the 12.6-acre (approximately) area identified as Area C. Area C is the location of new Trench 12. The lease agreement modification identifies the entire 12.6-acre Area C as "for the disposal of hazardous waste" and references the RCRA Permit as the document that establishes the requirements for waste disposal dimensions, design, construction, and operation. In accordance with the provisions of the 2007 lease agreement and the 2005 RCRA Permit, USEN has developed the necessary Final Design and supporting documentation for Trench 12 in order that this information may be included in a RCRA Permit modification.

The Trench 12 areal footprint is approximately 11.2 acres. The disposal trench will be approximately 1,350 feet long with a width that varies between approximately 225 and 430 feet. The trench will extend 75 feet below the original ground surface at 0.5:1.0 (Horizontal:Vertical) slopes, and upon completion will rise 75 feet above the original ground surface. Trench 12 will have a bottom and sidewall liner system that incorporates primary and secondary liner and leachate collection and recovery systems. The trench, including below-grade and above-grade

volumes will have an ultimate disposal capacity of approximately 1.65 million cubic yards of waste material.

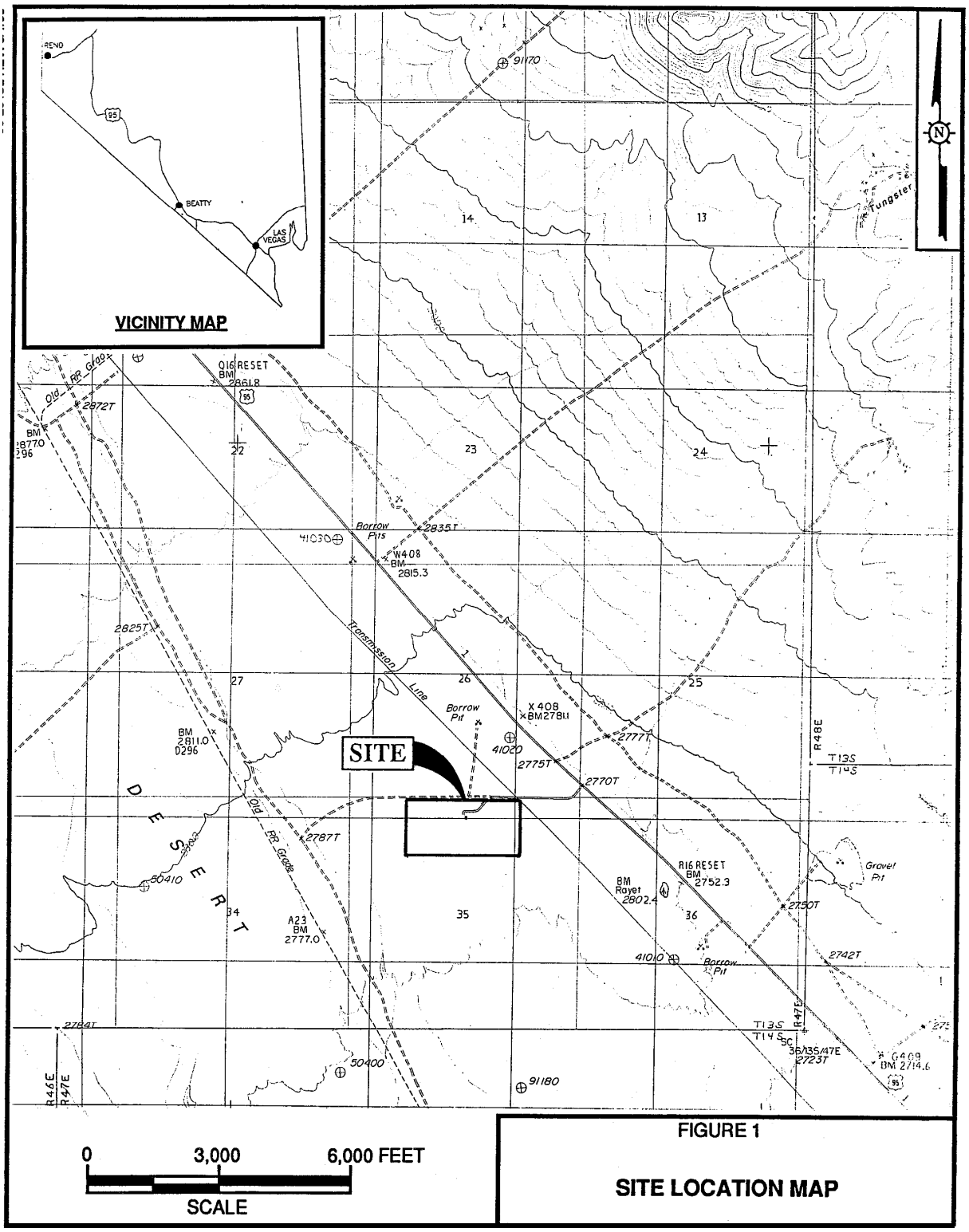


FIGURE 1

SITE LOCATION MAP

## 3. AREAS OF DESIGN REFINEMENT

Table 1, Correlation Between 1996 Design Documents and 2007 Final Design Documents, identifies design aspects and documentation that are modified in the Final Design, and identifies the locations within the Supplement and its attachments where the design refinement is discussed and documented. Table 1 also identifies the specific types of engineering calculations that were provided in support of the 1996 Design and which of those calculations has been revised to support the design refinements contained in the Final Design. The specific calculations revised in support of the Final Design are listed below and are included in Attachment 3.

- Slope Stability Evaluation with Surface Soil Improvement
- Liner Stresses (sidewall liner materials)
- Anchor Trench Stresses
- LCRS Infiltration Rate
- LCRS Flow Capacity and Pump Sizing
- LDS Flow Capacity and Pump Sizing
- LCRS Gravel Hydraulic Conductivity

Table 1 Correlation between 1996 Design Documents and 2007 Final Design Documents

## 4. TRENCH 12 LOCATION WITHIN LEASED PROPERTY

During 2007, USEN renewed its lease agreement with the State of Nevada for the property occupied by the Beatty facility, including the 12.6-acre Area C (location of new Trench 12). The terms of the new lease allow USEN to consider technically appropriate ways to effectively utilize the portion of its leased property between the southern limit of hazardous waste disposal in new Trench 12 and the northern limit of the adjoining closed LLRW disposal area.

In the 1996 Design, a "horizontal control line" defined the limit of excavation at ground surface. The horizontal control line, or HCL, also defined the horizontal limit of hazardous waste disposal in Trench 12. In that design, the HCL on the south side of Trench 12 was at least 150 feet from the horizontal limit of the closed LLRW disposal cells on the adjoining State property. This separation between Trench 12 and the closed LLRW cells was consistent with the terms of the Area C lease agreement at the time the 1996 Design was developed. The area of the Trench 12 footprint at ground level (i.e., the area inside the HCL) was about 8.2 acres.

The 2007 lease agreement did not include a specific restriction (offset) on hazardous waste disposal along the boundary with the LLRW disposal cells. Instead, the 2007 lease agreement identifies the entire 12.6-acre Area C as "for the disposal of hazardous waste" and references the RCRA Permit (rather than the lease agreement) as the document that establishes the requirements for waste disposal dimensions, design, construction, and operation. The Final Design includes an HCL that is as near as 50 feet from the horizontal limit of waste disposal in the LLRW cells. The area inside this larger Trench 12 HCL, marking the excavation footprint at ground level, is about 11.0 acres. The larger HCL allows placement of a larger waste volume in Trench 12, while providing the necessary geotechnical stability and worker protections during construction, disposal operations, and after closure.

The 1996 Design also included some above-grade (i.e., above natural ground level) waste disposal in the narrow area between Trenches 11 and 12. The 1996 design included constructing a double-liner system approximately at ground level to join the Trench 11 and 12 subgrade liner systems. The Final Design maintains the approximately 50-feet wide separation between the Trenches 11 and 12 and does not include hazardous waste disposal within the above-grade area

between the two trenches. For convenience of construction and to maintain stable final cover slopes, the final covers of the two trenches will merge in the area between the trenches, but only clean cover soil will occupy the 50-feet wide area between the trenches.

In accordance with the lease agreement, this Supplement and attachments (subsequent to NDEP approval) will establish the requirements for waste disposal dimensions, design, construction, and operation and will be referenced in a RCRA Permit modification.

# 5. CONSTRUCTION QUALITY ASSURANCE

## 5.1 CONSTRUCTION QUALITY ASSURANCE PLAN

The quality assurance/quality control (QA/QC) plan required by Compliance Schedule item 7.12.5 of the RCRA Permit is provided as the CQA Plan in Attachment 4 to this Supplement. The CQA Plan provides a description of the primarily administrative aspects of quality assurance (e.g., project position descriptions and responsibilities, meetings, and reporting). Appendices B and C to the CQA Plan provide construction materials and construction methods specifications, respectively.

## 5.2 CONSTRUCTION MATERIALS PROPERTIES

Compliance schedule items 7.12.2, 7.12.3, and 7.13.8 contain specific testing requirements for construction materials. The results of materials testing are summarized below and the actual laboratory testing results are included in Attachment 1. Also, some material testing is underway at the time this Supplement was being prepared for submittal to NDEP. The results of those additional tests will be provided separately to NDEP on a schedule consistent with RCRA Permit requirements.

### 5.2.1 Liner System Materials

Compliance schedule item 7.12.3 requires that the results of "stress-strain tests on the liner materials" be submitted to NDEP. On June 28, 2007, NDEP confirmed that this requirement will be satisfactorily addressed by including the liner material manufacturer's quality control results for the various liner system components in the project design and construction documents. Appendix B to the CQA Plan (Attachment 4) includes specifications for liner materials based upon the materials properties of the following specific materials.

| | |
|---|---|
| Geosynthetic clay liner | CETCO Bentomat DN |
| Geomembrane | GSE HD Textured and Single-Side Textured HDPE FML |
| Geocomposite | GSE FabriNet and Fabrinet UF |
| Geotextile | GSE NW8, NW10, and NW12 |
| Geonet | GSE Hypernet |

The updated liner strength calculations included in Attachment 3 to this Supplement were made using the properties of these specific materials. By these calculations, it was determined that the liner system (and its individual members) will perform satisfactorily under the conditions considered by the calculations (and as demonstrated and accepted by calculations contained in the 1996 Design). If alternative materials are proposed by the contractors retained by USEN to construct Trench 12, the Project Engineer (or other qualified person retained by USEN) will verify that the alternative materials have physical properties that are at least equivalent to those specified.

The formal results of physical properties testing by the manufacturer(s) of materials used for Trench 12 liner construction will be included in the project construction documents to be submitted to NDEP.

### 5.2.2 Liner Subgrade

The hydraulic conductivity requirement for the liner subgrade (per Section 7.12.2 of the RCRA Permit) is a maximum value of $1 \times 10^{-5}$ centimeters per second (cm/sec). USEN arranged for hydraulic conductivity testing of natural soil materials excavated from the Trench 12 area that can be used for liner subgrade material. Recompacted natural materials were determined to have hydraulic conductivities (see Attachment 1) between $2.6 \times 10^{-4}$ and $3.9 \times 10^{-7}$ cm/sec, with the difference appearing to relate directly to the amount of fine-grained materials (silt and clay) in the material. In general, it appears that natural materials can achieve the required hydraulic conductivity if the fine-grained fraction comprises at least 10 percent of the material. Since the gradation of the material that actually will be available for construction of the subgrade material is not certain, USEN is testing mixtures of natural materials and imported fine-grained materials (primarily from a local natural clay source) that will achieve the specification. The final specification for subgrade materials will be determined upon completion of this testing. USEN will provide testing results and the resulting material specification to NDEP in accordance with Section 7.12.2 of the RCRA Permit.

### 5.2.3 Sump Gravel

The RCRA Permit at Section 7.12.8 asks that USEN specify the gravel to be used in leachate sumps to obtain a “transmissivity” of 10 cm/sec. A calculation identifying the gravel

"permeability" as 10 cm/sec was accepted previously by NDEP. That gravel permeability is a conservative, mid-range textbook value considered typical for coarse-grained gravel and was used as a typical value in calculations for the 1996 Design. Recent materials tests by USEN have determined that a permeability between 1.0 and 2.0 cm/sec can be achieved using screened gravel from the Trench 12 excavation. This range also is conservative and is adequate to handle leachate flow in the LCRS and LDS systems. A calculation included in Attachment 3 shows that a gravel permeability specification of 1.0 cm/sec or higher is acceptable in the design application for LCRS collectors and sump and LDS sump.

Sump gravel testing results are provided in Attachment 1.

# 6. LEACHATE MANAGEMENT

Leachate management calculations for the 1996 design were done with the assumption that runoff generated by the design storm could be separated into 'clean water' that would not be allowed to come into contact with disposed waste and 'leachate" that would be allowed to come into contact with waste (including the initial layer of select fill in the definition of waste). After further discussions of this subject between USEN and NDEP, it was determined that it is impractical (and perhaps not possible) to maintain positive separation between in-cell precipitation and waste inside a disposal cell containing waste. Thus, for the purposes of the 2007 calculation, all water collected inside a disposal cell containing waste (including select fill) is considered to be leachate requiring appropriate management.

## 6.1 LCRS/LDS DESIGN

The following are important details that were considered in the 2007 calculations made to refine the LCRS and LDS designs.

- The 25-year, 24-hour storm generated about 2.0 inches of precipitation in a 24-hour period (NOAA, 1973);
- The sacrificial liner on trench sidewalls will cause all precipitation to collect on and be managed from the trench/cell floor; and
- All rainwater (or other precipitation) collected inside one or more disposal cells in Trench 12 (including precipitation on trench sidewalls) will be managed in the respective disposal cell as leachate.

Other assumptions made to make the LCRS and LDS design calculations are provided in Attachment 3.

## 6.2 LEACHATE MANAGEMENT

Compliance schedule items 7.12.6 (requirement for development of a Response Action Plan, or RAP) and 7.12.7 (requirement to demonstrate that there is capacity to store runoff generated from a 25-year, 24-hour storm event) are linked requirements. Both refer to liquids collected inside the waste disposal cell (i.e., leachate) that are to be addressed by the RAP and calculations that estimate leachate collection volume and pumping requirements. These permit requirements will be addressed by RAP language describing how leachate will be managed.

The RAP (to be provided separately at least 60 days prior to accepting waste in Trench 12) will acknowledge that collected leachate will be used for dust control inside Trench 12. If the collected leachate volume exceeds the volume that can be used for dust control, any excess leachate removed from the active cell will be disposed as a hazardous liquid.

# 7. EXCAVATION STABILITY

The Trench 12 excavation side slopes in the 1996 Design and the Final Design are identical at 0.5:1.0 (H:V) or about 63 degrees. The maximum depth below average ground surface of the Trench 12 excavation in the two designs also is identical at approximately 75 feet. Extensive slope stability evaluations were included in the 1996 Design and the supporting design documentation that are referenced in the RCRA Permit. Since design slopes, depths, and subsurface materials are unchanged between the 1996 Design and Final Design, the prior slope stability evaluations are equally applicable to both designs. Important aspects of the slope stability evaluations are summarized below.

- The 75-feet deep, 0.5:1.0 (H:V) excavation slopes were determined to be acceptably stable under static loading and pseudo-static loading. Pseudo-static loading simulates the maximum horizontal acceleration from a seismic event (earthquake) with a 90 percent or greater probability of not being exceeded in 250 years, per NAC 444.6793.

- Of the possible deep-seated failure planes evaluated, the planes exhibiting the lowest safety factors (but still higher than minimum requirements) extended from near the toe of the excavation slope to about 50 to 60 feet from the excavation crest.

- Considering the excavation crest location (i.e., HCL location) on south side of Trench 12 in the Final Design, this possible failure plane extends just a few feet (horizontally) into the area of the closed LLRW trenches.

- The period of time during which a deep-seated slope failure of this type is conceivable will be very brief, likely only a few months in duration, since waste disposal in Trench 12 will begin to buttress the excavation slope, and increase safety factors, as soon as the first waste is placed against the toe of the south trench side slope.

A calculation verifying acceptable excavation slope stability with the natural, relatively loose surface soil layer in place (and unimproved) are provided in Attachment 3.

# 8. SURFACE-WATER MANAGEMENT

## 8.1 DURING OPERATIONS

The 1996 Design and Final Design include measures to manage stormwater runoff during disposal operations and after final closure. During disposal operations, these measures will include temporary berms and drainage channels directing runoff to natural or enhanced drainage channels outside of the facility boundaries. With the exception of the disposal cell bottoms, neither design includes features intended to cause stormwater retention (ponding) inside or outside the facility boundaries.

Stormwater falling inside the trench during disposal operations will be managed as leachate. There are no situations where leachate would be allowed to enter surface water outside the trench.

## 8.2 POST-CLOSURE

With regard to post-closure surface-water management, the 1996 Design and Final Design include final covers that essentially are identical. Both final cover designs will incorporate measures intended to manage stormwater runoff from the cover and control cover material erosion. Stormwater runoff conveyances constructed on both covers lead to stormwater channels along the base of the cover that lead to natural or enhanced drainage channels outside of the facility boundaries.

The Final Design will include a corridor about 15-feet wide between the toe of the final Trench 12 cover and the toe of the closed LLRW site cover that will provide for permanent routing of surface-water runoff originating on the adjoining portions of Trench 12 and the closed LLRW site.

# 9. CONSTRUCTION HEALTH AND SAFETY

The RCRA Permit includes requirements whose primary purpose is to protect persons involved in the construction of Trench 12. In addition to providing protection against conditions and hazards associated with excavation, earthwork, and other common construction activities that will be required for Trench 12 construction, these RCRA Permit requirements address potential unique hazards that might be associated with construction near the closed LLRW disposal area. These Permit requirements include a pre-construction magnetic (geophysical) survey of Area C and development of a Construction Health and Safety Plan.

## 9.1 MAGNETIC (GEOPHYSICAL) SURVEY

A geophysical survey of Area C (except for the part of the area already excavated to more than 20 feet deep) was completed during the design process. The survey purpose was to identify buried metallic objects potentially related to the closed LLRW area. Features identified as possible buried metallic objects were exposed by excavation to determine their nature and appropriate management action.

No materials, metallic or otherwise, related to previous waste disposal activities in the LLRW area were identified by the geophysical survey. The metallic objects identified and exposed by excavation, with one exception, were small objects related to USEN use of Area C for temporary storage of construction materials, construction equipment, and scrap metal. The exception was the identification of a buried metal pipe (caisson casing) installed by the U.S. Geological Survey. That large metallic caisson casing was identified at the expected location. It is an object related to past investigation of the LLRW area, and is not a waste material. It will be removed by USEN during Trench 12 excavation.

The report of the geophysical survey is provided in Attachment 2.

## 9.2 CONSTRUCTION HEALTH AND SAFETY PLAN

Prior to the beginning of Trench 12 excavation, a Construction Health and Safety Plan (CHSP) will be prepared and submitted to NDEP. This CHSP will be implemented during construction activities and will remain in effect during subsurface disposal activities in Trench 12. The CHSP

will specifically address monitoring for radioactive decay particles within the excavation, guidelines to be followed if suspected materials of potential radiological significance are unearthed, and measures to be employed preventing impacts to existing radiological disposal trenches.

## 10. SITE ACCESSIBILITY

Trench 12 construction under the Final Design is not expected to have any effect on the LLRW area south of the fence marking the boundary between that area and Area C. Access along the south side of Trench 12 will be temporarily limited during trench excavation and liner construction. Passenger vehicle, light truck, or personnel access to the perimeter of Area C and the adjoining LLRW area will not be prevented by Trench 12 operation (except as access to all areas of the hazardous waste disposal facility is carefully controlled by USEN).

The interior fence between Area C and the LLRW area might be temporarily removed during Trench 12 construction. Security for Area C and the remainder of the USEN facility and for the LLRW area will be maintained during Trench 12 construction by a combination of permanent and temporarily relocated perimeter fencing and the presence of USEN and security service personnel.

In the Final Design, a corridor that is about 15-feet wide will remain between the toe of the final Trench 12 cover and the toe of the LLRW area cover. This dimension is sufficient for vehicular access along the boundary between the LLRW site and Area C, and also is sufficient for permanent routing of surface-water runoff originating on the adjoining portions of both sites.

## 11. REFERENCES

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# ATTACHMENT 1

# TRENCH 12 SOIL TESTING RESULTS

# Summary of Soil Testing Results for Trench 12 Samples

| Sample Number | Material | Grain Size (% by weight) | | | Amendment | ASTM D1557 Maximum Dry Density (pcf) (see Note 1) | ASTM D1557 Optimum Moisuture Content (%) | Hydraulic Conductivity Sample Properties | | | | Hydraulic Conductivity (cm/sec) | Direct Shear Test Sample Properties | | | | Cohesion (psf) | Friction Angle (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Gravel | Sand | Silt/Clay | | | | Dry Density (psf) | % MDD | Moisture Content (%) | Difference from OMC % + or (-) | | Dry Density (psf) | % MDD | Moisture Content (%) | Difference from OMC % + or (-) | | |
| **June-July 2007 Samples: Trench 12 samples for various trench construction objectives (subgrade, sump gravel, surface soil improvement, and final cover)** | | | | | | | | | | | | | | | | | | |
| **Zeolite clay (ZC)** | Imported fines | 24.0 | 23.0 | 53.0 | -- | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| **A1** | Subgrade | 31.0 | 59.7 | 9.3 | -- | 120.5 | 11.0 | 123.4 | 102.4% | 9.3 | (1.7) | 3.90E-07 | -- | -- | -- | -- | -- | -- |
| **A2** | Subgrade | 29.0 | 69.0 | 2.0 | -- | 114.5 | 6.0 | 117.0 | 102.2% | 6.1 | 0.1 | 2.60E-04 | -- | -- | -- | -- | -- | -- |
| **A2** | Subgrade | 47.0 | 48.1 | 4.9 | 5% Pit Run ZC | 106.0 | 7.0 | 106.5 | 100.5% | 6.8 | (0.2) | 5.30E-04 | -- | -- | -- | -- | -- | -- |
| **A3** | Subgrade | 21.0 | 74.8 | 4.2 | -- | 120.0 | 10.0 | 119.3 | 99.4% | 10.4 | 0.4 | 5.55E-04 | -- | -- | -- | -- | -- | -- |
| | | | | | | | | | | | | | | | | | | |
| **B1** | Gravel | 97.0 | 2.6 | 0.4 | -- | -- | -- | 88.3 (wet) | -- | -- | -- | 1.7 | -- | -- | -- | -- | -- | -- |
| **B1** | Gravel | 98.0 | 1.6 | 0.4 | -- | -- | -- | 88.1 (wet) | -- | -- | -- | 2.1 | -- | -- | -- | -- | -- | -- |
| | | | | | | | | | | | | | | | | | | |
| **C1** | Surface soil | 14.0 | 76.7 | 9.3 | -- | 115.0 | 9.5 | -- | -- | -- | -- | -- | 110.9 | 96.5% | 8.7 | (0.8) | 420 | 32.8 |
| **C2** | Surface soil | 20.0 | 70.9 | 9.1 | -- | 119.0 | 10.0 | -- | -- | -- | -- | -- | 114.2 | 95.9% | 8.4 | (1.6) | 320 | 39.9 |
| **C1-C2** | Surface soil | 17.0 | 72.0 | 11.0 | 5% Pit Run ZC | 118.0 | 10.0 | -- | -- | -- | -- | -- | 112.9 | 95.6% | 10.4 | 0.4 | 320 | 41.1 |
| | | | | | | | | | | | | | | | | | | |
| **D1** | Cover soil | 22.0 | 74.7 | 3.3 | -- | 118.5 | 12.0 | -- | -- | -- | -- | -- | 100.8 | 85.1% | 15.1 | 3.1 | 210 | 34.5 |
| **D2** | Cover soil | 26.0 | 68.8 | 5.2 | -- | 122.5 | 10.5 | -- | -- | -- | -- | -- | 101.3 | 82.7% | 12.5 | 2.0 | 130 | 36.7 |
| **D1-D2** | Cover soil | 30.0 | 62.6 | 7.4 | 5% Pit Run ZC | 124.0 | 9.5 | -- | -- | -- | -- | -- | 103.1 | 83.1% | 13.0 | 3.5 | 270 | 36.2 |
| **September-October 2007 Samples: Possible subgrade improvement samples** | | | | | | | | | | | | | | | | | | |
| **Mix 1** | Trench 12 material | 37 | 55 | 8 | 5% IMVite 1016 | 127.5 | 8.0 | 114.5 | 89.8% | 8.1 | 0.1 | 1.15E-05 | | | | | | |
| **Mix 2** | Trench 12 material | 38 | 51 | 11 | 10% IMVite 1016 | 127.5 | 8.5 | 114.9 | 90.1% | 8.5 | 0.0 | 6.32E-06 | | | | | | |
| **Mix 3** | Trench 12 material | 45 | 41 | 14 | 15% IMVite 1016 | 124.5 | 9.0 | 112.7 | 90.5% | 7.5 | (1.5) | 5.54E-06 | | | | | | |
| **Mix 4** | Trench 12 material | 46 | 42 | 12 | 10% SEP/SAP | 124.0 | 9.5 | 113.0 | 91.1% | 9.1 | (0.4) | 6.13E-06 | | | | | | |
| **Mix 5** | Trench 12 material | 45 | 39 | 16 | 15% SEP/SAP | 122.0 | 10.0 | 110.7 | 90.7% | 9.8 | (0.2) | 6.24E-06 | | | | | | |
| **Mix 6** | Trench 12 material | 47 | 45.5 | 7.5 | 5% Portland Cement | 128.0 | 7.5 | 115.5 | 90.2% | 7.3 | (0.2) | 6.68E-07 | | | | | | |
| **Mix 7** | Trench 12 material | 42 | 50.2 | 7.8 | 5% SEP/SAP | 127.0 | 8.0 | 114.5 | 90.2% | 8.0 | 0.0 | 8.34E-06 | | | | | | |

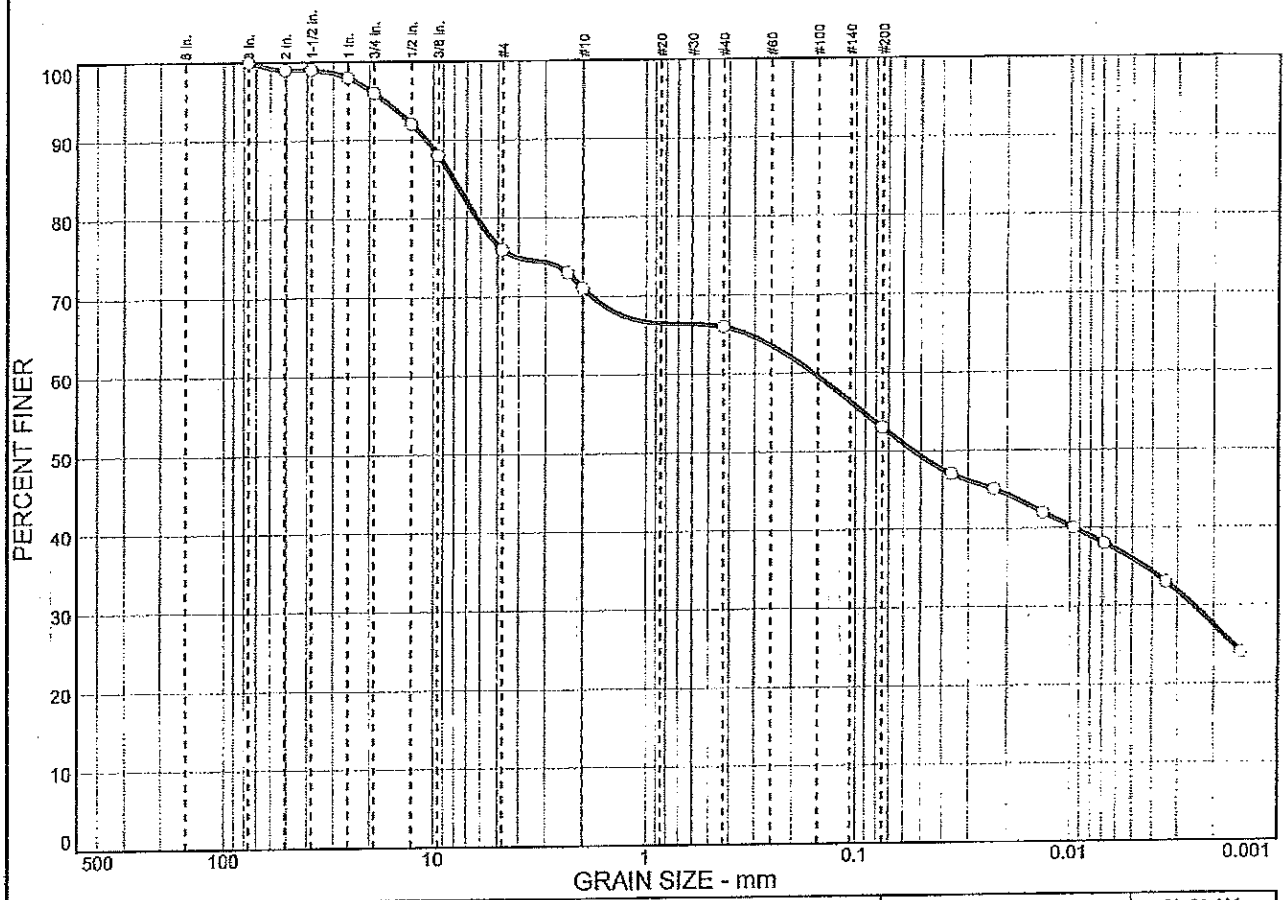
**NOTES** Values are not corrected for the presence of over-size materials

-- Indicates that the test was not run on this sample.

IMVite 1016 and SEP/SAP are clay products of IMV Nevada, Amargosa Valley NV

## Results of Particle Size Analyses

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 24 | 23 | 17 | 36 |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2 in. | 99 | | |
| 1-1/2 in. | 99 | | |
| 1 in. | 98 | | |
| 3/4 in. | 96 | | |
| 1/2 in. | 92 | | |
| 3/8 in. | 88 | | |
| #4 | 76 | | |
| #8 | 73 | | |
| #10 | 71 | | |
| #40 | 66 | | |
| #200 | 53 | | |

* (no specification provided)

**Soil Description**

Zeolite Clay

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 8.09 $D_{60}$= 0.157 $D_{50}$= 0.0543
$D_{30}$= 0.0025 $D_{15}$= $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

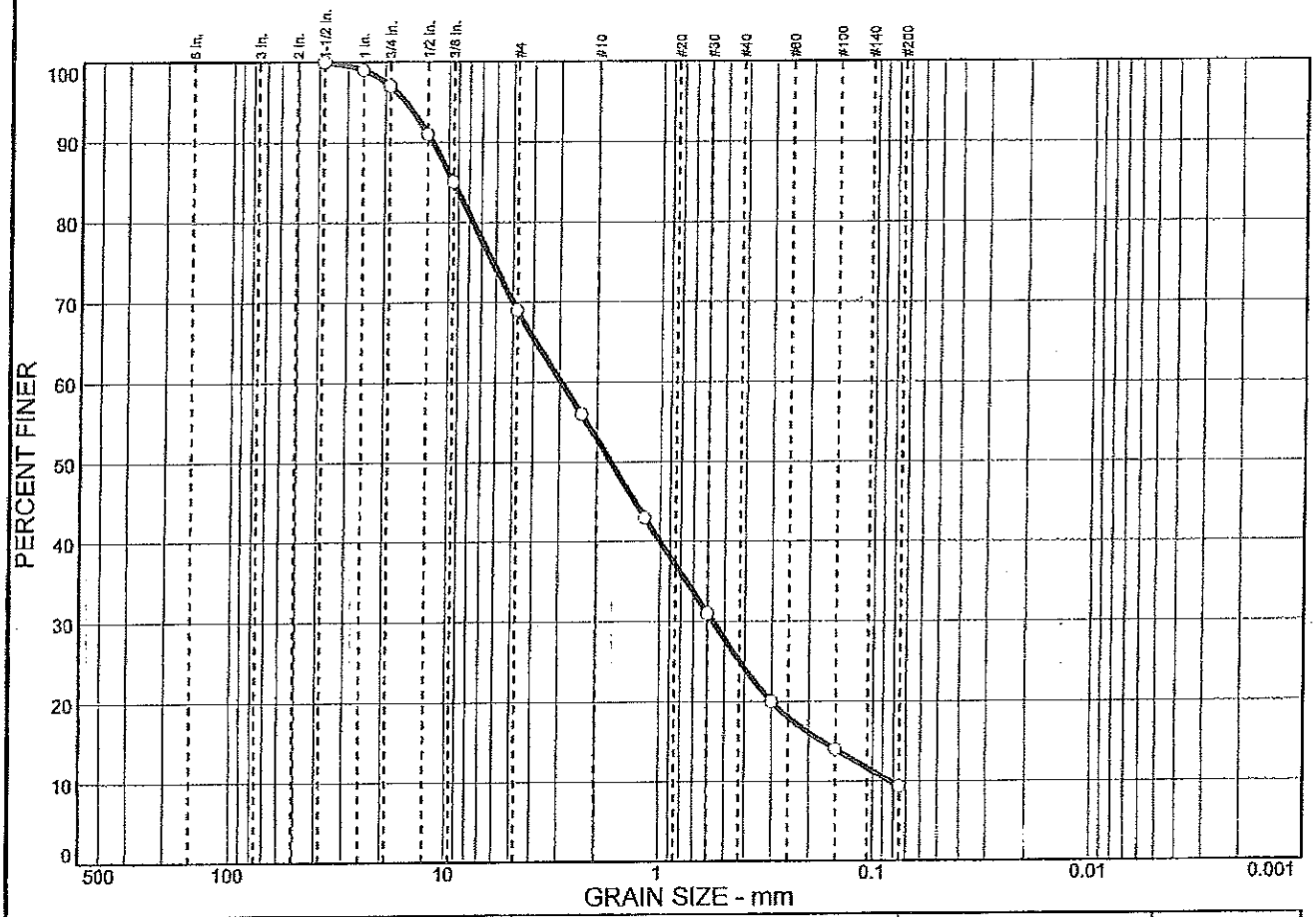
**Remarks**

**Sample No.:** 07-0510 **Source of Sample:** Zeolite Clay **Date:** 07/19/2007
**Location:** On-Site **Elev./Depth:**

JA CESARE AND ASSOCIATES INC
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0510

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 31 | 60 | 9 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 99 | | |
| 3/4 in. | 97 | | |
| 1/2 in. | 91 | | |
| 3/8 in. | 85 | | |
| #4 | 69 | | |
| #8 | 56 | | |
| #16 | 43 | | |
| #30 | 31 | | |
| #50 | 20 | | |
| #100 | 14 | | |
| #200 | 9.3 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 9.52 $D_{60}$= 2.95 $D_{50}$= 1.71
$D_{30}$= 0.567 $D_{15}$= 0.173 $D_{10}$= 0.0832
$C_u$= 35.50 $C_c$= 1.31

**Classification**

USCS= AASHTO=

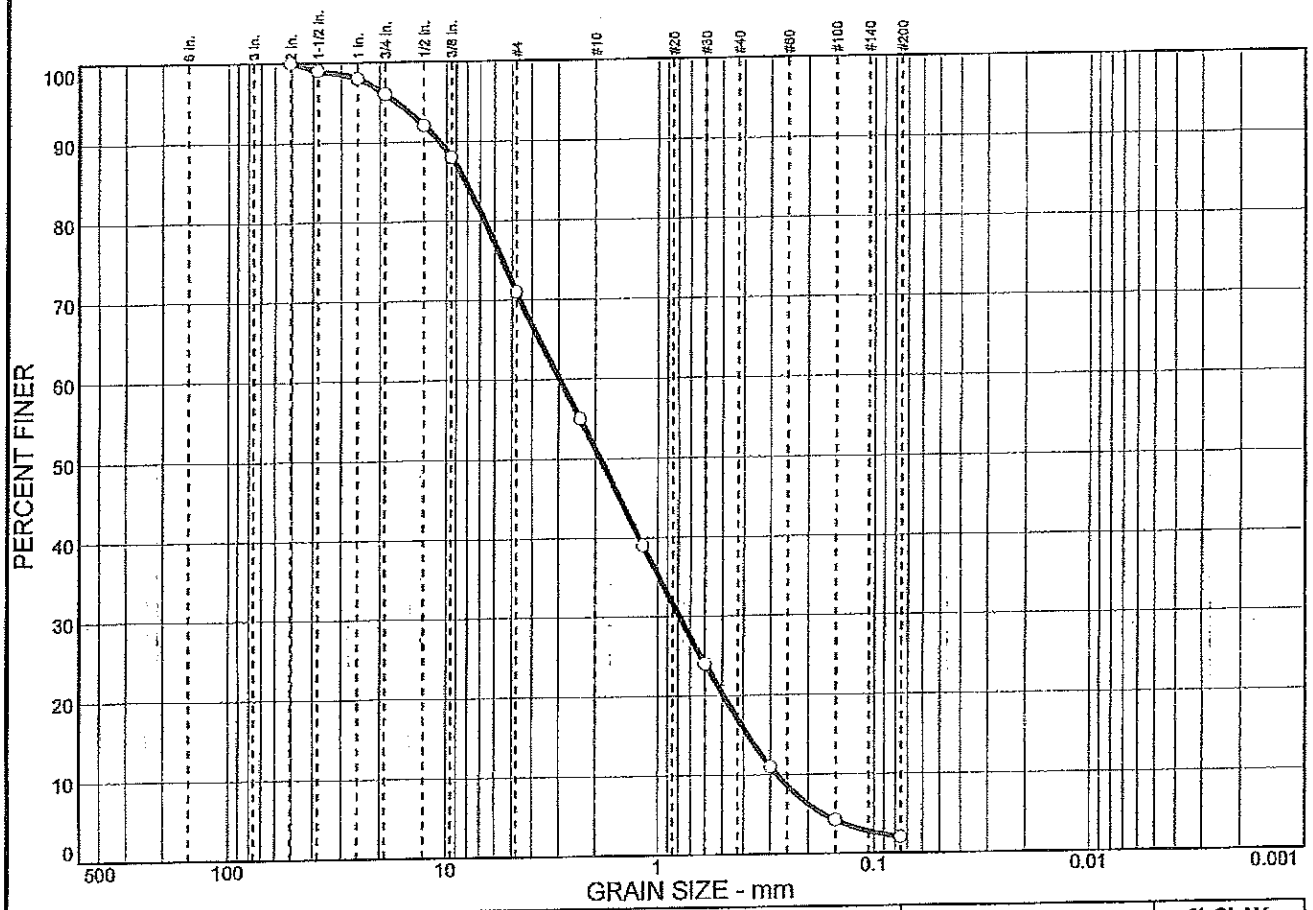
**Remarks**

**Sample No.:** 07-0430A **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-A1 **Elev./Depth:**

JA CESARE AND ASSOCIATES, INC.
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430A

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 29 | 69 | 2 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 2 in. | 100 | | |
| 1-1/2 in. | 99 | | |
| 1 in. | 98 | | |
| 3/4 in. | 96 | | |
| 1/2 in. | 92 | | |
| 3/8 in. | 88 | | |
| #4 | 71 | | |
| #8 | 55 | | |
| #16 | 39 | | |
| #30 | 24 | | |
| #50 | 11 | | |
| #100 | 4 | | |
| #200 | 2.0 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 8.21 $D_{60}$= 2.96 $D_{50}$= 1.89
$D_{30}$= 0.792 $D_{15}$= 0.382 $D_{10}$= 0.280
$C_u$= 10.59 $C_c$= 0.76

**Classification**

USCS= AASHTO=

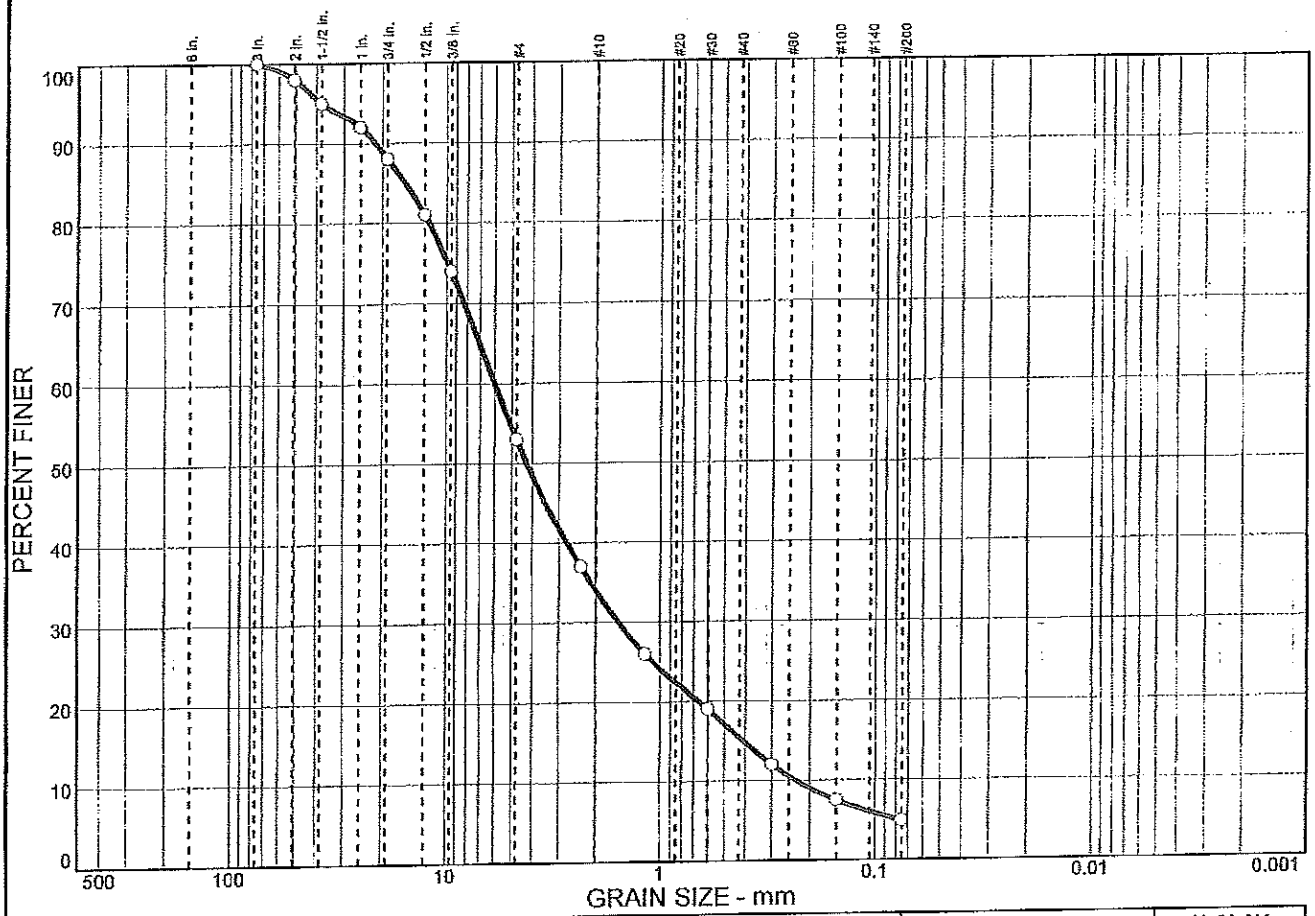
**Remarks**

**Sample No.:** 07-0430B **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-A2 **Elev./Depth:**

J.A. CESARE AND ASSOCIATES, INC.
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430B

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 47 | 48 | 5 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2 in. | 98 | | |
| 1-1/2 in. | 95 | | |
| 1 in. | 92 | | |
| 3/4 in. | 88 | | |
| 1/2 in. | 81 | | |
| 3/8 in. | 74 | | |
| #4 | 53 | | |
| #8 | 37 | | |
| #16 | 26 | | |
| #30 | 19 | | |
| #50 | 12 | | |
| #100 | 8 | | |
| #200 | 4.9 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 15.8 $D_{60}$= 6.00 $D_{50}$= 4.25
$D_{30}$= 1.57 $D_{15}$= 0.409 $D_{10}$= 0.232
$C_u$= 25.84 $C_c$= 1.77

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0605A **Source of Sample:** Native **Date:** 08/07/2007
**Location:** USEN-A2 w/5% Zeolite Clay **Elev./Depth:**

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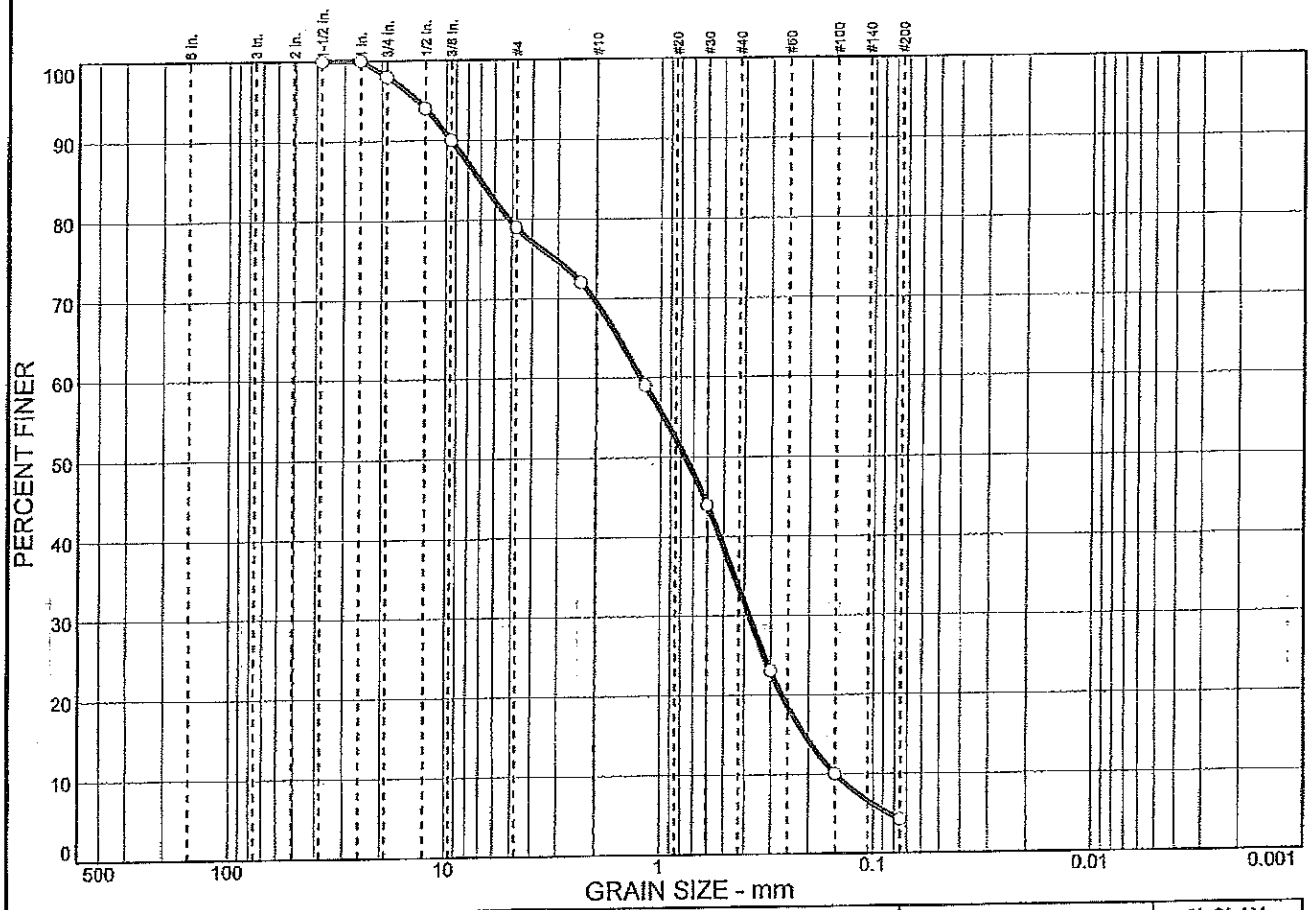
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0605A

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 21 | 75 | 4 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 100 | | |
| 3/4 in. | 98 | | |
| 1/2 in. | 94 | | |
| 3/8 in. | 90 | | |
| #4 | 79 | | |
| #8 | 72 | | |
| #16 | 59 | | |
| #30 | 44 | | |
| #50 | 23 | | |
| #100 | 10 | | |
| #200 | 4.2 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 7.06 $D_{60}$= 1.24 $D_{50}$= 0.765
$D_{30}$= 0.380 $D_{15}$= 0.210 $D_{10}$= 0.150
$C_u$= 8.26 $C_c$= 0.78

**Classification**

USCS= AASHTO=

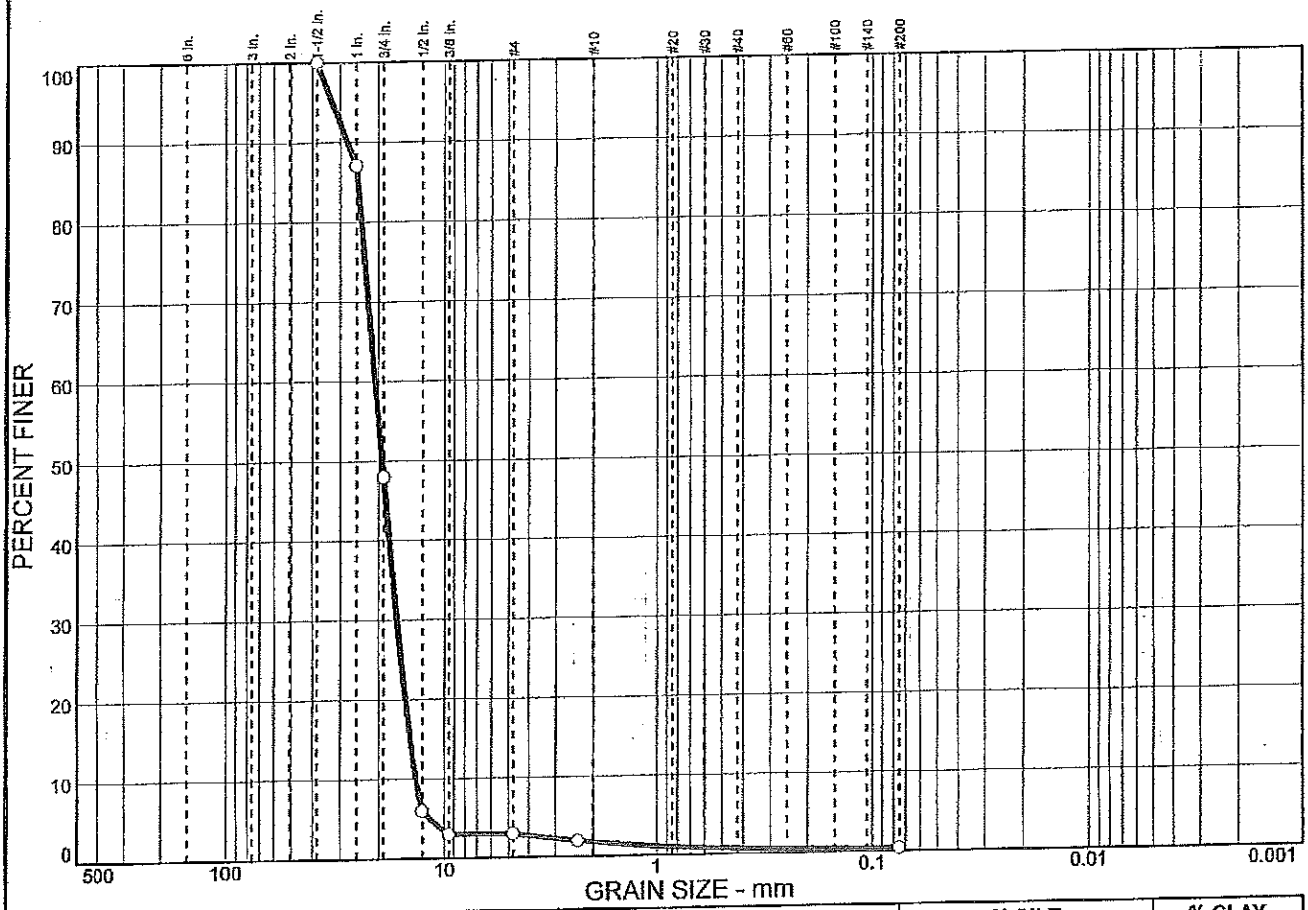
**Remarks**

**Sample No.:** 07-0430C **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-A3 **Elev./Depth:**

JA CESARE AND ASSOCIATES INC.
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430C

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 97 | 3 | 0 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 87 | | |
| 3/4 in. | 48 | | |
| 1/2 in. | 6 | | |
| 3/8 in. | 3 | | |
| #4 | 3 | | |
| #8 | 2 | | |
| #200 | 0.4 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 25.0 $D_{60}$= 20.8 $D_{50}$= 19.3
$D_{30}$= 16.6 $D_{15}$= 14.4 $D_{10}$= 13.6
$C_u$= 1.53 $C_c$= 0.97

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0430D **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-B1 **Elev./Depth:**

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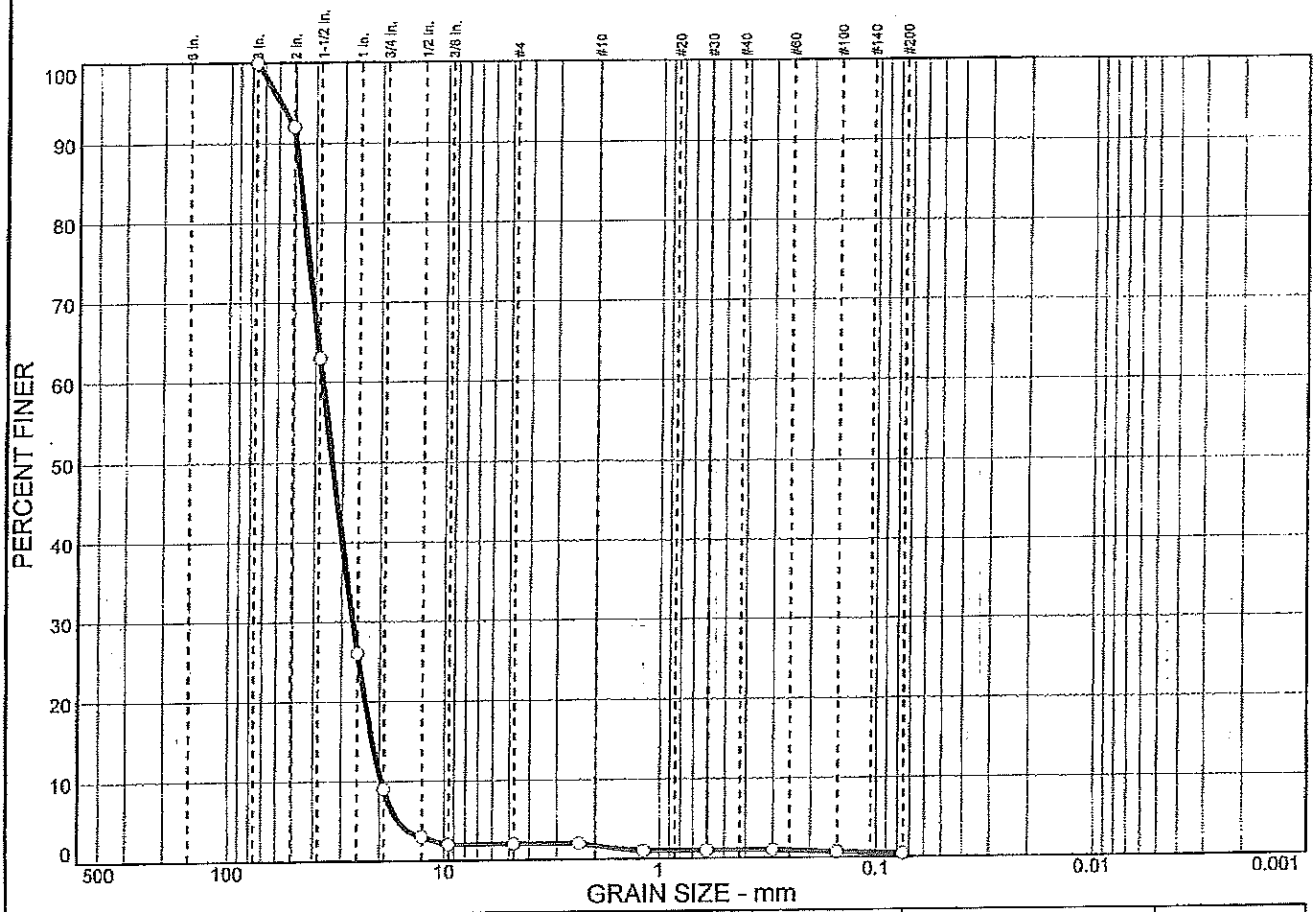
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430D

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 98 | 2 | 0 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2 in. | 92 | | |
| 1-1/2 in. | 63 | | |
| 1 in. | 26 | | |
| 3/4 in. | 9 | | |
| 1/2 in. | 3 | | |
| 3/8 in. | 2 | | |
| #4 | 2 | | |
| #8 | 2 | | |
| #16 | 1 | | |
| #30 | 1 | | |
| #50 | 1 | | |
| #100 | 1 | | |
| #200 | 0.4 | | |

* (no specification provided)

**Soil Description**

Gravel

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 47.4 $D_{60}$= 37.0 $D_{50}$= 33.4
$D_{30}$= 26.7 $D_{15}$= 21.6 $D_{10}$= 19.5
$C_u$= 1.89 $C_c$= 0.99

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0605E **Source of Sample:** Native **Date:** 08/15/2007
**Location:** USEN-B1 **Elev./Depth:**

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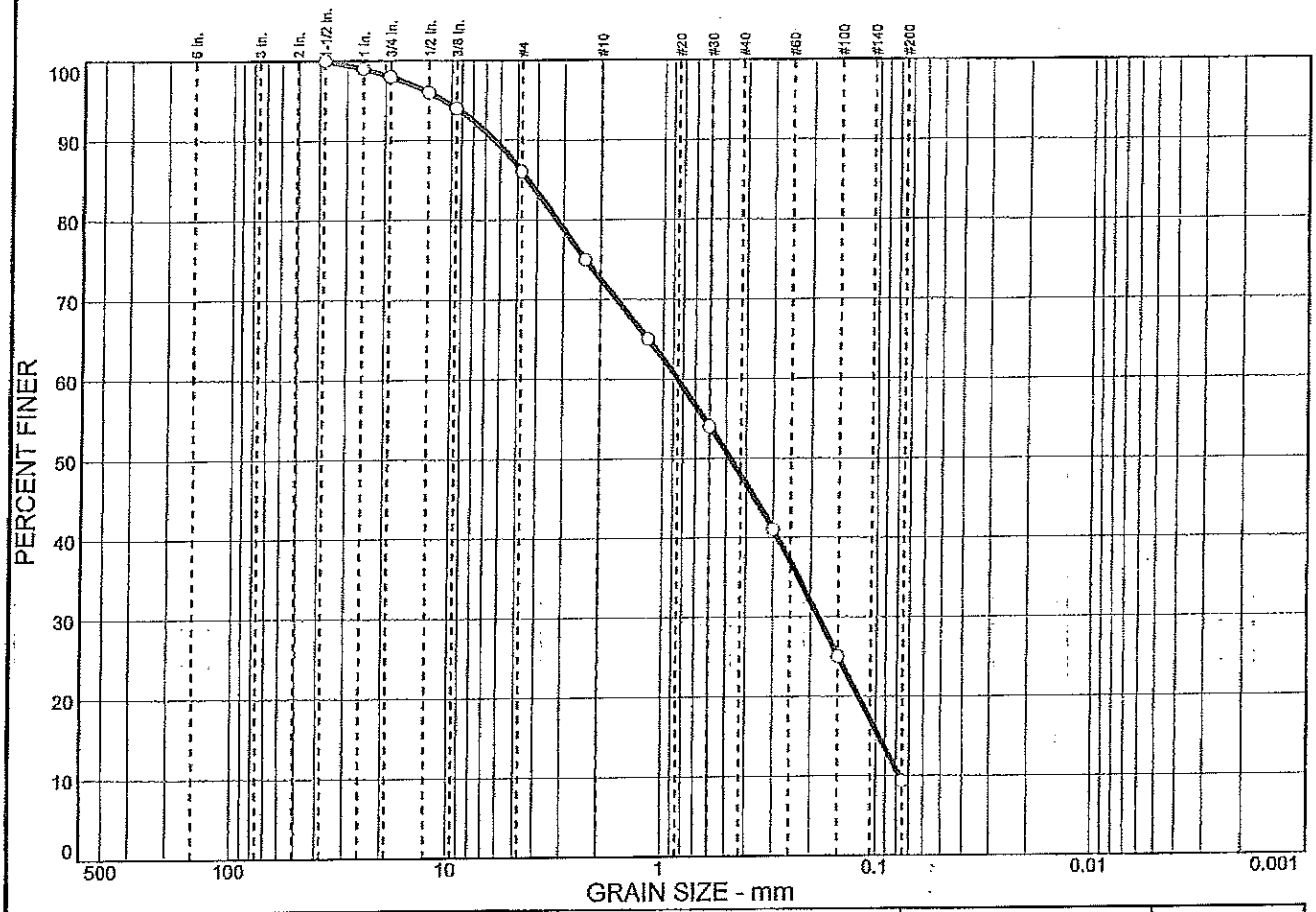
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0605E

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 14 | 77 | 9 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 99 | | |
| 3/4 in. | 98 | | |
| 1/2 in. | 96 | | |
| 3/8 in. | 94 | | |
| #4 | 86 | | |
| #8 | 75 | | |
| #16 | 65 | | |
| #30 | 54 | | |
| #50 | 41 | | |
| #100 | 25 | | |
| #200 | 9.3 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 4.44 $D_{60}$= 0.857 $D_{50}$= 0.478
$D_{30}$= 0.185 $D_{15}$= 0.0968 $D_{10}$= 0.0774
$C_u$= 11.08 $C_c$= 0.52

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0430E **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-C1 **Elev./Depth:**

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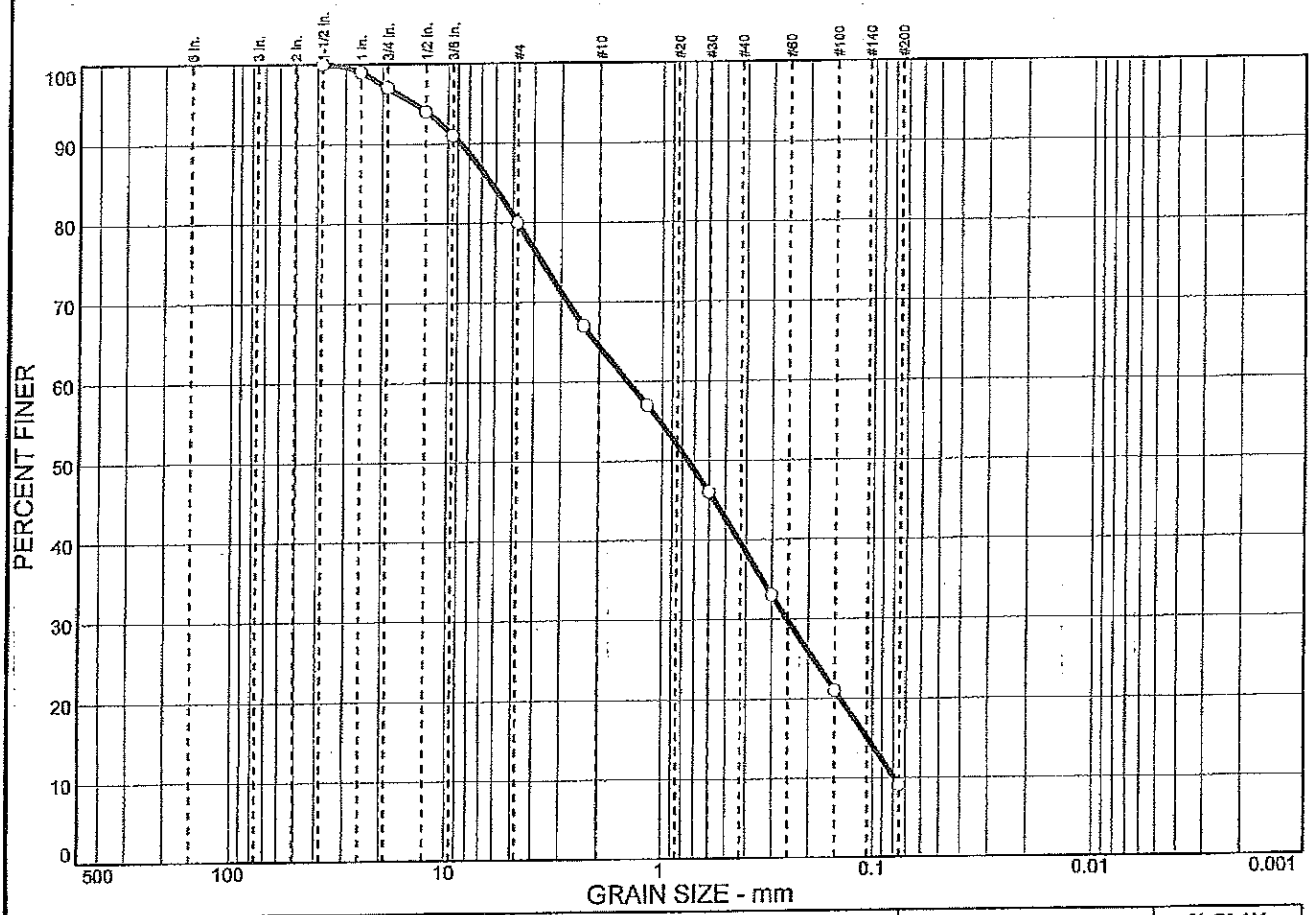
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430E

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 20 | 71 | 9 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 99 | | |
| 3/4 in. | 97 | | |
| 1/2 in. | 94 | | |
| 3/8 in. | 91 | | |
| #4 | 80 | | |
| #8 | 67 | | |
| #16 | 57 | | |
| #30 | 46 | | |
| #50 | 33 | | |
| #100 | 21 | | |
| #200 | 9.1 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 6.30 $D_{60}$= 1.46 $D_{50}$= 0.754
$D_{30}$= 0.254 $D_{15}$= 0.106 $D_{10}$= 0.0790
$C_u$= 18.51 $C_c$= 0.56

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0430F **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-C2 **Elev./Depth:**

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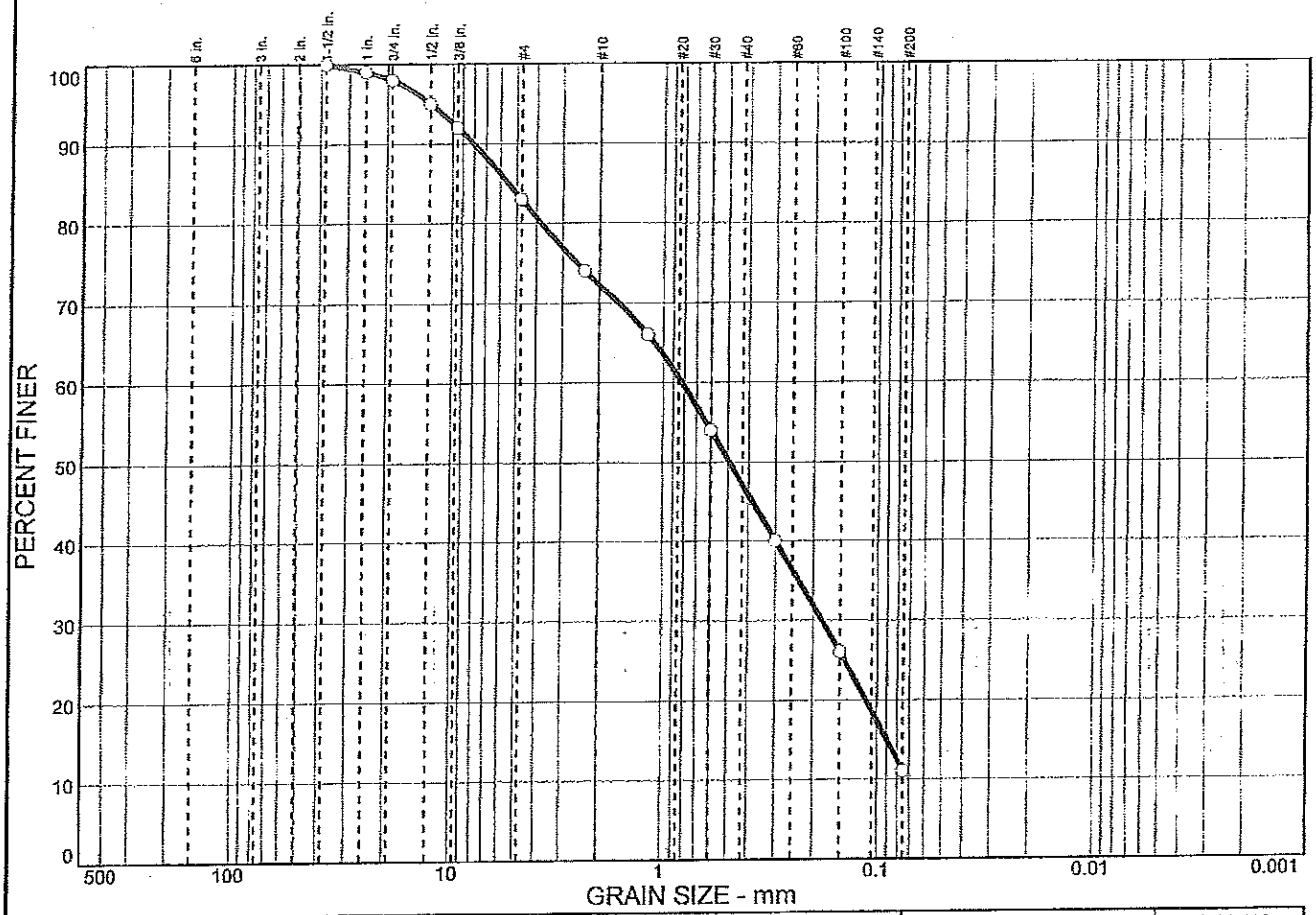
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430F

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 17 | 72 | 11 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 99 | | |
| 3/4 in. | 98 | | |
| 1/2 in. | 95 | | |
| 3/8 in. | 92 | | |
| #4 | 83 | | |
| #8 | 74 | | |
| #16 | 66 | | |
| #30 | 54 | | |
| #50 | 40 | | |
| #100 | 26 | | |
| #200 | 11 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 5.50 $D_{60}$= 0.820 $D_{50}$= 0.491
$D_{30}$= 0.182 $D_{15}$= 0.0899 $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

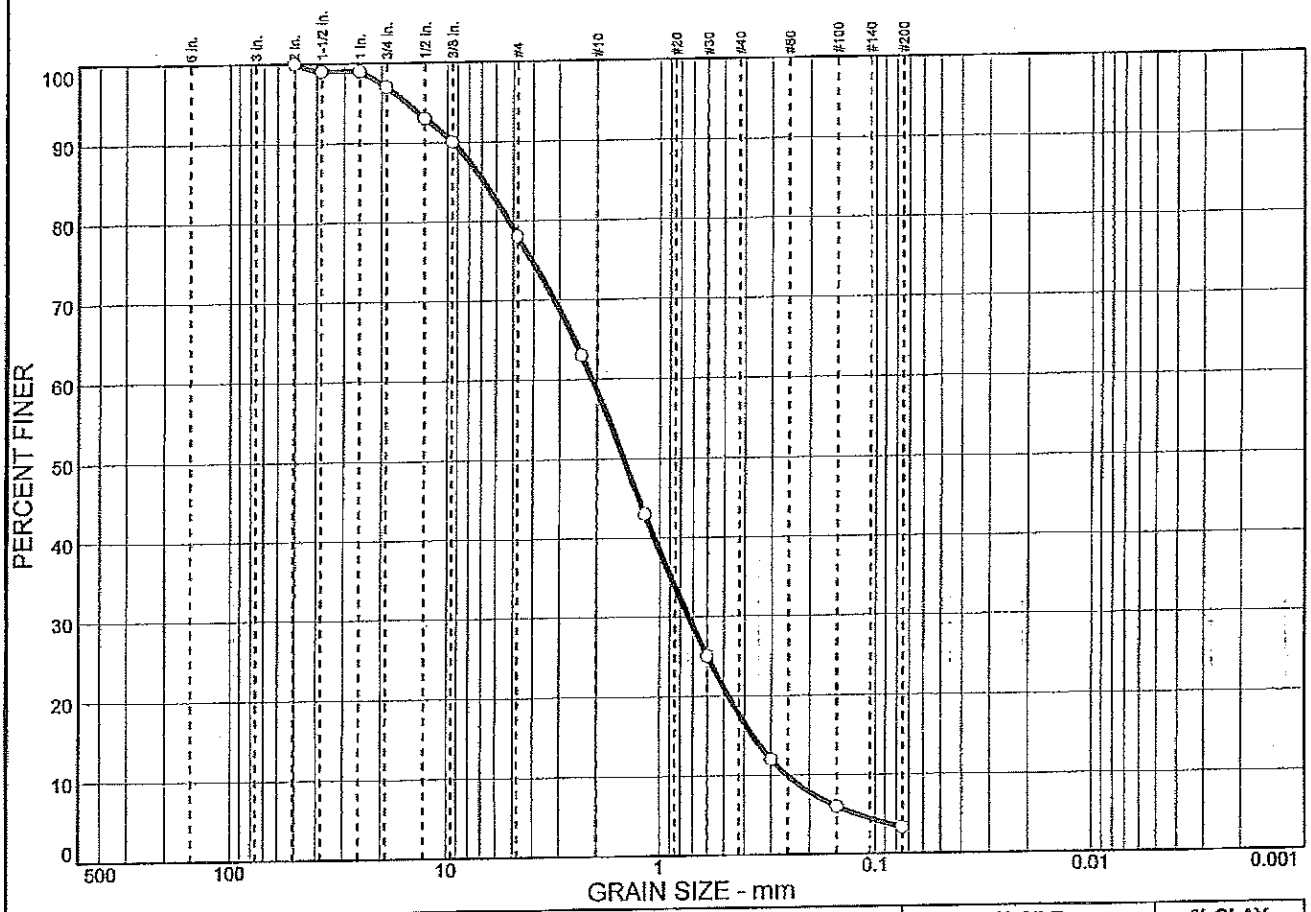
**Remarks**

**Sample No.:** 07-0605C **Source of Sample:** Native **Date:** 08/07/2007
**Location:** USEN-C1 and C2 w/5% Zeolite Clay **Elev./Depth:**

J.A. CESARE AND ASSOCIATES, INC.
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0605C

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 22 | 75 | 3 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 2 in. | 100 | | |
| 1-1/2 in. | 99 | | |
| 1 in. | 99 | | |
| 3/4 in. | 97 | | |
| 1/2 in. | 93 | | |
| 3/8 in. | 90 | | |
| #4 | 78 | | |
| #8 | 63 | | |
| #16 | 43 | | |
| #30 | 25 | | |
| #50 | 12 | | |
| #100 | 6 | | |
| #200 | 3.3 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 6.86 $D_{60}$= 2.11 $D_{50}$= 1.49
$D_{30}$= 0.736 $D_{15}$= 0.366 $D_{10}$= 0.254
$C_u$= 8.29 $C_c$= 1.01

**Classification**

USCS= AASHTO=

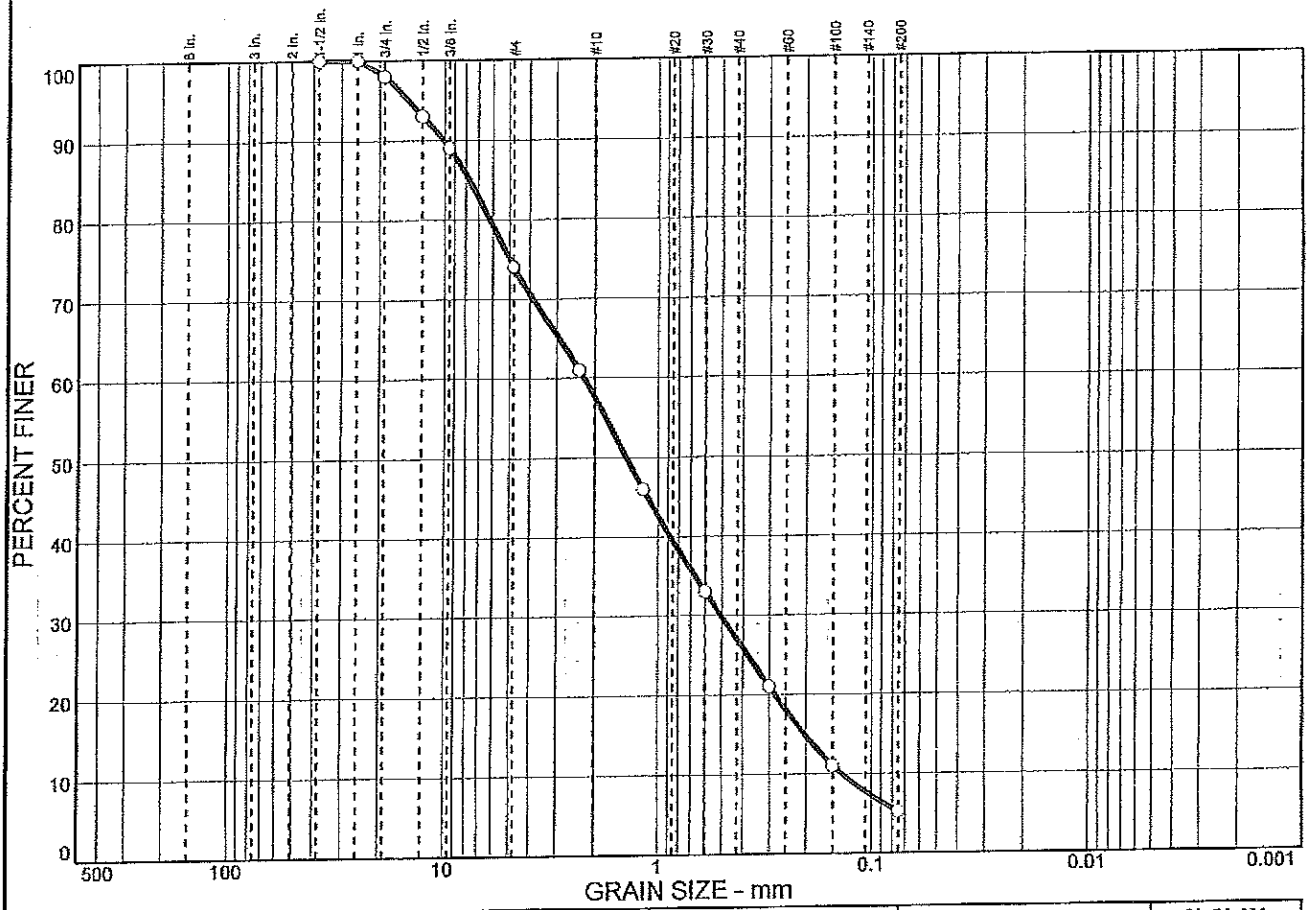
**Remarks**

**Sample No.:** 07-0430G **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-D1 **Elev./Depth:**

J.A. CESARE AND ASSOCIATES, INC.
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430G

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 26 | 69 | 5 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 100 | | |
| 3/4 in. | 98 | | |
| 1/2 in. | 93 | | |
| 3/8 in. | 89 | | |
| #4 | 74 | | |
| #8 | 61 | | |
| #16 | 46 | | |
| #30 | 33 | | |
| #50 | 21 | | |
| #100 | 11 | | |
| #200 | 5.2 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 7.73 $D_{60}$= 2.24 $D_{50}$= 1.42
$D_{30}$= 0.507 $D_{15}$= 0.204 $D_{10}$= 0.137
$C_u$= 16.43 $C_c$= 0.84

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0430H **Source of Sample:** Native **Date:** 06/14/2007
**Location:** USEN-D2 **Elev./Depth:**

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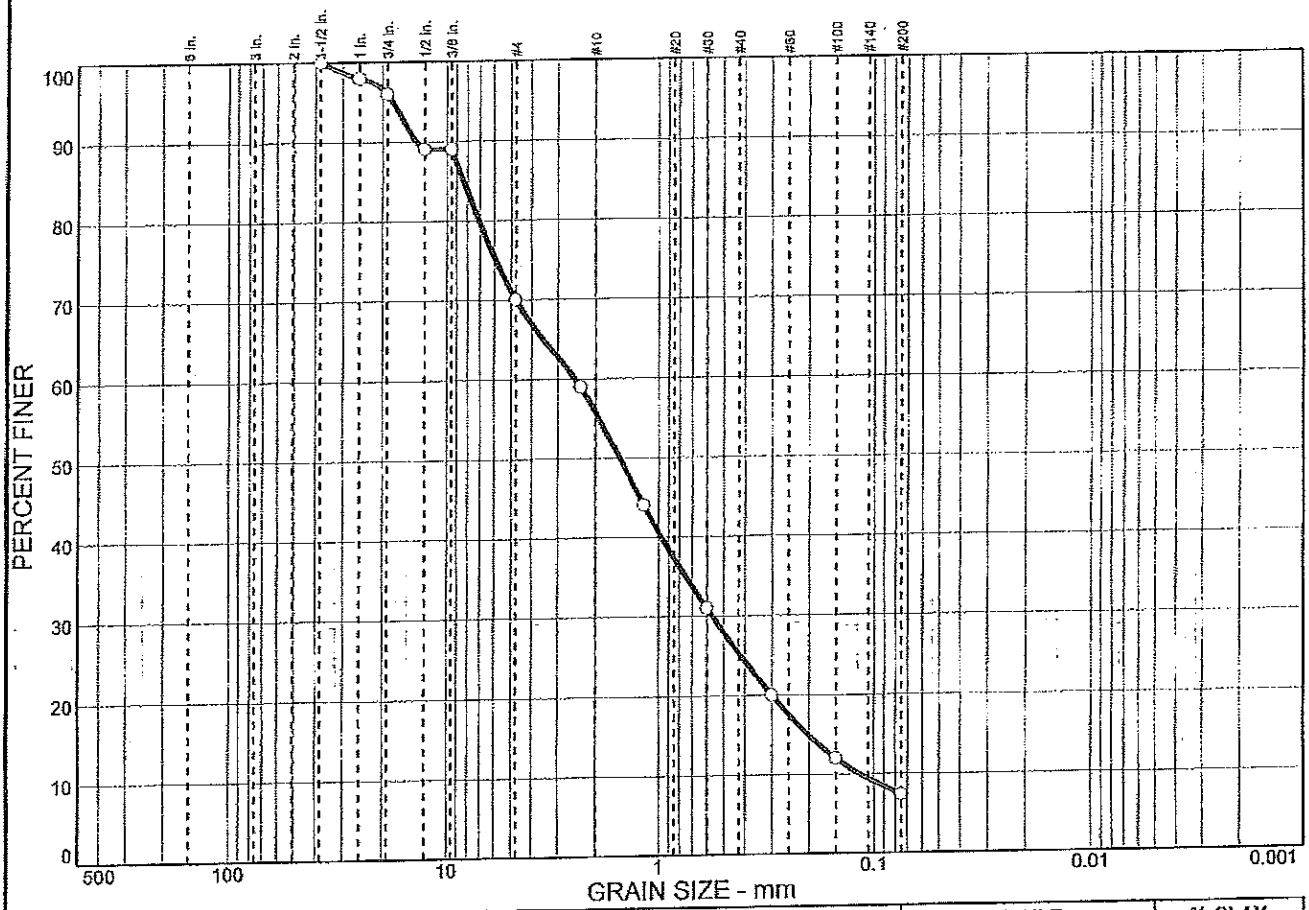
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0430H

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 30 | 63 | 7 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1-1/2 in. | 100 | | |
| 1 in. | 98 | | |
| 3/4 in. | 96 | | |
| 1/2 in. | 89 | | |
| 3/8 in. | 89 | | |
| #4 | 70 | | |
| #8 | 59 | | |
| #16 | 44 | | |
| #30 | 31 | | |
| #50 | 20 | | |
| #100 | 12 | | |
| #200 | 7.4 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 8.36 $D_{60}$= 2.50 $D_{50}$= 1.54
$D_{30}$= 0.566 $D_{15}$= 0.202 $D_{10}$= 0.116
$C_u$= 21.65 $C_c$= 1.11

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0605D **Source of Sample:** Native **Date:** 08/07/2007
**Location:** USEN-D1 and D2 w/5% Zeolite Clay **Elev./Depth:**

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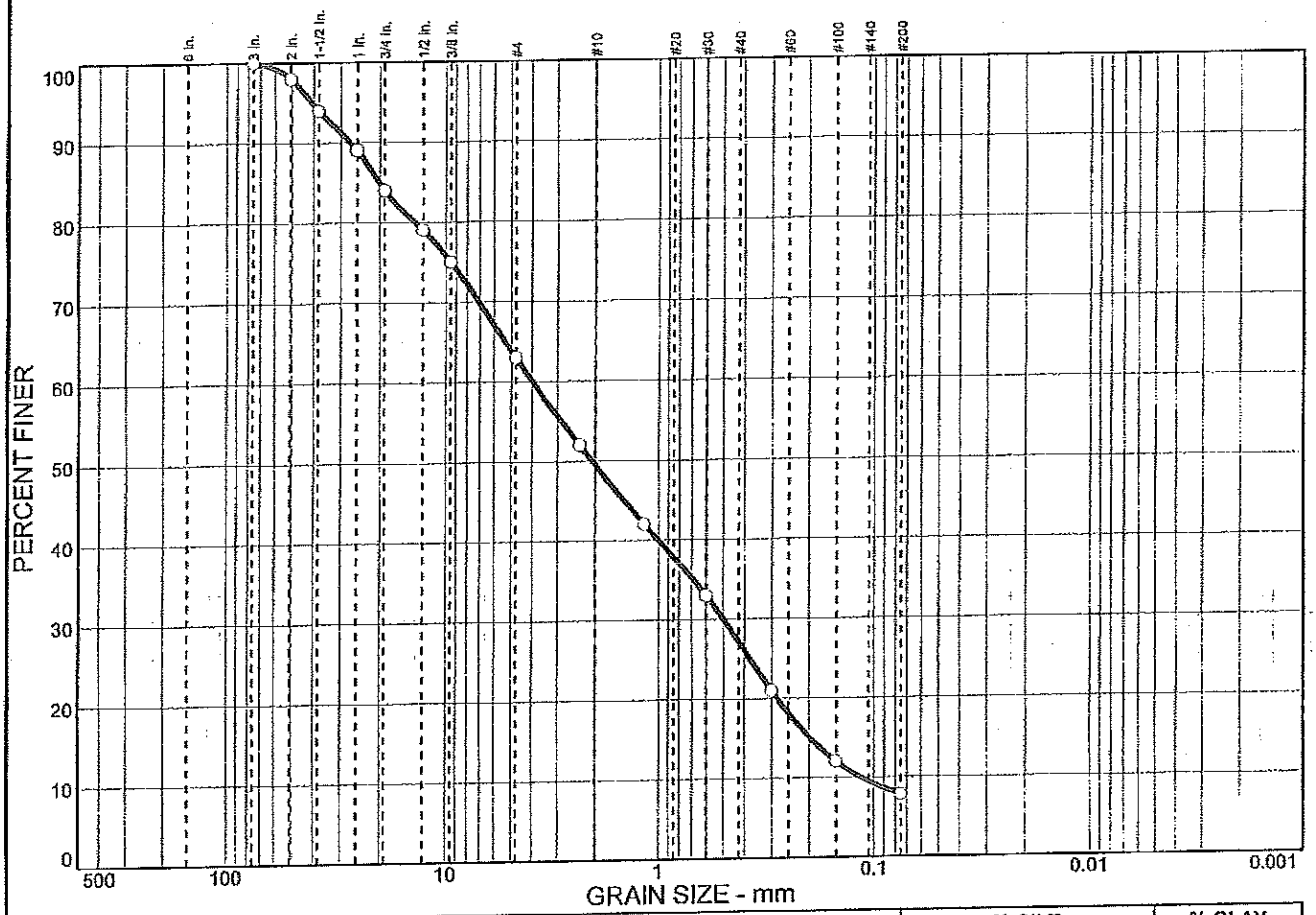
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0605D

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 37 | 55 | 8 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2.0 in. | 98 | | |
| 1-1/2 in. | 94 | | |
| 1 in. | 89 | | |
| 3/4 in. | 84 | | |
| 1/2 in. | 79 | | |
| 3/8 in. | 75 | | |
| #4 | 63 | | |
| #8 | 52 | | |
| #16 | 42 | | |
| #30 | 33 | | |
| #50 | 21 | | |
| #100 | 12 | | |
| #200 | 7.8 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 20.2 $D_{60}$= 3.96 $D_{50}$= 2.07
$D_{30}$= 0.500 $D_{15}$= 0.199 $D_{10}$= 0.115
$C_u$= 34.49 $C_c$= 0.55

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0705A **Source of Sample:** Native **Date:** 9/14/07
**Location:** Trench 12 Material mixed w/5% Imvite 1016 MIX 1 **Elev./Depth:**

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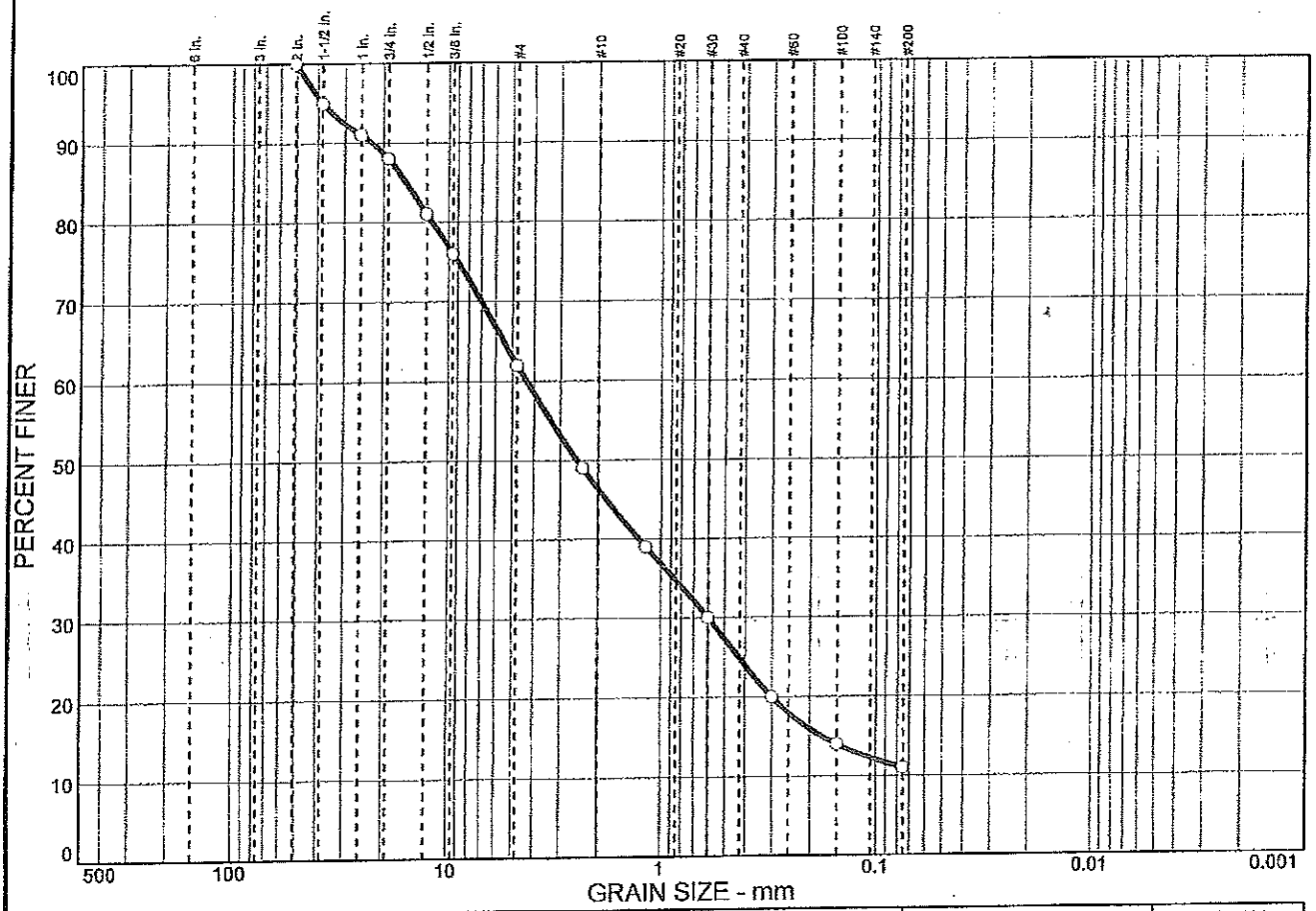
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705A

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 38 | 51 | 11 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 2 in. | 100 | | |
| 1-1/2 in. | 95 | | |
| 1 in. | 91 | | |
| 3/4 in. | 88 | | |
| 1/2 in. | 81 | | |
| 3/8 in. | 76 | | |
| #4 | 62 | | |
| #8 | 49 | | |
| #16 | 39 | | |
| #30 | 30 | | |
| #50 | 20 | | |
| #100 | 14 | | |
| #200 | 11 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 15.8 $D_{60}$= 4.30 $D_{50}$= 2.51
$D_{30}$= 0.600 $D_{15}$= 0.176 $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0705B **Source of Sample:** Native **Date:** 9/14/07
**Location:** Trench 12 Material mixed w/10% Imvite 1016 MIX 2 **Elev./Depth:**

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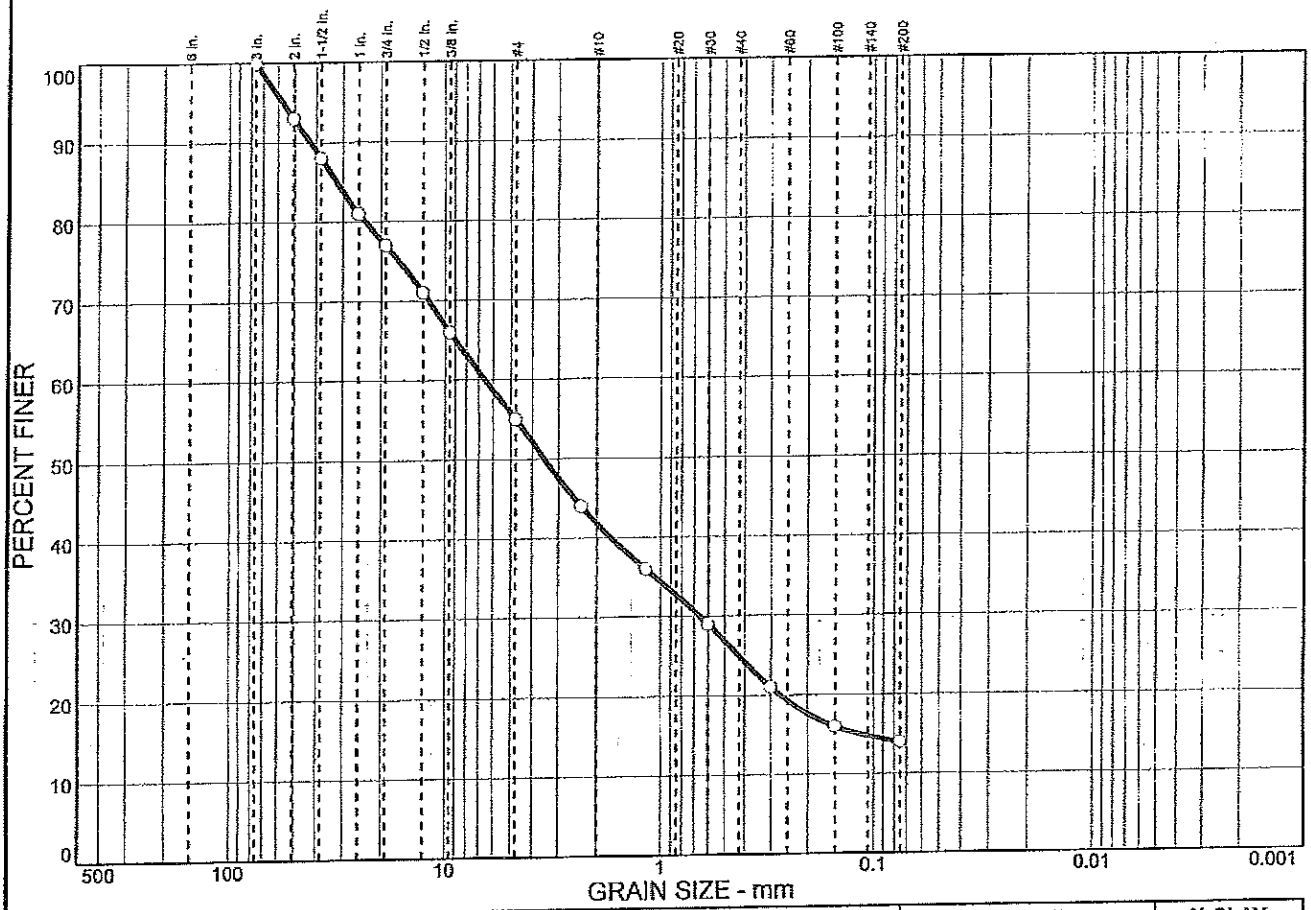
**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705B

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 45 | 41 | 14 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2.0 in. | 93 | | |
| 1-1/2 in. | 88 | | |
| 1 in. | 81 | | |
| 3/4 in. | 77 | | |
| 1/2 in. | 71 | | |
| 3/8 in. | 66 | | |
| #4 | 55 | | |
| #8 | 44 | | |
| #16 | 36 | | |
| #30 | 29 | | |
| #50 | 21 | | |
| #100 | 16 | | |
| #200 | 14 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 32.2 $D_{60}$= 6.56 $D_{50}$= 3.49
$D_{30}$= 0.656 $D_{15}$= 0.114 $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0705C **Source of Sample:** Native **Date:** 9/14/07
**Location:** Trench 12 Material mixed w/15% lmvite MIX 3 **Elev./Depth:**

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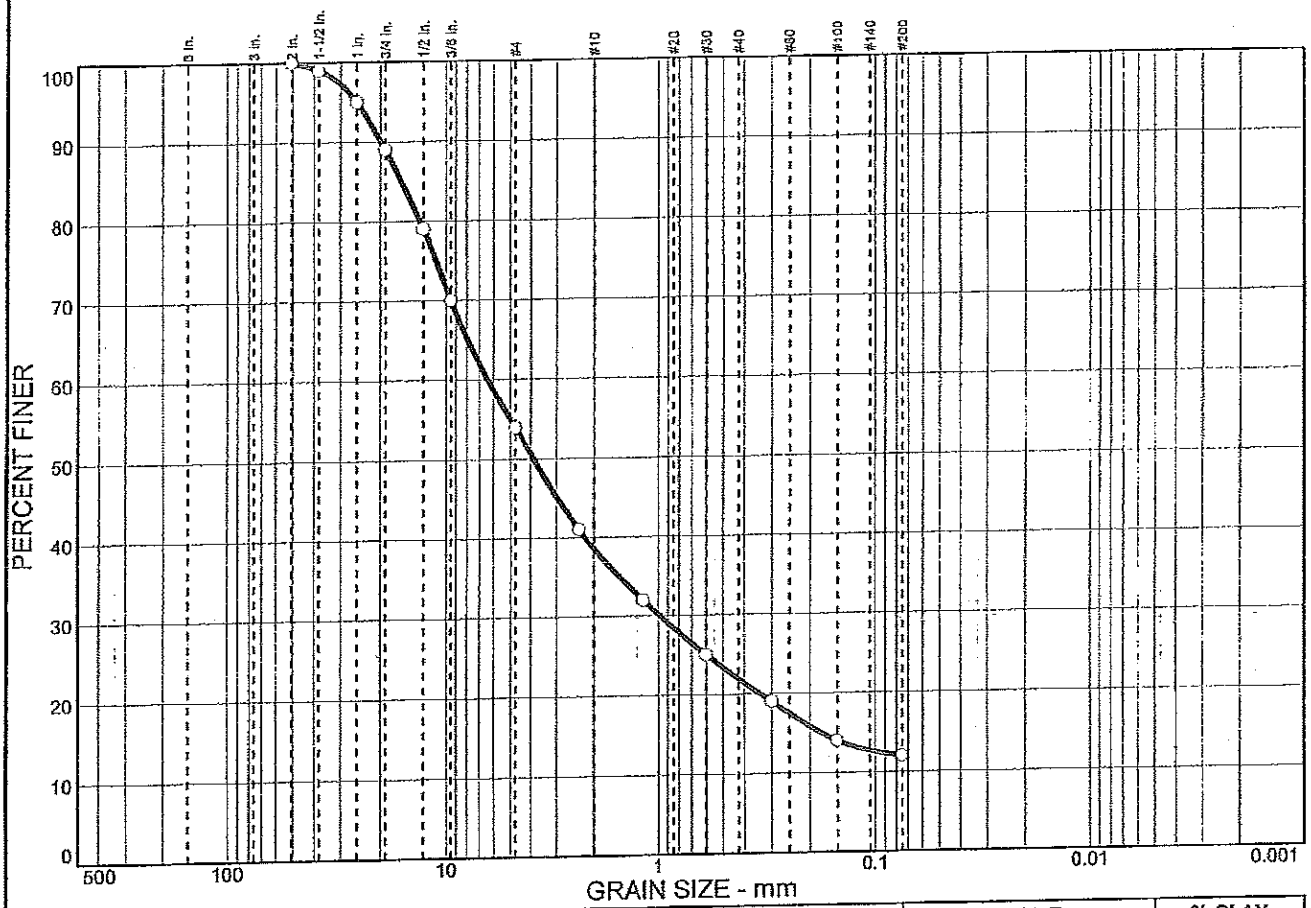
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705C

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 46 | 42 | 12 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 2 in. | 100 | | |
| 1-1/2 in. | 99 | | |
| 1 in. | 95 | | |
| 3/4 in. | 89 | | |
| 1/2 in. | 79 | | |
| 3/8 in. | 70 | | |
| #4 | 54 | | |
| #8 | 41 | | |
| #16 | 32 | | |
| #30 | 25 | | |
| #50 | 19 | | |
| #100 | 14 | | |
| #200 | 12 | | |

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 16.0 $D_{60}$= 6.39 $D_{50}$= 3.88
$D_{30}$= 0.983 $D_{15}$= 0.178 $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

**Remarks**

* (no specification provided)

**Sample No.:** 07-0705D **Source of Sample:** Native **Date:** 9/14/07
**Location:** Trench 12 Material mixed w/10% SEP/SAP MIX 4 **Elev./Depth:**

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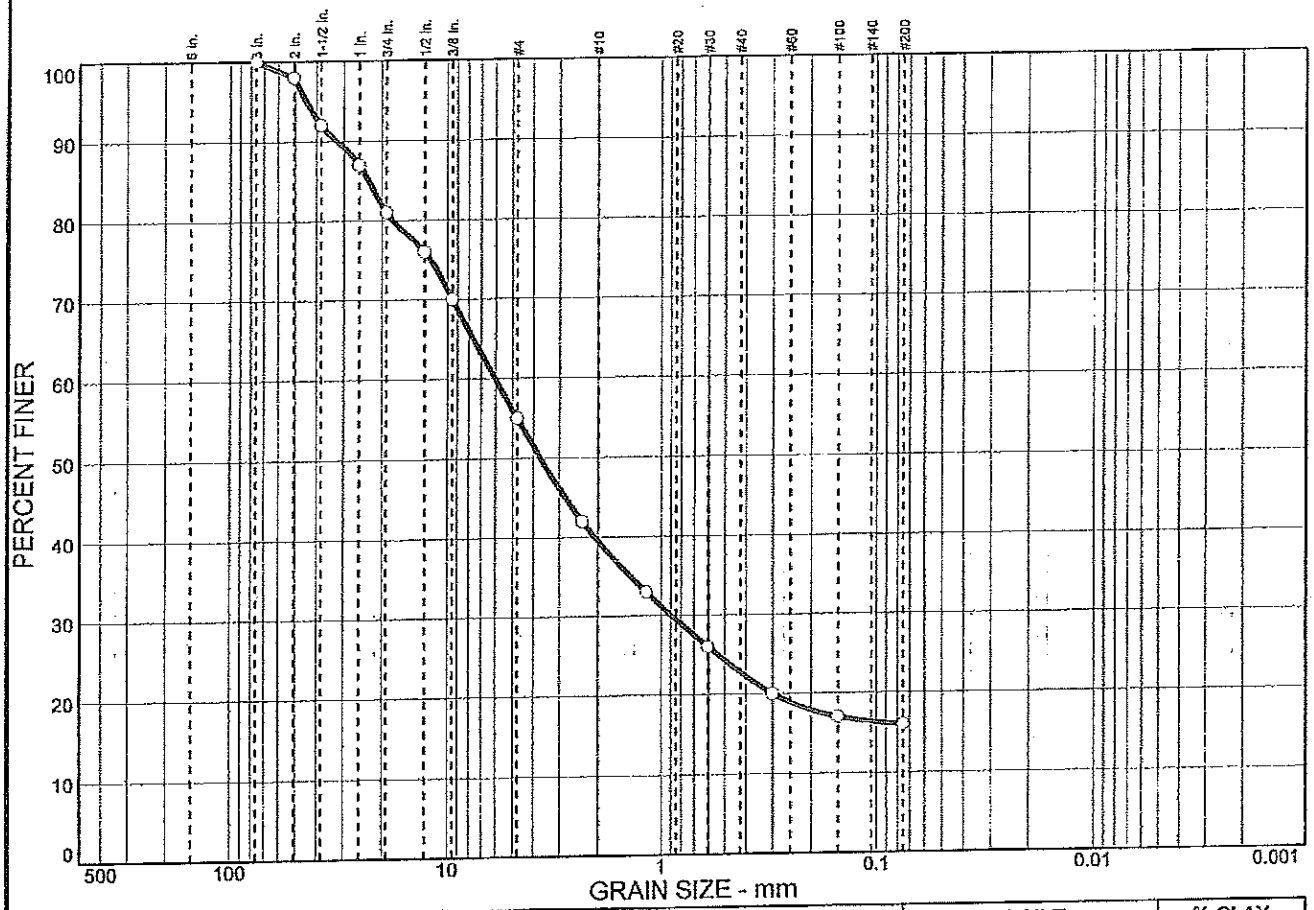
**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705D

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 45 | 39 | 16 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2.0 in. | 98 | | |
| 1.5 in. | 92 | | |
| 1.0 in. | 87 | | |
| 3/4 in. | 81 | | |
| 1/2 in. | 76 | | |
| 3/8 in. | 70 | | |
| #4 | 55 | | |
| #8 | 42 | | |
| #16 | 33 | | |
| #30 | 26 | | |
| #50 | 20 | | |
| #100 | 17 | | |
| #200 | 16 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 23.0 $D_{60}$= 6.05 $D_{50}$= 3.70
$D_{30}$= 0.892 $D_{15}$= $D_{10}$=
$C_u$= $C_c$=

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0705E **Source of Sample:** Native **Date:** 9/14/07
**Location:** Trench 12 material mixed w/15% SEP/SAP MIX 5 **Elev./Depth:**

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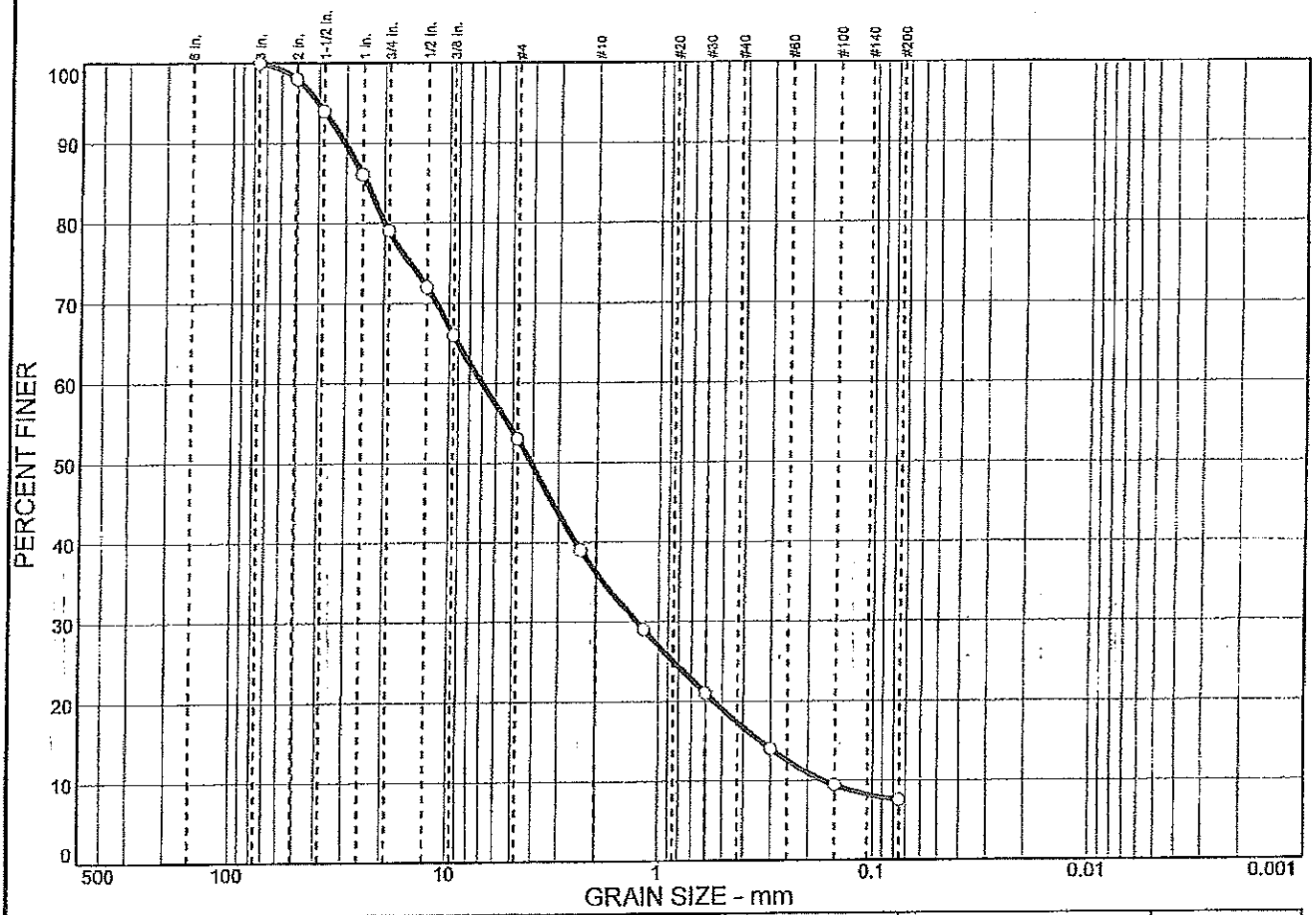
**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705E

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 47 | 46 | 8 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 3 in. | 100 | | |
| 2 in. | 98 | | |
| 1-1/2 in. | 94 | | |
| 1 in. | 86 | | |
| 3/4 in. | 79 | | |
| 1/2 in. | 72 | | |
| 3/8 in. | 66 | | |
| #4 | 53 | | |
| #8 | 39 | | |
| #16 | 29 | | |
| #30 | 21 | | |
| #50 | 14 | | |
| #100 | 9 | | |
| #200 | 7.5 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 24.4 $D_{60}$= 6.97 $D_{50}$= 4.09
$D_{30}$= 1.28 $D_{15}$= 0.336 $D_{10}$= 0.170
$C_u$= 41.04 $C_c$= 1.38

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0705F **Source of Sample:** Native **Date:** 09/14/2007
**Location:** Trench 12 Material Mixed w/5% Portland Cement MIX 6 **Elev./Depth:**

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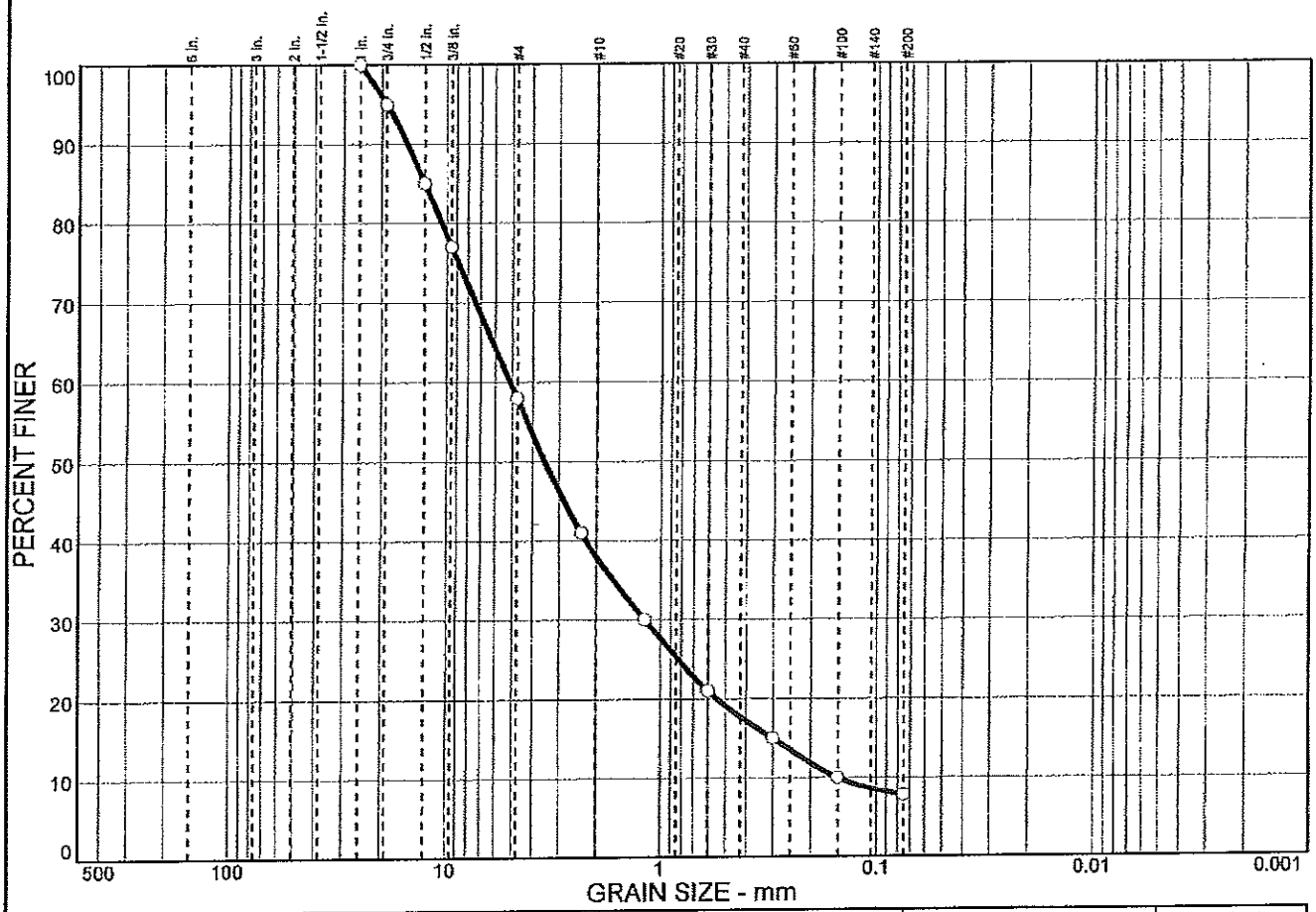
Geotechnical Engineering Consultants

**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0705F

# Particle Size Distribution Report




| % COBBLES | % GRAVEL | % SAND | % SILT | % CLAY |
|---|---|---|---|---|
| 0 | 42 | 50 | 8 | |

| SIEVE SIZE | PERCENT FINER | SPEC.* PERCENT | PASS? (X=NO) |
|---|---|---|---|
| 1 in. | 100 | | |
| 3/4 in. | 95 | | |
| 1/2 in. | 85 | | |
| 3/8 in. | 77 | | |
| #4 | 58 | | |
| #8 | 41 | | |
| #16 | 30 | | |
| #30 | 21 | | |
| #50 | 15 | | |
| #100 | 10 | | |
| #200 | 7.8 | | |

* (no specification provided)

**Soil Description**

**Atterberg Limits**

PL= LL= PI=

**Coefficients**

$D_{85}$= 12.7 $D_{60}$= 5.12 $D_{50}$= 3.50
$D_{30}$= 1.18 $D_{15}$= 0.300 $D_{10}$= 0.150
$C_u$= 34.12 $C_c$= 1.81

**Classification**

USCS= AASHTO=

**Remarks**

**Sample No.:** 07-0852 **Source of Sample:** Native **Date:** 11/7/2007
**Location:** Trench 12 Material Mixed w/5% SEP/SAP MIX 7 **Elev./Depth:**

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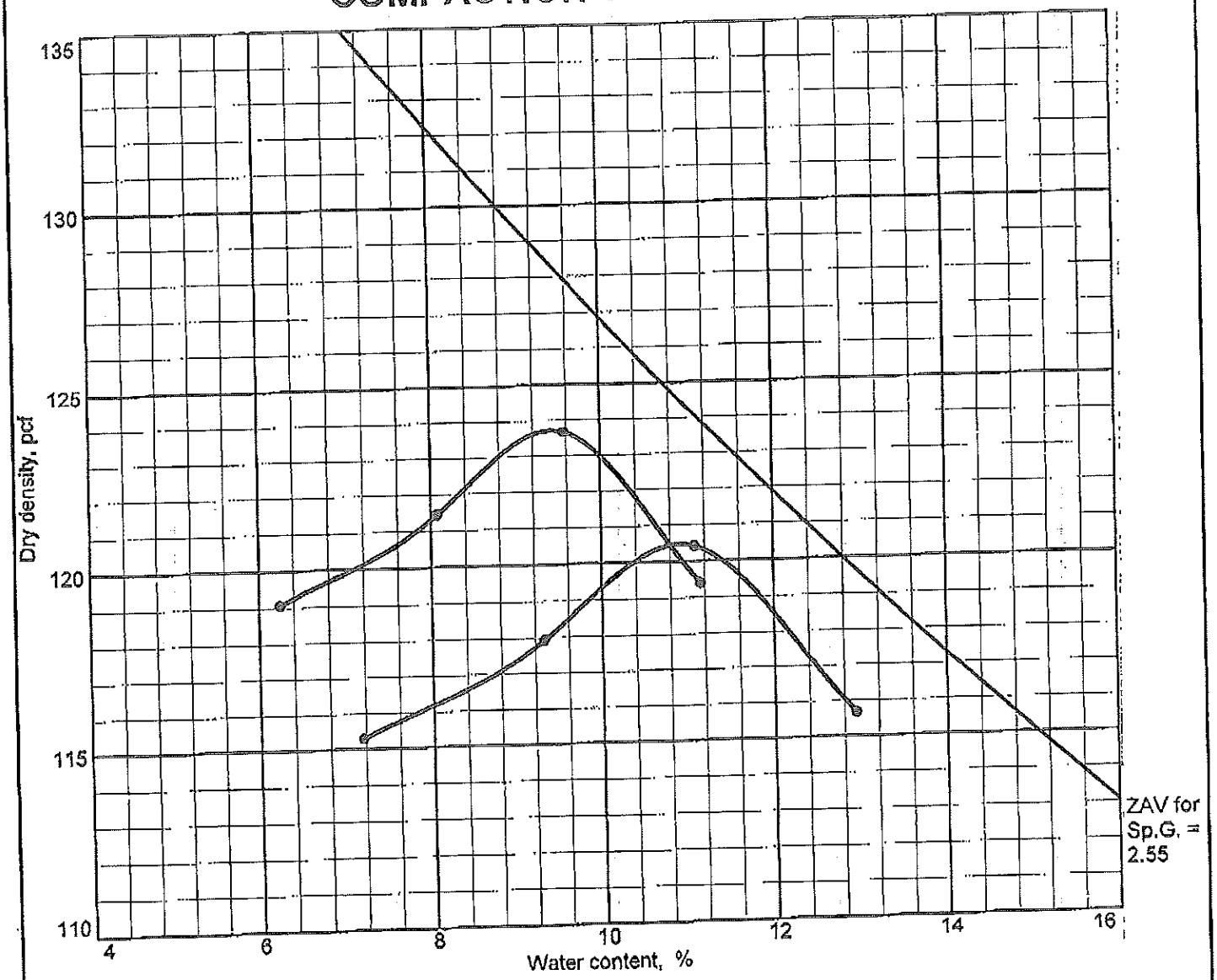
**Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Project No:** 07.1243 **Figure** 07-0852

**Results of ASTM D1557 Moisture-Density Relationship Testing**

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 In. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SW-SC | | | 2.34 | 34 | 15 | 15.0 | 9.3 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 123.5 pcf | 120.5 pcf | Well-graded sand with clay and gravel |
| Optimum moisture = 9.5 % | 11 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-A1

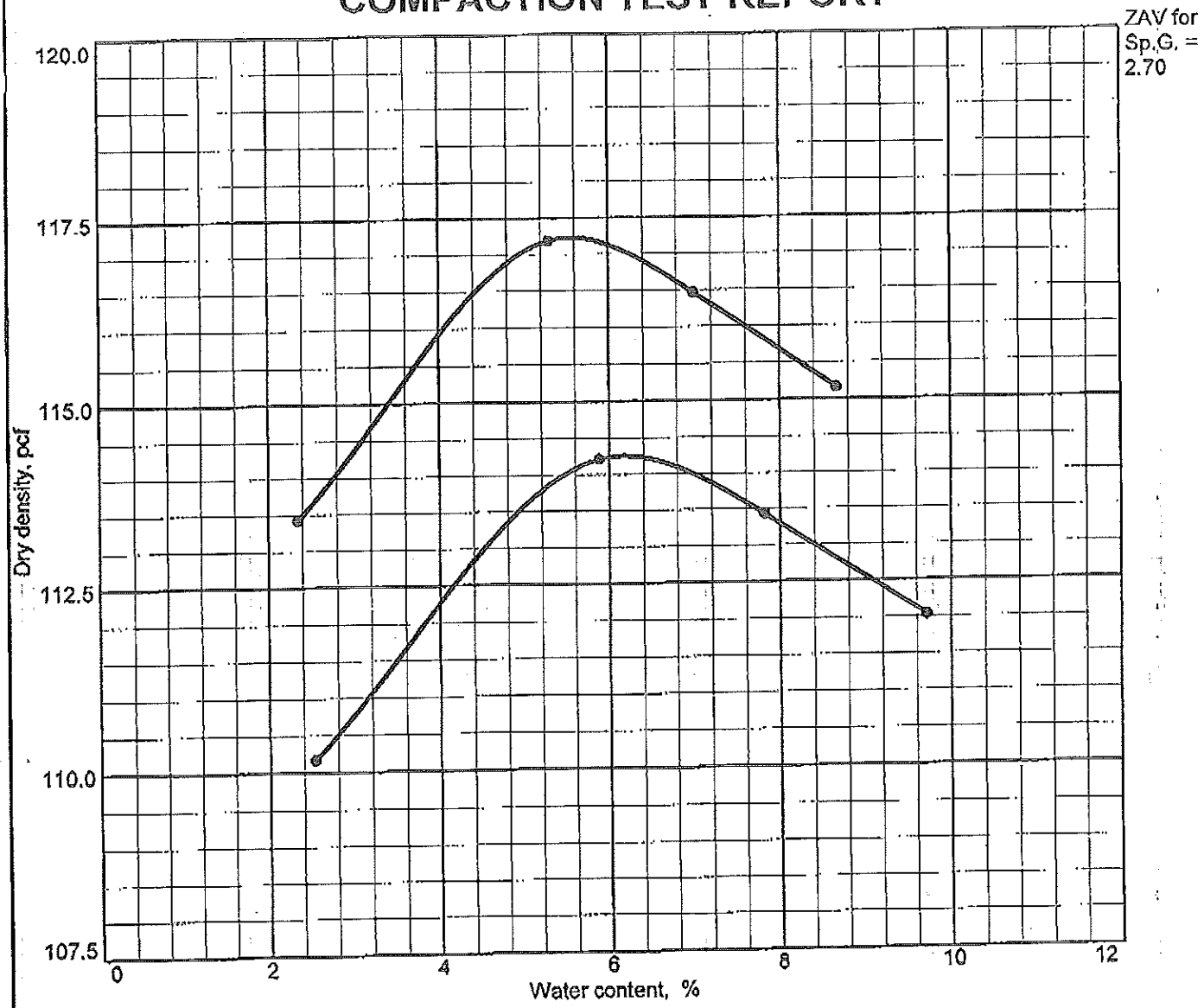
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0430A

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 In. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SP | | | 2.32 | NP | NP | 12.0 | 2.0 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 117 pcf | 114.5 pcf | Poorly graded sand with gravel |
| Optimum moisture = 5.5 % | 6 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

**Location:** USEN-A2

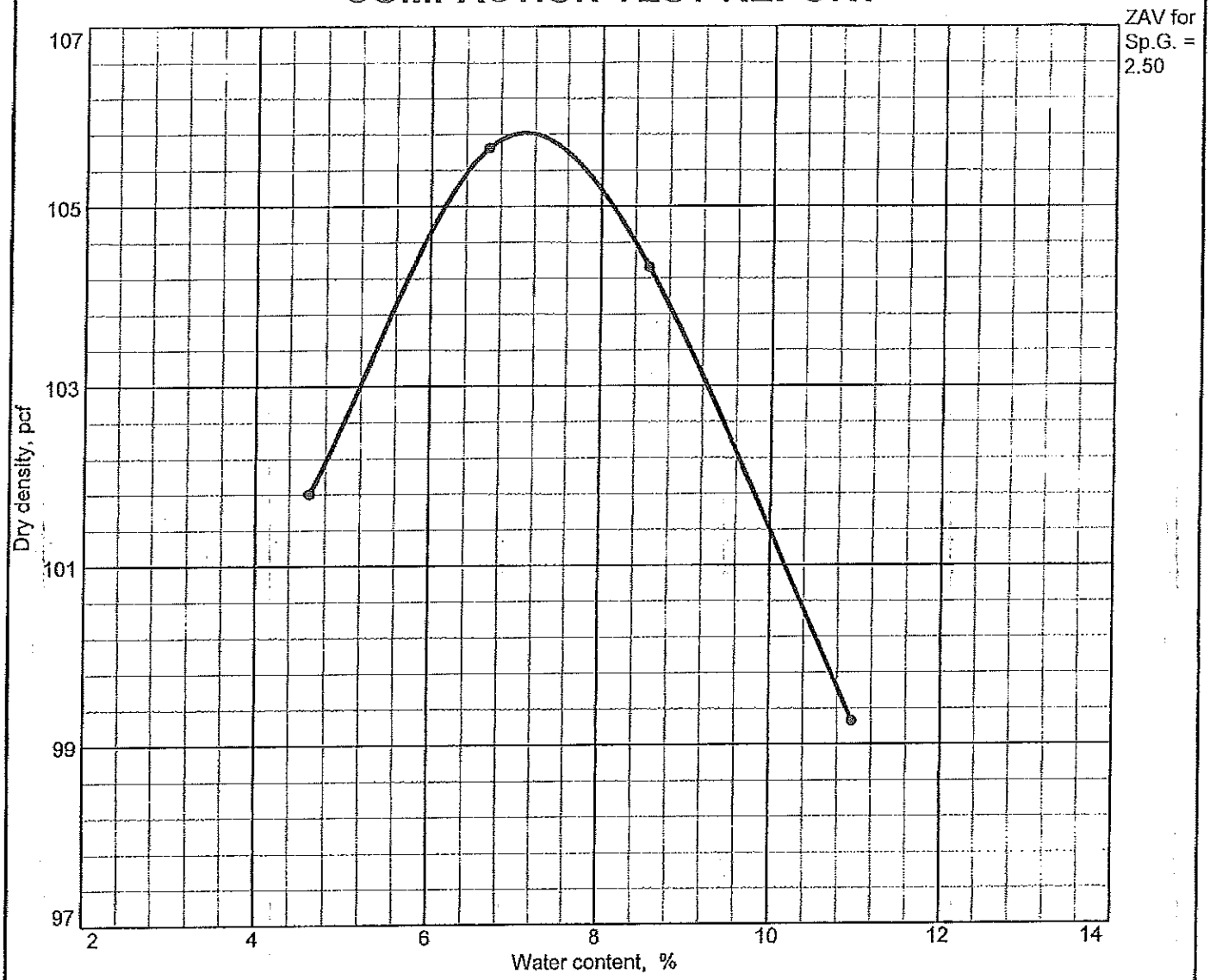
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

Figure 07-0430B

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure A Modified
Oversize correction applied to final results

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > No.4 | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | | | | 12.0 | |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 110 pcf | 106 pcf | |
| Optimum moisture = 6 % | 7 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-A2 w/5% Zeolite Clay

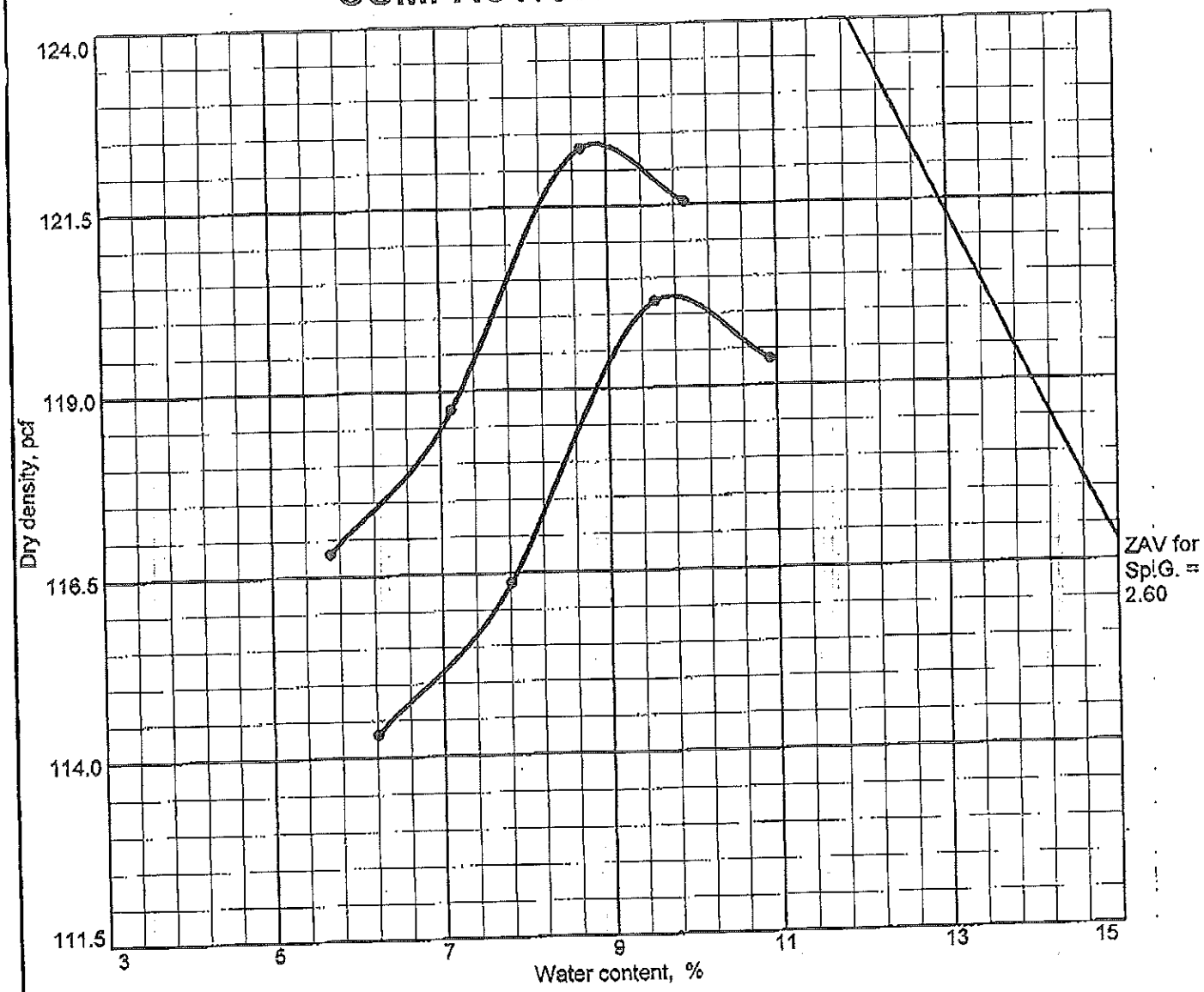
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0605A

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SP | | | 2.33 | NP | NP | 10.0 | 4.2 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED |
|---|---|
| Maximum dry density = 122.5 pcf | 120 pcf |
| Optimum moisture = 9 % | 10 % |

**MATERIAL DESCRIPTION**
Poorly graded sand with gravel

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
**Location:** USEN-A3

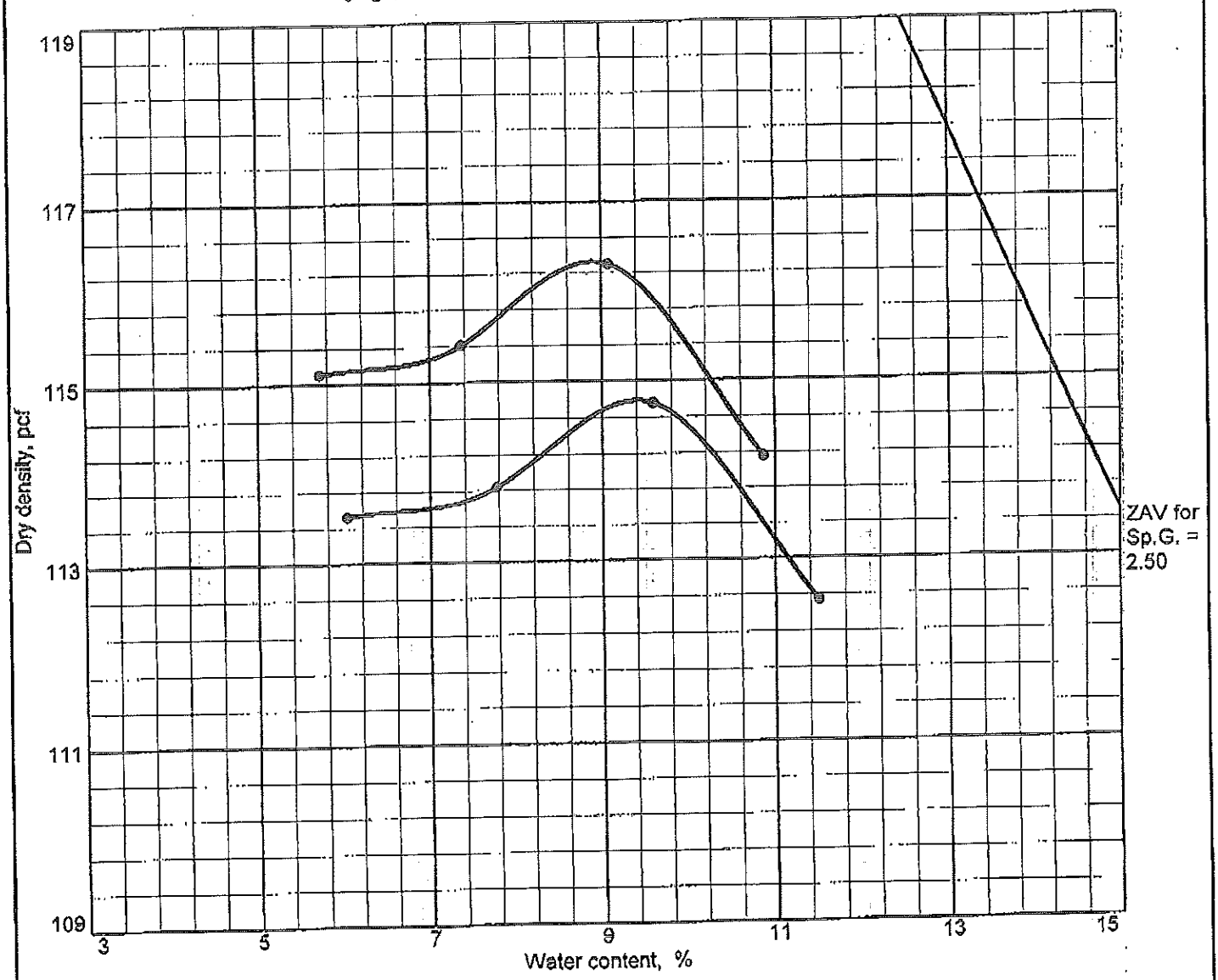
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0430C

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SP-SM | | | 2.36 | NP | NP | 6.0 | 9.3 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 116.5 pcf | 115 pcf | Poorly graded sand with silt |
| Optimum moisture = 9 % | 9.5 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-C1

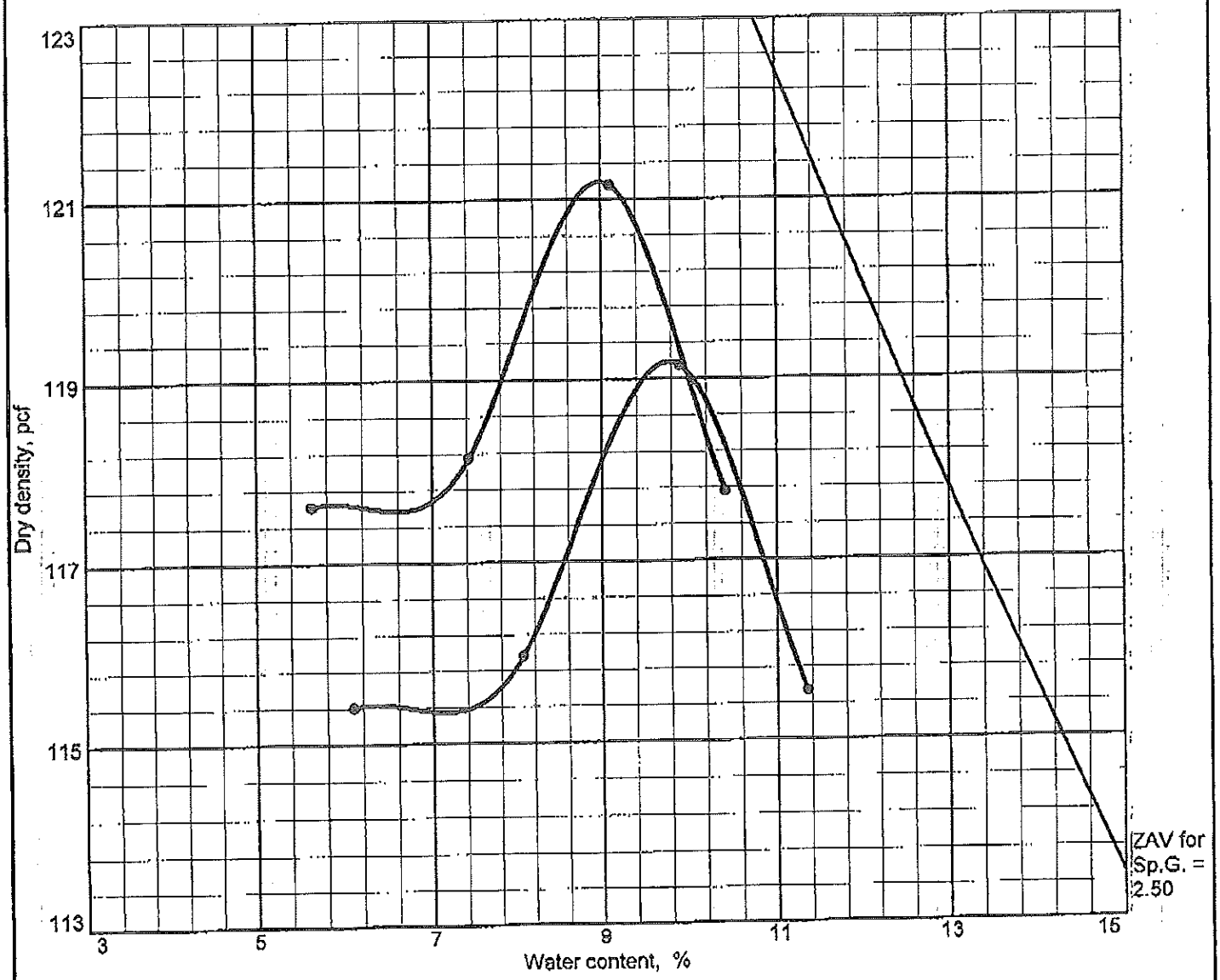
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0430E

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SP-SM | | | 2.34 | NP | NP | 9.0 | 9.1 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 121 pcf | 119 pcf | Poorly graded sand with silt and gravel |
| Optimum moisture = 9 % | 10 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-C2

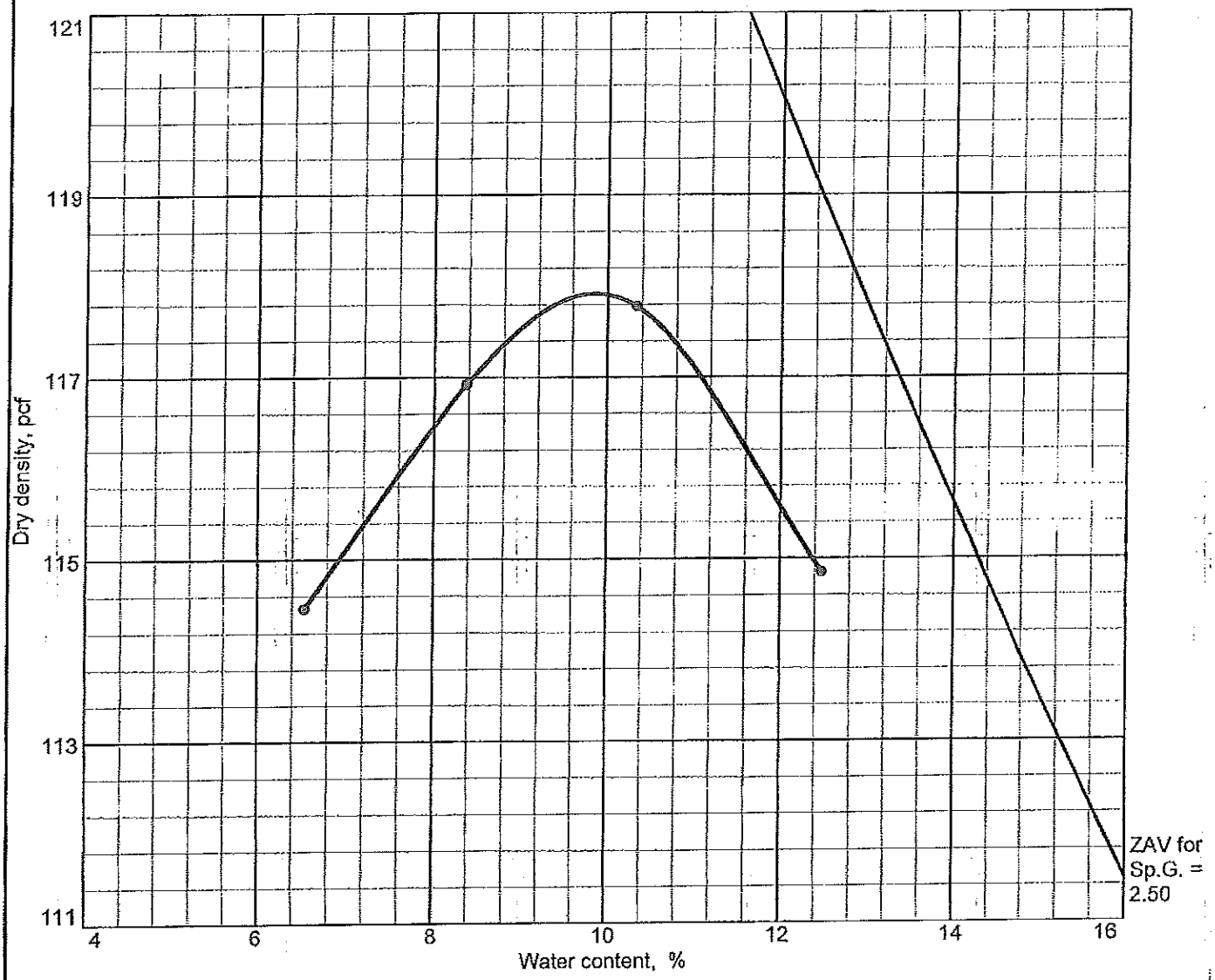
Remarks:

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

Figure 07-0430F

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure A Modified

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > No.4 | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | | | | 18.0 | |

| TEST RESULTS | MATERIAL DESCRIPTION |
|---|---|
| Maximum dry density = 118 pcf<br>Optimum moisture = 10 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-C1 and C2 w/5% Zeolite Clay

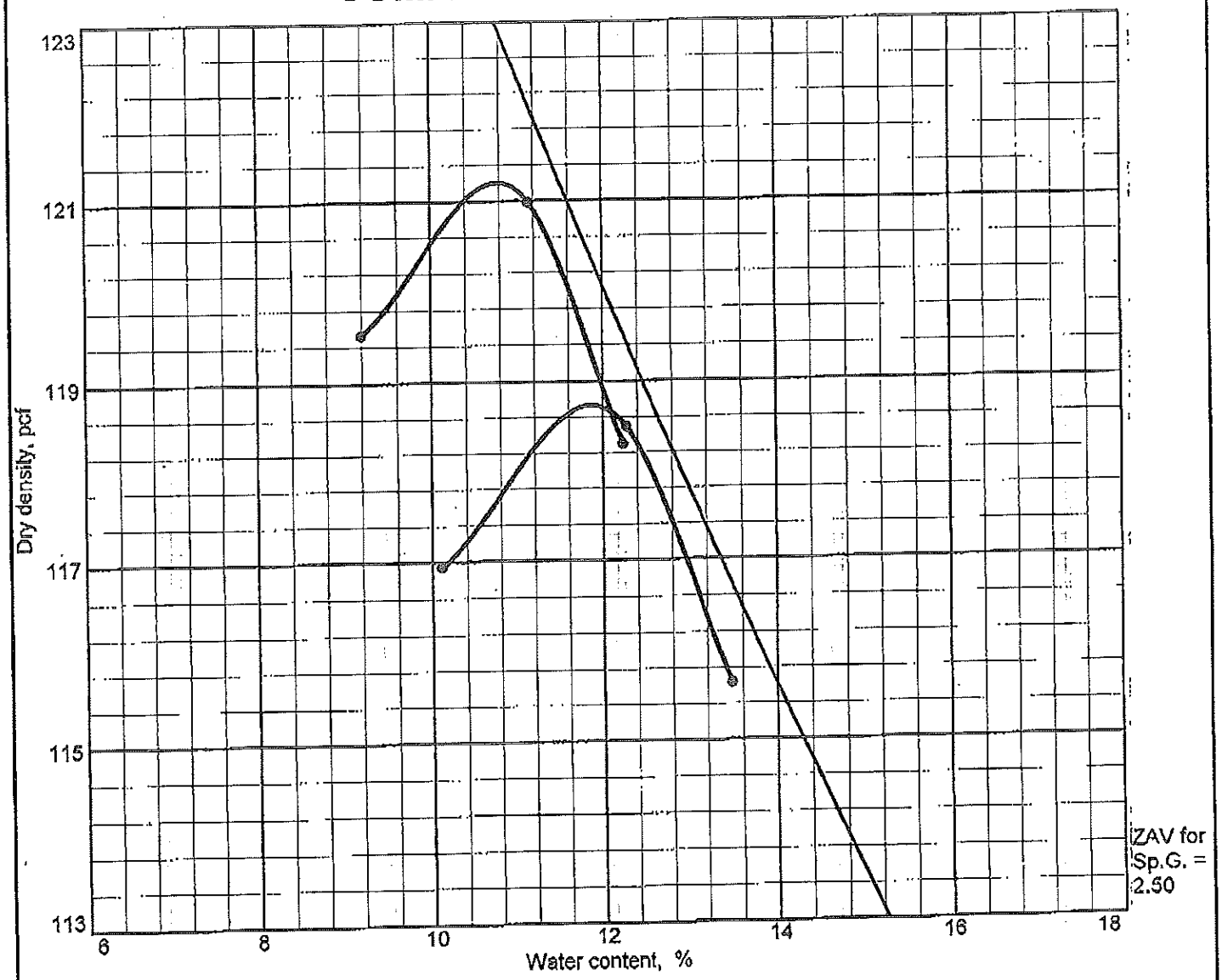
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

Figure 07-0605C

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SW | | | 2.39 | NP | NP | 10.0 | 3.3 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 121 pcf | 118.5 pcf | Well-graded sand with gravel |
| Optimum moisture = 11 % | 12 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** USEN-D1

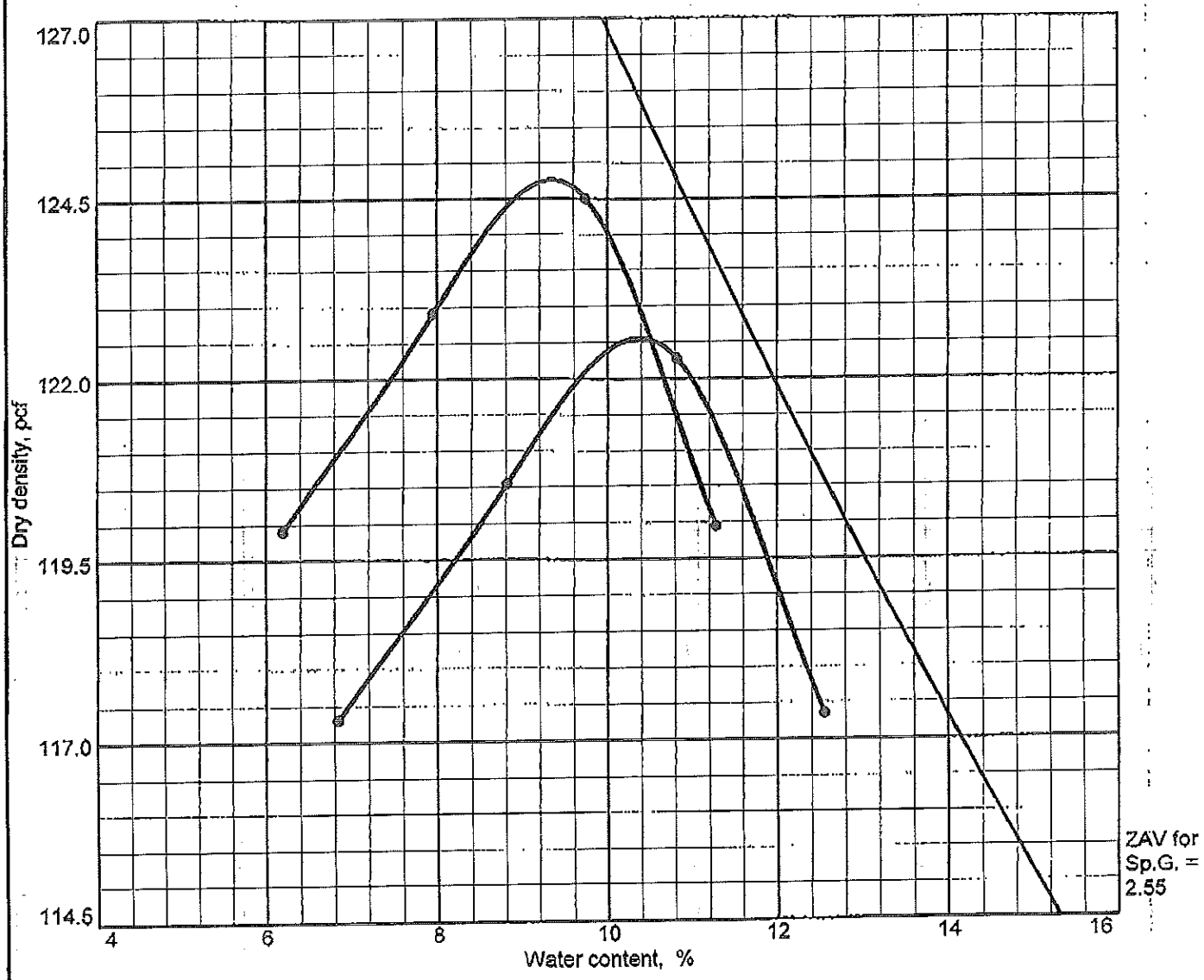
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0430G

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 In. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | SP-SM | | | 2.34 | NP | NP | 11.0 | 5.2 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED |
|---|---|
| Maximum dry density = 125 pcf | 122.5 pcf |
| Optimum moisture = 9.5 % | 10.5 % |

**MATERIAL DESCRIPTION**

Poorly graded sand with silt and gravel

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

**Location:** USEN-D2

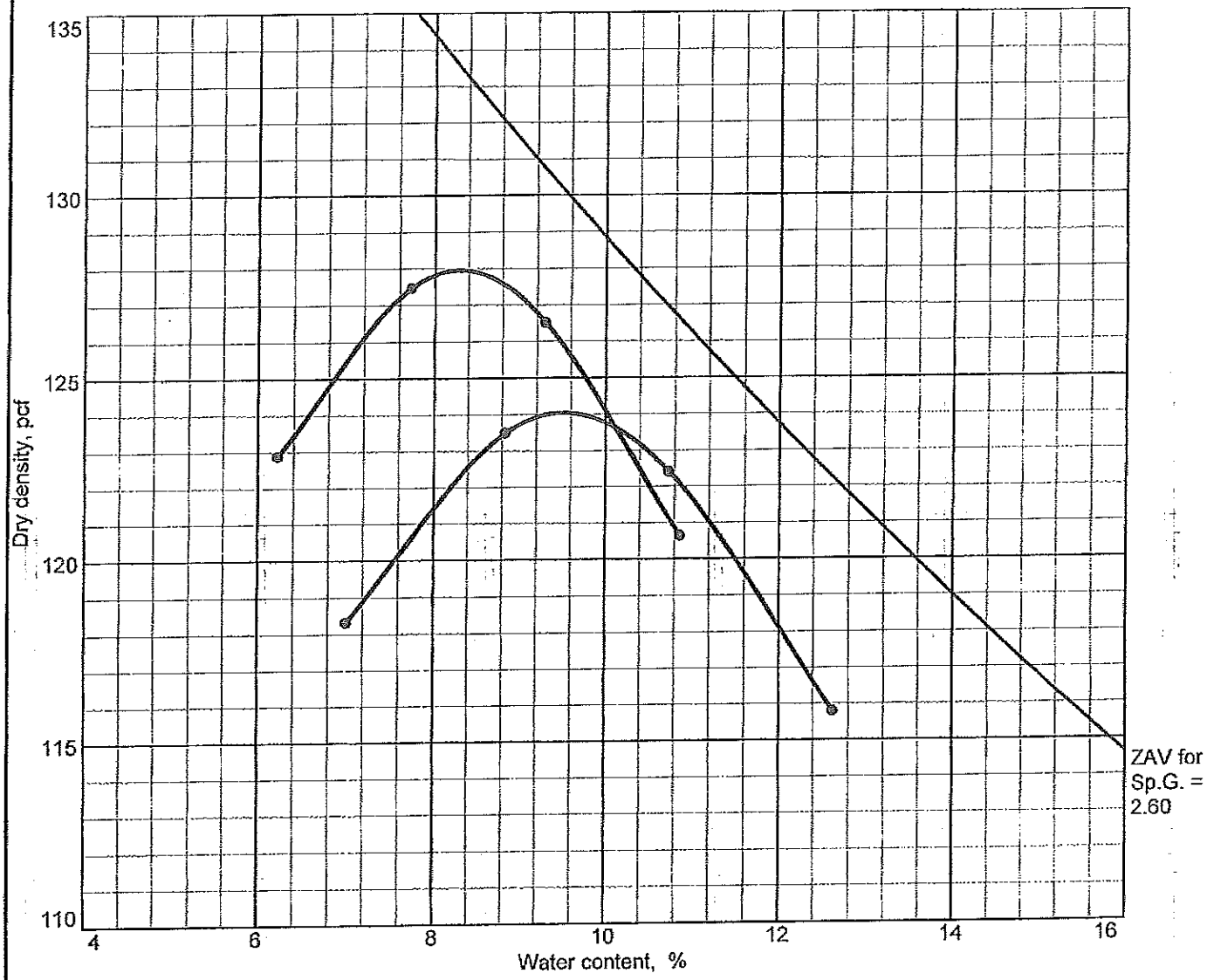
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0430H

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure B Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/8 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.41 | | | 17.4 | |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 128 pcf | 124 pcf | |
| Optimum moisture = 8.5 % | 9.5 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

**Location:** USEN-D1 and D2 w/5% Zeolite Clay

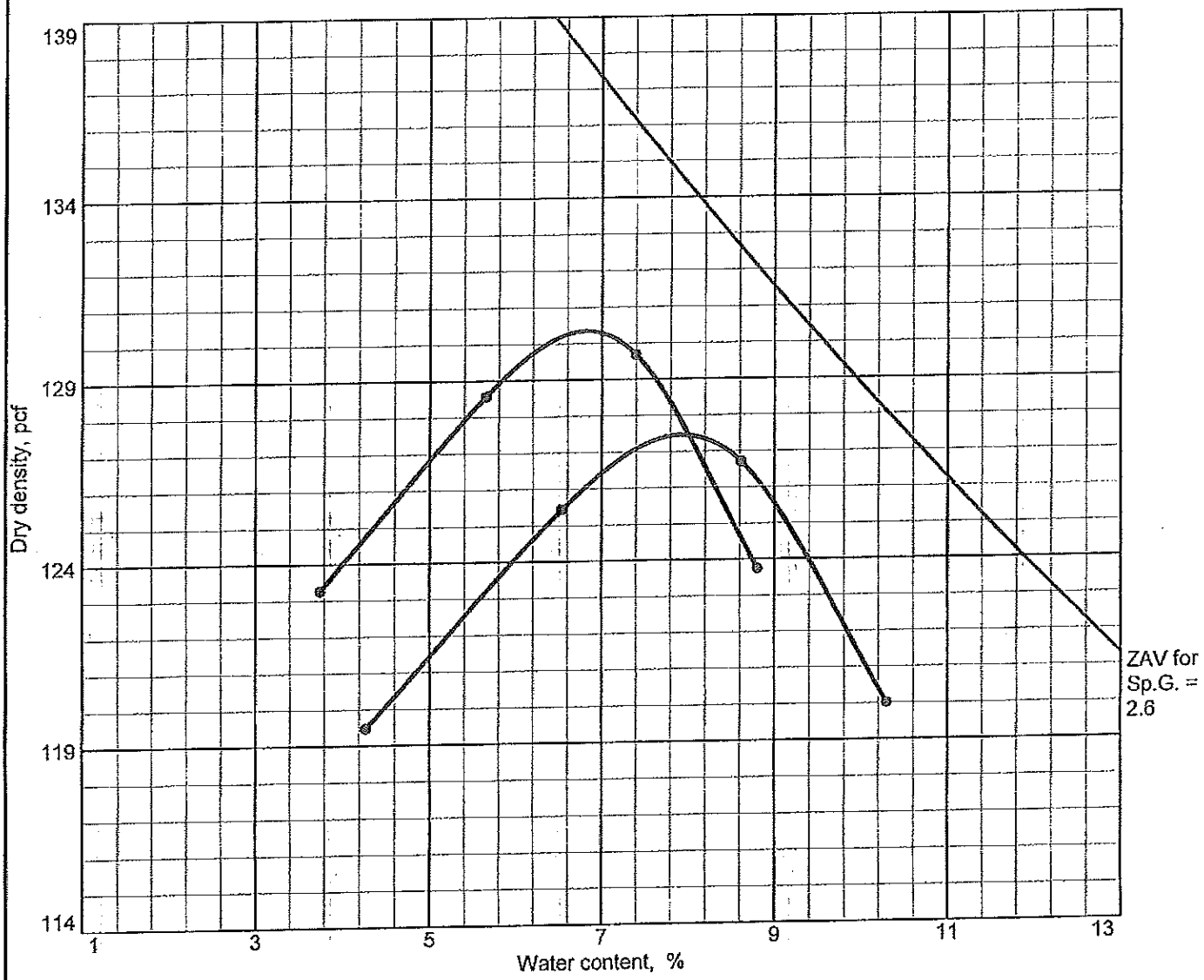
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0605D

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.37 | | | 16.0 | 7.8 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 130.5 pcf | 127.5 pcf | |
| Optimum moisture = 7 % | 8 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
● **Location:** Trench 12 Material mixed w/5% Imvite 1016 MIX 1

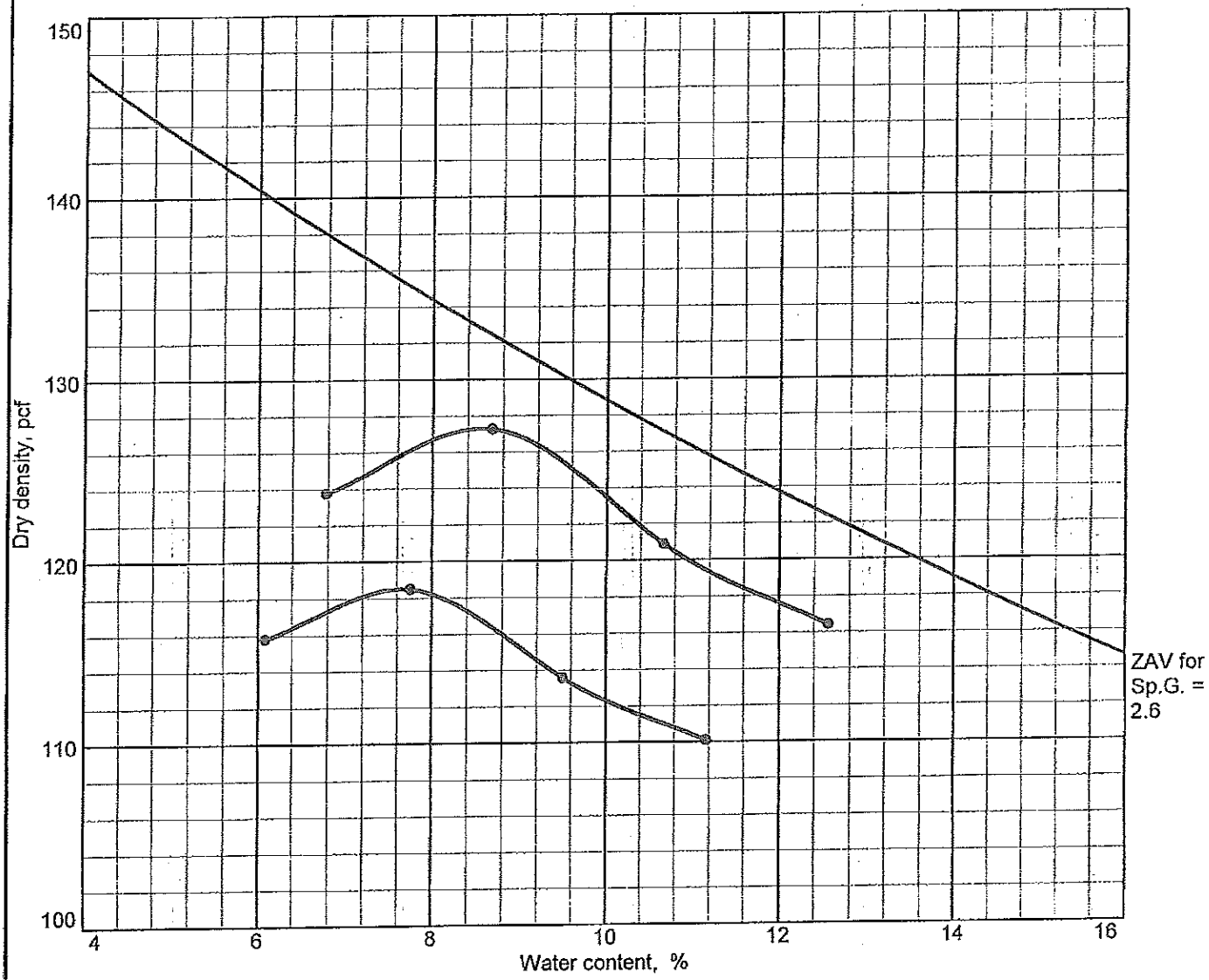
**Remarks:**
Sampled 9/14/07 ; Native w/5% Imvite 1016 ; Lab#07-0705A

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0705A

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 1.26 | | | 12.0 | 11 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 118.5 pcf | 127.5 pcf | |
| Optimum moisture = 7.5 % | 8.5 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
● **Location:** Trench 12 Material mixed w/10% Imvite 1016 MIX 2

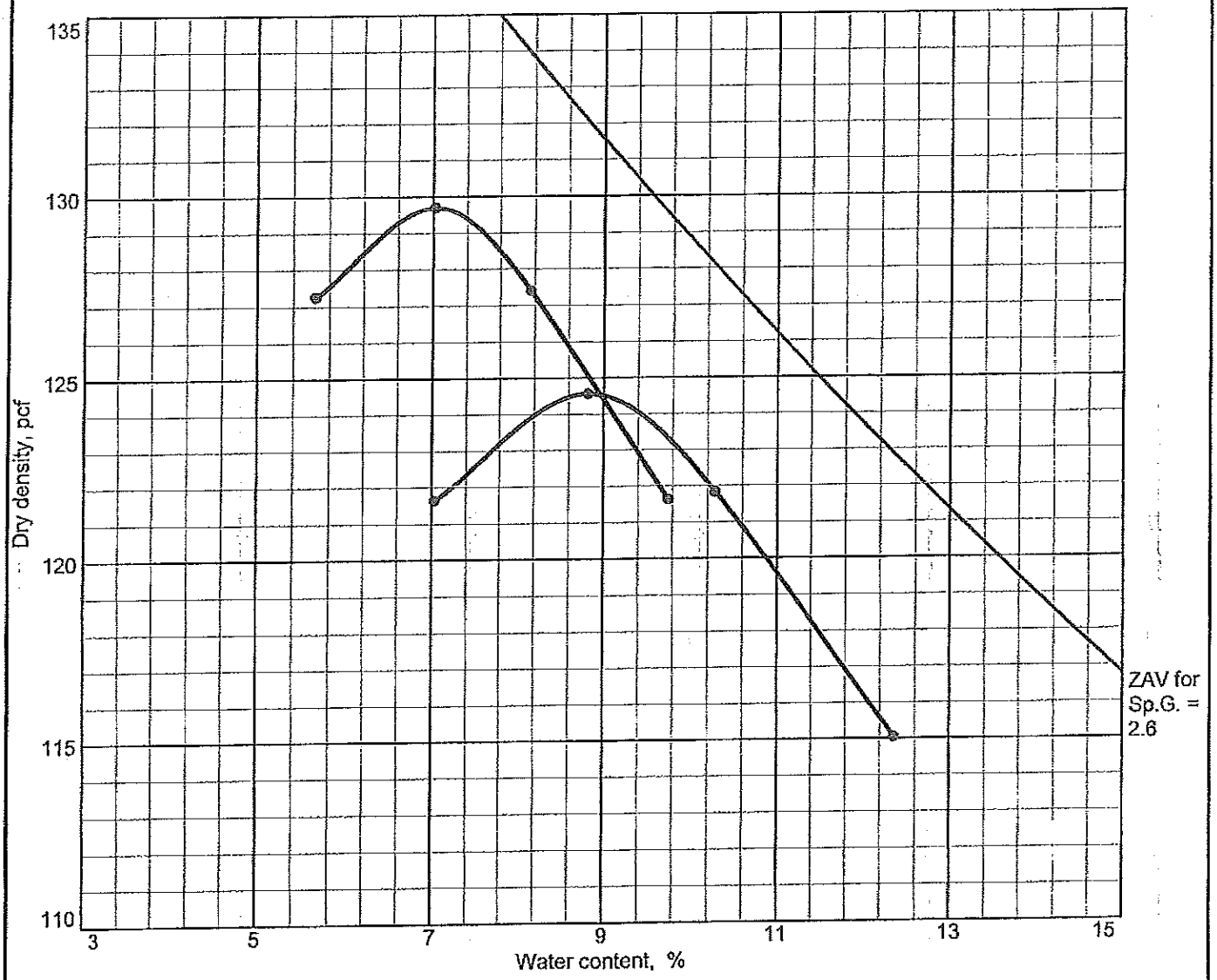
**Remarks:**
Samled 9/14/07 ; Native mixed w/10% Imvite ; Lab#07-0705B

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0705B

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.41 | | | 23.0 | 14 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 129.5 pcf | 124.5 pcf | |
| Optimum moisture = 7 % | 9 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
● **Location:** Trench 12 Material mixed w/15% Imvite MIX 3

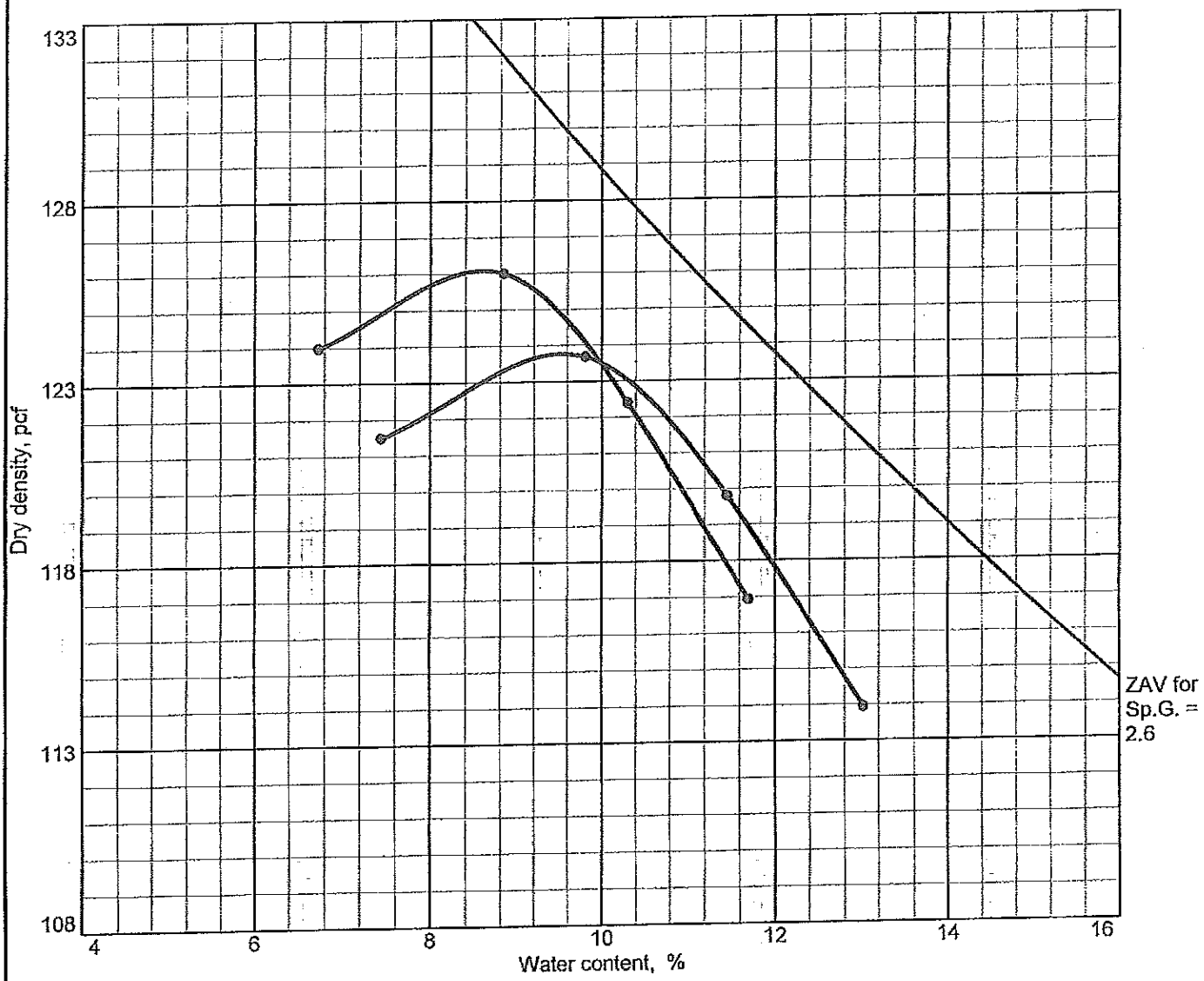
**Remarks:**
Sampled 9/14/07 ; ;Native mixed w/15% Imvite1016 ; Lab#07- 0705C

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0705C

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.38 | | | 11.0 | 12 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 126 pcf | 124 pcf | |
| Optimum moisture = 8.5 % | 9.5 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
● **Location:** Trench 12 Material mixed w/10% SEP/SAP MIX 4

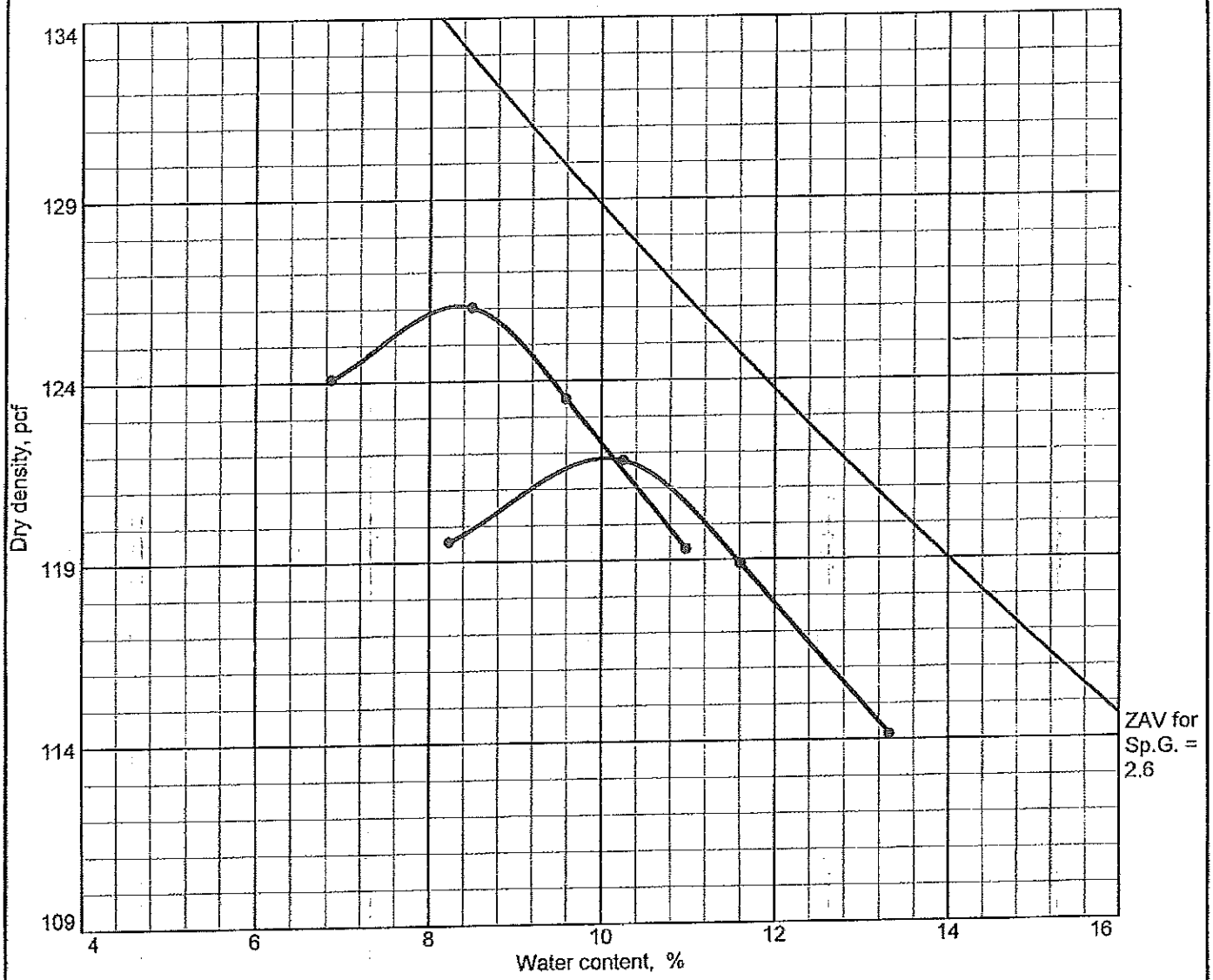
**Remarks:**
Sampled 9/14/07 ; Native mixed w/SEP/SAP ; Lab#07-0750D

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0705D

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.37 | | | 19.0 | 16 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 126 pcf | 122 pcf | |
| Optimum moisture = 8.5 % | 10 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113

● **Location:** Trench 12 material mixed w/15% SEP/SAP MIX 5

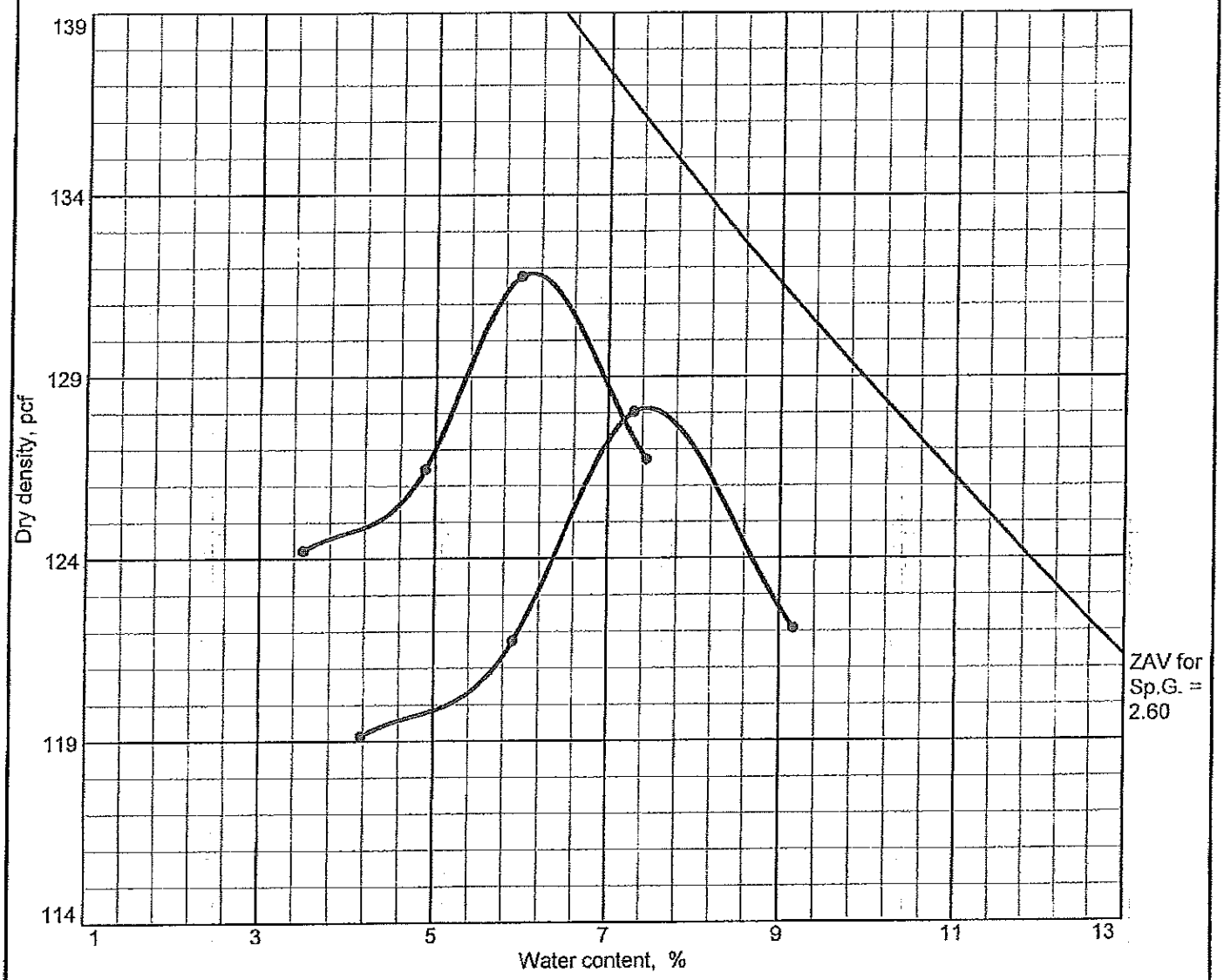
**Remarks:**
Sampled 9/14/07 ; Native mixed with 15% SEP/SAP ; Lab#07- 0705E

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

**Figure** 07-0705E

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.37 | | | 21.0 | 7.5 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED | MATERIAL DESCRIPTION |
|---|---|---|
| Maximum dry density = 132 pcf | 128 pcf | |
| Optimum moisture = 6 % | 7.5 % | |

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
• **Location:** Trench 12 Material Mixed w/5% Portland Cement MIX 6

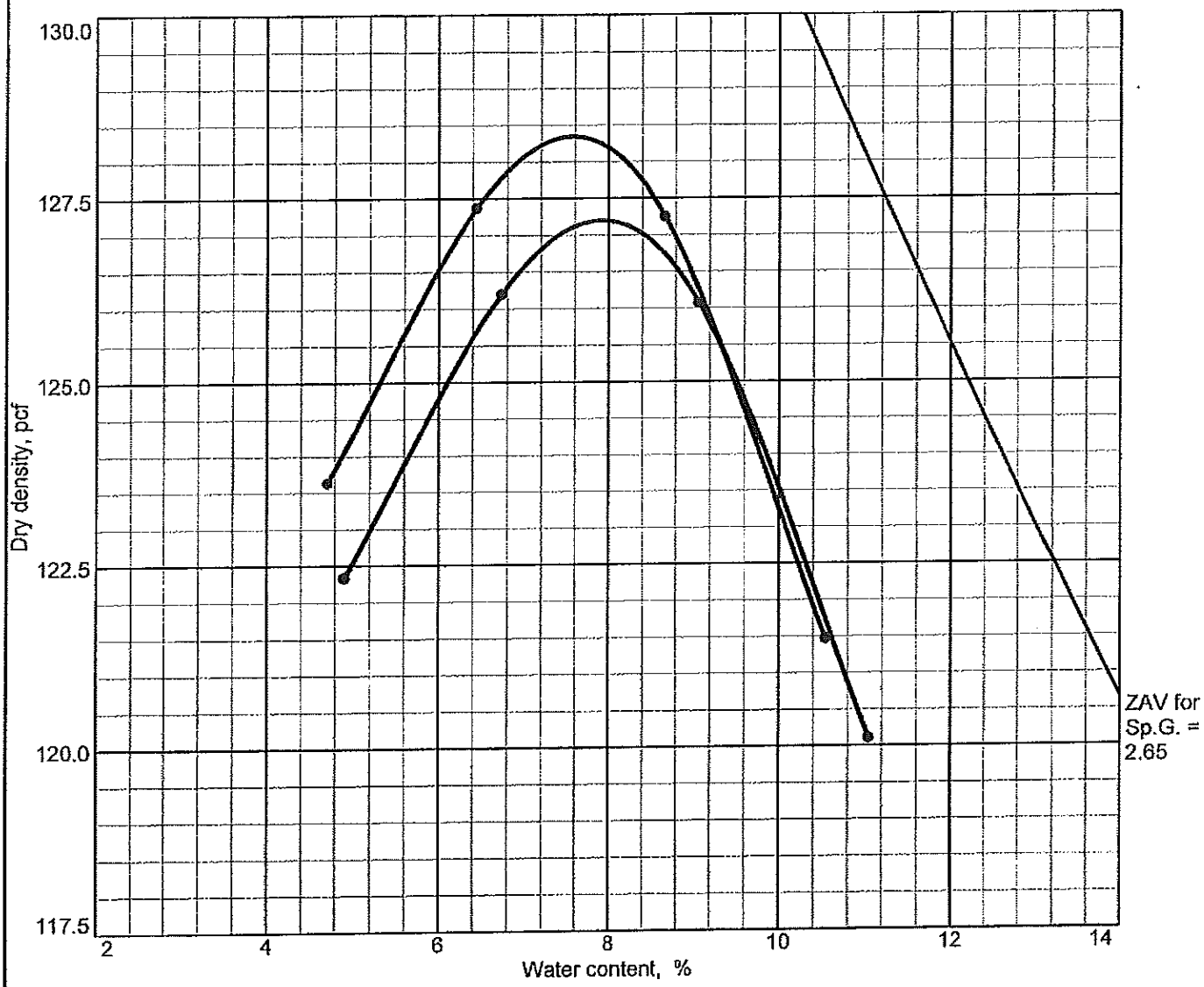
**Remarks:**

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

Figure 07-0705F

# COMPACTION TEST REPORT




Test specification: ASTM D 1557-00 Procedure C Modified
Oversize correction applied to each point

| Elev/ Depth | Classification | | Nat. Moist. | Sp.G. | LL | PI | % > 3/4 in. | % < No.200 |
|---|---|---|---|---|---|---|---|---|
| | USCS | AASHTO | | | | | | |
| | | | | 2.48 | | | | 7.8 |

| ROCK CORRECTED TEST RESULTS | UNCORRECTED |
|---|---|
| Maximum dry density = 128.5 pcf | 127 pcf |
| Optimum moisture = 7.5 % | 8 % |

MATERIAL DESCRIPTION

**Project No.** 07.1243 **Client:** U.S. Ecology-NV
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.# 07.3113
● **Location:** Trench 12 Material Mixed w/5% SEP/SAP MIX 7

Remarks:

COMPACTION TEST REPORT

**JOSEPH A. CESARE AND ASSOCIATES, INC.**

Figure 07-0852

## Result of Permeability Testing

**Knight Piésold** CONSULTING

# Falling Head Permeability

*Manual of Soil Laboratory Testing (K.H. Head) Section 10.7.2*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 7/23 - 7/31/07 |
| Sample No. | 07-0430A | Tested By | spb |
| Location | Native, USEN-A1 1800 ml | Checked By | SPB |

Specimen Data

| | | | | | |
|---|---|---|---|---|---|
| Sample Parameters: | Wet Sample Mass, g | 7366.5 | | | |
| | Dry Sample Mass, g | 6739.7 | | | |
| | Dry Unit Weight, pcf | 123.4 | | | |
| | Moisture Content, % | 9.3 | | | |
| Specimen Diameter, | in. | 8.020 | mm | 203.7 | |
| Specimen Height, | in. | 4.119 | mm | 104.6 | |
| Standpipe Diameter | in. | 0.250 | mm | 6.4 | |
| Specimen Area, | in.$^2$ | 50.52 | mm$^2$ | 32,591.6 | |
| Standpipe Area, | in.$^2$ | 0.05 | mm$^2$ | 31.7 | |

Permeability Trial Data

| Trial No. | Elapsed Time sec | Initial Head $h_1$ mm | Final Head $h_2$ mm | $h_1/h_2$ | log10($h_1/h_2$) | Hydraulic Conductivity k m/s | Hydraulic Conductivity k cm/sec |
|---|---|---|---|---|---|---|---|
| 1 | 60240.0 | 647.0 | 70.0 | 9.243 | 0.965806 | 3.8E-09 | 3.8E-07 |
| 2 | 2580.0 | 587.0 | 531.0 | 1.105 | 0.043544 | 4.0E-09 | 4.0E-07 |
| 3 | 5860.0 | 53.1 | 42.4 | 1.252 | 0.097729 | 3.9E-09 | 3.9E-07 |
| 4 | 4360.0 | 42.4 | 35.7 | 1.188 | 0.074698 | 4.0E-09 | 4.0E-07 |
| 5 | 6600.0 | 35.7 | 27.7 | 1.289 | 0.110188 | 3.9E-09 | 3.9E-07 |
| Averages | | | | | | 3.9E-09 | 3.9E-07 |

General Notes:

$$k = \frac{3.84 * a * L}{A * t} \log10(h1/h2) \times 1E\text{-}05$$

a = standpipe cross sectional area, mm$^2$

L = specimen length, mm

A = specimen cross sectional area, mm$^2$

t = elapsed time, minutes

**Knight Piésold** CONSULTING

# Constant Head Permeability

*USBR 5605, Amended*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 7/25 - 7/26/07 |
| Sample No. | 07-0430B | Tested By | spb |
| Location | Native, USEN-A2 | Checked By | SPB |

## Specimen Data

| | | | |
|---|---|---|---|
| Target Dry Density, pcf | 117.0 | Wet Sample Wt. + Tare, lbs. | 16.458 |
| Target Density, t/m$^3$ | NA | Tare, lbs. | 0.000 |
| Moisture Content, % | 6.1 | Wet Sample Wt., lbs. | 16.458 |
| Mold Diameter, in. | 8.02 | Sample Length, in. | 4.488 |
| Mold Area, in.$^2$ | 50.52 | Sample Volume, in.$^3$ | 226.7 |
| Mold Area, ft$^2$ | 0.3508 | Sample Volume, ft$^3$ | 0.1312 |
| Depth to Mold Bottom, in. | 8.701 | Wet Density, pcf | 125.4 |
| | | Initial Depth to Plate, in. | 4.213 |
| Normal Stress Range, psf | 144 | | |

## Permeability Trial Data

| | | | | | |
|---|---|---|---|---|---|
| Normal Stress, psf | 144 | | | Head, cm | 11.6 |
| Avg. Depth to Plate, in. | 4.252 | Consolidated Length, in. | 4.449 | Wet Density, pcf | 126.5 |

| Trial No. | Q cc | Time sec | Flow cc/sec | Permeability k, cm/sec |
|---|---|---|---|---|
| 1 | 34.3 | 240.00 | 0.143 | 4.3E-04 |
| 2 | 40.8 | 360.00 | 0.113 | 3.4E-04 |
| 3 | 58.9 | 540.00 | 0.109 | 3.3E-04 |
| 4 | 90.6 | 1020.00 | 0.089 | 2.7E-04 |
| 5 | 148.6 | 1740.00 | 0.085 | 2.6E-04 |
| 6 | 586.4 | 6840.00 | 0.086 | 2.6E-04 |
| 7 | 864.2 | 9780.00 | 0.088 | 2.6E-04 |
| Averages | | | 0.102 | 2.6E-04 |

General Notes:

1) Tap water was used as permeant.
2) Flow conditions may vary depending on the particle distribution in the field.
3) The sample was allowed to saturate overnight prior to initializing flow trials.
4) The sample was prepared by placing the material in three lifts to achieve the desired 100% MDD target density.

**Knight Piésold** CONSULTING

# Constant Head Permeability

*USBR 5605, Amended*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 08/22/07 |
| Sample No. | 07-0605A | Tested By | spb |
| Location | A2 WITH 5% ZEOLITE CLAY | Checked By | SPB |

Specimen Data

| | | | |
|---|---|---|---|
| Target Dry Density, pcf | 106.5 | Wet Sample Wt. + Tare, lbs. | 18.193 |
| Target Density, t/m$^3$ | NA | Tare, lbs. | 0.170 |
| Moisture Content, % | 6.8 | Wet Sample Wt., lbs. | 18.023 |
| Mold Diameter, in. | 8.02 | Sample Length, in. | 5.422 |
| Mold Area, in.$^2$ | 50.52 | Sample Volume, in.$^3$ | 273.9 |
| Mold Area, ft$^2$ | 0.3508 | Sample Volume, ft$^3$ | 0.1585 |
| Depth to Mold Bottom, in. | 8.701 | Wet Density, pcf | 113.7 |
| | | Initial Depth to Plate, in. | 3.279 |
| Normal Stress Range, psf | 144 | | |

Permeability Trial Data

| | | | | | |
|---|---|---|---|---|---|
| Normal Stress, psf | 144 | | | Head, cm | 10.2 |
| Avg. Depth to Plate, in. | 0.070 | Consolidated Length, in. | 8.631 | Wet Density, pcf | 71.4 |

| Trial No. | Q cc | Time sec | Flow cc/sec | Permeability k, cm/sec |
|---|---|---|---|---|
| 1 | 219.7 | 3029.00 | 0.073 | 4.8E-04 |
| 2 | 396.4 | 4672.00 | 0.085 | 5.6E-04 |
| 3 | 312.6 | 3875.00 | 0.081 | 5.3E-04 |
| 4 | 756.7 | 9520.00 | 0.079 | 5.2E-04 |
| 5 | 557.9 | 6883.00 | 0.081 | 5.3E-04 |
| Averages | | | 0.080 | 5.3E-04 |

General Notes:

1) Tap water was used as permeant.
2) Flow conditions may vary depending on the particle distribution in the field.
3) The sample was allowed to saturate overnight prior to initializing flow trials.
4) The sample was prepared by placing the material in the mold loosely and then lightly tapping the sides of the mold.

## FLEXIBLE WALL PERMEABILITY TEST
### ASTM D 5084-03
### Falling Head/Increasing Tailwater Pressure

| | | | |
|---|---|---|---|
| CLIENT: | J.A. Cesare | | |
| PROJECT: | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | PROJECT NO. : | DV108-59.7 |
| BORING NO. | | LAB NO. : | |
| DEPTH | | SAMPLE ID: | |
| SAMPLE NO. | 07-0605B (A3) | TEST STARTED : | 08/21/07 |
| SAMPLE TYPE | Cal. Liner | TEST FINISHED : | 08/24/07 |
| CONF. PRESSURE. (psi) | 3 | SATURATED TEST: | YES |

| MOISTURE/DENSITY DATA | BEFORE TEST | AFTER TEST |
|---|---|---|
| Wt. Soil + Moisture (g) | 1685.40 | 1751.80 |
| Wt. Wet Soil & Pan (g) | 1685.40 | 2170.70 |
| Wt. Dry Soil & Pan (g) | 1527.10 | 1946.00 |
| Wt. Moisture Lost (g) | 158.30 | 224.70 |
| Wt. of Pan Only (g) | 0.00 | 418.90 |
| Wt. of Dry Soil (g) | 1527.10 | 1527.10 |
| Moisture Content % | 10.4 | 14.7 |
| Wet Density (pcf) | 131.7 | 137.8 |
| Dry Density (pcf) | 119.3 | 120.1 |

| | | |
|---|---|---|
| Init. Diameter (in) | 3.940 | (cm) 10.008 |
| Init. Area (sq in) | 12.192 | (sq cm) 78.659 |
| Init. Height (in) | 4.000 | (cm) 10.160 |
| Height Change (in) | 0.024 | (cm) 0.061 |
| Consol. Height (in) | 3.976 | (cm) 10.099 |
| Area After Consol. (sq in) | 12.184 | (sq cm) 78.609 |

| | | |
|---|---|---|
| Vol. Before Consol. (cu ft) | 0.02822 | Specific Gravity 2.67 |
| Vol. Before Consol. (cc) | 799.2 | Assumed? Yes |
| Change in Vol. (cc) | 5.3 | |
| Cell Exp. (cc) | 0.0 | Init. Saturation 69.7 |
| Vol. After Consol. (cc) | 793.9 | Init. Void Ratio 0.397 |
| Vol. After Consol. (cu ft) | 0.02804 | Final Saturation 100.0 |
| Effective Porosity % | 28.43 | Final Void Ratio 0.388 |
| Pressure Difference (psi): | 0.00 | |
| C = | 0.13604 | Buret Constant, a 0.920 |
| k, cm/s = (C/t)*log(h1/h2) | | Buret Stand 3 |

### Permeability Test Trials

| Time min. | Cap Elevation cc | Pedestal Elevation cc | Elevation Head cm | Total Head cm | Permeability k cm/sec |
|---|---|---|---|---|---|
| 0.00 | 48.0 | 1.5 | 50.2 | 50.2 | |
| 0.25 | 45.1 | 4.7 | 43.6 | 43.6 | 5.5E-04 |
| 0.25 | 42.2 | 7.5 | 37.5 | 37.5 | 6.0E-04 |
| 0.25 | 39.8 | 9.8 | 32.4 | 32.4 | 5.7E-04 |
| 0.25 | 37.8 | 11.8 | 28.1 | 28.1 | 5.6E-04 |
| 0.25 | 36.0 | 13.6 | 24.2 | 24.2 | 5.9E-04 |
| 0.25 | 34.5 | 15.1 | 21.0 | 21.0 | 5.7E-04 |
| | | | Avg.of Last 4 Rdgs. | | 5.7E-04 |

General Test Notes:
1) Tap water was used as the permeant.
2) Back pressure saturation continued until 'B' parameter a minimum of 0.95.

## FLEXIBLE WALL PERMEABILITY TEST

### ASTM D 5084-03

### Falling Head/Increasing Tailwater Pressure

| | | | |
|---|---|---|---|
| CLIENT: | J.A. Cesare | | |
| PROJECT: | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | PROJECT NO. : | DV108-59.7 |
| BORING NO. | | LAB NO. : | |
| DEPTH | | SAMPLE ID: | |
| SAMPLE NO. | 07-0605B (A3) | TEST STARTED : | 08/21/07 |
| SAMPLE TYPE | Cal. Liner | TEST FINISHED : | 08/24/07 |
| CONF. PRESSURE. (psi) | 10 | SATURATED TEST: | YES |

| MOISTURE/DENSITY DATA | BEFORE TEST | AFTER TEST |
|---|---|---|
| Wt. Soil + Moisture (g) | 1685.40 | 1749.80 |
| Wt. Wet Soil & Pan (g) | 1685.40 | 2168.70 |
| Wt. Dry Soil & Pan (g) | 1527.10 | 1946.00 |
| Wt. Moisture Lost (g) | 158.30 | 222.70 |
| Wt. of Pan Only (g) | 0.00 | 418.90 |
| Wt. of Dry Soil (g) | 1527.10 | 1527.10 |
| Moisture Content % | 10.4 | 14.6 |
| Wet Density (pcf) | 131.7 | 137.9 |
| Dry Density (pcf) | 119.3 | 120.4 |

| | | | |
|---|---|---|---|
| Init. Diameter (in) | 3.940 | (cm) | 10.008 |
| Init. Area (sq in) | 12.192 | (sq cm) | 78.659 |
| Init. Height (in) | 4.000 | (cm) | 10.160 |
| Height Change (in) | 0.024 | (cm) | 0.061 |
| Consol. Height (in) | 3.976 | (cm) | 10.099 |
| Area After Consol. (sq in) | 12.153 | (sq cm) | 78.411 |

| | | | |
|---|---|---|---|
| Vol. Before Consol. (cu ft) | 0.02822 | Specific Gravity | 2.67 |
| Vol. Before Consol. (cc) | 799.2 | Assumed? | Yes |
| Change in Vol. (cc) | 7.3 | | |
| Cell Exp. (cc) | 0.0 | Init. Saturation | 69.7 |
| Vol. After Consol. (cc) | 791.9 | Init. Void Ratio | 0.397 |
| Vol. After Consol. (cu ft) | 0.02796 | Final Saturation | 100.0 |
| Effective Porosity % | 28.43 | Final Void Ratio | 0.385 |
| Pressure Difference (psi): | 0.00 | | |
| C = | 0.13638 | Buret Constant, a | 0.920 |
| k, cm/s = (C/t)*log(h1/h2) | | Buret Stand | 3 |

### Permeability Test Trials

| Time min. | Cap Elevation cc | Pedestal Elevation cc | Elevation Head cm | Total Head cm | Permeability k cm/sec |
|---|---|---|---|---|---|
| 0.00 | 48.7 | 2.0 | 50.4 | 50.4 | |
| 0.25 | 45.9 | 5.0 | 44.2 | 44.2 | 5.2E-04 |
| 0.25 | 43.1 | 7.6 | 38.3 | 38.3 | 5.6E-04 |
| 0.25 | 40.9 | 10.0 | 33.4 | 33.4 | 5.5E-04 |
| 0.25 | 38.8 | 11.9 | 29.1 | 29.1 | 5.5E-04 |
| | | | Avg.of Last 4 Rdgs. | | 5.4E-04 |

General Test Notes:
1) Tap water was used as the permeant.
2) Back pressure saturation continued until 'B' parameter a minimum of 0.95.

**Knight Piésold** CONSULTING

# Constant Head Permeability

*USBR 5605, Amended*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 7/21 - 7/22/07 |
| Sample No. | 07-0430D | Tested By | spb |
| Location | Native, USEN-B1 | Checked By | SPB |

## Specimen Data

| | | | |
|---|---|---|---|
| Target Dry Density, pcf | NA | Wet Sample Wt. + Tare, lbs. | 37.119 |
| Target Density, t/m$^3$ | NA | Tare, lbs. | 17.813 |
| Moisture Content, % | NA | Wet Sample Wt., lbs. | 19.306 |
| Mold Diameter, in. | 8.02 | Sample Length, in. | 7.520 |
| Mold Area, in.$^2$ | 50.52 | Sample Volume, in.$^3$ | 379.9 |
| Mold Area, ft$^2$ | 0.3508 | Sample Volume, ft$^3$ | 0.2198 |
| Depth to Mold Bottom, in. | 8.701 | Wet Density, pcf | 87.8 |
| | | Initial Depth to Plate, in. | 1.181 |
| Normal Stress Range, psf | 144 | | |

## Permeability Trial Data

| | | | | | |
|---|---|---|---|---|---|
| Normal Stress, psf | 144 | | | Head, cm | 1.3 |
| Avg. Depth to Plate, in. | 1.220 | Consolidated Length, in. | 7.481 | Wet Density, pcf | 88.3 |

| Trial No. | Q cc | Time sec | Flow cc/sec | Permeability k, cm/sec |
|---|---|---|---|---|
| 1 | 1132.5 | 29.67 | 38.2 | 1.7E+00 |
| 2 | 1132.5 | 29.47 | 38.4 | 1.7E+00 |
| 3 | 1132.5 | 29.41 | 38.5 | 1.7E+00 |
| 4 | 1132.5 | 29.56 | 38.3 | 1.7E+00 |
| 5 | 1132.5 | 29.73 | 38.1 | 1.7E+00 |
| 6 | 1132.5 | 29.81 | 38.0 | 1.7E+00 |
| 7 | 1132.5 | 29.66 | 38.2 | 1.7E+00 |
| Averages | | | 38.241 | 1.7E+00 |

General Notes:

1) Tap water was used as permeant.
2) Flow conditions may vary depending on the particle distribution in the field.
3) The sample was allowed to saturate overnight prior to initializing flow trials.
4) The sample was prepared by placing the material in the mold loosely and then lightly tapping the sides of the mold.

**Knight Piésold** CONSULTING

# Constant Head Permeability

*USBR 5605, Amended*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 08/20/07 |
| Sample No. | 07-0605E | Tested By | spb |
| Location | Native, USEN-B1, SECOND SAMPLE | Checked By | SPB |

Specimen Data

| | | | |
|---|---|---|---|
| Target Dry Density, pcf | NA | Wet Sample Wt. + Tare, lbs. | 38.158 |
| Target Density, t/m$^3$ | NA | Tare, lbs. | 15.920 |
| Moisture Content, % | NA | Wet Sample Wt., lbs. | 22.238 |
| Mold Diameter, in. | 8.02 | Sample Length, in. | 8.701 |
| Mold Area, in.$^2$ | 50.52 | Sample Volume, in.$^3$ | 439.5 |
| Mold Area, ft$^2$ | 0.3508 | Sample Volume, ft$^3$ | 0.2544 |
| Depth to Mold Bottom, in. | 8.701 | Wet Density, pcf | 87.4 |
| | | Initial Depth to Plate, in. | 0.000 |
| Normal Stress Range, psf | 144 | | |

Permeability Trial Data

| | | | | | |
|---|---|---|---|---|---|
| Normal Stress, psf | 144 | | | Head, cm | 1.2 |
| Avg. Depth to Plate, in. | 0.070 | Consolidated Length, in. | 8.631 | Wet Density, pcf | 88.1 |

| Trial No. | Q cc | Time sec | Flow cc/sec | Permeability k, cm/sec |
|---|---|---|---|---|
| 1 | 453 | 11.87 | 38.2 | 2.1E+00 |
| 2 | 453 | 12.13 | 37.3 | 2.1E+00 |
| 3 | 453 | 12.18 | 37.2 | 2.1E+00 |
| 4 | 453 | 11.88 | 38.1 | 2.1E+00 |
| 5 | 453 | 12.04 | 37.6 | 2.1E+00 |
| 6 | 453 | 12.08 | 37.5 | 2.1E+00 |
| 7 | 453 | 12.00 | 37.8 | 2.1E+00 |
| Averages | | | 37.672 | 2.1E+00 |

General Notes:

1) Tap water was used as permeant.
2) Flow conditions may vary depending on the particle distribution in the field.
3) The sample was allowed to saturate overnight prior to initializing flow trials.
4) The sample was prepared by placing the material in the mold loosely and then lightly tapping the sides of the mold.

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd. Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Report to :
Attention :
Sample Identification : 07-07705A (#8289)
Sample description: Trench #12 Material mixed w/ 5% Invite 1016

Project Name: U.S. Ecology NV
Date Received: 1·
Date of Report :
Reported By: *Juan L. Martinez*

OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density

MIX 1

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 30 | psi | |
| Upper Cap Pressure: | 27 | psi | |
| Lower Cap Pressure: | 26.2 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 56.44 | cm | |
| Maximum Dry Density: | 127.5 | $lbs/ft^3$ | |
| Optimum % Moisture: | 8.0 % | | |
| Weight of Sample: | 588.9 | grams | |
| Sample % Moisture: | 8.1 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 114.5 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 89.8 % | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.1 | 0.1 | 0.1 | 0.1 | |
| Final Inlet Burette Reading: | 18.5 | 19.1 | 19.9 | 15.6 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 5.5 | 5.1 | 4.3 | 8.4 | |
| Initial Reading Time: | 4:38:00 AM | 7:59:00 AM | 11:39:00 AM | 3:10:00 PM | |
| Final Reading Time: | 7:45:00 AM | 11:15 AM | 2:45:00 PM | 5:00:00 PM | |
| Elapsed Time [T-S] (H:M:S): | 3:07:00 | 3:16:00 | 3:06:00 | 1:50:00 | |
| Elapsed Time (seconds) | 11220 | 11760 | 11160 | 6600 | |
| Inlet Flow [P-O]: | 18.4 | 19.0 | 19.8 | 15.5 | |
| Outlet Flow [R-Q] (should be * 5 % of W): | 18.5 | 18.9 | 19.7 | 15.6 | |
| Temperature (°C): | 20.1 | 20.1 | 19.5 | 19.5 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 1.00215 | 1.00215 | 1.01686 | 1.01686 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 1.012 E-05 | 9.970 E-06 | 1.111 E-05 | 1.471 E-05 | |

**Average Permeability (cm/s):** 1.148 E-05 cm/s

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd. Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Project Name: U.S. Ecology NV
Report to :
Date Received: 1
Attention :
Date of Report :
Sample Identification : 07-07705B (#8290)
Reported By: *Juan L. Martinez*
Sample description: Trench #12 Material mixed w/ 10% Invite 1016
OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density

MIX2

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 30 | psi | |
| Upper Cap Pressure: | 27 | psi | |
| Lower Cap Pressure: | 26.2 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 56.44 | cm | |
| Maximum Dry Density: | 127.5 | $lbs/ft^3$ | |
| Optimum % Moisture: | 8.5 % | | |
| Weight of Sample: | 589.5 | grams | |
| Sample % Moisture: | 8.5 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 114.9 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 90.1% | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.1 | 0.1 | 0.1 | 0.1 | |
| Final Inlet Burette Reading: | 15.6 | 16.3 | 15.2 | 15.8 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 8.3 | 7.3 | 7.8 | 9.2 | |
| Initial Reading Time: | 4:36:00 AM | 7:45:00 AM | 11:35:00 AM | 3:10:00 PM | |
| Final Reading Time: | 7:45:00 AM | 11:15:00 AM | 2:55:00 PM | 6:32:00 PM | |
| Elapsed Time [T-S] (H:M:S | 3:09:00 | 3:30:00 | 3:20:00 | 3:22:00 | |
| Elapsed Time (seconds) | 11340 | 12600 | 12000 | 12120 | |
| Inlet Flow [P-O]: | 18.4 | 19.0 | 19.8 | 15.5 | |
| Outlet Flow [R-Q] (should be * 5 % of W): | 18.5 | 18.9 | 19.7 | 15.6 | |
| Temperature (°C): | 20.9 | 20.1 | 19.9 | 19.5 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 0.98253 | 1.00215 | 1.00705 | 1.01686 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z] | 5.471 E-06 | 6.125 E-06 | 6.193 E-06 | 6.471 E-06 | |

**Average Permeability (cm/s): 6.315 E-06 cm/s**

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd. Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Report to :
Attention :
Sample Identification : 07-07705C (#8291)
Sample description: Trench #12 Material mixed w/ 15% Invite

Project Name: U.S. Ecology NV
Date Received: 1'
Date of Report :
Reported By: *Juan L. Martinez*

OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

MIX 3

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 30 | psi | |
| Upper Cap Pressure: | 27 | psi | |
| Lower Cap Pressure: | 26 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 70.56 | cm | |
| Maximum Dry Density: | 124.5 | $lbs/ft^3$ | |
| Optimum % Moisture: | 9.0 % | | |
| Weight of Sample: | 576.4 | grams | |
| Sample % Moisture: | 7.5 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 112.7 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 90.5 % | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.1 | 0.1 | 0.1 | 0.1 | |
| Final Inlet Burette Reading: | 11.7 | 12.1 | 12.2 | 10.2 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 12.5 | 12.3 | 12.0 | 13.6 | |
| Initial Reading Time: | 4:35:00 AM | 7:55:00 AM | 11:30:00 AM | 3:00:00 PM | |
| Final Reading Time: | 7:45:00 AM | 11:15 AM | 2:45:00 PM | 5:00:00 PM | |
| Elapsed Time [T-S] (H:M:S): | 3:10:00 | 3:20:00 | 3:15:00 | 2:00:00 | |
| Elapsed Time (seconds) | 11400 | 12000 | 11700 | 7200 | |
| Inlet Flow [P-O]: | 11.6 | 12.0 | 12.1 | 10.1 | |
| Outlet Flow [R-Q] (should be " 5 % of W): | 11.5 | 11.7 | 12.0 | 10.4 | |
| Temperature (°C): | 20.1 | 20.1 | 19.5 | 19.5 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 1.00215 | 1.00215 | 1.01686 | 1.01686 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 5.023 E-06 | 4.936 E-06 | 5.180 E-06 | 7.026 E-06 | |

**Average Permeability (cm/s): 5.541 E-06 cm/s**

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd, Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Report to :
Attention :
Sample identification : 07-07705D (#8292)
Sample description: Trench #12 Material mixed w/ 10% SEP/SAP

Project Name: U.S. Ecology NV
Date Received: 1·
Date of Report :
Reported By: *Juan L. Martinez*

OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density MIX 4

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 30 | psi | |
| Upper Cap Pressure: | 27 | psi | |
| Lower Cap Pressure: | 26 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 70.56 | cm | |
| Maximum Dry Density: | 124 | $lbs/ft^3$ | |
| Optimum % Moisture: | 9.5 % | | |
| Weight of Sample: | 586.4 | grams | |
| Sample % Moisture: | 9.1 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 113.0 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 91.1 % | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.0 | 0.0 | 0.0 | 0.0 | |
| Final Inlet Burette Reading: | 15.1 | 15.5 | 15.0 | 15.6 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 9.0 | 8.4 | 8.9 | 8.4 | |
| Initial Reading Time: | 5:50:00 AM | 9:33:00 AM | 1:15:00 PM | 6:46:00 AM | |
| Final Reading Time: | 9:15:00 AM | 1:00 PM | 4:35:00 PM | 10:15:00 AM | |
| Elapsed Time [T-S] (H:M:S): | 3:25:00 | 3:27:00 | 3:20:00 | 3:29:00 | |
| Elapsed Time (seconds) | 12300 | 12420 | 12000 | 12540 | |
| Inlet Flow [P-O]: | 15.1 | 15.5 | 15.0 | 15.6 | |
| Outlet Flow [R-Q] (should be * 5 % of W): | 15.0 | 15.6 | 15.1 | 15.6 | |
| Temperature (*C): | 20.9 | 20.1 | 19.9 | 19.5 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 0.98253 | 1.00215 | 1.00705 | 1.01686 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 5.937 E-06 | 6.156 E-06 | 6.196 E-06 | 6.227 E-06 | |

Average Permeability (cm/s): 6.129 E-06 cm/s

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd. Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Report to :
Attention :
Sample Identification : 07-07705E (#8293)
Sample description: Trench #12 Material mixed w/ 15% SEP/SAP

Project Name: U.S. Ecology NV
Date Received: 1·
Date of Report :
Reported By: *Juan L. Martinez*

OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

MIX 5

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 30 | psi | |
| Upper Cap Pressure: | 27 | psi | |
| Lower Cap Pressure: | 26 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 70.56 | cm | |
| Maximum Dry Density: | 122 | $lbs/ft^3$ | |
| Optimum % Moisture: | 10.0 % | | |
| Weight of Sample: | 578.1 | grams | |
| Sample % Moisture: | 9.8 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 110.7 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 90.7 % | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.0 | 0.0 | 0.0 | 0.0 | |
| Final Inlet Burette Reading: | 16.4 | 15.9 | 16.9 | 15.3 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 7.6 | 8.1 | 7.1 | 8.7 | |
| Initial Reading Time: | 5:45:00 AM | 9:25:00 AM | 1:08:00 PM | 6:34:00 AM | |
| Final Reading Time: | 9:15:00 AM | 12:58 PM | 4:34:00 PM | 10:14:00 AM | |
| Elapsed Time [T-S] (H:M:S): | 3:30:00 | 3:33:00 | 3:26:00 | 3:40:00 | |
| Elapsed Time (seconds) | 12600 | 12780 | 12360 | 13200 | |
| Inlet Flow [P-O]: | 16.4 | 15.9 | 16.9 | 15.3 | |
| Outlet Flow [R-Q] (should be * 5 % of W): | 16.4 | 15.9 | 16.9 | 15.3 | |
| Temperature (*C): | 21.2 | 20.1 | 19.9 | 19.5 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 0.97518 | 1.00215 | 1.00705 | 1.01686 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 6.248 E-06 | 6.137 E-06 | 6.778 E-06 | 5.802 E-06 | |

**Average Permeability (cm/s): 6.241 E-06 cm/s**

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd. Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-33102-01
Report to :
Attention :
Sample Identification : 07-07705F (#8294)
Sample description: Trench #12 Material mixed w/ 5% of Portland Cement

Project Name: U.S. Ecology NV
Date Received: 1
Date of Report :
Reported By: *Juan L. Martinez*

OBS: Test performed on material passing #4, compacted 90% of the uncorrected Maximum dry density

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

MIX 6.

| | | | Average |
|---|---|---|---|
| Initial Height of Sample (inches): | 4.000 | | 4.000 |
| Final Height of Sample (inches): | 4.000 | | 4.000 |
| Initial Diameter of Sample (inches): | 2.400 | | 2.402 |
| Final Diameter of Sample (inches): | 2.400 | | 2.400 |
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ | |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ | |
| Cell Pressure: | 40 | psi | |
| Upper Cap Pressure: | 38 | psi | |
| Lower Cap Pressure: | 36 | psi | |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 141.11 | cm | |
| Maximum Dry Density: | 128 | $lbs/ft^3$ | |
| Optimum % Moisture: | 7.5 % | | |
| Weight of Sample: | 589.7 | grams | |
| Sample % Moisture: | 7.3 % | | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 115.5 | $lbs/ft^3$ | |
| Sample % Compaction [M/Ix100]: | 90.2 % | | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.0 | 0.0 | 0.0 | 0.0 | |
| Final Inlet Burette Reading: | 9.7 | 9.9 | 12.5 | 10.3 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 14.1 | 14.2 | 11.4 | 13.9 | |
| Initial Reading Time: | 5:25:00 AM | 6:12:00 AM | 4:30:00 AM | 6:46:00 AM | |
| Final Reading Time: | 3:34:00 PM | 4:33:00 PM | 4:35:00 PM | 5:31:00 PM | |
| Elapsed Time [T-S] (H:M:S): | 10:09:00 | 10:21:00 | 12:05:00 | 10:45:00 | |
| Elapsed Time (seconds) | 36540 | 37260 | 43500 | 38700 | |
| Inlet Flow [P-O]: | 9.7 | 9.9 | 12.5 | 10.3 | |
| Outlet Flow [R-Q] (should be ± 5 % of W): | 9.9 | 9.8 | 12.6 | 10.1 | |
| Temperature (°C): | 20.2 | 20.1 | 20.1 | 20.2 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 0.9997 | 1.00215 | 1.00215 | 0.9997 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 6.529 E-07 | 6.551 E-07 | 7.087 E-07 | 6.547 E-07 | |

**Average Permeability (cm/s):** 6.679 E-07 cm/s

**Converse Consultants**
*Geotechnical Engineering and Environmental Sciences*

222 Huntington Rd, Suite 211
Monrovia - California 91016
Telephone: (626) 930 1200
Facsimile:(626) 930 1212

Project Number :07-1243
Report to : JA Cesar
Attention : Joshua Williams
Sample Identification : 07-0852
Sample description: Trench 12 Material w/5% SEP/SAP

Project Name: US Ecology Testing
Date Received: 11
Date of Report : 12/11/2007
Reported By: Juan L. Martinez

MIX 7

OBS: Test performed on material passing #4, compacted 90% of the uncorrected maximum dry density

## PERMEABILITY OF FINE GRAINED SOILS

ASTM D 5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials using a Flexible Wall Permeameter" Method A

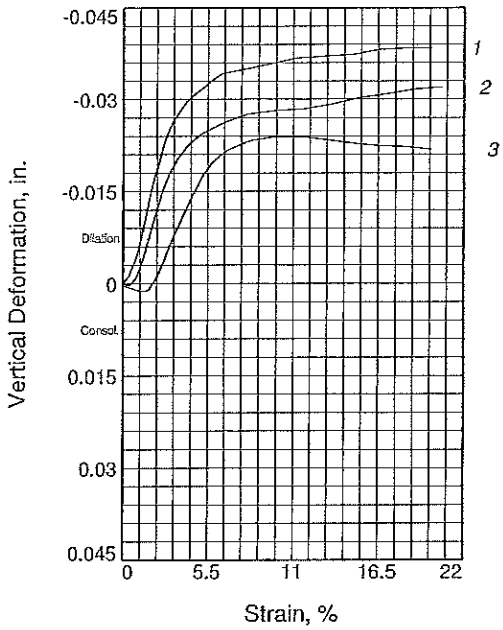
| | | | | | Average |
|---|---|---|---|---|---|
| Initial Height of Sample (inches): | 4.012 | 4.018 | 4.022 | 4.011 | 4.016 |
| Final Height of Sample (inches): | | | | | |
| Initial Diameter of Sample (inches): | 2.409 | 2.402 | 2.411 | 2.402 | 2.402 |
| Final Diameter of Sample (inches): | | | | | |

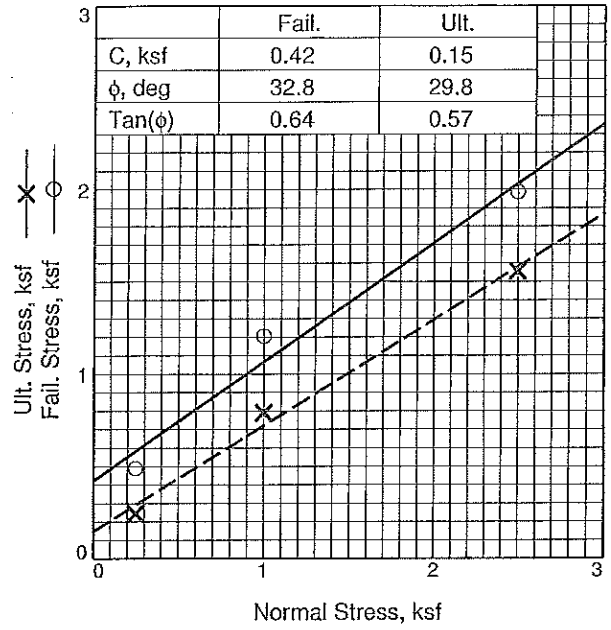
| | | |
|---|---|---|
| Area of Sample [ 3.1416 x $B^2$ / 4 ]: | 4.531 | $in^2$ |
| Area of Sample [ C x 6.452 ]: | 29.234 | $cm^2$ |
| Cell Pressure: | 25 | psi |
| Upper Cap Pressure: | 23 | psi |
| Lower Cap Pressure: | 22 | psi |
| Loss of Head [( F - G ) / 0.036 x 2.54]: | 70.56 | cm |
| Maximum Dry Density: | 127 | $lbs/ft^3$ |
| Optimum % Moisture: | 8.0 % | |
| Weight of Sample: | 590.7 | grams |
| Sample % Moisture: | 8.0 % | |
| Dry Density [K/(AxC)x3.8095x(1+L/100)]: | 114.5 | $lbs/ft^3$ |
| Sample % Compaction [M/Ix100]: | 90.2 % | |

| | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Initial Inlet Burette Reading: | 0.1 | 0.1 | 0.1 | 0.1 | |
| Final Inlet Burette Reading: | 22.6 | 23.2 | 22.0 | 20.4 | |
| Initial Outlet Burette Reading: | 24.0 | 24.0 | 24.0 | 24.0 | |
| Final Outlet Burette Reading: | 1.5 | 0.8 | 2.3 | 3.3 | |
| Initial Reading Time: | 5:23:00 AM | 9:14:00 AM | 1:02:00 PM | 5:30:00 AM | |
| Final Reading Time: | 9:14:00 AM | 1:02:00 PM | 4:34:00 PM | 8:56:00 AM | |
| Elapsed Time [T-S] (H:M:S): | 3:51:00 | 3:48:00 | 3:32:00 | 3:26:00 | |
| Elapsed Time (seconds) | 13860 | 13680 | 12720 | 12360 | |
| Inlet Flow [P-O]: | 22.5 | 23.1 | 21.9 | 20.3 | |
| Outlet Flow [R-Q] (should be ± 5 % of W): | 22.5 | 23.2 | 21.7 | 20.7 | |
| Temperature (°C): | 19.1 | 19.8 | 20.5 | 19.6 | |
| Correction Factor [ -0.02452 x Y + 1.495 ]: | 1.02667 | 1.0095 | 0.99234 | 1.01441 | |
| Permeability [(A x W x 2.54) / (D x H x V) x Z]: | 8.241 E-06 | 8.429 E-06 | 8.448 E-06 | 8.238 E-06 | |

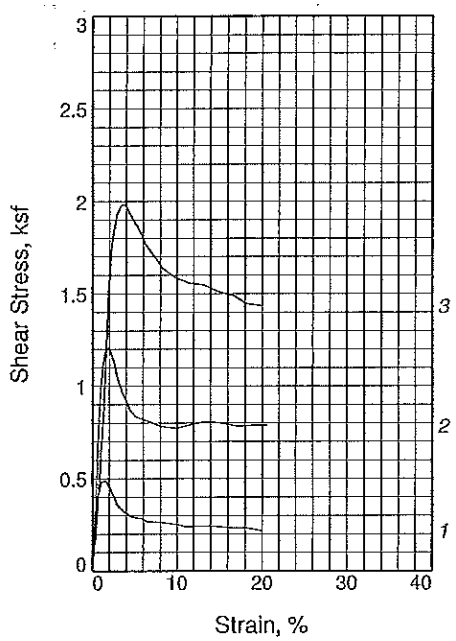
**Average Permeability (cm/s): 8.339 E-06 cm/s**

## Results of Direct Shear Testing




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.42 | 0.15 |
| ϕ, deg | 32.8 | 29.8 |
| Tan(ϕ) | 0.64 | 0.57 |




| | Sample No. | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 10.6 | 10.2 | 10.3 |
| | Dry Density, pcf | 109.3 | 109.7 | 109.6 |
| | Saturation, % | 53.0 | 51.3 | 51.8 |
| | Void Ratio | 0.5425 | 0.5360 | 0.5379 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 8.8 | 8.6 | 8.8 |
| | Dry Density, pcf | 110.2 | 111.1 | 111.5 |
| | Saturation, % | 45.0 | 45.2 | 46.3 |
| | Void Ratio | 0.5295 | 0.5168 | 0.5119 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 0.99 | 0.99 | 0.98 |
| Normal Stress, ksf | | 0.25 | 1.00 | 2.50 |
| Fail. Stress, ksf | | 0.49 | 1.21 | 1.99 |
| Strain, % | | 1.4 | 1.9 | 3.6 |
| Ult. Stress, ksf | | 0.25 | 0.79 | 1.56 |
| Strain, % | | 13.0 | 11.6 | 11.4 |
| Strain rate, %/min. | | 0.30 | 0.30 | 0.30 |

**Sample Type:** Remolded, 95% MDD, OMC
**Description:** sand

**Assumed Specific Gravity=** 2.7
**Remarks:** Failure tangents drawn at peak shear stress and approximately 12% strain. Specimens were unsaturated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-C1
**Sample Number:** 07-0430E
**Proj. No.:** 07.1243 **Date Sampled:** 7/18/07

Knight Piésold CONSULTING

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

7/24/2007

| | |
|---|---|
| **Date:** | 7/18/07 |
| **Client:** | J.A. Cesare & Associates, Inc. |
| **Project:** | U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113 |
| **Project No.:** | 07.1243 |
| **Location:** | USEN-C1 |
| **Sample Number:** | 07-0430E |
| **Description:** | sand |
| **Remarks:** | Failure tangents drawn at peak shear stress and approximately 12% strain. Specimens were unsaturated. |
| **Type of Sample:** | Remolded, 95% MDD, OMC |

**Assumed Specific Gravity=**2.7 **LL=** **PL=** **PI=**

## Parameters for Specimen No. 1

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 256.200 |
| Moisture content: Dry soil+tare, gms. | | | 244.590 |
| Moisture content: Tare, gms. | | | 113.090 |
| Moisture, % | 10.6 | 8.8 | 8.8 |
| Moist specimen weight, gms. | 145.5 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 120.9 | 119.9 | |
| Dry density, pcf | 109.3 | 110.2 | |
| Void ratio | 0.5425 | 0.5295 | |
| Saturation, % | 53.0 | 45.0 | |

## Test Readings for Specimen No. 1

**Load ring constant =** 31.4108 lbs. per input unit

**Normal stress =** 0.25 ksf

**Strain rate, %/min. =** 0.30

**Fail. Stress =** 0.49 ksf **at reading no.** 5

**Ult. Stress =** 0.25 ksf **at reading no.** 23

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0000 |
| 1 | 0.0100 | 0.3311 | 10.4 | 0.4 | 0.33 | 0.0013 |
| 2 | 0.0150 | 0.4043 | 12.7 | 0.6 | 0.40 | 0.0026 |
| 3 | 0.0200 | 0.4521 | 14.2 | 0.8 | 0.45 | 0.0041 |
| 4 | 0.0250 | 0.4839 | 15.2 | 1.0 | 0.48 | 0.0059 |
| 5 | 0.0350 | 0.4966 | 15.6 | 1.4 | 0.49 | 0.0105 |
| 6 | 0.0400 | 0.4903 | 15.4 | 1.7 | 0.48 | 0.0130 |
| 7 | 0.0450 | 0.4775 | 15.0 | 1.9 | 0.47 | 0.0153 |
| 8 | 0.0500 | 0.4553 | 14.3 | 2.1 | 0.45 | 0.0176 |
| 9 | 0.0560 | 0.4330 | 13.6 | 2.3 | 0.43 | 0.0196 |
| 10 | 0.0610 | 0.4139 | 13.0 | 2.5 | 0.41 | 0.0215 |
| 11 | 0.0650 | 0.3948 | 12.4 | 2.7 | 0.39 | 0.0230 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 12 | 0.0700 | 0.3693 | 11.6 | 2.9 | 0.36 | 0.0244 |
| 13 | 0.0750 | 0.3566 | 11.2 | 3.1 | 0.35 | 0.0256 |
| 14 | 0.0800 | 0.3438 | 10.8 | 3.3 | 0.34 | 0.0266 |
| 15 | 0.0900 | 0.3279 | 10.3 | 3.7 | 0.32 | 0.0282 |
| 16 | 0.1000 | 0.3152 | 9.9 | 4.1 | 0.31 | 0.0297 |
| 17 | 0.1100 | 0.2993 | 9.4 | 4.6 | 0.30 | 0.0306 |
| 18 | 0.1450 | 0.2865 | 9.0 | 6.0 | 0.28 | 0.0336 |
| 19 | 0.1560 | 0.2738 | 8.6 | 6.5 | 0.27 | 0.0342 |
| 20 | 0.2000 | 0.2674 | 8.4 | 8.3 | 0.26 | 0.0352 |
| 21 | 0.2450 | 0.2547 | 8.0 | 10.1 | 0.25 | 0.0362 |
| 22 | 0.2700 | 0.2420 | 7.6 | 11.2 | 0.24 | 0.0368 |
| 23 | 0.3150 | 0.2483 | 7.8 | 13.0 | 0.25 | 0.0371 |
| 24 | 0.3610 | 0.2451 | 7.7 | 14.9 | 0.24 | 0.0374 |
| 25 | 0.4010 | 0.2356 | 7.4 | 16.6 | 0.23 | 0.0382 |
| 26 | 0.4450 | 0.2356 | 7.4 | 18.4 | 0.23 | 0.0384 |
| 27 | 0.4800 | 0.2229 | 7.0 | 19.9 | 0.22 | 0.0385 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 255.380 |
| Moisture content: Dry soil+tare, gms. | | | 243.960 |
| Moisture content: Tare, gms. | | | 111.900 |
| Moisture, % | 10.2 | 8.6 | 8.6 |
| Moist specimen weight, gms. | 145.5 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 120.9 | 120.7 | |
| Dry density, pcf | 109.7 | 111.1 | |
| Void ratio | 0.5360 | 0.5168 | |
| Saturation, % | 51.3 | 45.2 | |

## Test Readings for Specimen No. 2

Load ring constant = 31.4108 lbs. per input unit

Normal stress = 1.0 ksf

Strain rate, %/min. = 0.30

Fail. Stress = 1.21 ksf at reading no. 9

Ult. Stress = 0.79 ksf at reading no. 25

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0050 | 0.1210 | 3.8 | 0.2 | 0.12 | -0.0001 |
| 2 | 0.0100 | 0.3820 | 12.0 | 0.4 | 0.38 | -0.0001 |
| 3 | 0.0150 | 0.6686 | 21.0 | 0.6 | 0.66 | 0.0002 |
| 4 | 0.0200 | 0.8755 | 27.5 | 0.8 | 0.86 | 0.0010 |
| 5 | 0.0250 | 1.0251 | 32.2 | 1.0 | 1.01 | 0.0022 |
| 6 | 0.0300 | 1.1270 | 35.4 | 1.2 | 1.11 | 0.0037 |
| 7 | 0.0350 | 1.1843 | 37.2 | 1.4 | 1.17 | 0.0054 |
| 8 | 0.0400 | 1.2161 | 38.2 | 1.7 | 1.20 | 0.0072 |
| 9 | 0.0450 | 1.2225 | 38.4 | 1.9 | 1.21 | 0.0091 |
| 10 | 0.0500 | 1.2130 | 38.1 | 2.1 | 1.20 | 0.0110 |
| 11 | 0.0550 | 1.1843 | 37.2 | 2.3 | 1.17 | 0.0127 |
| 12 | 0.0600 | 1.1588 | 36.4 | 2.5 | 1.14 | 0.0145 |
| 13 | 0.0650 | 1.1206 | 35.2 | 2.7 | 1.11 | 0.0160 |
| 14 | 0.0700 | 1.0761 | 33.8 | 2.9 | 1.06 | 0.0173 |
| 15 | 0.0750 | 1.0379 | 32.6 | 3.1 | 1.02 | 0.0185 |
| 16 | 0.0800 | 1.0092 | 31.7 | 3.3 | 1.00 | 0.0194 |
| 17 | 0.0850 | 0.9806 | 30.8 | 3.5 | 0.97 | 0.0203 |
| 18 | 0.0950 | 0.9424 | 29.6 | 3.9 | 0.93 | 0.0217 |
| 19 | 0.1000 | 0.9137 | 28.7 | 4.1 | 0.90 | 0.0224 |
| 20 | 0.1100 | 0.8755 | 27.5 | 4.6 | 0.86 | 0.0234 |
| 21 | 0.1250 | 0.8468 | 26.6 | 5.2 | 0.84 | 0.0246 |
| 22 | 0.1600 | 0.8214 | 25.8 | 6.6 | 0.81 | 0.0264 |
| 23 | 0.1950 | 0.7927 | 24.9 | 8.1 | 0.78 | 0.0277 |
| 24 | 0.2400 | 0.7832 | 24.6 | 9.9 | 0.77 | 0.0283 |
| 25 | 0.2800 | 0.8023 | 25.2 | 11.6 | 0.79 | 0.0285 |
| 26 | 0.3250 | 0.8214 | 25.8 | 13.5 | 0.81 | 0.0293 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 27 | 0.3700 | 0.8118 | 25.5 | 15.3 | 0.80 | 0.0304 |
| 28 | 0.4150 | 0.7927 | 24.9 | 17.2 | 0.78 | 0.0311 |
| 29 | 0.4550 | 0.7991 | 25.1 | 18.8 | 0.79 | 0.0318 |
| 30 | 0.4960 | 0.7991 | 25.1 | 20.5 | 0.79 | 0.0321 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 256.950 |
| Moisture content: Dry soil+tare, gms. | | | 245.380 |
| Moisture content: Tare, gms. | | | 113.490 |
| Moisture, % | 10.3 | 8.8 | 8.8 |
| Moist specimen weight, gms. | 145.5 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 120.9 | 121.3 | |
| Dry density, pcf | 109.6 | 111.5 | |
| Void ratio | 0.5379 | 0.5119 | |
| Saturation, % | 51.8 | 46.3 | |

## Test Readings for Specimen No. 3

Load ring constant = 31.4108 lbs. per input unit

Normal stress = 2.5 ksf

Strain rate, %/min. = 0.30

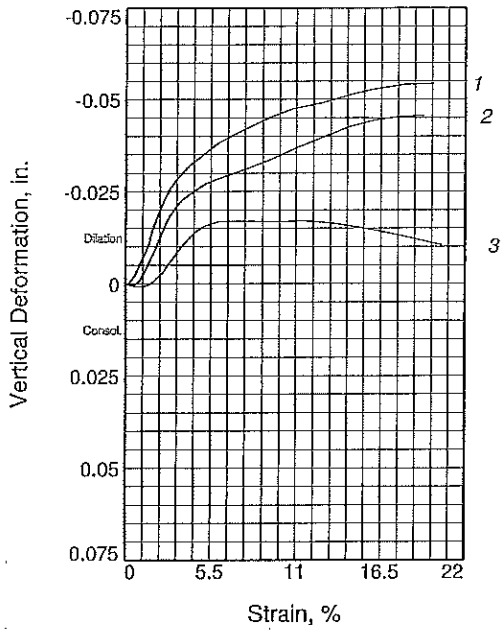
Fail. Stress = 1.99 ksf at reading no. 17

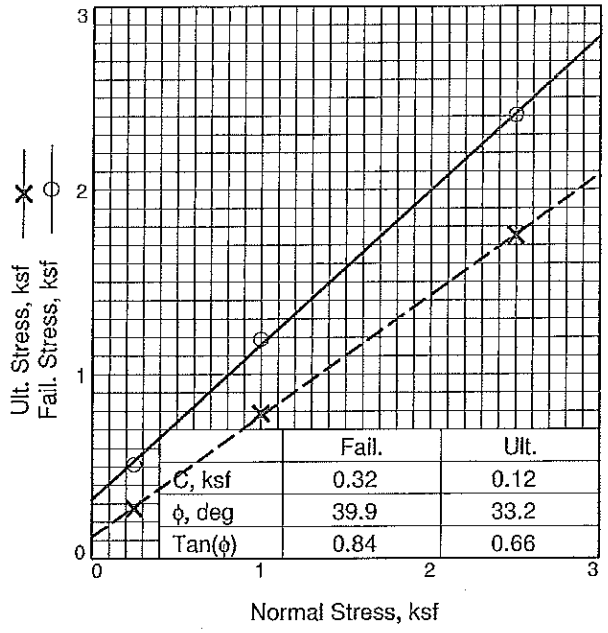
Ult. Stress = 1.56 ksf at reading no. 27

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0010 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0002 |
| 2 | 0.0010 | 0.0605 | 1.9 | 0.0 | 0.06 | -0.0002 |
| 3 | 0.0100 | 0.1846 | 5.8 | 0.4 | 0.18 | -0.0006 |
| 4 | 0.0150 | 0.3438 | 10.8 | 0.6 | 0.34 | -0.0007 |
| 5 | 0.0200 | 0.5030 | 15.8 | 0.8 | 0.50 | -0.0009 |
| 6 | 0.0250 | 0.6686 | 21.0 | 1.0 | 0.66 | -0.0010 |
| 7 | 0.0310 | 0.8341 | 26.2 | 1.3 | 0.82 | -0.0011 |
| 8 | 0.0350 | 0.9901 | 31.1 | 1.4 | 0.98 | -0.0011 |
| 9 | 0.0400 | 1.1588 | 36.4 | 1.7 | 1.14 | -0.0009 |
| 10 | 0.0450 | 1.4899 | 46.8 | 1.9 | 1.47 | -0.0002 |
| 11 | 0.0500 | 1.6491 | 51.8 | 2.1 | 1.63 | 0.0007 |
| 12 | 0.0550 | 1.7892 | 56.2 | 2.3 | 1.77 | 0.0017 |
| 13 | 0.0600 | 1.8465 | 58.0 | 2.5 | 1.82 | 0.0028 |
| 14 | 0.0650 | 1.9070 | 59.9 | 2.7 | 1.88 | 0.0040 |
| 15 | 0.0700 | 1.9547 | 61.4 | 2.9 | 1.93 | 0.0054 |
| 16 | 0.0800 | 1.9993 | 62.8 | 3.3 | 1.97 | 0.0080 |
| 17 | 0.0860 | 2.0120 | 63.2 | 3.6 | 1.99 | 0.0092 |
| 18 | 0.0960 | 2.0057 | 63.0 | 4.0 | 1.98 | 0.0116 |

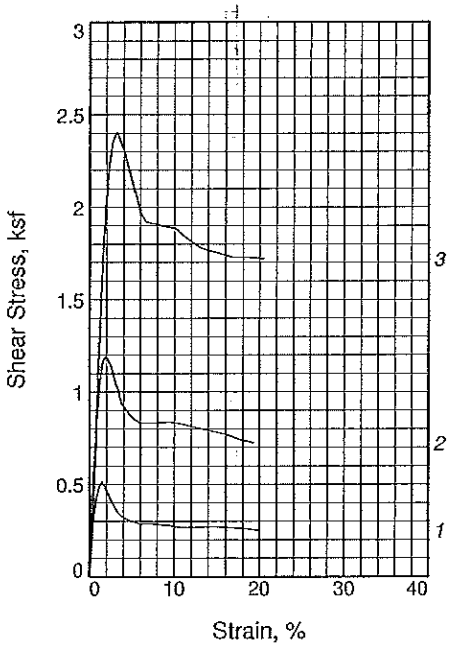
## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 19 | 0.1060 | 1.9611 | 61.6 | 4.4 | 1.93 | 0.0139 |
| 20 | 0.1260 | 1.8974 | 59.6 | 5.2 | 1.87 | 0.0179 |
| 21 | 0.1400 | 1.8465 | 58.0 | 5.8 | 1.82 | 0.0198 |
| 22 | 0.1510 | 1.7956 | 56.4 | 6.3 | 1.77 | 0.0208 |
| 23 | 0.1660 | 1.7510 | 55.0 | 6.9 | 1.73 | 0.0219 |
| 24 | 0.1850 | 1.7032 | 53.5 | 7.7 | 1.68 | 0.0228 |
| 25 | 0.2000 | 1.6618 | 52.2 | 8.3 | 1.64 | 0.0234 |
| 26 | 0.2360 | 1.6109 | 50.6 | 9.8 | 1.59 | 0.0240 |
| 27 | 0.2760 | 1.5791 | 49.6 | 11.4 | 1.56 | 0.0241 |
| 28 | 0.3200 | 1.5695 | 49.3 | 13.2 | 1.55 | 0.0235 |
| 29 | 0.3650 | 1.5281 | 48.0 | 15.1 | 1.51 | 0.0229 |
| 30 | 0.4050 | 1.5090 | 47.4 | 16.8 | 1.49 | 0.0225 |
| 31 | 0.4360 | 1.4676 | 46.1 | 18.0 | 1.45 | 0.0224 |
| 32 | 0.4800 | 1.4549 | 45.7 | 19.9 | 1.44 | 0.0220 |




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.32 | 0.12 |
| ϕ, deg | 39.9 | 33.2 |
| Tan(ϕ) | 0.84 | 0.66 |




| Sample No. | | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 9.6 | 9.0 | 9.6 |
| | Dry Density, pcf | 112.2 | 112.8 | 112.2 |
| | Saturation, % | 51.5 | 49.0 | 51.6 |
| | Void Ratio | 0.5025 | 0.4940 | 0.5029 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 8.1 | 8.6 | 8.6 |
| | Dry Density, pcf | 113.2 | 114.3 | 115.0 |
| | Saturation, % | 44.7 | 48.7 | 50.1 |
| | Void Ratio | 0.4891 | 0.4744 | 0.4651 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 0.99 | 0.99 | 0.97 |
| Normal Stress, ksf | | 0.25 | 1.00 | 2.50 |
| Fail. Stress, ksf | | 0.51 | 1.19 | 2.41 |
| Strain, % | | 1.5 | 1.9 | 3.1 |
| Ult. Stress, ksf | | 0.27 | 0.79 | 1.75 |
| Strain, % | | 14.5 | 14.5 | 15.1 |
| Strain rate, %/min. | | 0.30 | 0.30 | 0.30 |

**Sample Type:** Remolded 95% MDD, OMC
**Description:** sand

**Assumed Specific Gravity=** 2.7
**Remarks:** Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-C2
**Sample Number:** 07-0430F
**Proj. No.:** 07.1243 **Date Sampled:** 7/18/07

Knight Piésold CONSULTING

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

7/24/2007

**Date:** 7/18/07
**Client:** J.A. Cesare & Associates, Inc.
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113
**Project No.:** 07.1243
**Location:** USEN-C2
**Sample Number:** 07-0430F
**Description:** sand
**Remarks:** Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated.
**Type of Sample:** Remolded 95% MDD, OMC
**Assumed Specific Gravity=**2.7 **LL=** **PL=** **PI=**

## Parameters for Specimen No. 1

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 259.770 |
| Moisture content: Dry soil+tare, gms. | | | 248.830 |
| Moisture content: Tare, gms. | | | 113.830 |
| Moisture, % | 9.6 | 8.1 | 8.1 |
| Moist specimen weight, gms. | 147.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.² | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 122.9 | 122.4 | |
| Dry density, pcf | 112.2 | 113.2 | |
| Void ratio | 0.5025 | 0.4891 | |
| Saturation, % | 51.5 | 44.7 | |

## Test Readings for Specimen No. 1

**Load ring constant =** 31.4108 lbs. per input unit
**Normal stress =** 0.25 ksf
**Strain rate, %/min. =** 0.30
**Fail. Stress =** 0.51 ksf **at reading no.** 7
**Ult. Stress =** 0.27 ksf **at reading no.** 25

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0050 | 0.1751 | 5.5 | 0.2 | 0.17 | 0.0002 |
| 2 | 0.0100 | 0.2993 | 9.4 | 0.4 | 0.30 | 0.0012 |
| 3 | 0.0160 | 0.3725 | 11.7 | 0.7 | 0.37 | 0.0027 |
| 4 | 0.0200 | 0.4298 | 13.5 | 0.8 | 0.42 | 0.0046 |
| 5 | 0.0250 | 0.4744 | 14.9 | 1.0 | 0.47 | 0.0066 |
| 6 | 0.0310 | 0.5094 | 16.0 | 1.3 | 0.50 | 0.0085 |
| 7 | 0.0360 | 0.5189 | 16.3 | 1.5 | 0.51 | 0.0109 |
| 8 | 0.0400 | 0.5062 | 15.9 | 1.7 | 0.50 | 0.0135 |
| 9 | 0.0450 | 0.4935 | 15.5 | 1.9 | 0.49 | 0.0161 |
| 10 | 0.0500 | 0.4680 | 14.7 | 2.1 | 0.46 | 0.0185 |
| 11 | 0.0550 | 0.4489 | 14.1 | 2.3 | 0.44 | 0.0207 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 12 | 0.0600 | 0.4266 | 13.4 | 2.5 | 0.42 | 0.0227 |
| 13 | 0.0650 | 0.4043 | 12.7 | 2.7 | 0.40 | 0.0245 |
| 14 | 0.0700 | 0.3884 | 12.2 | 2.9 | 0.38 | 0.0261 |
| 15 | 0.0760 | 0.3693 | 11.6 | 3.1 | 0.36 | 0.0274 |
| 16 | 0.0800 | 0.3534 | 11.1 | 3.3 | 0.35 | 0.0285 |
| 17 | 0.0900 | 0.3343 | 10.5 | 3.7 | 0.33 | 0.0304 |
| 18 | 0.1000 | 0.3215 | 10.1 | 4.1 | 0.32 | 0.0322 |
| 19 | 0.1150 | 0.3088 | 9.7 | 4.8 | 0.30 | 0.0343 |
| 20 | 0.1450 | 0.2897 | 9.1 | 6.0 | 0.29 | 0.0384 |
| 21 | 0.1850 | 0.2897 | 9.1 | 7.7 | 0.29 | 0.0419 |
| 22 | 0.2250 | 0.2833 | 8.9 | 9.3 | 0.28 | 0.0454 |
| 23 | 0.2600 | 0.2706 | 8.5 | 10.8 | 0.27 | 0.0476 |
| 24 | 0.3060 | 0.2738 | 8.6 | 12.7 | 0.27 | 0.0492 |
| 25 | 0.3500 | 0.2770 | 8.7 | 14.5 | 0.27 | 0.0514 |
| 26 | 0.3900 | 0.2706 | 8.5 | 16.1 | 0.27 | 0.0530 |
| 27 | 0.4350 | 0.2674 | 8.4 | 18.0 | 0.26 | 0.0542 |
| 28 | 0.4800 | 0.2547 | 8.0 | 19.9 | 0.25 | 0.0545 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 260.920 |
| Moisture content: Dry soil+tare, gms. | | | 249.300 |
| Moisture content: Tare, gms. | | | 113.530 |
| Moisture, % | 9.0 | 8.6 | 8.6 |
| Moist specimen weight, gms. | 147.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 122.9 | 124.1 | |
| Dry density, pcf | 112.8 | 114.3 | |
| Void ratio | 0.4940 | 0.4744 | |
| Saturation, % | 49.0 | 48.7 | |

## Test Readings for Specimen No. 2

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 1.0 ksf

**Strain rate, %/min.** = 0.30

**Fail. Stress** = 1.19 ksf **at reading no.** 11

**Ult. Stress** = 0.79 ksf **at reading no.** 28

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0010 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 2 | 0.0010 | 0.0382 | 1.2 | 0.0 | 0.04 | 0.0001 |
| 3 | 0.0050 | 0.2324 | 7.3 | 0.2 | 0.23 | -0.0003 |
| 4 | 0.0100 | 0.5253 | 16.5 | 0.4 | 0.52 | -0.0003 |
| 5 | 0.0150 | 0.6272 | 19.7 | 0.6 | 0.62 | -0.0002 |
| 6 | 0.0200 | 0.8405 | 26.4 | 0.8 | 0.83 | 0.0007 |
| 7 | 0.0250 | 0.9837 | 30.9 | 1.0 | 0.97 | 0.0019 |
| 8 | 0.0300 | 1.0856 | 34.1 | 1.2 | 1.07 | 0.0035 |
| 9 | 0.0350 | 1.1493 | 36.1 | 1.4 | 1.13 | 0.0053 |
| 10 | 0.0400 | 1.1875 | 37.3 | 1.7 | 1.17 | 0.0072 |
| 11 | 0.0460 | 1.2066 | 37.9 | 1.9 | 1.19 | 0.0093 |
| 12 | 0.0500 | 1.2002 | 37.7 | 2.1 | 1.18 | 0.0113 |
| 13 | 0.0600 | 1.1620 | 36.5 | 2.5 | 1.15 | 0.0153 |
| 14 | 0.0650 | 1.1302 | 35.5 | 2.7 | 1.12 | 0.0172 |
| 15 | 0.0700 | 1.0920 | 34.3 | 2.9 | 1.08 | 0.0187 |
| 16 | 0.0750 | 1.0538 | 33.1 | 3.1 | 1.04 | 0.0200 |
| 17 | 0.0800 | 1.0283 | 32.3 | 3.3 | 1.01 | 0.0212 |
| 18 | 0.0850 | 0.9901 | 31.1 | 3.5 | 0.98 | 0.0222 |
| 19 | 0.0900 | 0.9519 | 29.9 | 3.7 | 0.94 | 0.0231 |
| 20 | 0.1000 | 0.9264 | 29.1 | 4.1 | 0.91 | 0.0244 |
| 21 | 0.1100 | 0.9010 | 28.3 | 4.6 | 0.89 | 0.0256 |
| 22 | 0.1250 | 0.8691 | 27.3 | 5.2 | 0.86 | 0.0273 |
| 23 | 0.1450 | 0.8437 | 26.5 | 6.0 | 0.83 | 0.0287 |
| 24 | 0.1850 | 0.8437 | 26.5 | 7.7 | 0.83 | 0.0311 |
| 25 | 0.2250 | 0.8500 | 26.7 | 9.3 | 0.84 | 0.0339 |
| 26 | 0.2650 | 0.8373 | 26.3 | 11.0 | 0.83 | 0.0369 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 27 | 0.3060 | 0.8182 | 25.7 | 12.7 | 0.81 | 0.0398 |
| 28 | 0.3500 | 0.7991 | 25.1 | 14.5 | 0.79 | 0.0428 |
| 29 | 0.3900 | 0.7800 | 24.5 | 16.1 | 0.77 | 0.0445 |
| 30 | 0.4250 | 0.7545 | 23.7 | 17.6 | 0.74 | 0.0454 |
| 31 | 0.4650 | 0.7354 | 23.1 | 19.2 | 0.73 | 0.0457 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | | | 264.980 |
| Moisture content: Dry soil+tare, gms. | | | 253.340 |
| Moisture content: Tare, gms. | | | 118.380 |
| Moisture, % | 9.6 | 8.6 | 8.6 |
| Moist specimen weight, gms. | 147.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.97 | |
| Net decrease in height, in. | | 0.03 | |
| Wet Density, pcf | 122.9 | 125.0 | |
| Dry density, pcf | 112.2 | 115.0 | |
| Void ratio | 0.5029 | 0.4651 | |
| Saturation, % | 51.6 | 50.1 | |

## Test Readings for Specimen No. 3

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 2.5 ksf

**Strain rate, %/min.** = 0.30

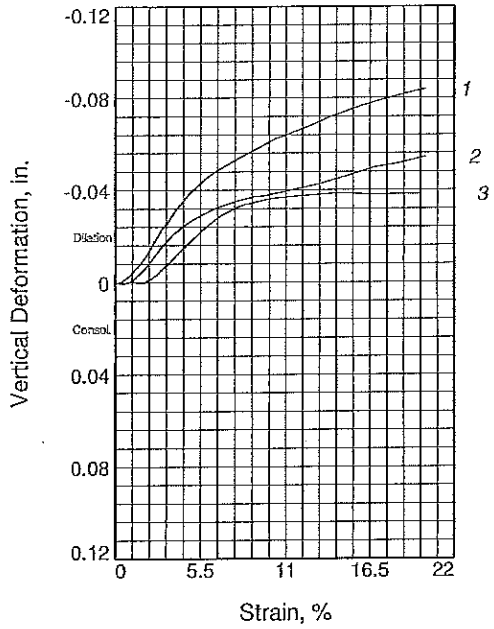
**Fail. Stress** = 2.41 ksf **at reading no.** 15

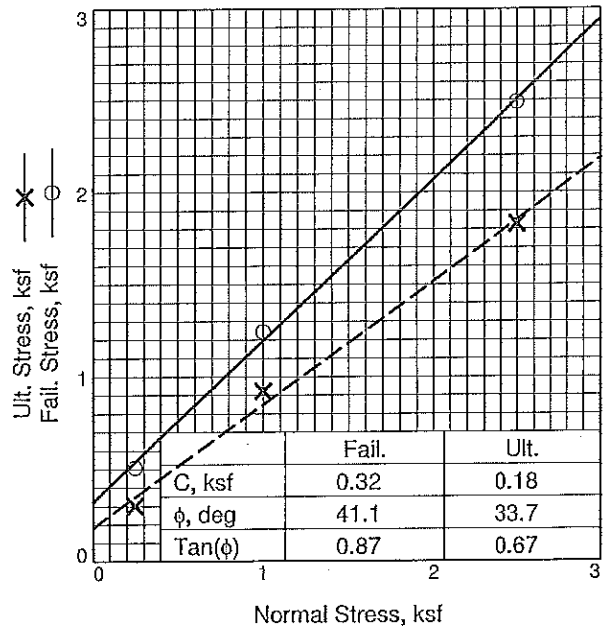
**Ult. Stress** = 1.75 ksf **at reading no.** 28

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0010 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 2 | 0.0050 | 0.1146 | 3.6 | 0.2 | 0.11 | -0.0002 |
| 3 | 0.0100 | 0.2802 | 8.8 | 0.4 | 0.28 | -0.0004 |
| 4 | 0.0150 | 0.5508 | 17.3 | 0.6 | 0.54 | -0.0006 |
| 5 | 0.0200 | 0.8309 | 26.1 | 0.8 | 0.82 | -0.0007 |
| 6 | 0.0250 | 1.1111 | 34.9 | 1.0 | 1.10 | -0.0007 |
| 7 | 0.0300 | 1.3753 | 43.2 | 1.2 | 1.36 | -0.0005 |
| 8 | 0.0350 | 1.6109 | 50.6 | 1.4 | 1.59 | -0.0002 |
| 9 | 0.0400 | 1.8115 | 56.9 | 1.7 | 1.79 | 0.0003 |
| 10 | 0.0450 | 1.9929 | 62.6 | 1.9 | 1.97 | 0.0010 |
| 11 | 0.0500 | 2.1330 | 67.0 | 2.1 | 2.10 | 0.0018 |
| 12 | 0.0560 | 2.2508 | 70.7 | 2.3 | 2.22 | 0.0028 |
| 13 | 0.0610 | 2.3240 | 73.0 | 2.5 | 2.29 | 0.0038 |
| 14 | 0.0650 | 2.3845 | 74.9 | 2.7 | 2.35 | 0.0050 |
| 15 | 0.0760 | 2.4387 | 76.6 | 3.1 | 2.41 | 0.0074 |
| 16 | 0.0800 | 2.4259 | 76.2 | 3.3 | 2.39 | 0.0086 |
| 17 | 0.0960 | 2.3495 | 73.8 | 4.0 | 2.32 | 0.0119 |

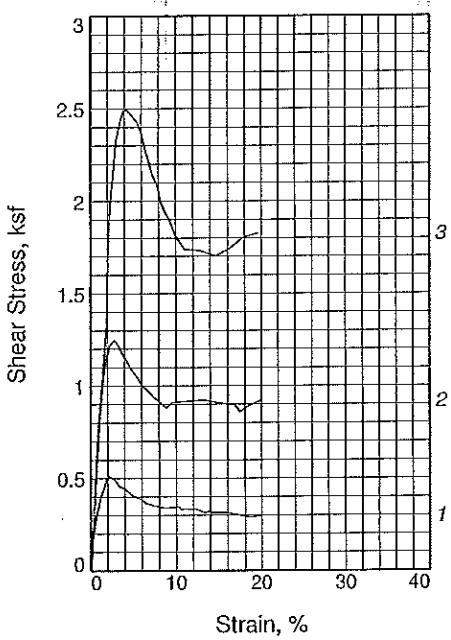
## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 18 | 0.1050 | 2.2827 | 71.7 | 4.3 | 2.25 | 0.0136 |
| 19 | 0.1150 | 2.2158 | 69.6 | 4.8 | 2.19 | 0.0149 |
| 20 | 0.1250 | 2.1458 | 67.4 | 5.2 | 2.12 | 0.0159 |
| 21 | 0.1360 | 2.0757 | 65.2 | 5.6 | 2.05 | 0.0165 |
| 22 | 0.1450 | 1.9993 | 62.8 | 6.0 | 1.97 | 0.0170 |
| 23 | 0.1600 | 1.9484 | 61.2 | 6.6 | 1.92 | 0.0171 |
| 24 | 0.2000 | 1.9293 | 60.6 | 8.3 | 1.90 | 0.0170 |
| 25 | 0.2460 | 1.9102 | 60.0 | 10.2 | 1.88 | 0.0169 |
| 26 | 0.2750 | 1.8592 | 58.4 | 11.4 | 1.83 | 0.0172 |
| 27 | 0.3200 | 1.8019 | 56.6 | 13.2 | 1.78 | 0.0166 |
| 28 | 0.3650 | 1.7765 | 55.8 | 15.1 | 1.75 | 0.0154 |
| 29 | 0.4050 | 1.7510 | 55.0 | 16.8 | 1.73 | 0.0141 |
| 30 | 0.4500 | 1.7510 | 55.0 | 18.6 | 1.73 | 0.0124 |
| 31 | 0.4950 | 1.7446 | 54.8 | 20.5 | 1.72 | 0.0106 |




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.32 | 0.18 |
| ϕ, deg | 41.1 | 33.7 |
| Tan(ϕ) | 0.87 | 0.67 |




| Sample No. | | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 10.8 | 10.8 | 10.8 |
| | Dry Density, pcf | 111.1 | 110.8 | 111.3 |
| | Saturation, % | 56.6 | 56.0 | 56.8 |
| | Void Ratio | 0.5168 | 0.5216 | 0.5148 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 10.6 | 10.2 | 10.5 |
| | Dry Density, pcf | 112.4 | 112.5 | 113.7 |
| | Saturation, % | 57.3 | 55.3 | 58.9 |
| | Void Ratio | 0.4999 | 0.4985 | 0.4829 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 0.99 | 0.98 | 0.98 |
| Normal Stress, ksf | | 0.25 | 1.00 | 2.50 |
| Fail. Stress, ksf | | 0.51 | 1.24 | 2.49 |
| Strain, % | | 2.3 | 2.9 | 3.9 |
| Ult. Stress, ksf | | 0.30 | 0.92 | 1.83 |
| Strain, % | | 20.1 | 20.1 | 19.7 |
| Strain rate, %/min. | | 0.25 | 0.25 | 0.25 |

**Sample Type:** Remolded, 95% MDD @ OMC
**Description:** sand

**Assumed Specific Gravity=** 2.7
**Remarks:** Failure tangents drawn at peak shear stress and approximately 20% strain. Specimens were not saturated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-C1 & C2, 5% Zeolite Clay
**Sample Number:** 07-0605C
**Proj. No.:** 07.1243 **Date Sampled:** 8/23/07

Knight Piésold CONSULTING

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

8/24/2007

| | |
|---|---|
| **Date:** | 8/23/07 |
| **Client:** | J.A. Cesare & Associates, Inc. |
| **Project:** | U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113 |
| **Project No.:** | 07.1243 |
| **Location:** | USEN-C1 & C2, 5% Zeolite Clay |
| **Sample Number:** | 07-0605C |
| **Description:** | sand |
| **Remarks:** | Failure tangents drawn at peak shear stress and approximately 20% strain. Specimens were not saturated. |
| **Type of Sample:** | Remolded, 95% MDD @ OMC |

**Assumed Specific Gravity=**2.7 **LL=** **PL=** **PI=**

## Parameters for Specimen No. 1

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 528.780 | | 238.950 |
| Moisture content: Dry soil+tare, gms. | 489.810 | | 224.760 |
| Moisture content: Tare, gms. | 129.880 | | 90.950 |
| Moisture, % | 10.8 | 10.6 | 10.6 |
| Moist specimen weight, gms. | 148.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.² | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 123.2 | 124.3 | |
| Dry density, pcf | 111.1 | 112.4 | |
| Void ratio | 0.5168 | 0.4999 | |
| Saturation, % | 56.6 | 57.3 | |

## Test Readings for Specimen No. 1

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 0.25 ksf

**Strain rate, %/min.** = 0.25

**Fail. Stress** = 0.51 ksf **at reading no.** 11

**Ult. Stress** = 0.30 ksf **at reading no.** 32

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0001 |
| 1 | 0.0050 | 0.1464 | 4.6 | 0.2 | 0.14 | -0.0002 |
| 2 | 0.0100 | 0.2260 | 7.1 | 0.4 | 0.22 | 0.0003 |
| 3 | 0.0150 | 0.2865 | 9.0 | 0.6 | 0.28 | 0.0012 |
| 4 | 0.0200 | 0.3375 | 10.6 | 0.8 | 0.33 | 0.0023 |
| 5 | 0.0250 | 0.3757 | 11.8 | 1.0 | 0.37 | 0.0036 |
| 6 | 0.0300 | 0.4171 | 13.1 | 1.2 | 0.41 | 0.0052 |
| 7 | 0.0360 | 0.4457 | 14.0 | 1.5 | 0.44 | 0.0069 |
| 8 | 0.0410 | 0.4775 | 15.0 | 1.7 | 0.47 | 0.0086 |
| 9 | 0.0460 | 0.5030 | 15.8 | 1.9 | 0.50 | 0.0103 |
| 10 | 0.0500 | 0.5221 | 16.4 | 2.1 | 0.52 | 0.0121 |
| 11 | 0.0550 | 0.5157 | 16.2 | 2.3 | 0.51 | 0.0144 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 12 | 0.0650 | 0.5030 | 15.8 | 2.7 | 0.50 | 0.0191 |
| 13 | 0.0750 | 0.4839 | 15.2 | 3.1 | 0.48 | 0.0238 |
| 14 | 0.0800 | 0.4648 | 14.6 | 3.3 | 0.46 | 0.0251 |
| 15 | 0.0950 | 0.4521 | 14.2 | 3.9 | 0.45 | 0.0315 |
| 16 | 0.1050 | 0.4362 | 13.7 | 4.3 | 0.43 | 0.0349 |
| 17 | 0.1150 | 0.4202 | 13.2 | 4.8 | 0.41 | 0.0382 |
| 18 | 0.1250 | 0.4075 | 12.8 | 5.2 | 0.40 | 0.0410 |
| 19 | 0.1450 | 0.3916 | 12.3 | 6.0 | 0.39 | 0.0459 |
| 20 | 0.1550 | 0.3725 | 11.7 | 6.4 | 0.37 | 0.0478 |
| 21 | 0.1750 | 0.3597 | 11.3 | 7.2 | 0.35 | 0.0511 |
| 22 | 0.2100 | 0.3438 | 10.8 | 8.7 | 0.34 | 0.0564 |
| 23 | 0.2500 | 0.3502 | 11.0 | 10.3 | 0.35 | 0.0624 |
| 24 | 0.2550 | 0.3375 | 10.6 | 10.6 | 0.33 | 0.0628 |
| 25 | 0.3000 | 0.3375 | 10.6 | 12.4 | 0.33 | 0.0675 |
| 26 | 0.3250 | 0.3184 | 10.0 | 13.5 | 0.31 | 0.0705 |
| 27 | 0.3350 | 0.3311 | 10.4 | 13.9 | 0.33 | 0.0717 |
| 28 | 0.3450 | 0.3184 | 10.0 | 14.3 | 0.31 | 0.0726 |
| 29 | 0.3850 | 0.3184 | 10.0 | 15.9 | 0.31 | 0.0766 |
| 30 | 0.4160 | 0.3056 | 9.6 | 17.2 | 0.30 | 0.0791 |
| 31 | 0.4560 | 0.2929 | 9.2 | 18.9 | 0.29 | 0.0819 |
| 32 | 0.4850 | 0.3056 | 9.6 | 20.1 | 0.30 | 0.0838 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 528.780 | | 266.510 |
| Moisture content: Dry soil+tare, gms. | 489.810 | | 252.920 |
| Moisture content: Tare, gms. | 129.880 | | 119.760 |
| Moisture, % | 10.8 | 10.2 | 10.2 |
| Moist specimen weight, gms. | 147.7 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 122.8 | 124.0 | |
| Dry density, pcf | 110.8 | 112.5 | |
| Void ratio | 0.5216 | 0.4985 | |
| Saturation, % | 56.0 | 55.3 | |

## Test Readings for Specimen No. 2

**Load ring constant =** 31.4108 lbs. per input unit

**Normal stress =** 1.0 ksf

**Strain rate, %/min. =** 0.25

**Fail. Stress =** 1.24 ksf **at reading no.** 13

**Ult. Stress =** 0.92 ksf **at reading no.** 32

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0000 |
| 1 | 0.0050 | 0.1146 | 3.6 | 0.2 | 0.11 | -0.0002 |
| 2 | 0.0100 | 0.3120 | 9.8 | 0.4 | 0.31 | -0.0004 |
| 3 | 0.0150 | 0.5094 | 16.0 | 0.6 | 0.50 | -0.0005 |
| 4 | 0.0200 | 0.6813 | 21.4 | 0.8 | 0.67 | -0.0001 |
| 5 | 0.0250 | 0.8214 | 25.8 | 1.0 | 0.81 | 0.0007 |
| 6 | 0.0300 | 0.9360 | 29.4 | 1.2 | 0.92 | 0.0016 |
| 7 | 0.0350 | 1.0315 | 32.4 | 1.4 | 1.02 | 0.0028 |
| 8 | 0.0400 | 1.1047 | 34.7 | 1.7 | 1.09 | 0.0041 |
| 9 | 0.0450 | 1.1652 | 36.6 | 1.9 | 1.15 | 0.0056 |
| 10 | 0.0500 | 1.2034 | 37.8 | 2.1 | 1.19 | 0.0072 |
| 11 | 0.0550 | 1.2352 | 38.8 | 2.3 | 1.22 | 0.0090 |
| 12 | 0.0650 | 1.2607 | 39.6 | 2.7 | 1.24 | 0.0126 |
| 13 | 0.0700 | 1.2607 | 39.6 | 2.9 | 1.24 | 0.0144 |
| 14 | 0.0810 | 1.2352 | 38.8 | 3.4 | 1.22 | 0.0179 |
| 15 | 0.0900 | 1.1907 | 37.4 | 3.7 | 1.17 | 0.0206 |
| 16 | 0.1050 | 1.1461 | 36.0 | 4.3 | 1.13 | 0.0242 |
| 17 | 0.1150 | 1.1111 | 34.9 | 4.8 | 1.10 | 0.0261 |
| 18 | 0.1250 | 1.0856 | 34.1 | 5.2 | 1.07 | 0.0278 |
| 19 | 0.1350 | 1.0570 | 33.2 | 5.6 | 1.04 | 0.0293 |
| 20 | 0.1450 | 1.0188 | 32.0 | 6.0 | 1.01 | 0.0307 |
| 21 | 0.1600 | 0.9933 | 31.2 | 6.6 | 0.98 | 0.0326 |
| 22 | 0.1750 | 0.9583 | 30.1 | 7.2 | 0.95 | 0.0341 |
| 23 | 0.1900 | 0.9328 | 29.3 | 7.9 | 0.92 | 0.0353 |
| 24 | 0.2150 | 0.8946 | 28.1 | 8.9 | 0.88 | 0.0372 |
| 25 | 0.2310 | 0.9232 | 29.0 | 9.6 | 0.91 | 0.0375 |
| 26 | 0.2750 | 0.9296 | 29.2 | 11.4 | 0.92 | 0.0400 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 27 | 0.3200 | 0.9360 | 29.4 | 13.2 | 0.92 | 0.0429 |
| 28 | 0.3610 | 0.9201 | 28.9 | 14.9 | 0.91 | 0.0460 |
| 29 | 0.4050 | 0.9105 | 28.6 | 16.8 | 0.90 | 0.0499 |
| 30 | 0.4200 | 0.8723 | 27.4 | 17.4 | 0.86 | 0.0506 |
| 31 | 0.4450 | 0.9041 | 28.4 | 18.4 | 0.89 | 0.0518 |
| 32 | 0.4850 | 0.9360 | 29.4 | 20.1 | 0.92 | 0.0544 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 528.780 | | 267.630 |
| Moisture content: Dry soil+tare, gms. | 489.810 | | 253.550 |
| Moisture content: Tare, gms. | 129.880 | | 119.840 |
| Moisture, % | 10.8 | 10.5 | 10.5 |
| Moist specimen weight, gms. | 148.4 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 123.3 | 125.6 | |
| Dry density, pcf | 111.3 | 113.7 | |
| Void ratio | 0.5148 | 0.4829 | |
| Saturation, % | 56.8 | 58.9 | |

## Test Readings for Specimen No. 3

**Load ring constant =** 31.4108 lbs. per input unit

**Normal stress =** 2.5 ksf

**Strain rate, %/min. =** 0.25

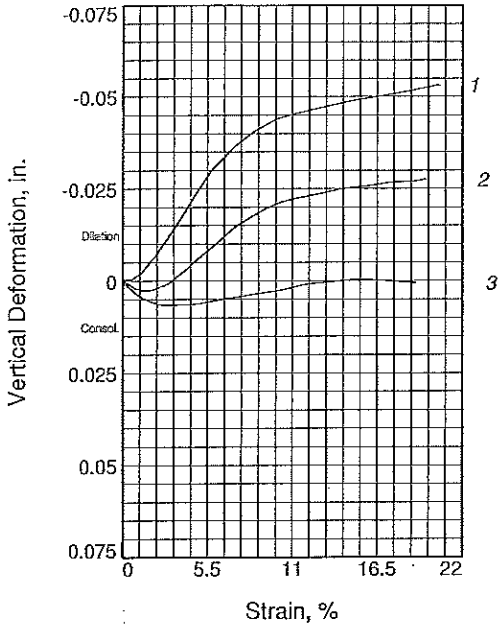
**Fail. Stress =** 2.49 ksf **at reading no.** 17

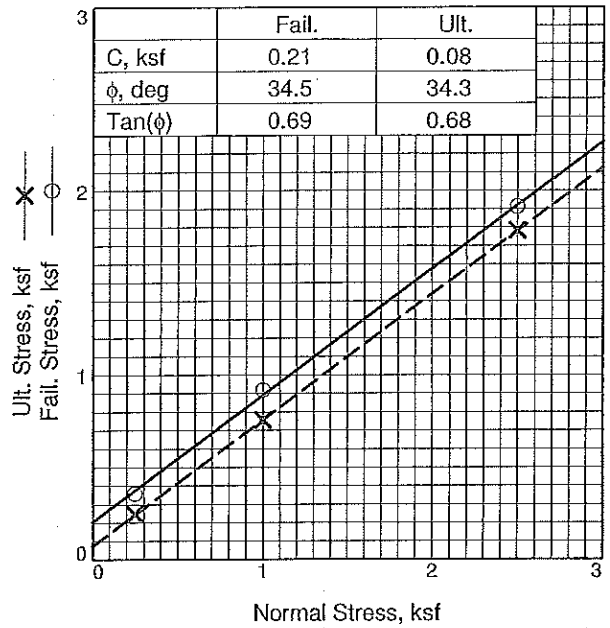
**Ult. Stress =** 1.83 ksf **at reading no.** 35

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0000 |
| 1 | 0.0050 | 0.1643 | 5.2 | 0.2 | 0.16 | -0.0001 |
| 2 | 0.0100 | 0.3168 | 10.0 | 0.4 | 0.31 | -0.0002 |
| 3 | 0.0150 | 0.5481 | 17.2 | 0.6 | 0.54 | -0.0003 |
| 4 | 0.0200 | 0.7235 | 22.7 | 0.8 | 0.71 | 0.0001 |
| 5 | 0.0260 | 0.8862 | 27.8 | 1.1 | 0.87 | 0.0004 |
| 6 | 0.0300 | 0.9507 | 29.9 | 1.2 | 0.94 | 0.0003 |
| 7 | 0.0350 | 1.0697 | 33.6 | 1.4 | 1.06 | -0.0002 |
| 8 | 0.0400 | 1.1875 | 37.3 | 1.7 | 1.17 | -0.0002 |
| 9 | 0.0450 | 1.3308 | 41.8 | 1.9 | 1.31 | -0.0002 |
| 10 | 0.0500 | 1.7892 | 56.2 | 2.1 | 1.77 | 0.0006 |
| 11 | 0.0550 | 1.9547 | 61.4 | 2.3 | 1.93 | 0.0014 |
| 12 | 0.0600 | 2.0916 | 65.7 | 2.5 | 2.06 | 0.0024 |
| 13 | 0.0660 | 2.2031 | 69.2 | 2.7 | 2.17 | 0.0035 |
| 14 | 0.0700 | 2.2954 | 72.1 | 2.9 | 2.26 | 0.0047 |
| 15 | 0.0750 | 2.3750 | 74.6 | 3.1 | 2.34 | 0.0061 |
| 16 | 0.0860 | 2.4705 | 77.6 | 3.6 | 2.44 | 0.0088 |

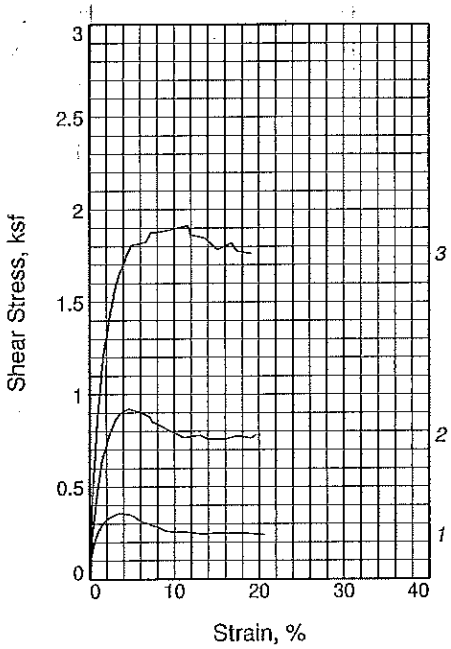
## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 17 | 0.0950 | 2.5246 | 79.3 | 3.9 | 2.49 | 0.0116 |
| 18 | 0.1000 | 2.5278 | 79.4 | 4.1 | 2.49 | 0.0130 |
| 19 | 0.1050 | 2.5278 | 79.4 | 4.3 | 2.49 | 0.0145 |
| 20 | 0.1350 | 2.4578 | 77.2 | 5.6 | 2.42 | 0.0223 |
| 21 | 0.1450 | 2.4004 | 75.4 | 6.0 | 2.37 | 0.0247 |
| 22 | 0.1550 | 2.3177 | 72.8 | 6.4 | 2.29 | 0.0269 |
| 23 | 0.1650 | 2.2476 | 70.6 | 6.8 | 2.22 | 0.0290 |
| 24 | 0.1750 | 2.1744 | 68.3 | 7.2 | 2.15 | 0.0306 |
| 25 | 0.1910 | 2.1012 | 66.0 | 7.9 | 2.07 | 0.0327 |
| 26 | 0.2000 | 2.0248 | 63.6 | 8.3 | 2.00 | 0.0337 |
| 27 | 0.2100 | 1.9738 | 62.0 | 8.7 | 1.95 | 0.0343 |
| 28 | 0.2250 | 1.9197 | 60.3 | 9.3 | 1.89 | 0.0354 |
| 29 | 0.2400 | 1.8401 | 57.8 | 9.9 | 1.82 | 0.0362 |
| 30 | 0.2660 | 1.7637 | 55.4 | 11.0 | 1.74 | 0.0371 |
| 31 | 0.3100 | 1.7574 | 55.2 | 12.8 | 1.73 | 0.0379 |
| 32 | 0.3550 | 1.7255 | 54.2 | 14.7 | 1.70 | 0.0388 |
| 33 | 0.3950 | 1.7701 | 55.6 | 16.3 | 1.75 | 0.0381 |
| 34 | 0.4300 | 1.8274 | 57.4 | 17.8 | 1.80 | 0.0382 |
| 35 | 0.4750 | 1.8529 | 58.2 | 19.7 | 1.83 | 0.0383 |




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.21 | 0.08 |
| $\phi$, deg | 34.5 | 34.3 |
| Tan($\phi$) | 0.69 | 0.68 |




| Sample No. | | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 15.9 | 15.9 | 15.9 |
| | Dry Density, pcf | 98.4 | 98.4 | 98.4 |
| | Saturation, % | 60.2 | 60.2 | 60.2 |
| | Void Ratio | 0.7134 | 0.7134 | 0.7134 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 15.4 | 15.0 | 15.0 |
| | Dry Density, pcf | 98.9 | 100.4 | 103.1 |
| | Saturation, % | 58.9 | 59.7 | 63.8 |
| | Void Ratio | 0.7048 | 0.6782 | 0.6356 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 0.98 | 0.95 |
| Normal Stress, ksf | | 0.25 | 1.00 | 2.50 |
| Fail. Stress, ksf | | 0.36 | 0.92 | 1.91 |
| Strain, % | | 3.7 | 4.6 | 11.6 |
| Ult. Stress, ksf | | 0.25 | 0.76 | 1.78 |
| Strain, % | | 16.8 | 14.1 | 15.1 |
| Strain rate, %/min. | | 0.30 | 0.30 | 0.30 |

**Sample Type:** Remolded loose, +4% OMC
**Description:** sand

**Assumed Specific Gravity=** 2.7
**Remarks:** Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-D1
**Sample Number:** 07-0430G
**Proj. No.:** 07.1243 **Date Sampled:** 7/19/07

Knight Piésold CONSULTING

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

7/24/2007

**Date:** 7/19/07
**Client:** J.A. Cesare & Associates, Inc.
**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113
**Project No.:** 07.1243
**Location:** USEN-D1
**Sample Number:** 07-0430G
**Description:** sand
**Remarks:** Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated.
**Type of Sample:** Remolded loose, +4% OMC
**Assumed Specific Gravity=**2.7 **LL=** **PL=** **PI=**

## Parameters for Specimen No. 1

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 317.320 | | 252.960 |
| Moisture content: Dry soil+tare, gms. | 294.330 | | 235.150 |
| Moisture content: Tare, gms. | 149.820 | | 119.330 |
| Moisture, % | 15.9 | 15.4 | 15.4 |
| Moist specimen weight, gms. | 137.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 114.0 | 114.1 | |
| Dry density, pcf | 98.4 | 98.9 | |
| Void ratio | 0.7134 | 0.7048 | |
| Saturation, % | 60.2 | 58.9 | |

## Test Readings for Specimen No. 1

**Load ring constant =** 31.4108 lbs. per input unit
**Normal stress =** 0.25 ksf
**Strain rate, %/min. =** 0.30
**Fail. Stress =** 0.36 ksf **at reading no.** 15
**Ult. Stress =** 0.25 ksf **at reading no.** 29

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0002 |
| 1 | 0.0010 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0000 |
| 2 | 0.0050 | 0.1305 | 4.1 | 0.2 | 0.13 | 0.0001 |
| 3 | 0.0110 | 0.1783 | 5.6 | 0.5 | 0.18 | 0.0001 |
| 4 | 0.0160 | 0.2133 | 6.7 | 0.7 | 0.21 | 0.0004 |
| 5 | 0.0200 | 0.2388 | 7.5 | 0.8 | 0.24 | 0.0009 |
| 6 | 0.0250 | 0.2642 | 8.3 | 1.0 | 0.26 | 0.0015 |
| 7 | 0.0310 | 0.2802 | 8.8 | 1.3 | 0.28 | 0.0023 |
| 8 | 0.0350 | 0.2961 | 9.3 | 1.4 | 0.29 | 0.0032 |
| 9 | 0.0400 | 0.3088 | 9.7 | 1.7 | 0.30 | 0.0042 |
| 10 | 0.0450 | 0.3215 | 10.1 | 1.9 | 0.32 | 0.0054 |
| 11 | 0.0500 | 0.3311 | 10.4 | 2.1 | 0.33 | 0.0064 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 12 | 0.0600 | 0.3406 | 10.7 | 2.5 | 0.34 | 0.0089 |
| 13 | 0.0700 | 0.3502 | 11.0 | 2.9 | 0.35 | 0.0112 |
| 14 | 0.0800 | 0.3597 | 11.3 | 3.3 | 0.35 | 0.0139 |
| 15 | 0.0900 | 0.3629 | 11.4 | 3.7 | 0.36 | 0.0165 |
| 16 | 0.1150 | 0.3534 | 11.1 | 4.8 | 0.35 | 0.0235 |
| 17 | 0.1300 | 0.3406 | 10.7 | 5.4 | 0.34 | 0.0275 |
| 18 | 0.1400 | 0.3279 | 10.3 | 5.8 | 0.32 | 0.0299 |
| 19 | 0.1510 | 0.3152 | 9.9 | 6.3 | 0.31 | 0.0318 |
| 20 | 0.1660 | 0.3056 | 9.6 | 6.9 | 0.30 | 0.0346 |
| 21 | 0.1750 | 0.2961 | 9.3 | 7.2 | 0.29 | 0.0362 |
| 22 | 0.1950 | 0.2865 | 9.0 | 8.1 | 0.28 | 0.0389 |
| 23 | 0.2050 | 0.2770 | 8.7 | 8.5 | 0.27 | 0.0402 |
| 24 | 0.2150 | 0.2674 | 8.4 | 8.9 | 0.26 | 0.0413 |
| 25 | 0.2400 | 0.2579 | 8.1 | 9.9 | 0.25 | 0.0438 |
| 26 | 0.2800 | 0.2579 | 8.1 | 11.6 | 0.25 | 0.0456 |
| 27 | 0.3210 | 0.2483 | 7.8 | 13.3 | 0.25 | 0.0472 |
| 28 | 0.3660 | 0.2547 | 8.0 | 15.1 | 0.25 | 0.0490 |
| 29 | 0.4060 | 0.2515 | 7.9 | 16.8 | 0.25 | 0.0500 |
| 30 | 0.4510 | 0.2515 | 7.9 | 18.7 | 0.25 | 0.0515 |
| 31 | 0.4950 | 0.2451 | 7.7 | 20.5 | 0.24 | 0.0531 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 317.320 | | 252.850 |
| Moisture content: Dry soil+tare, gms. | 294.330 | | 235.320 |
| Moisture content: Tare, gms. | 149.820 | | 118.420 |
| Moisture, % | 15.9 | 15.0 | 15.0 |
| Moist specimen weight, gms. | 137.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 114.0 | 115.5 | |
| Dry density, pcf | 98.4 | 100.4 | |
| Void ratio | 0.7134 | 0.6782 | |
| Saturation, % | 60.2 | 59.7 | |

## Test Readings for Specimen No. 2

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 1.0 ksf

**Strain rate, %/min.** = 0.30

**Fail. Stress** = 0.92 ksf **at reading no.** 18

**Ult. Stress** = 0.76 ksf **at reading no.** 28

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0001 |
| 1 | 0.0050 | 0.1305 | 4.1 | 0.2 | 0.13 | -0.0005 |
| 2 | 0.0100 | 0.2674 | 8.4 | 0.4 | 0.26 | -0.0010 |
| 3 | 0.0150 | 0.3725 | 11.7 | 0.6 | 0.37 | -0.0016 |
| 4 | 0.0200 | 0.4616 | 14.5 | 0.8 | 0.46 | -0.0021 |
| 5 | 0.0260 | 0.5253 | 16.5 | 1.1 | 0.52 | -0.0024 |
| 6 | 0.0300 | 0.5826 | 18.3 | 1.2 | 0.57 | -0.0026 |
| 7 | 0.0350 | 0.6367 | 20.0 | 1.4 | 0.63 | -0.0027 |
| 8 | 0.0400 | 0.6781 | 21.3 | 1.7 | 0.67 | -0.0027 |
| 9 | 0.0460 | 0.7163 | 22.5 | 1.9 | 0.71 | -0.0025 |
| 10 | 0.0500 | 0.7482 | 23.5 | 2.1 | 0.74 | -0.0023 |
| 11 | 0.0550 | 0.7800 | 24.5 | 2.3 | 0.77 | -0.0019 |
| 12 | 0.0600 | 0.8055 | 25.3 | 2.5 | 0.79 | -0.0016 |
| 13 | 0.0650 | 0.8309 | 26.1 | 2.7 | 0.82 | -0.0013 |
| 14 | 0.0700 | 0.8532 | 26.8 | 2.9 | 0.84 | -0.0008 |
| 15 | 0.0750 | 0.8755 | 27.5 | 3.1 | 0.86 | -0.0004 |
| 16 | 0.0850 | 0.9041 | 28.4 | 3.5 | 0.89 | 0.0010 |
| 17 | 0.1010 | 0.9264 | 29.1 | 4.2 | 0.91 | 0.0032 |
| 18 | 0.1100 | 0.9328 | 29.3 | 4.6 | 0.92 | 0.0047 |
| 19 | 0.1150 | 0.9328 | 29.3 | 4.8 | 0.92 | 0.0055 |
| 20 | 0.1460 | 0.9137 | 28.7 | 6.0 | 0.90 | 0.0099 |
| 21 | 0.1700 | 0.8946 | 28.1 | 7.0 | 0.88 | 0.0136 |
| 22 | 0.1800 | 0.8628 | 27.1 | 7.5 | 0.85 | 0.0150 |
| 23 | 0.2010 | 0.8437 | 26.5 | 8.3 | 0.83 | 0.0173 |
| 24 | 0.2250 | 0.8182 | 25.7 | 9.3 | 0.81 | 0.0196 |
| 25 | 0.2460 | 0.7991 | 25.1 | 10.2 | 0.79 | 0.0213 |
| 26 | 0.2700 | 0.7768 | 24.4 | 11.2 | 0.77 | 0.0222 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 27 | 0.3150 | 0.7895 | 24.8 | 13.0 | 0.78 | 0.0238 |
| 28 | 0.3410 | 0.7673 | 24.1 | 14.1 | 0.76 | 0.0248 |
| 29 | 0.3850 | 0.7673 | 24.1 | 15.9 | 0.76 | 0.0257 |
| 30 | 0.4200 | 0.7864 | 24.7 | 17.4 | 0.78 | 0.0267 |
| 31 | 0.4600 | 0.7736 | 24.3 | 19.0 | 0.76 | 0.0270 |
| 32 | 0.4750 | 0.7927 | 24.9 | 19.7 | 0.78 | 0.0275 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 317.320 | | 246.390 |
| Moisture content: Dry soil+tare, gms. | 294.330 | | 229.000 |
| Moisture content: Tare, gms. | 149.820 | | 113.120 |
| Moisture, % | 15.9 | 15.0 | 15.0 |
| Moist specimen weight, gms. | 137.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.95 | |
| Net decrease in height, in. | | 0.05 | |
| Wet Density, pcf | 114.0 | 118.5 | |
| Dry density, pcf | 98.4 | 103.1 | |
| Void ratio | 0.7134 | 0.6356 | |
| Saturation, % | 60.2 | 63.8 | |

## Test Readings for Specimen No. 3

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 2.5 ksf

**Strain rate, %/min.** = 0.30

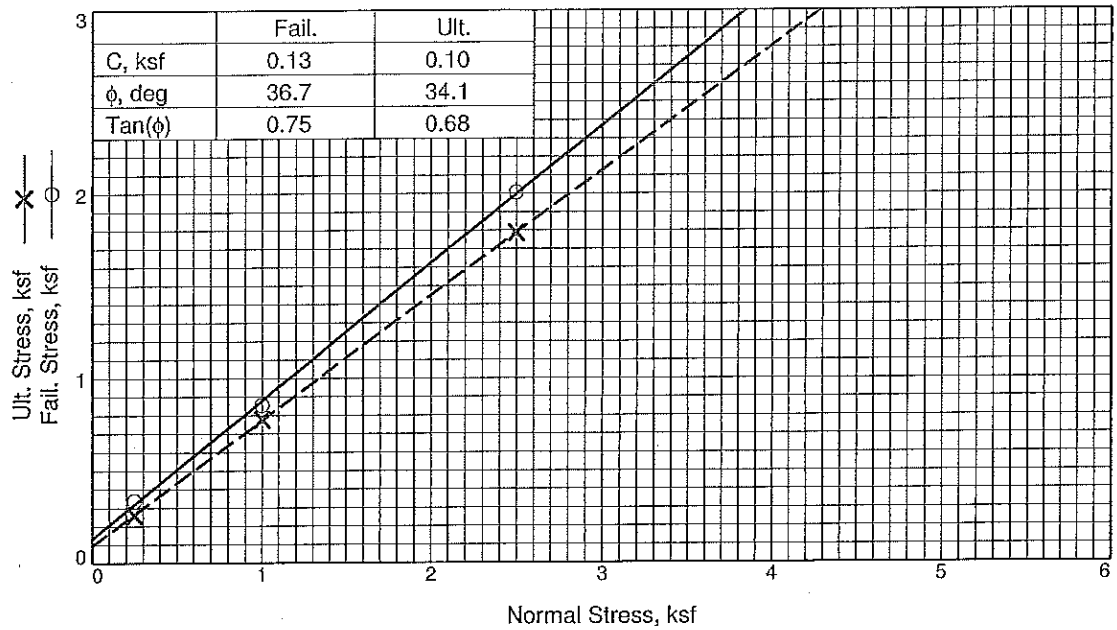
**Fail. Stress** = 1.91 ksf **at reading no.** 24

**Ult. Stress** = 1.78 ksf **at reading no.** 27

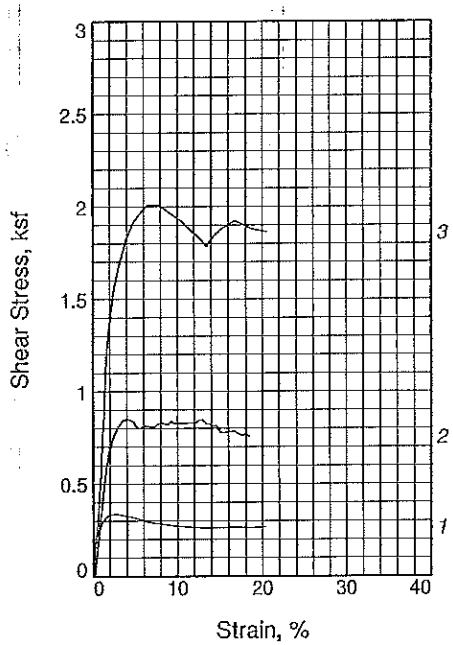
| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0002 |
| 1 | 0.0050 | 0.3024 | 9.5 | 0.2 | 0.30 | -0.0012 |
| 2 | 0.0100 | 0.4998 | 15.7 | 0.4 | 0.49 | -0.0019 |
| 3 | 0.0150 | 0.6781 | 21.3 | 0.6 | 0.67 | -0.0027 |
| 4 | 0.0200 | 0.8182 | 25.7 | 0.8 | 0.81 | -0.0035 |
| 5 | 0.0250 | 0.9328 | 29.3 | 1.0 | 0.92 | -0.0041 |
| 6 | 0.0300 | 1.0347 | 32.5 | 1.2 | 1.02 | -0.0047 |
| 7 | 0.0350 | 1.1302 | 35.5 | 1.4 | 1.12 | -0.0051 |
| 8 | 0.0400 | 1.2130 | 38.1 | 1.7 | 1.20 | -0.0055 |
| 9 | 0.0450 | 1.2925 | 40.6 | 1.9 | 1.28 | -0.0059 |
| 10 | 0.0510 | 1.3467 | 42.3 | 2.1 | 1.33 | -0.0062 |
| 11 | 0.0550 | 1.4103 | 44.3 | 2.3 | 1.39 | -0.0065 |
| 12 | 0.0600 | 1.4613 | 45.9 | 2.5 | 1.44 | -0.0066 |
| 13 | 0.0650 | 1.5059 | 47.3 | 2.7 | 1.49 | -0.0068 |
| 14 | 0.0700 | 1.5568 | 48.9 | 2.9 | 1.54 | -0.0068 |
| 15 | 0.0750 | 1.6077 | 50.5 | 3.1 | 1.59 | -0.0068 |
| 16 | 0.0850 | 1.6714 | 52.5 | 3.5 | 1.65 | -0.0067 |

## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 17 | 0.0950 | 1.7160 | 53.9 | 3.9 | 1.69 | -0.0067 |
| 18 | 0.1050 | 1.7733 | 55.7 | 4.3 | 1.75 | -0.0066 |
| 19 | 0.1200 | 1.8306 | 57.5 | 5.0 | 1.81 | -0.0063 |
| 20 | 0.1600 | 1.8497 | 58.1 | 6.6 | 1.82 | -0.0050 |
| 21 | 0.1750 | 1.9006 | 59.7 | 7.2 | 1.88 | -0.0047 |
| 22 | 0.2150 | 1.9102 | 60.0 | 8.9 | 1.88 | -0.0035 |
| 23 | 0.2500 | 1.9261 | 60.5 | 10.3 | 1.90 | -0.0026 |
| 24 | 0.2810 | 1.9388 | 60.9 | 11.6 | 1.91 | -0.0013 |
| 25 | 0.2900 | 1.8879 | 59.3 | 12.0 | 1.86 | -0.0010 |
| 26 | 0.3300 | 1.8720 | 58.8 | 13.7 | 1.85 | -0.0004 |
| 27 | 0.3650 | 1.8083 | 56.8 | 15.1 | 1.78 | 0.0002 |
| 28 | 0.4050 | 1.8433 | 57.9 | 16.8 | 1.82 | 0.0000 |
| 29 | 0.4200 | 1.7987 | 56.5 | 17.4 | 1.77 | -0.0002 |
| 30 | 0.4600 | 1.7860 | 56.1 | 19.0 | 1.76 | -0.0007 |




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.13 | 0.10 |
| ϕ, deg | 36.7 | 34.1 |
| Tan(ϕ) | 0.75 | 0.68 |




| | Sample No. | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 14.6 | 14.6 | 14.6 |
| | Dry Density, pcf | 100.2 | 100.2 | 100.2 |
| | Saturation, % | 57.9 | 57.9 | 57.9 |
| | Void Ratio | 0.6817 | 0.6816 | 0.6816 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 11.0 | 12.8 | 13.8 |
| | Dry Density, pcf | 100.6 | 101.2 | 102.2 |
| | Saturation, % | 44.0 | 52.0 | 57.3 |
| | Void Ratio | 0.6759 | 0.6648 | 0.6488 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 0.99 | 0.98 |
| | Normal Stress, ksf | 0.25 | 1.00 | 2.50 |
| | Fail. Stress, ksf | 0.34 | 0.85 | 2.01 |
| | Strain, % | 2.5 | 3.9 | 6.4 |
| | Ult. Stress, ksf | 0.26 | 0.78 | 1.79 |
| | Strain, % | 15.1 | 15.1 | 13.5 |
| | Strain rate, %/min. | 0.30 | 0.33 | 0.33 |

**Sample Type:** Remolded loose, +4% OMC
**Description:** sand

**Assumed Specific Gravity=** 2.7
**Remarks:** Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-D2
**Sample Number:** 07-0430H
**Proj. No.:** 07.1243 **Date Sampled:** 7/20/07

**Knight Piésold CONSULTING**

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

7/24/2007

| | |
|---|---|
| **Date:** | 7/20/07 |
| **Client:** | J.A. Cesare & Associates, Inc. |
| **Project:** | U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113 |
| **Project No.:** | 07.1243 |
| **Location:** | USEN-D2 |
| **Sample Number:** | 07-0430H |
| **Description:** | sand |
| **Remarks:** | Failure tangents drawn at peak shear stress and approximately 15% strain. Specimens were not inundated. |
| **Type of Sample:** | Remolded loose, +4% OMC |

**Assumed Specific Gravity**=2.7 **LL=** **PL=** **PI=**

**Parameters for Specimen No. 1**

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 280.420 | | 251.180 |
| Moisture content: Dry soil+tare, gms. | 259.040 | | 237.710 |
| Moisture content: Tare, gms. | 112.680 | | 115.340 |
| Moisture, % | 14.6 | 11.0 | 11.0 |
| Moist specimen weight, gms. | 138.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 1.00 | |
| Net decrease in height, in. | | 0.00 | |
| Wet Density, pcf | 114.9 | 111.6 | |
| Dry density, pcf | 100.2 | 100.6 | |
| Void ratio | 0.6817 | 0.6759 | |
| Saturation, % | 57.9 | 44.0 | |

**Test Readings for Specimen No. 1**

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 0.25 ksf

**Strain rate, %/min.** = 0.30

**Fail. Stress** = 0.34 ksf **at reading no.** 13

**Ult. Stress** = 0.26 ksf **at reading no.** 24

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 |
| 1 | 0.0010 | 0.0003 | 0.0 | 0.0 | 0.00 |
| 2 | 0.0050 | 0.1560 | 4.9 | 0.2 | 0.15 |
| 3 | 0.0100 | 0.2133 | 6.7 | 0.4 | 0.21 |
| 4 | 0.0150 | 0.2451 | 7.7 | 0.6 | 0.24 |
| 5 | 0.0200 | 0.2706 | 8.5 | 0.8 | 0.27 |
| 6 | 0.0250 | 0.2897 | 9.1 | 1.0 | 0.29 |
| 7 | 0.0300 | 0.3024 | 9.5 | 1.2 | 0.30 |
| 8 | 0.0350 | 0.3184 | 10.0 | 1.4 | 0.31 |
| 9 | 0.0400 | 0.3279 | 10.3 | 1.7 | 0.32 |
| 10 | 0.0450 | 0.3343 | 10.5 | 1.9 | 0.33 |
| 11 | 0.0500 | 0.3387 | 10.6 | 2.1 | 0.33 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 12 | 0.0560 | 0.3396 | 10.7 | 2.3 | 0.34 |
| 13 | 0.0600 | 0.3412 | 10.7 | 2.5 | 0.34 |
| 14 | 0.0650 | 0.3406 | 10.7 | 2.7 | 0.34 |
| 15 | 0.0700 | 0.3406 | 10.7 | 2.9 | 0.34 |
| 16 | 0.1100 | 0.3279 | 10.3 | 4.6 | 0.32 |
| 17 | 0.1250 | 0.3184 | 10.0 | 5.2 | 0.31 |
| 18 | 0.1400 | 0.3088 | 9.7 | 5.8 | 0.30 |
| 19 | 0.1600 | 0.2961 | 9.3 | 6.6 | 0.29 |
| 20 | 0.2000 | 0.2865 | 9.0 | 8.3 | 0.28 |
| 21 | 0.2350 | 0.2770 | 8.7 | 9.7 | 0.27 |
| 22 | 0.2760 | 0.2706 | 8.5 | 11.4 | 0.27 |
| 23 | 0.3200 | 0.2642 | 8.3 | 13.2 | 0.26 |
| 24 | 0.3650 | 0.2642 | 8.3 | 15.1 | 0.26 |
| 25 | 0.4050 | 0.2706 | 8.5 | 16.8 | 0.27 |
| 26 | 0.4510 | 0.2642 | 8.3 | 18.7 | 0.26 |
| 27 | 0.4900 | 0.2738 | 8.6 | 20.3 | 0.27 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 280.420 | | 253.590 |
| Moisture content: Dry soil+tare, gms. | 259.040 | | 237.960 |
| Moisture content: Tare, gms. | 112.680 | | 115.800 |
| Moisture, % | 14.6 | 12.8 | 12.8 |
| Moist specimen weight, gms. | 138.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.99 | |
| Net decrease in height, in. | | 0.01 | |
| Wet Density, pcf | 114.9 | 114.2 | |
| Dry density, pcf | 100.2 | 101.2 | |
| Void ratio | 0.6816 | 0.6648 | |
| Saturation, % | 57.9 | 52.0 | |

## Test Readings for Specimen No. 2

Normal stress = 1.0 ksf

Strain rate, %/min. = 0.33

Fail. Stress = 0.85 ksf at reading no. 15

Ult. Stress = 0.78 ksf at reading no. 42

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 0 | 0.0060 | 0.000 | 0.0 | 0.0 | 0.00 |
| 1 | 0.0110 | 0.400 | 0.4 | 0.2 | 0.01 |
| 2 | 0.0160 | 2.800 | 2.8 | 0.4 | 0.09 |
| 3 | 0.0210 | 5.700 | 5.7 | 0.6 | 0.18 |
| 4 | 0.0260 | 8.700 | 8.7 | 0.8 | 0.27 |
| 5 | 0.0310 | 11.700 | 11.7 | 1.0 | 0.37 |
| 6 | 0.0410 | 17.100 | 17.1 | 1.4 | 0.54 |
| 7 | 0.0510 | 20.900 | 20.9 | 1.9 | 0.66 |
| 8 | 0.0610 | 23.300 | 23.3 | 2.3 | 0.73 |
| 9 | 0.0660 | 24.200 | 24.2 | 2.5 | 0.76 |
| 10 | 0.0710 | 24.900 | 24.9 | 2.7 | 0.78 |
| 11 | 0.0760 | 25.500 | 25.5 | 2.9 | 0.80 |
| 12 | 0.0860 | 26.500 | 26.5 | 3.3 | 0.83 |
| 13 | 0.0910 | 26.900 | 26.9 | 3.5 | 0.84 |
| 14 | 0.0960 | 26.800 | 26.8 | 3.7 | 0.84 |
| 15 | 0.1010 | 27.200 | 27.2 | 3.9 | 0.85 |
| 16 | 0.1110 | 26.900 | 26.9 | 4.3 | 0.84 |
| 17 | 0.1210 | 26.700 | 26.7 | 4.8 | 0.84 |
| 18 | 0.1310 | 25.700 | 25.7 | 5.2 | 0.81 |
| 19 | 0.1410 | 25.500 | 25.5 | 5.6 | 0.80 |
| 20 | 0.1510 | 25.800 | 25.8 | 6.0 | 0.81 |
| 21 | 0.1610 | 25.900 | 25.9 | 6.4 | 0.81 |
| 22 | 0.1700 | 25.700 | 25.7 | 6.8 | 0.81 |
| 23 | 0.1800 | 25.700 | 25.7 | 7.2 | 0.81 |
| 24 | 0.1900 | 26.100 | 26.1 | 7.6 | 0.82 |
| 25 | 0.2000 | 26.500 | 26.5 | 8.0 | 0.83 |
| 26 | 0.2100 | 26.300 | 26.3 | 8.4 | 0.83 |
| 27 | 0.2200 | 26.100 | 26.1 | 8.9 | 0.82 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 28 | 0.2300 | 26.700 | 26.7 | 9.3 | 0.84 |
| 29 | 0.2400 | 26.300 | 26.3 | 9.7 | 0.83 |
| 30 | 0.2500 | 26.500 | 26.5 | 10.1 | 0.83 |
| 31 | 0.2600 | 26.300 | 26.3 | 10.5 | 0.83 |
| 32 | 0.2700 | 26.300 | 26.3 | 10.9 | 0.83 |
| 33 | 0.2810 | 26.500 | 26.5 | 11.4 | 0.83 |
| 34 | 0.2900 | 26.400 | 26.4 | 11.8 | 0.83 |
| 35 | 0.3000 | 26.500 | 26.5 | 12.2 | 0.83 |
| 36 | 0.3100 | 26.900 | 26.9 | 12.6 | 0.84 |
| 37 | 0.3210 | 26.900 | 26.9 | 13.0 | 0.84 |
| 38 | 0.3300 | 26.300 | 26.3 | 13.4 | 0.83 |
| 39 | 0.3410 | 26.200 | 26.2 | 13.9 | 0.82 |
| 40 | 0.3500 | 25.900 | 25.9 | 14.2 | 0.81 |
| 41 | 0.3600 | 25.900 | 25.9 | 14.7 | 0.81 |
| 42 | 0.3700 | 24.800 | 24.8 | 15.1 | 0.78 |
| 43 | 0.3810 | 24.700 | 24.7 | 15.5 | 0.78 |
| 44 | 0.3900 | 24.900 | 24.9 | 15.9 | 0.78 |
| 45 | 0.4000 | 24.900 | 24.9 | 16.3 | 0.78 |
| 46 | 0.4100 | 24.900 | 24.9 | 16.7 | 0.78 |
| 47 | 0.4200 | 24.600 | 24.6 | 17.1 | 0.77 |
| 48 | 0.4300 | 24.200 | 24.2 | 17.5 | 0.76 |
| 49 | 0.4400 | 24.500 | 24.5 | 18.0 | 0.77 |
| 50 | 0.4500 | 24.100 | 24.1 | 18.4 | 0.76 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 280.420 | | 257.980 |
| Moisture content: Dry soil+tare, gms. | 259.040 | | 241.440 |
| Moisture content: Tare, gms. | 112.680 | | 121.290 |
| Moisture, % | 14.6 | 13.8 | 13.8 |
| Moist specimen weight, gms. | 138.2 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 114.9 | 116.3 | |
| Dry density, pcf | 100.2 | 102.2 | |
| Void ratio | 0.6816 | 0.6488 | |
| Saturation, % | 57.9 | 57.3 | |

## Test Readings for Specimen No. 3

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 2.5 ksf

**Strain rate, %/min.** = 0.33

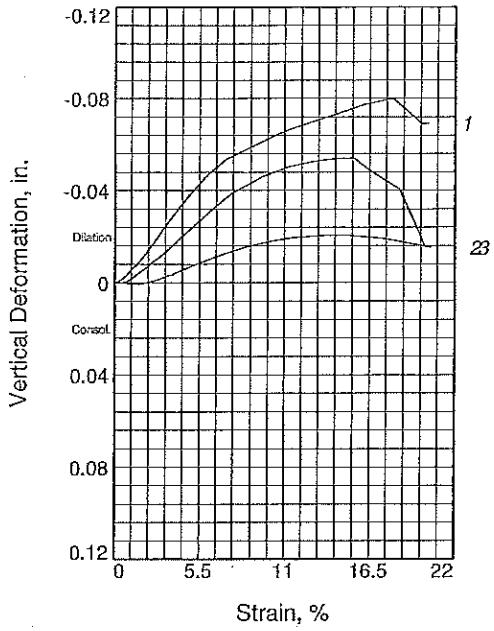
**Fail. Stress** = 2.01 ksf **at reading no.** 22

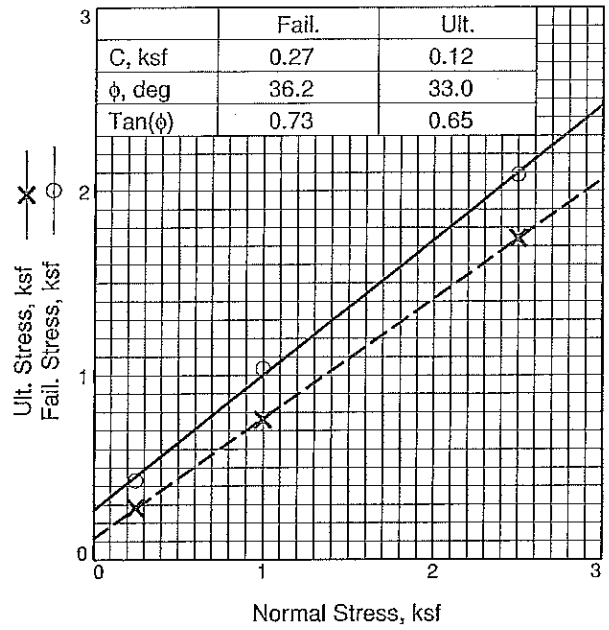
**Ult. Stress** = 1.79 ksf **at reading no.** 28

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 |
| 1 | 0.0050 | 0.1719 | 5.4 | 0.2 | 0.17 |
| 2 | 0.0100 | 0.2197 | 6.9 | 0.4 | 0.22 |
| 3 | 0.0160 | 0.3470 | 10.9 | 0.7 | 0.34 |
| 4 | 0.0200 | 0.4998 | 15.7 | 0.8 | 0.49 |
| 5 | 0.0250 | 0.6781 | 21.3 | 1.0 | 0.67 |
| 6 | 0.0300 | 0.8564 | 26.9 | 1.2 | 0.84 |
| 7 | 0.0350 | 1.0601 | 33.3 | 1.4 | 1.05 |
| 8 | 0.0400 | 1.2098 | 38.0 | 1.7 | 1.19 |
| 9 | 0.0450 | 1.3339 | 41.9 | 1.9 | 1.32 |
| 10 | 0.0500 | 1.4231 | 44.7 | 2.1 | 1.40 |
| 11 | 0.0550 | 1.4995 | 47.1 | 2.3 | 1.48 |
| 12 | 0.0600 | 1.5759 | 49.5 | 2.5 | 1.55 |
| 13 | 0.0650 | 1.6205 | 50.9 | 2.7 | 1.60 |
| 14 | 0.0700 | 1.6650 | 52.3 | 2.9 | 1.64 |
| 15 | 0.0750 | 1.7096 | 53.7 | 3.1 | 1.69 |
| 16 | 0.0850 | 1.7765 | 55.8 | 3.5 | 1.75 |
| 17 | 0.0950 | 1.8465 | 58.0 | 3.9 | 1.82 |
| 18 | 0.1050 | 1.8943 | 59.5 | 4.3 | 1.87 |
| 19 | 0.1150 | 1.9356 | 60.8 | 4.8 | 1.91 |
| 20 | 0.1300 | 1.9770 | 62.1 | 5.4 | 1.95 |
| 21 | 0.1510 | 2.0248 | 63.6 | 6.3 | 2.00 |
| 22 | 0.1550 | 2.0343 | 63.9 | 6.4 | 2.01 |
| 23 | 0.1900 | 2.0343 | 63.9 | 7.9 | 2.01 |
| 24 | 0.2250 | 1.9866 | 62.4 | 9.3 | 1.96 |
| 25 | 0.2560 | 1.9452 | 61.1 | 10.6 | 1.92 |
| 26 | 0.2810 | 1.8974 | 59.6 | 11.6 | 1.87 |

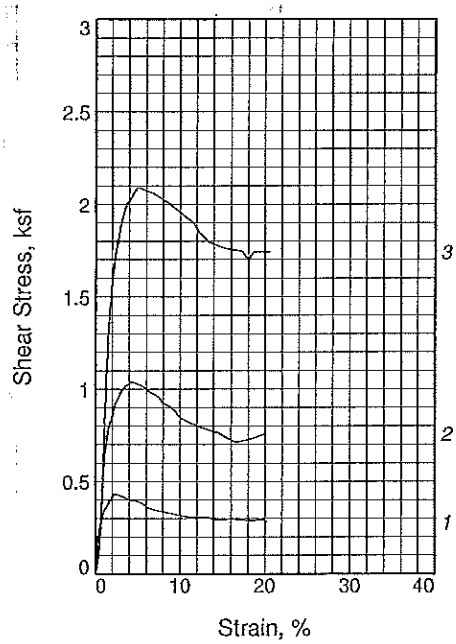
## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf |
|---|---|---|---|---|---|
| 27 | 0.3050 | 1.8561 | 58.3 | 12.6 | 1.83 |
| 28 | 0.3250 | 1.8115 | 56.9 | 13.5 | 1.79 |
| 29 | 0.3460 | 1.8688 | 58.7 | 14.3 | 1.84 |
| 30 | 0.3710 | 1.9102 | 60.0 | 15.4 | 1.88 |
| 31 | 0.4050 | 1.9516 | 61.3 | 16.8 | 1.93 |
| 32 | 0.4500 | 1.9070 | 59.9 | 18.6 | 1.88 |
| 33 | 0.4950 | 1.8879 | 59.3 | 20.5 | 1.86 |




| | Fail. | Ult. |
|---|---|---|
| C, ksf | 0.27 | 0.12 |
| ϕ, deg | 36.2 | 33.0 |
| Tan(ϕ) | 0.73 | 0.65 |




| Sample No. | | 1 | 2 | 3 |
|---|---|---|---|---|
| Initial | Water Content, % | 13.4 | 13.4 | 13.4 |
| | Dry Density, pcf | 101.0 | 101.0 | 101.0 |
| | Saturation, % | 54.2 | 54.2 | 54.2 |
| | Void Ratio | 0.6682 | 0.6682 | 0.6682 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 1.00 | 1.00 |
| At Test | Water Content, % | 12.9 | 13.2 | 12.8 |
| | Dry Density, pcf | 101.3 | 103.0 | 104.9 |
| | Saturation, % | 52.5 | 55.8 | 56.9 |
| | Void Ratio | 0.6632 | 0.6372 | 0.6070 |
| | Diameter, in. | 2.42 | 2.42 | 2.42 |
| | Height, in. | 1.00 | 0.98 | 0.96 |
| Normal Stress, ksf | | 0.25 | 1.00 | 2.50 |
| Fail. Stress, ksf | | 0.43 | 1.04 | 2.09 |
| Strain, % | | 2.3 | 4.1 | 5.0 |
| Ult. Stress, ksf | | 0.28 | 0.76 | 1.74 |
| Strain, % | | 20.3 | 20.1 | 20.5 |
| Strain rate, %/min. | | 0.25 | 0.25 | 0.25 |

**Sample Type:** Remolded 83% MDD @ OMC +4%

**Description:** sand

**Assumed Specific Gravity=** 2.7

**Remarks:** Failure tangents drawn at peak shear stress and approximately 20% strain. Specimens were not inundated.

**Fig.** _____

**Client:** J.A. Cesare & Associates, Inc.

**Project:** U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113

**Location:** USEN-D1 & D2, 5% Zeolite Clay

**Sample Number:** 07-0605D

**Proj. No.:** 07.1243 **Date Sampled:** 8/20/07

Knight Piésold CONSULTING

**Tested By:** jdb **Checked By:** spb

Cursory interpretations provided require review by a professional engineer. Knight Piesold accepts no responsibility in subsequent analyses.

# DIRECT SHEAR TEST

8/24/2007

| | |
|---|---|
| **Date:** | 8/20/07 |
| **Client:** | J.A. Cesare & Associates, Inc. |
| **Project:** | U.S. Ecology-NV Miscellaneous Testing Proj.#07-3113 |
| **Project No.:** | 07.1243 |
| **Location:** | USEN-D1 & D2, 5% Zeolite Clay |
| **Sample Number:** | 07-0605D |
| **Description:** | sand |
| **Remarks:** | Failure tangents drawn at peak shear stress and approximately 20% strain. Specimens were not inundated. |
| **Type of Sample:** | Remolded 83% MDD @ OMC +4% |

**Assumed Specific Gravity=**2.7 **LL=** **PL=** **PI=**

## Parameters for Specimen No. 1

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 486.240 | | 512.660 |
| Moisture content: Dry soil+tare, gms. | 442.370 | | 497.050 |
| Moisture content: Tare, gms. | 115.320 | | 376.050 |
| Moisture, % | 13.4 | 12.9 | 12.9 |
| Moist specimen weight, gms. | 137.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 1.00 | |
| Net decrease in height, in. | | 0.00 | |
| Wet Density, pcf | 114.6 | 114.4 | |
| Dry density, pcf | 101.0 | 101.3 | |
| Void ratio | 0.6682 | 0.6632 | |
| Saturation, % | 54.2 | 52.5 | |

## Test Readings for Specimen No. 1

**Load ring constant =** 31.4108 lbs. per input unit

**Normal stress =** 0.25 ksf

**Strain rate, %/min. =** 0.25

**Fail. Stress =** 0.43 ksf **at reading no.** 11

**Ult. Stress =** 0.28 ksf **at reading no.** 29

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0001 |
| 1 | 0.0050 | 0.1751 | 5.5 | 0.2 | 0.17 | 0.0004 |
| 2 | 0.0100 | 0.2388 | 7.5 | 0.4 | 0.24 | 0.0014 |
| 3 | 0.0160 | 0.2897 | 9.1 | 0.7 | 0.29 | 0.0025 |
| 4 | 0.0200 | 0.3215 | 10.1 | 0.8 | 0.32 | 0.0038 |
| 5 | 0.0250 | 0.3470 | 10.9 | 1.0 | 0.34 | 0.0052 |
| 6 | 0.0300 | 0.3661 | 11.5 | 1.2 | 0.36 | 0.0067 |
| 7 | 0.0360 | 0.3852 | 12.1 | 1.5 | 0.38 | 0.0083 |
| 8 | 0.0410 | 0.4011 | 12.6 | 1.7 | 0.40 | 0.0099 |
| 9 | 0.0460 | 0.4171 | 13.1 | 1.9 | 0.41 | 0.0114 |
| 10 | 0.0500 | 0.4298 | 13.5 | 2.1 | 0.42 | 0.0130 |
| 11 | 0.0550 | 0.4362 | 13.7 | 2.3 | 0.43 | 0.0150 |

## Test Readings for Specimen No. 1

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 12 | 0.0610 | 0.4362 | 13.7 | 2.5 | 0.43 | 0.0171 |
| 13 | 0.0800 | 0.4234 | 13.3 | 3.3 | 0.42 | 0.0249 |
| 14 | 0.0900 | 0.4107 | 12.9 | 3.7 | 0.41 | 0.0286 |
| 15 | 0.1150 | 0.4011 | 12.6 | 4.8 | 0.40 | 0.0374 |
| 16 | 0.1300 | 0.3916 | 12.3 | 5.4 | 0.39 | 0.0422 |
| 17 | 0.1400 | 0.3789 | 11.9 | 5.8 | 0.37 | 0.0452 |
| 18 | 0.1450 | 0.3693 | 11.6 | 6.0 | 0.36 | 0.0467 |
| 19 | 0.1550 | 0.3597 | 11.3 | 6.4 | 0.35 | 0.0491 |
| 20 | 0.1750 | 0.3470 | 10.9 | 7.2 | 0.34 | 0.0537 |
| 21 | 0.2150 | 0.3343 | 10.5 | 8.9 | 0.33 | 0.0593 |
| 22 | 0.2500 | 0.3184 | 10.0 | 10.3 | 0.31 | 0.0641 |
| 23 | 0.2800 | 0.3088 | 9.7 | 11.6 | 0.30 | 0.0674 |
| 24 | 0.3250 | 0.3088 | 9.7 | 13.5 | 0.30 | 0.0714 |
| 25 | 0.3460 | 0.2961 | 9.3 | 14.3 | 0.29 | 0.0733 |
| 26 | 0.3900 | 0.3024 | 9.5 | 16.1 | 0.30 | 0.0775 |
| 27 | 0.4350 | 0.2929 | 9.2 | 18.0 | 0.29 | 0.0802 |
| 28 | 0.4800 | 0.2961 | 9.3 | 19.9 | 0.29 | 0.0691 |
| 29 | 0.4900 | 0.2865 | 9.0 | 20.3 | 0.28 | 0.0694 |

## Parameters for Specimen No. 2

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 486.240 | | 533.060 |
| Moisture content: Dry soil+tare, gms. | 442.370 | | 517.040 |
| Moisture content: Tare, gms. | 115.320 | | 395.480 |
| Moisture, % | 13.4 | 13.2 | 13.2 |
| Moist specimen weight, gms. | 137.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.98 | |
| Net decrease in height, in. | | 0.02 | |
| Wet Density, pcf | 114.6 | 116.5 | |
| Dry density, pcf | 101.0 | 103.0 | |
| Void ratio | 0.6682 | 0.6372 | |
| Saturation, % | 54.2 | 55.8 | |

## Test Readings for Specimen No. 2

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 1.0 ksf

**Strain rate, %/min.** = 0.25

**Fail. Stress** = 1.04 ksf **at reading no.** 16

**Ult. Stress** = 0.76 ksf **at reading no.** 31

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | 0.0000 |
| 1 | 0.0050 | 0.0541 | 1.7 | 0.2 | 0.05 | -0.0001 |
| 2 | 0.0100 | 0.1337 | 4.2 | 0.4 | 0.13 | -0.0002 |
| 3 | 0.0150 | 0.2770 | 8.7 | 0.6 | 0.27 | 0.0001 |
| 4 | 0.0200 | 0.5157 | 16.2 | 0.8 | 0.51 | 0.0005 |
| 5 | 0.0250 | 0.6367 | 20.0 | 1.0 | 0.63 | 0.0014 |
| 6 | 0.0300 | 0.7163 | 22.5 | 1.2 | 0.71 | 0.0024 |
| 7 | 0.0350 | 0.7736 | 24.3 | 1.4 | 0.76 | 0.0035 |
| 8 | 0.0400 | 0.8182 | 25.7 | 1.7 | 0.81 | 0.0046 |
| 9 | 0.0460 | 0.8500 | 26.7 | 1.9 | 0.84 | 0.0057 |
| 10 | 0.0510 | 0.8882 | 27.9 | 2.1 | 0.88 | 0.0068 |
| 11 | 0.0550 | 0.9201 | 28.9 | 2.3 | 0.91 | 0.0079 |
| 12 | 0.0600 | 0.9455 | 29.7 | 2.5 | 0.93 | 0.0091 |
| 13 | 0.0660 | 0.9678 | 30.4 | 2.7 | 0.95 | 0.0101 |
| 14 | 0.0750 | 1.0060 | 31.6 | 3.1 | 0.99 | 0.0122 |
| 15 | 0.0850 | 1.0283 | 32.3 | 3.5 | 1.01 | 0.0146 |
| 16 | 0.1000 | 1.0506 | 33.0 | 4.1 | 1.04 | 0.0185 |
| 17 | 0.1050 | 1.0538 | 33.1 | 4.3 | 1.04 | 0.0199 |
| 18 | 0.1360 | 1.0283 | 32.3 | 5.6 | 1.01 | 0.0277 |
| 19 | 0.1550 | 0.9997 | 31.4 | 6.4 | 0.99 | 0.0323 |
| 20 | 0.1800 | 0.9710 | 30.5 | 7.5 | 0.96 | 0.0379 |
| 21 | 0.1900 | 0.9424 | 29.6 | 7.9 | 0.93 | 0.0397 |
| 22 | 0.2150 | 0.9137 | 28.7 | 8.9 | 0.90 | 0.0437 |
| 23 | 0.2300 | 0.8882 | 27.9 | 9.5 | 0.88 | 0.0461 |
| 24 | 0.2400 | 0.8596 | 27.0 | 9.9 | 0.85 | 0.0471 |
| 25 | 0.2750 | 0.8246 | 25.9 | 11.4 | 0.81 | 0.0506 |
| 26 | 0.3100 | 0.7991 | 25.1 | 12.8 | 0.79 | 0.0526 |

## Test Readings for Specimen No. 2

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 27 | 0.3510 | 0.7736 | 24.3 | 14.5 | 0.76 | 0.0542 |
| 28 | 0.3750 | 0.7482 | 23.5 | 15.5 | 0.74 | 0.0541 |
| 29 | 0.4000 | 0.7227 | 22.7 | 16.6 | 0.71 | 0.0486 |
| 30 | 0.4460 | 0.7418 | 23.3 | 18.5 | 0.73 | 0.0406 |
| 31 | 0.4860 | 0.7704 | 24.2 | 20.1 | 0.76 | 0.0154 |

## Parameters for Specimen No. 3

| Specimen Parameter | Initial | Consolidated | Final |
|---|---|---|---|
| Moisture content: Moist soil+tare, gms. | 486.240 | | 532.550 |
| Moisture content: Dry soil+tare, gms. | 442.370 | | 516.900 |
| Moisture content: Tare, gms. | 115.320 | | 394.650 |
| Moisture, % | 13.4 | 12.8 | 12.8 |
| Moist specimen weight, gms. | 137.9 | | |
| Diameter, in. | 2.42 | 2.42 | |
| Area, in.$^2$ | 4.58 | 4.58 | |
| Height, in. | 1.00 | 0.96 | |
| Net decrease in height, in. | | 0.04 | |
| Wet Density, pcf | 114.6 | 118.3 | |
| Dry density, pcf | 101.0 | 104.9 | |
| Void ratio | 0.6682 | 0.6070 | |
| Saturation, % | 54.2 | 56.9 | |

## Test Readings for Specimen No. 3

**Load ring constant** = 31.4108 lbs. per input unit

**Normal stress** = 2.5 ksf

**Strain rate, %/min.** = 0.25

**Fail. Stress** = 2.09 ksf **at reading no.** 20

**Ult. Stress** = 1.74 ksf **at reading no.** 32

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0 | 0.0 | 0.00 | -0.0001 |
| 1 | 0.0060 | 0.0669 | 2.1 | 0.2 | 0.07 | -0.0002 |
| 2 | 0.0110 | 0.1369 | 4.3 | 0.5 | 0.14 | -0.0002 |
| 3 | 0.0150 | 0.2642 | 8.3 | 0.6 | 0.26 | -0.0003 |
| 4 | 0.0200 | 0.4998 | 15.7 | 0.8 | 0.49 | -0.0004 |
| 5 | 0.0250 | 0.7800 | 24.5 | 1.0 | 0.77 | -0.0006 |
| 6 | 0.0300 | 1.0219 | 32.1 | 1.2 | 1.01 | -0.0008 |
| 7 | 0.0350 | 1.2161 | 38.2 | 1.4 | 1.20 | -0.0008 |
| 8 | 0.0400 | 1.3785 | 43.3 | 1.7 | 1.36 | -0.0006 |
| 9 | 0.0450 | 1.5186 | 47.7 | 1.9 | 1.50 | -0.0004 |
| 10 | 0.0500 | 1.6173 | 50.8 | 2.1 | 1.60 | -0.0002 |
| 11 | 0.0550 | 1.7001 | 53.4 | 2.3 | 1.68 | 0.0002 |
| 12 | 0.0600 | 1.7733 | 55.7 | 2.5 | 1.75 | 0.0006 |
| 13 | 0.0660 | 1.8369 | 57.7 | 2.7 | 1.81 | 0.0011 |
| 14 | 0.0700 | 1.8815 | 59.1 | 2.9 | 1.86 | 0.0015 |
| 15 | 0.0750 | 1.9293 | 60.6 | 3.1 | 1.90 | 0.0020 |
| 16 | 0.0850 | 2.0025 | 62.9 | 3.5 | 1.98 | 0.0032 |
| 17 | 0.0900 | 2.0350 | 63.9 | 3.7 | 2.01 | 0.0033 |

## Test Readings for Specimen No. 3

| No. | Horizontal Def. Dial in. | Load Dial | Load lbs. | Strain % | Shear Stress ksf | Vertical Def. Dial in. |
|---|---|---|---|---|---|---|
| 18 | 0.0950 | 2.0375 | 64.0 | 3.9 | 2.01 | 0.0040 |
| 19 | 0.1100 | 2.0916 | 65.7 | 4.6 | 2.06 | 0.0059 |
| 20 | 0.1200 | 2.1171 | 66.5 | 5.0 | 2.09 | 0.0071 |
| 21 | 0.1250 | 2.1171 | 66.5 | 5.2 | 2.09 | 0.0077 |
| 22 | 0.1660 | 2.0853 | 65.5 | 6.9 | 2.06 | 0.0118 |
| 23 | 0.2100 | 2.0343 | 63.9 | 8.7 | 2.01 | 0.0157 |
| 24 | 0.2450 | 1.9770 | 62.1 | 10.1 | 1.95 | 0.0180 |
| 25 | 0.2800 | 1.9261 | 60.5 | 11.6 | 1.90 | 0.0195 |
| 26 | 0.2950 | 1.8752 | 58.9 | 12.2 | 1.85 | 0.0198 |
| 27 | 0.3250 | 1.8210 | 57.2 | 13.5 | 1.80 | 0.0203 |
| 28 | 0.3700 | 1.7860 | 56.1 | 15.3 | 1.76 | 0.0203 |
| 29 | 0.4160 | 1.7701 | 55.6 | 17.2 | 1.75 | 0.0192 |
| 30 | 0.4350 | 1.7223 | 54.1 | 18.0 | 1.70 | 0.0183 |
| 31 | 0.4500 | 1.7669 | 55.5 | 18.6 | 1.74 | 0.0176 |
| 32 | 0.4950 | 1.7669 | 55.5 | 20.5 | 1.74 | 0.0153 |

# ATTACHMENT 2

# RESULTS OF GEOPHYSICAL SURVEY OF TRENCH 12 AREA

**Zonge Geosciences, Inc.**

*1990 S. Garrison Street, Suite #2*
*Lakewood, CO 80227*
*Phone: (720) 962-4444*
*Fax: 720-962-0417*
*zongecolo@zonge.com*

July 23, 2007

Chris Bolin
Steve Wampler
AquAeTer, Inc.
7340 East Caley Avenue
Suite 200
Centennial, CO 80111
303-771-9150

Subject: ***Geophysical Investigation at the US Ecology Nevada facility, Beatty, NV***

This letter represents the final report for the geophysical investigation conducted at the US Ecology Nevada facility near Beatty, NV (see Figure 1). The work was performed under a contract agreement between AquAeTer, Inc. and Zonge Geosciences, Inc. (Zonge). Geophysical data were collected from July 9th to July 11th, 2007. The report is composed of two sections, an Objective/Scope of Work section and Results section. Figures are presented at the end of the report.

## Objective/Scope of Work

The objective of the geophysical investigation was to detect any buried metallic objects that may be related to burial pits, trenches or 55-gallon drums. To meet the project objective two geophysical methods were employed: time-domain electromagnetics (TDEM) and magnetics. Zonge utilized the Geonics EM61-MK2 high-sensitivity metal detector for the TDEM field surveys and the Geometrics G858 total-field magnetometer.

The EM61-MK2 (pictured at right) is a high resolution metal detector, capable of detecting buried ferrous and non-ferrous (e.g., iron and aluminum, respectively) metallic objects. The system is comprised of two 1 by ½ meter coils mounted one over the other. The lower coil contains a transmitter and a receiver, and the upper coil is strictly a receiver coil. The lower coil is positioned approximately 16 inches off the ground while the top coil is placed an additional 12 inches above the lower coil.

The EM61-MK2 can detect very small metallic objects (e.g., cans, small rebar, etc.), and the occurrence of a large amount of surface metal debris will likely screen the response from a deeper metal object or target. Depth of investigation is target and soil dependent. Larger items may be detected at greater depths (i.e., 55 gallon drums may be detected to depths up to 10 feet below the surface per the manufacturers specifications) while smaller items (pliers, hammer, etc.) may not be detected beyond 12 inches beneath the surface.

The G858 (pictured at left) measures the earth's total magnetic field and the superposition of the magnetic field associated with ferrous objects. The detection capability depends on the size and ferrous content of the causative body but a 55-gallon drum may easily be detected at a depth of 15 feet if interference due to other bodies or buildings is minimal. Barrows and Rocchio (1980) indicate that a 55-gallon drum in a horizontal position and located 11 feet away from the sensor will have a total response of 80nT and an areal extent of more than 25 feet. This article was obtained from the Geometrics website (www.geomterics.com) on August 2, 2007 and has been included in the appendices. Although the authors report that a 55-gallon drum would be easily detectable at 11 feet from the sensor, actual detection capabilities will vary depending on local site conditions. The magnetic sensor was placed approximately 2-3 feet off the ground for this survey. A magnetic base station was not used for this survey.

Both geophysical instruments were coupled with a Real Time Kinematic (RTK) Global Positioning System (GPS) for data positioning. With proper satellite coverage and data acquisition, data may be positioned to within ±15cm of their true location.

Data were collected with the G858 and the EM61-MK2 at 10 readings per second. At a walking speed of 2-3 miles per hour this results in a recorded data value every 0.3 to 0.4 feet. A 5-6 foot line spacing was used for both systems.

For more information regarding the methodology and operation of these instruments please refer to the attached appendices.

**Results**

The G858 magnetometer was the primary geophysical tool used for the survey because of its ability to detect metallic debris to greater depths than the EM61-MK2. The EM61-MK2 was used in areas where above ground metallic cultural features negatively impacted the magnetic data. These areas included along the chain link fence and office buildings. Figure 2 shows a plan view of the facility. Areas surveyed with each instrument have been identified and plotted on Figure 2. Approximately 8.5 acres of geophysical data were collected.

Figure 3 shows the resulting magnetic data collected at the facility while the EM61-MK2 data are shown in Figure 4. Data are displayed using local coordinate system supplied by AquAeTer. Items to note regarding both the magnetic and EM61-MK2 data collection include:

1. The metal fence located along the northern, western, and southern border is visible in both the magnetic and EM data and may conceal anomalies of interest in close proximity to the fence (< 5feet);
2. EM61-MK2 data were only collected in areas where cultural features influenced the magnetic data;
3. Magnetic data were not collected in the building area due to the large number of cultural features present;
4. Areas selected for investigation have been outlined with solid lines and are listed in Table 2 for reference;
5. Anomalous areas were identified as those that had the highest chance of containing 55-gallon drums or similar objects;
6. An additional column in Table 2 identifies the probability that selected anomalies are the result of 55 gallon drums or burial trenches.
7. Anomalous areas with an areal extent with a diameter greater than 15 feet are identified with a 2, those that are smaller are identified with a 1. Anomalous areas that are interpreted to be trenches are identified with a 3.
8. There is no indication of buried trenches containing metallic debris in the geophysical data.
9. Depth estimates for detected anomalies were not made.

Table 1 lists the coordinates used to reference the anomalous zones to a local coordinate system. The point used for the GPS base station is also listed.

**Table 1 – Coordinates of fence posts and GPS base station**

| ID | State Plane Coordinate (Nevada Central)(feet) | | Local (feet) | |
|---|---|---|---|---|
| | X | Y | X | Y |
| NW Fence Corner | 1631907.6 | 20420109.1 | 10003.7 | 9997.5 |
| SW Fence Corner | 1631904.7 | 20419629.6 | 10002.4 | 9519.0 |
| GPS Base | 1633094.3 | 20420107.6 | 11187.9 | 10000.1 |

Twenty-eight (28) areas were marked out in the field and are shown on Figures 2 and 3 with a solid line. The coordinates of the polygons drawn around each area are presented in Table 2 in both a local coordinate system using the northwest corner fencepost as the origin and also in WGS84/State Plane Nevada Central Zone coordinates in feet. As listed in Table 2 nine (9) anomalies have the areal extent that may be expected for a 55-gallon drum.

All but one of the anomalies (#10) are more than likely the result of single metallic objects. This interpretation is based on the areal extent, magnitude, and shape of the anomaly. Anomaly #10 appears to be the result of multiple metallic objects based on the multiple dipolar features in this

area. As discussed with Bob Marchand of US Ecology Nevada, anomaly #1 is likely the result of a caisson buried by the United States Geological Survey (USGS).

It is Zonge's recommendation that a hand held metal detector (i.e. Schonstedt or similar instrument) be used to aid the anomaly excavation. The hand held instrument will allow the excavation team to determine if the metallic object is still buried deeper or has been removed during the digging.

As stated previously depth estimates were not made from the geophysical data. Anomaly signatures will vary depending upon local site conditions. A local test plot that contained multiple 55-gallon drums at varying depths may have provided enough information to make estimates of anomaly depths. Although helpful it would not have constrained the depth estimates to any value closer than ±50% of the estimated depth.

**Conclusions**

Data were collected using both the EM61-MK2 and G858 magnetometer. The geophysical data were successful at identifying subsurface metallic debris at 28 locations. These anomalous zones have been labeled 1 through 28 and marked on Figures 3 and 4.

If you have any questions regarding the objective, field methods including acquisition and processing, please do not hesitate to contact me. We appreciate the opportunity to work with you and hope the geophysical investigation will aid in your assessment of the site.

Respectfully,

Todd Meglich
Senior Geophysicist
Zonge Geosciences, Inc.

**Figure 1 - Survey area (marked with yellow X) located along Highway 95, southeast of Beatty, NV (maps.google.com, retrieved July 19, 2007)**

**Table 2 - Coordinates of anomalous areas**

| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 1 | 1632643 | 20419737 | 10739 | 9629 | **2** |
| | 1632636 | 20419734 | 10732 | 9625 | |
| | 1632634 | 20419731 | 10730 | 9622 | |
| | 1632635 | 20419727 | 10730 | 9618 | |
| | 1632638 | 20419723 | 10734 | 9615 | |
| | 1632645 | 20419719 | 10741 | 9611 | |
| | 1632652 | 20419719 | 10748 | 9610 | |
| | 1632657 | 20419721 | 10752 | 9612 | |
| | 1632658 | 20419724 | 10754 | 9616 | |
| | 1632658 | 20419728 | 10754 | 9620 | |
| | 1632657 | 20419733 | 10752 | 9624 | |
| | 1632651 | 20419737 | 10747 | 9628 | |
| | 1632645 | 20419737 | 10741 | 9629 | |
| 2 | 1632510 | 20419704 | 10606 | 9596 | **2** |
| | 1632507 | 20419704 | 10603 | 9596 | |
| | 1632504 | 20419701 | 10600 | 9593 | |
| | 1632503 | 20419697 | 10599 | 9588 | |
| | 1632506 | 20419695 | 10602 | 9587 | |
| | 1632509 | 20419697 | 10605 | 9588 | |
| | 1632511 | 20419701 | 10607 | 9592 | |
| | 1632510 | 20419703 | 10607 | 9594 | |
| 3 | 1632696 | 20419773 | 10791 | 9665 | **2** |
| | 1632694 | 20419767 | 10789 | 9658 | |
| | 1632696 | 20419763 | 10792 | 9655 | |
| | 1632701 | 20419763 | 10796 | 9655 | |
| | 1632703 | 20419769 | 10798 | 9661 | |
| | 1632702 | 20419774 | 10798 | 9666 | |
| | 1632698 | 20419774 | 10793 | 9666 | |
| 4 | 1632702 | 20419840 | 10797 | 9731 | **1** |
| | 1632700 | 20419837 | 10795 | 9729 | |
| | 1632701 | 20419834 | 10796 | 9726 | |
| | 1632704 | 20419833 | 10799 | 9725 | |
| | 1632705 | 20419836 | 10800 | 9728 | |
| | 1632705 | 20419839 | 10800 | 9731 | |

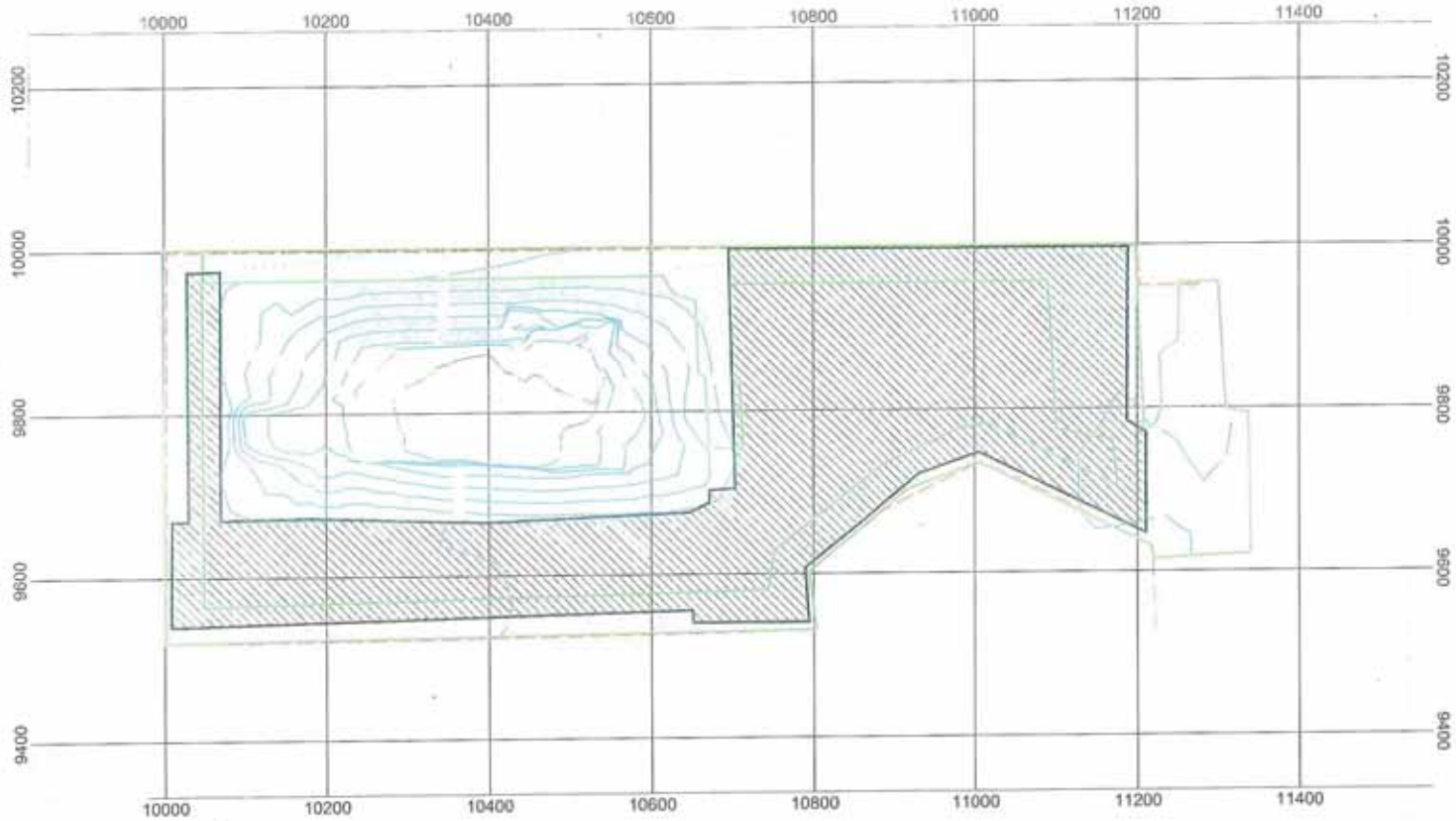
| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 5 | 1632800 | 20419892 | 10895 | 9784 | **2** |
| | 1632795 | 20419889 | 10890 | 9781 | |
| | 1632794 | 20419884 | 10889 | 9776 | |
| | 1632797 | 20419882 | 10892 | 9774 | |
| | 1632801 | 20419882 | 10896 | 9774 | |
| | 1632804 | 20419884 | 10899 | 9776 | |
| | 1632805 | 20419889 | 10900 | 9781 | |
| | 1632803 | 20419892 | 10898 | 9784 | |
| 6 | 1632822 | 20419845 | 10917 | 9737 | **1** |
| | 1632820 | 20419845 | 10915 | 9737 | |
| | 1632818 | 20419842 | 10913 | 9734 | |
| | 1632820 | 20419841 | 10915 | 9733 | |
| | 1632822 | 20419842 | 10917 | 9734 | |
| | 1632823 | 20419845 | 10918 | 9737 | |
| 7 | 1632869 | 20419890 | 10964 | 9782 | **2** |
| | 1632864 | 20419898 | 10958 | 9790 | |
| | 1632854 | 20419894 | 10949 | 9787 | |
| | 1632853 | 20419883 | 10948 | 9775 | |
| | 1632859 | 20419880 | 10954 | 9772 | |
| | 1632870 | 20419882 | 10965 | 9774 | |
| 8 | 1632790 | 20420004 | 10885 | 9895 | **2** |
| | 1632786 | 20420001 | 10881 | 9893 | |
| | 1632784 | 20419996 | 10878 | 9887 | |
| | 1632786 | 20419994 | 10881 | 9886 | |
| | 1632790 | 20419994 | 10885 | 9886 | |
| | 1632792 | 20419998 | 10887 | 9890 | |
| | 1632792 | 20420001 | 10887 | 9893 | |
| 9 | 1632793 | 20420045 | 10887 | 9937 | **1** |
| | 1632791 | 20420047 | 10886 | 9939 | |
| | 1632788 | 20420046 | 10882 | 9938 | |
| | 1632788 | 20420042 | 10882 | 9933 | |
| | 1632791 | 20420040 | 10886 | 9932 | |
| | 1632793 | 20420042 | 10887 | 9933 | |

| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 10 | 1632711 | 20419944 | 10806 | 9836 | **2** |
| | 1632715 | 20419941 | 10810 | 9833 | |
| | 1632724 | 20419944 | 10819 | 9836 | |
| | 1632730 | 20419948 | 10825 | 9840 | |
| | 1632729 | 20419951 | 10824 | 9843 | |
| | 1632729 | 20419955 | 10823 | 9846 | |
| | 1632725 | 20419958 | 10820 | 9850 | |
| | 1632719 | 20419962 | 10814 | 9853 | |
| | 1632715 | 20419962 | 10810 | 9853 | |
| | 1632712 | 20419959 | 10807 | 9851 | |
| | 1632708 | 20419954 | 10803 | 9845 | |
| | 1632708 | 20419950 | 10803 | 9842 | |
| | 1632708 | 20419947 | 10803 | 9839 | |
| 11 | 1632713 | 20419981 | 10808 | 9872 | **1** |
| | 1632706 | 20419979 | 10801 | 9870 | |
| | 1632706 | 20419975 | 10801 | 9867 | |
| | 1632710 | 20419972 | 10804 | 9864 | |
| | 1632714 | 20419974 | 10809 | 9865 | |
| | 1632716 | 20419976 | 10811 | 9868 | |
| | 1632714 | 20419980 | 10809 | 9872 | |
| 12 | 1632690 | 20419966 | 10785 | 9858 | **1** |
| | 1632690 | 20419969 | 10784 | 9860 | |
| | 1632688 | 20419968 | 10783 | 9860 | |
| | 1632687 | 20419967 | 10782 | 9858 | |
| | 1632687 | 20419965 | 10782 | 9856 | |
| | 1632690 | 20419965 | 10785 | 9856 | |
| | 1632691 | 20419966 | 10786 | 9857 | |
| 13 | 1632703 | 20419901 | 10798 | 9793 | **1** |
| | 1632697 | 20419905 | 10792 | 9797 | |
| | 1632691 | 20419905 | 10787 | 9796 | |
| | 1632689 | 20419897 | 10784 | 9789 | |
| | 1632691 | 20419895 | 10786 | 9786 | |
| | 1632696 | 20419892 | 10791 | 9784 | |
| | 1632701 | 20419897 | 10797 | 9788 | |
| | 1632702 | 20419899 | 10797 | 9790 | |

| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 14 | 1632669 | 20419937 | 10764 | 9829 | **1** |
| | 1632665 | 20419937 | 10760 | 9828 | |
| | 1632664 | 20419935 | 10759 | 9827 | |
| | 1632664 | 20419932 | 10760 | 9824 | |
| | 1632668 | 20419932 | 10763 | 9824 | |
| | 1632670 | 20419934 | 10765 | 9826 | |
| 15 | 1632657 | 20419955 | 10752 | 9846 | **1** |
| | 1632656 | 20419952 | 10751 | 9843 | |
| | 1632659 | 20419951 | 10754 | 9842 | |
| | 1632665 | 20419951 | 10760 | 9843 | |
| | 1632664 | 20419954 | 10759 | 9846 | |
| | 1632660 | 20419957 | 10755 | 9848 | |
| 16 | 1632707 | 20419936 | 10802 | 9828 | **1** |
| | 1632704 | 20419937 | 10799 | 9829 | |
| | 1632703 | 20419934 | 10798 | 9826 | |
| | 1632706 | 20419935 | 10801 | 9826 | |
| 17 | 1632686 | 20419931 | 10781 | 9822 | **1** |
| | 1632685 | 20419932 | 10780 | 9824 | |
| | 1632682 | 20419932 | 10777 | 9824 | |
| | 1632682 | 20419929 | 10777 | 9821 | |
| | 1632682 | 20419929 | 10778 | 9820 | |
| | 1632685 | 20419929 | 10780 | 9820 | |
| 18 | 1632636 | 20420004 | 10731 | 9895 | **1** |
| | 1632638 | 20420006 | 10732 | 9897 | |
| | 1632636 | 20420008 | 10730 | 9899 | |
| | 1632633 | 20420007 | 10728 | 9898 | |
| | 1632633 | 20420004 | 10728 | 9896 | |
| | 1632635 | 20420004 | 10730 | 9895 | |
| 19 | 1632615 | 20419979 | 10710 | 9870 | **1** |
| | 1632618 | 20419983 | 10713 | 9874 | |
| | 1632616 | 20419985 | 10711 | 9876 | |
| | 1632614 | 20419986 | 10709 | 9877 | |
| | 1632612 | 20419985 | 10707 | 9876 | |
| | 1632610 | 20419983 | 10705 | 9874 | |
| | 1632610 | 20419981 | 10705 | 9872 | |
| | 1632614 | 20419979 | 10709 | 9870 | |

| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 20 | 1632672 | 20419988 | 10766 | 9880 | **1** |
| | 1632668 | 20419990 | 10763 | 9881 | |
| | 1632664 | 20419989 | 10758 | 9881 | |
| | 1632663 | 20419987 | 10758 | 9879 | |
| | 1632662 | 20419985 | 10757 | 9876 | |
| | 1632664 | 20419984 | 10759 | 9875 | |
| | 1632669 | 20419984 | 10764 | 9875 | |
| | 1632671 | 20419985 | 10766 | 9876 | |
| | 1632671 | 20419987 | 10766 | 9878 | |
| 21 | 1632699 | 20420012 | 10793 | 9904 | **1** |
| | 1632695 | 20420013 | 10790 | 9905 | |
| | 1632692 | 20420013 | 10786 | 9904 | |
| | 1632691 | 20420011 | 10785 | 9902 | |
| | 1632692 | 20420009 | 10787 | 9901 | |
| | 1632697 | 20420010 | 10791 | 9901 | |
| | 1632699 | 20420010 | 10793 | 9902 | |
| 22 | 1633078 | 20419891 | 11173 | 9784 | **1** |
| | 1633077 | 20419889 | 11171 | 9782 | |
| | 1633077 | 20419887 | 11171 | 9780 | |
| | 1633080 | 20419885 | 11175 | 9778 | |
| | 1633082 | 20419885 | 11177 | 9778 | |
| | 1633083 | 20419888 | 11178 | 9781 | |
| | 1633083 | 20419889 | 11177 | 9782 | |
| | 1633080 | 20419891 | 11175 | 9784 | |
| | 1633079 | 20419891 | 11174 | 9784 | |
| 23 | 1633010 | 20419834 | 11105 | 9727 | **2** |
| | 1633010 | 20419836 | 11104 | 9729 | |
| | 1633007 | 20419837 | 11102 | 9730 | |
| | 1633005 | 20419837 | 11100 | 9730 | |
| | 1633003 | 20419836 | 11097 | 9729 | |
| | 1633000 | 20419833 | 11095 | 9726 | |
| | 1633002 | 20419830 | 11097 | 9723 | |
| | 1633006 | 20419830 | 11101 | 9723 | |
| | 1633010 | 20419833 | 11104 | 9726 | |

| Anomaly | State Plane Coordinate (Nevada Central)(feet) | | Local Coordinate (feet) | | Identifier |
|---|---|---|---|---|---|
| | X (East) | Y (North) | X (East) | Y (North) | 1 = diameter < drum<br>2 = diameter => drum<br>3 = trench |
| 24 | 1632998 | 20419949 | 11092 | 9842 | **1** |
| | 1632994 | 20419952 | 11088 | 9845 | |
| | 1632992 | 20419951 | 11086 | 9844 | |
| | 1632991 | 20419948 | 11086 | 9841 | |
| | 1632993 | 20419945 | 11087 | 9838 | |
| | 1632998 | 20419945 | 11093 | 9837 | |
| | 1632999 | 20419947 | 11093 | 9839 | |
| 25 | 1632941 | 20419892 | 11035 | 9784 | **1** |
| | 1632938 | 20419894 | 11033 | 9787 | |
| | 1632935 | 20419894 | 11030 | 9786 | |
| | 1632933 | 20419892 | 11028 | 9785 | |
| | 1632935 | 20419890 | 11029 | 9782 | |
| | 1632937 | 20419889 | 11032 | 9781 | |
| | 1632940 | 20419889 | 11034 | 9781 | |
| | 1632941 | 20419890 | 11035 | 9783 | |
| 26 | 1632901 | 20419902 | 10995 | 9795 | **2** |
| | 1632899 | 20419905 | 10994 | 9797 | |
| | 1632896 | 20419905 | 10991 | 9797 | |
| | 1632895 | 20419902 | 10990 | 9795 | |
| | 1632897 | 20419901 | 10992 | 9793 | |
| | 1632900 | 20419900 | 10995 | 9793 | |
| 27 | 1632321 | 20419676 | 10417 | 9567 | **1** |
| | 1632318 | 20419677 | 10415 | 9568 | |
| | 1632317 | 20419676 | 10413 | 9567 | |
| | 1632317 | 20419675 | 10414 | 9565 | |
| | 1632319 | 20419674 | 10416 | 9565 | |
| | 1632320 | 20419675 | 10417 | 9566 | |
| 28 | 1632861 | 20419851 | 10956 | 9741 | **1** |
| | 1632858 | 20419849 | 10953 | 9740 | |
| | 1632858 | 20419846 | 10953 | 9737 | |
| | 1632860 | 20419845 | 10955 | 9735 | |
| | 1632864 | 20419846 | 10959 | 9737 | |
| | 1632864 | 20419849 | 10959 | 9740 | |



Scale 1:1800

100 0 100 200 300

(feet)

Plant Coordinates

**Notes**

This map shows coverage from both the magnetic and EM geophysical surveys.

**Legend**

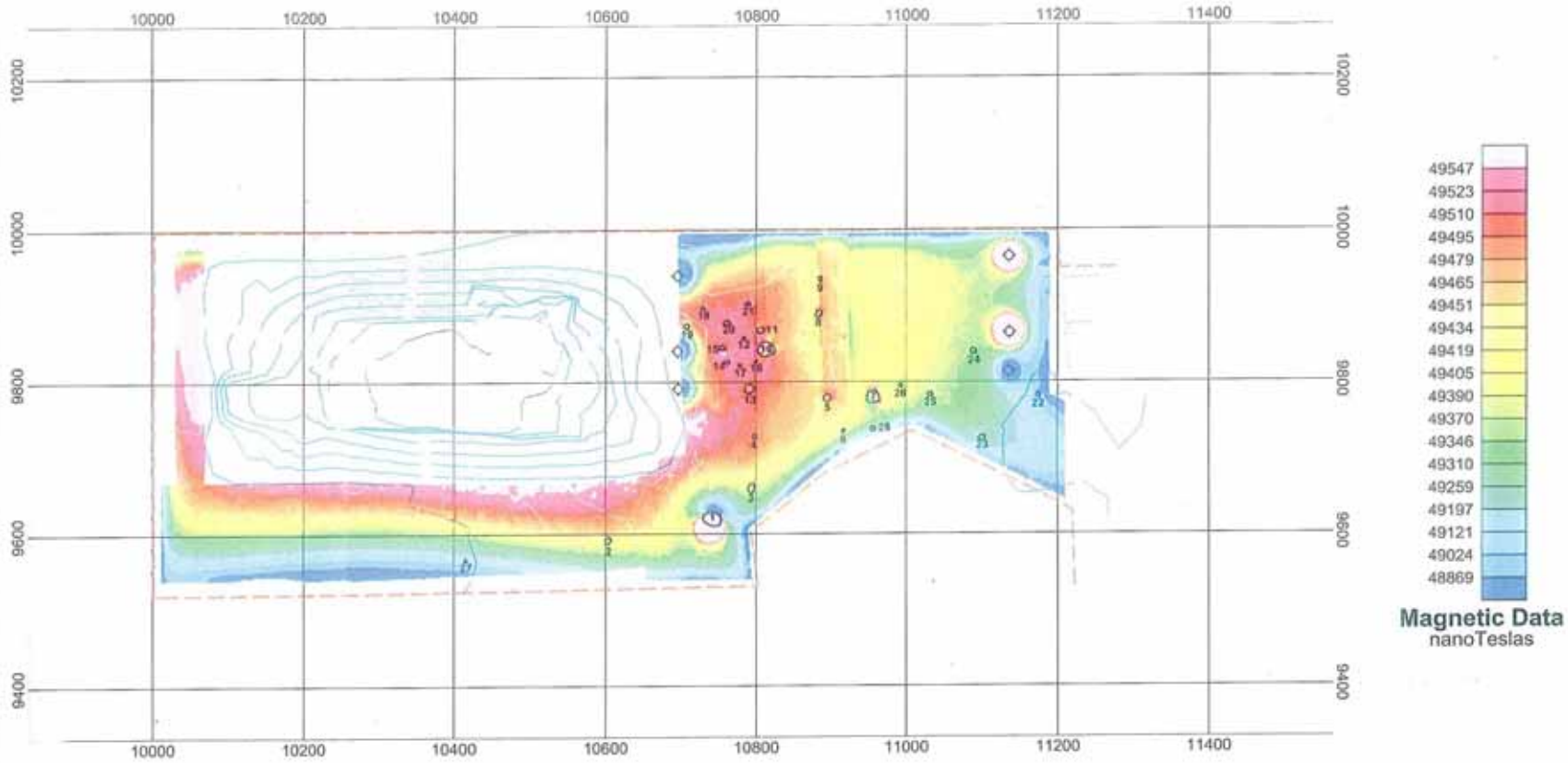
- Steel Posts
- Chain Link Fence
- Major Contour Lines
- Minor Contour Lines
- Magnetic data coverage
- EM61 data coverage
- Building

AquAeTer, Inc.

**Geophysical Survey**
**US Ecology Nevada**
**Beatty, NV**

Figure 2
Coverage Map
Magnetic and EM Data
July 9th-11th, 2007

***Zonge Geosciences, Denver, CO***



Scale 1:1800

100 0 100 200 300

(feet)

Plant Coordinates

**Notes**

This map shows the magnetic data collected at the site. Anomalies have been labeled and marked on the map along with known cultural features.

**Legend**

- Steel Posts
- Chain Link Fence
- Major Contour Lines
- Minor Contour Lines
- Anomaly
- Building

AquAeTer, Inc.

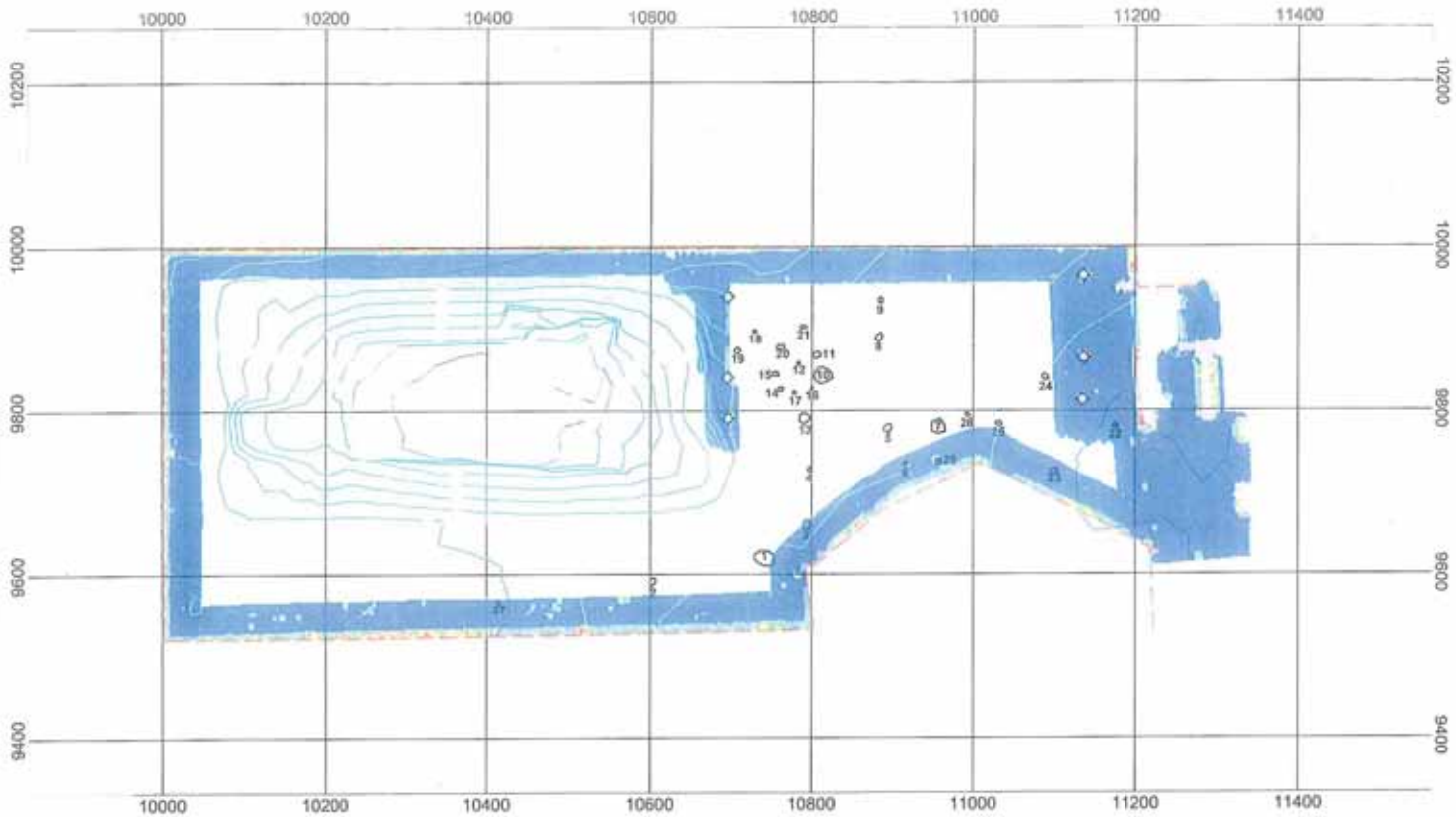
**Geophysical Survey**
**US Ecology Nevada**
**Beatty, NV**

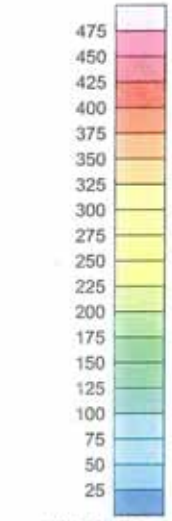
Figure 3

Magnetic Data

July 9th-11th, 2007

***Zonge Geosciences, Denver, CO***




**EM61 Data**
Channel 2 (milliVolts)

Scale 1:1800

Plant Coordinates

**Notes**

This map shows the EM data collected at the site. EM data were collected to fill coverage gaps in the magnetic data. Coverage gaps were areas where the magnetic data were negatively impacted by cultural features. Anomalies have been labeled and marked on the map along with known cultural features.

**Legend**

- Steel Posts
- Chain Link Fence
- Major Contour Lines
- Minor Contour Lines
- Anomaly
- Building

AquAeTer, Inc.

**Geophysical Survey**
**US Ecology Nevada**
**Beatty, NV**

Figure 4
EM Data
July 9th-11th, 2007

***Zonge Geosciences, Denver, CO***

# Method Appendices

# TIME DOMAIN ELECTROMAGNETICS
# THE GEONICS EM61-MK2

**Basic Methodology and Instrument Design**
In order to generate EM fields, electrical current is passed through the lower coil and then turned off. After a short period of time the current is turned on again and the process repeated at 75 Hz. Turning on or off the current creates a changing EM field, and this forms the basis of the method.

When a changing EM field penetrates an object that conducts electricity, secondary electrical currents are induced to flow in the conductor. These currents then generate secondary changing EM fields that can be detected by a coil. These secondary EM fields are detected while the transmitter current is off. Secondary currents in highly conductive objects take longer to decay than do those in less conductive objects. Thus, the decay curves due to the conductivity of the ground decay relatively fast compared to those from metal objects. When no metal is present, a low-level or constant signal is received. An increased signal is received when metal is present. This signal is generally highest when the coils are located directly over the object, resulting in "bulls-eye" type anomalies for isolated metal objects and simplifies data analysis.

The EM61-MK2 uses electromagnetic (EM) fields (also called EM waves) to detect buried metallic objects. The instrument has two rectangular coils, 1.0 by 0.5 meters in size, mounted one above the other as shown in the figure on the right. The lower coil is the transmitter and also acts as a receiver and the upper coil is a receiver only. The instrument uses EM fields to locate buried metal, therefore any metal that conducts electrical current can be detected, including both ferrous and non-ferrous metal.

The EM61-MK2 allows the measurement of the secondary EM fields at certain times after the transmitter current has been turned off. These times are often called data channels, or time gates. These time gates are centered at approximately 216, 366, 660 and 1266 microseconds after the current has been turned

off. The top coil measures the secondary EM field 660 microseconds. The instrument provides the option to either measure all four times from the lower coil or the earliest three times from the lower coil and one reading from the top coil.

**Field Data Recording**
Data positioning may be accomplished using three different methods. The most accurate method of positioning the data involves the coupling of Global Positioning System (GPS) data with the geophysical data. GPS data is streamed directly into the recording console and merged with the geophysical data. Positioning of the data with GPS may result in a horizontal positional resolution of <5 cm. When using GPS for positioning, data are collected at user defined time intervals. The EM61-MK2 has the ability to collect up to 10 data points per second.

The other two methods are not as accurate and require additional work prior to surveying. One method uses an optical encoder housed in a single wheel of EM61. This method uses a predefined distance (rotation of the wheel) to collect data. Data collected in this manner normally have nominal along line-spacing of 0.63 feet. The final method allows for the collection of more data along the survey line but requires open areas for accurate positioning. This last method collects at user defined time intervals. This is the same mode of data collection as with GPS. During data acquisition marks are placed in the data. These marks are referenced to the survey grid and used to position the data during processing.

# MAGNETIC SURVEYS

**Introduction** Magnetic surveys are conducted to evaluate geology, locate lava tubes in igneous rocks, find buried metal such as Underground Storage Tanks (UST) and pipelines and to locate Unexploded Ordnance (UXO).

The depth of investigation varies widely, depending on the target. Geologic structure can be determined to depths of many thousands of feet. UST's, pipelines and UXO targets are usually shallow. The method will probably only locate shallow lava tubes.

**Basic Principles of the Magnetic Method**

The magnetic field of the earth is a vector quantity and has, therefore, a direction and a magnitude. The shape of this field is that which would be produced if a large magnet were placed inside the Earth. Superimposed on this field are time varying fluctuations resulting from electrical activity in the ionosphere, usually caused by solar flares.

The Earth's magnetic field induces a secondary magnetic field in ferromagnetic objects, or geological structure that contains magnetite or other minerals that are magnetizable. This secondary magnetic field then "disturbs" the magnetic field of the earth creating an anomaly that can be detected with a magnetometer. Most magnetometers measure the magnitude of the magnetic field and can do so several times per second.

Figure 1 presents a schematic illustrating the magnetic field from a cylindrical ferromagnetic object. In this picture the Earth's field magnitude has been removed leaving only the magnitude of the field due to the ferromagnetic cylinder, often called the magnitude of the anomalous field.

Because the magnitude Earth's magnetic field changes with time, generally with daily cycles, called Diurnal changes, these changes have to be removed from the field data. In order to do this a base station is usually set up at a site near the survey area where magnetic anomalies are minimal. This instrument then records the magnitude of the magnetic field at regular intervals throughout the duration of the survey. This allows the diurnal variations in the magnetic field to be removed from the survey data during processing.

In addition to induced magnetization, remnant magnetization can also produce anomalies. Remnant magnetization occurs in geologic materials, usually volcanic and igneous rocks, which originate as hot

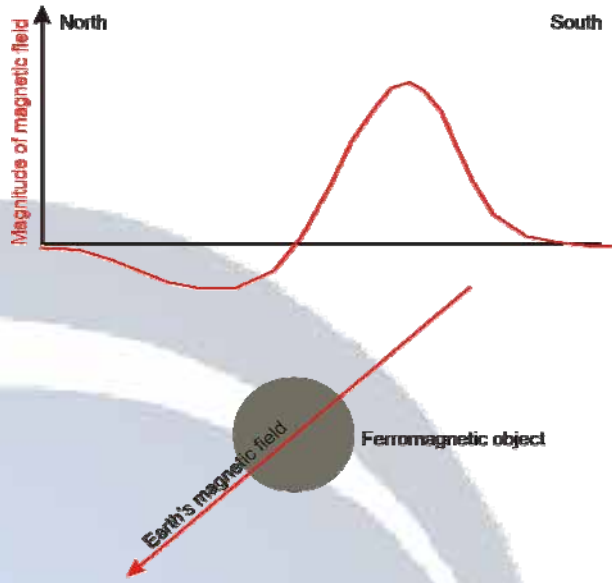



*Figure 1*
*The Magnitude of the anomalous magnetic field created by a ferromagnetic cylinder in the presence of the Earth's field.*

fluid lava and then cool before eventually solidifying. When the lava, or igneous material, cools below a temperature called the Curie point, the magnetic domains in the rock (usually magnetite) are oriented in the direction of the existing magnetic field at that time. Since the direction of the Earth's magnetic field changes over geologic time, the Remnant magnetic field can have a direction that is different from that produced by induction with the present Earth's magnetic field.

**Field Data Recording**

Magnetic surveys are conducted by first setting up a base station, as described above. The survey is then conducted by walking across the area of interest while the magnetometer records data, usually at several times per second. The data is stored in solid state memory in the instrument. In order to position the data, some magnetometers can be assembled with differential Global Positioning Systems (DGPS) allowing the spatial coordinates to be acquired simultaneously with the magnetic data. Conventional, or GPS, surveying of the ends of the lines may be required if DGPS data is not acquired with the magnetometer data. Linear interpolation methods can then be used to assign spatial coordinates to the data.

**Interpretation**

Magnetic data can be interpreted using computer software to model the anomalies. Generally, an initial model is developed for the source of the anomaly and the program then calculates the anomaly resulting from this source. The program then modifies the depth and geometry of the source and recalculates the anomaly. It does this until a reasonable fit is obtained between the field and model data. This process is called inversion.

Another interpretation method is to calculate a function called the Analytic Signal from the field data. Figure 2 illustrates this function for a cylindrical source along with the magnitude of the field (Anomaly Magnitude). Since the Analytic Signal peaks over the top of the source, the location of the source is easier to position than it is from the anomaly magnitude data. In addition, the amplitude of the Analytic Signal is related to the susceptibility of the source and the width is related to the depth to the top of the source.

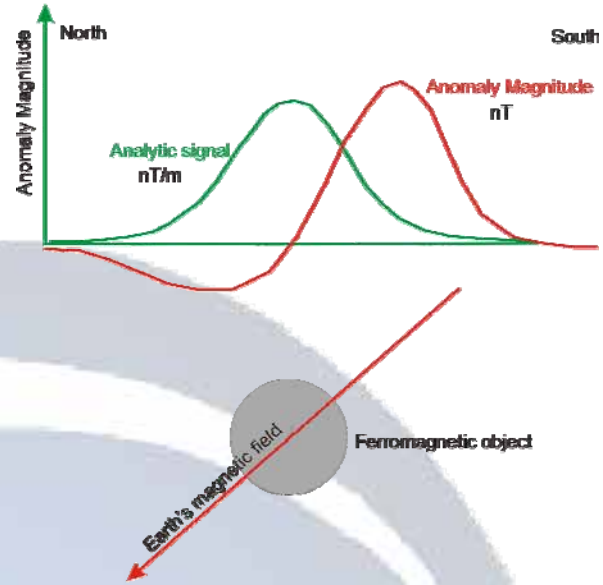



*Figure 2*
*Anomaly magnitude and Analytic Signal over a ferromagnetic object.*

**Method Limitations**

The magnetic method only detects objects composed of ferromagnetic materials, and not metals such as copper or aluminum. In interpreting magnetic data for geologic targets, there are generally several different solutions that can provide a theoretical fit of the field and model data, therefore each interpreted source is not necessarily unique. Such an interpretation is often called a "permissive" interpretation. This means that it is a valid theoretical interpretation but may be one of several possibilities. Non unique interpretations are not a concern when searching for buried ferromagnetic objects.

During severe magnetic storms, when the time varying magnetic field changes are significant, it may not be feasible to record field data.

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# Magnetic Surveying for Buried Metallic Objects

*by Larry Barrows and Judith E. Rocchio*

**Abstract**

Field tests were conducted to determine representative total-intensity magnetic anomalies due to the presence of underground storage tanks and 55-gallon steel drums. Three different drums were suspended from a non-magnetic tripod and the underlying field surveyed with each drum in an upright and a flipped plus rotated orientation. At drum-to-sensor separations of 11 feet, the anomalies had peak values of around 50 gammas and half-widths about equal to the drum-to-sensor separation. Remanent and induced magnetizations were comparable; crushing one of the drums significantly reduced both. A profile over a single underground storage tank had a 1000-gamma anomaly, which was similar to the modeled anomaly due to an infinitely long cylinder horizontally magnetized perpendicular to its axis. A profile over two adjacent tanks had a. smooth 350-gamma single-peak anomaly even though models of two tanks produced dual-peaked anomalies. Demagnetization could explain why crushing a drum reduced its induced magnetization and why two adjacent tanks produced a single-peak anomaly.

A 40-acre abandoned landfill was surveyed on a 50- by 100-foot rectangular grid and along several detailed profiles; The observed field had broad positive and negative anomalies that were similar to modeled anomalies due to thickness variations in a layer of uniformly magnetized material. It was not comparable to the anomalies due to induced magnetization in multiple, randomly located, randomly sized, independent spheres, suggesting that demagnetization may have limited the effective susceptibility of the landfill material. A different 6-acre site survey conducted on a 10- by 10-foot grid was analyzed to determine the maximum station spacing and line separation that could have been used. Essentially, all of the anomalies at this site would have been resolved by a survey conducted on a 20- by 20-foot grid and the larger anomalies would have been detected by a 50- by 50-foot grid.

## Introduction

Magnetic surveys have traditionally been used by geologists to locate changes in rock type such as might be associated with ore bodies, fault contacts, or igneous intrusives. Another common application is determining the probable depth to basement beneath sedimentary rocks. For these applications, the principal geologic variable is the distribution of ferromagnetic minerals, mainly magnetite, within the earth. The theory and survey procedures are described in a variety of references (e.g., Grant and West 1965, S.E.G. 1966, Parasins 1975, Nettleton 1976, Telford and others 1977, Robinson and Coruh 1988). A particularly concise review of surveying with portable magnetometers is given by Breiner (1973).

Magnetic surveys are used in hazardous waste site investigations to locate 55-gallon drums, underground storage tanks, buried pipes, and the edges of covered landfills. These applications usually involve shallow iron or steel objects, which influence the way the surveys should be conducted and interpreted. Tyagi and others (1983) describe controlled field tests in which single drums and clusters of drums were buried at various depths. The test site was. then surveyed with a variety of geophysical instruments including a total intensity magnetometer. They found the magnetic detection limit for a single drum was 6 to 11 feet below the surface and that the boundaries of a dump site containing steel drums can be easily determined. Gilkeson and others (1986) describe a magnetic survey of a series of landfill trenches that had been used to dispose of steel drums. They found a distinctive pattern of magnetic highs over the trenches and lows over the intertrench corridors. They noted that these signals were similar to the calculated magnetic anomalies due to infinitely long rectangular bodies having dimensions comparable to the trenches and a magnetic susceptibility of $k = 0.1$. As explained later, a susceptibility of this magnitude is expected for a mass containing many disseminated ferrous metal objects. Frischknecht and others (1985) and Jachens and others (1986) describe field tests and models that demonstrate the use of magnetic surveys to locate covered abandoned well casings. This application is important because abandoned wells are potential pathways for the vertical migration of contaminated ground water. They found strong positive anomalies over the wells that closely resemble models of simple magnetic dipoles having the positive pole at the top of

the casing and the negative pole at its base.

In this paper, the theory behind magnetic surveying is briefly reviewed and the field tests conducted to determine the total-intensity magnetic anomalies due to 55-gallon steel drums and underground storage tanks are briefly described. The anomalies due to the three drums tested had peak amplitudes of around 50 gammas and half-widths approximately equal to the 11-foot separation between the drum and the magnetometer sensor. The half-width is the distance between the two sides of an anomaly at intensities of one-half of its peak value. These anomalies were similar to those due to isolated dipoles but in addition to the magnetization induced by the earth's ambient field, both remanent magnetization and demagnetization seemed to affect the signals. Remanent magnetization is a permanent magnetization that is independent of the ambient field. Demagnetization is a limit on the strength of induced magnetization within an object imposed by the internal field due to the object itself. The surveyed anomaly due to one underground storage tank was similar to that due to an infinitely long cylinder magnetized perpendicular to its axis. However, the anomaly due to two adjacent tanks also resembled that of a single body. Again, remanent magnetization and demagnetization are thought to affect these signals. If the results described herein are representative, then the strengths of anomalies due to drums and tanks may depend more on their volume than on their metal content. Also, it may be difficult to infer from the shape of a magnetic anomaly the exact location and nature of the causative body. Demagnetization may also influence the magnetic signals from landfills containing many metal objects. One site survey is described in which the total-intensity field resembled that due to a uniformly magnetized layer of varying thickness but did not resemble that due to an assembledge of magnetically independent objects. One implication is that magnetic surveys may not be able to locate concentrations of metal objects, such as drums, within a landfill. Another is that successful landfill surveys may be conducted on a relatively coarse station grid. The data from a second survey conducted on a 10- by 10-foot square grid were analyzed to determine the maximum station spacing that could have been used. For this particular site, essentially all of the signal would have been resolved with stations on a 20- by 20-foot grid and the stronger anomalies would have been detected on a 50- by 50-foot grid.

## Theory

### The Geomagnetic Environment

The signals in a magnetic survey are partially the result of, and strongly influenced by, the ambient magnetic field of the earth. As a first approximation this geomagnetic field resembles that due to a single axial dipole whose negative or south magnetic pole is toward the geographic north pole. The strength of this field varies from 60,000 gammas near the poles, where it plunges vertically into the ground, to 25,000 gammas near the equator where it parallels the earth's surface. In any particular region the ambient field is described by its intensity, inclination (or angle to the horizontal), and declination (or angle to geographic north). Breiner (1973) includes large-scale maps of these parameters for the continental United States. Fabino and others (1979) give more detailed maps.

The geomagnetic field is not constant both in the sense of diurnal variations of several tens of gammas and occasional periods of rapid, irregular, transient variations (magnetic storms). The diurnal variations can be removed from survey data by drift corrections based on either regular base station ties or the record from a fixed base-station magnetometer. Magnetic storms vary in intensity and can make surveying impractical. The Space Environment Services Division of the National Oceanic and Atmospheric Administration provides recorded information on the current level of these fluctuations (telephone number (303) 497-3235) and a forecast of the projected level for the next five days (telephone number (303) 497-3171). It is normally desirable to know the condition of the earth's field during each day of a field survey.

### Magnetic Anomalies

Following Telford and others (1976, p. 111, Equation 3.11), the magnetic field at an external point (f, due to a magnetized body can be expressed as:

$$\vec{F}(\vec{r}_o) = \vec{\nabla} \int\int\int_{\text{volume}} \vec{M}(\vec{r}) \bullet \vec{\nabla} \frac{1}{|\vec{r} - \vec{r}_o|} \, dV(\vec{r})$$

where: $\vec{r}$ is a position vector within the body,
$\vec{\nabla}$ is the gradient operator,
$|\vec{r} - \vec{r}_o$ is the distance between the external point and position within the body,
• indicates the vector dot product, and
$\vec{M}(\vec{r})$ is the net magnetization per unit volume.

The net magnetization is the vector sum of induced plus remanent magnetizations. Remanent magnetization is a permanent magnetic moment per unit volume and induced magnetization is temporary magnetization that disappears if the material is not in a magnetic field. Generally, the induced magnetization is parallel with and proportional to the inducing field. Algorithms for calculating the magnetic fields due to uniformly magnetized, simple geometric shapes are given in several texts (e.g., Grant and West 1965, Nettleton 1976, Telford and others 1976, Robinson and Coruh 1988).

Magnetic fields are vectors and magnetometers measure some attribute of this vector field. Proton precession magnetometers measure the maximum intensity (or total length of the vector) and flux gate magnetometers measure the intensity in a particular direction (or vector component). When used with dual sensors, magnetometers also measure the gradient of the attribute; usually in the vertical direction.

The net magnetic field to which the magnetometer responds is the vector sum of the field due to local magnetized materials and the ambient field of the earth. Figure 1 shows the total intensity field due to a simple magnetic dipole, the ambient field of the earth, and the total-intensity anomaly that would he detected during

a survey. In this case, the magnetization of the object is parallel to the ambient field (induced magnetization). There is a magnetic low to the north of the center of the body and a larger high to the south.

**Effective Susceptibility**

Magnetic susceptibility, k, is the dimensionless proportionality constant relating induced magnetization within a body to the inducing field. In general, the inducing field is the vector sum of both the earth's ambient field and the field due to the object itself. This feedback is referred to as demagnetization and is expressed as a reduction in the effective susceptibility of the object:

$$k_{eff} = \frac{k_{mat}}{1 + \lambda k_{mat}}$$

where: $k_{mat}$, is the material susceptibility, and A is the demagnetization factor. Grant and West (1965) describe the physical basis for demagnetization and the derivation of this relation.

Demagnetization factors are dependent on both the shape of the object and its orientation to the ambient field. For a sphere $\lambda = 4/3\ \pi$; normal to the axis of the cylinder $\lambda = 2\ \pi$; and normal to a flat sheet $\lambda = 4\ \pi$ (Strangway 1967). Figure 2 shows the resulting relations between effective and material susceptibility for these simple shapes and orientations. Note that for material susceptibility less than about k = 0.05, the effective and material susceptibilities are approximately equal. Most rock units have susceptibilities less than this, therefore, demagnetization does not usually affect the interpretation of geologic surveys. However, ferrous metals have susceptibilities of tens or hundreds, therefore, the effective susceptibility of ferrous metal objects, like steel drums, is limited by demagnetization to a few tenths. If the ferrous metal content of a landfill is several percent of the volume, then the effective susceptibility of landfill material would also be limited. In this case, local concentrations of metal within the landfill would not be expected to significantly increase the local effective susceptibility.

Demagnetization also limits the applicability of the algorithms used to calculate the magnetic effects of simple models. These algorithms usually assume that magnetization is uniform throughout the material, a condition not realized if the field due to the body itself is irregular. For hazardous waste site investigations there is a need to develop magnetic modeling techniques that accommodate demagnetization phenomena. Until this is accomplished, magnetic models of ferrous metal objects (including the models in this report) should be interpreted cautiously.

## Field Tests

### 55-Gallon Drums

The objectives of these tests were to establish the magnetic signal of a 55-gallon steel drum and to compare this result with analytical models. A secondary objective was to determine the extent to which demagnetization limits the effective susceptibility of a steel drum.

A 60- by 60-foot test site was laid out in a flat empty

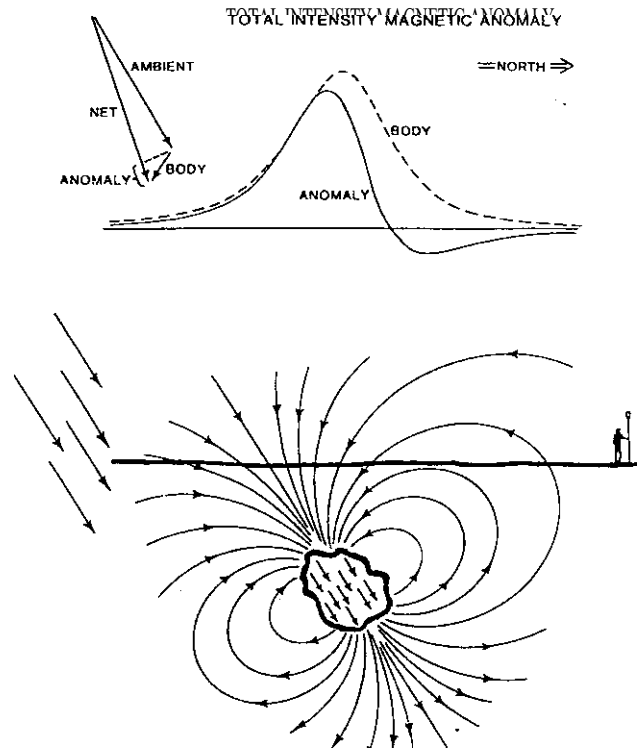


**Figure L Magnetic effect of an isolated body magnetized in the direction of the earth's ambient field. The measured total magnetic intensity is the vector sum of the ambient field plus the field due to the body:**

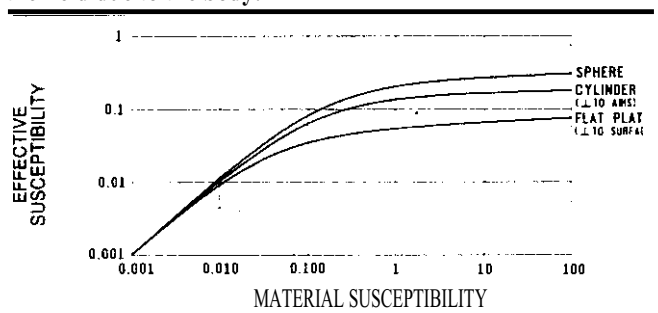


**Figure 2. Effective vs. material susceptibility for several simple shapes and orientations. Demagnetization limits the effective susceptibility to a few tenths regardless of the susceptibility of the material (from Strangway 1967, p. 455).**

field and a nearby base station was selected. Survey stations were at 3-foot intervals along north-south lines, spaced 6 feet apart (231 stations). In the center of the site a non-magnetic (PVC pipe) tripod was constructed from which the drums were suspended. The drums were 19 feet above ground level; therefore, with the 8-foot sensor height of the magnetometer, the signals were similar to those from drums buried at 3 feet (Figure 3). Running the surveys beneath, instead of over, the objects reversed the signals through an east-west line. This resulted in a reversal of the positions of the positive peak and related trough.

The site was first surveyed with an empty tripod to establish a baseline, which was removed from all subsequent surveys. For each survey, the ends of the north-south lines were first read and linearly drift-corrected to the base station and then the individual stations were read and linearly drift-corrected to the line ends. All data were relative to the first reading at the base station

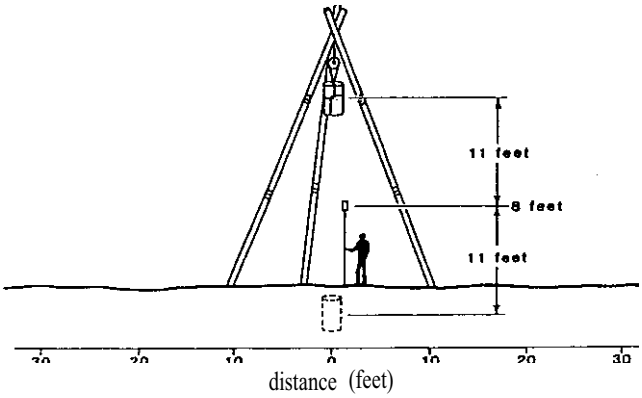


**Figure 3. Test apparatus used to simulate the magnetic response of a buried 55-gallon steel drum. The anomaly due to the suspended drum is similar to that of a buried drum except that the positions of the high and low are reversed.**

and all were gathered with a total intensity proton-procession magnetometer (Geometrics Model 856). **Figure 4 is a perspective diagram of a representative anomaly. The anomaly has a peak amplitude near 50 gammas, and has a half-width about equal to the drum-to-sensor separation (11 feet). It is less than 5 gammas at twice the separation.**

Tests were run with three different drums. For each drum, the field beneath the drum was surveyed, the drum was flipped and rotated to reverse the direction of the remanent magnetization, and the new field was surveyed. Along the north-south center line, the average of the two fields is attributable to induced magnetization and one-half their difference is attributable to remanent magnetization. For two of the three drums tested, the anomaly due to remanent magnetization was comparable to that due to induced magnetization. For the third drum, it was 40 percent as large.

The third drum was then crushed to a 1.1 cubic foot, drum-shaped mass. This crushed drum was surveyed in both its upright and reversed orientations. Figure 5 shows the observed data along the north-south central profile for both the whole and crushed drums in both of their orientations. In its crushed configuration, the drum showed very little remanant magnetization, possibly because the magnetized sheet metal had been folded over on itself. The anomaly due to induced magnetization was only 30 percent of that of the uncrushed drum even though both configurations contained the same steel.

Modeled profiles of the total intensity anomaly of uniformly magnetized spheres were matched to the induced-magnetization anomalies of both the whole and crushed drums. The sphere volumes were identical to their respective drums. For the whole drum, the modeled sphere had an effective susceptibility of k = 0.10, for the crushed drum k = 0.18.

Underground Storage Tanks

Magnetic surveys are used to locate underground storage tanks either for their removal or as an aid in positioning boreholes in which leak detectors are to be installed. The following field tests demonstrate the character of the associated total-intensity signals. Again, the data were gathered with a total-field proton-procession magnetometer.

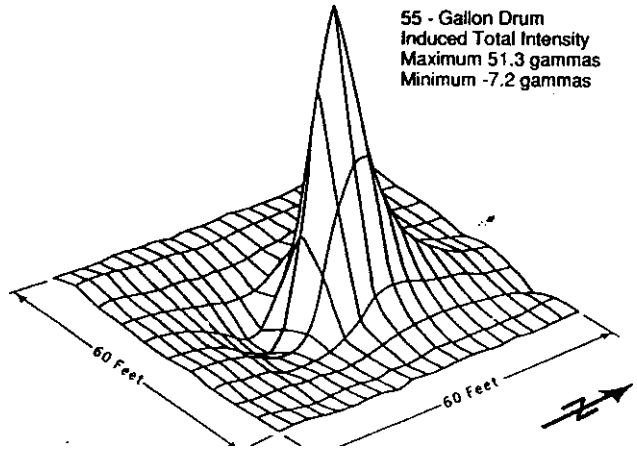


**Figure 4. Total intensity anomaly due to induced magnetization in a single 55-gallon drum. The configured surface is one-half the sum of the anomaly due to a drum in its upright orientation plus that due to the same drum in a flipped plus rotated orientation. Survey stations were located at each of the grid intersections.**

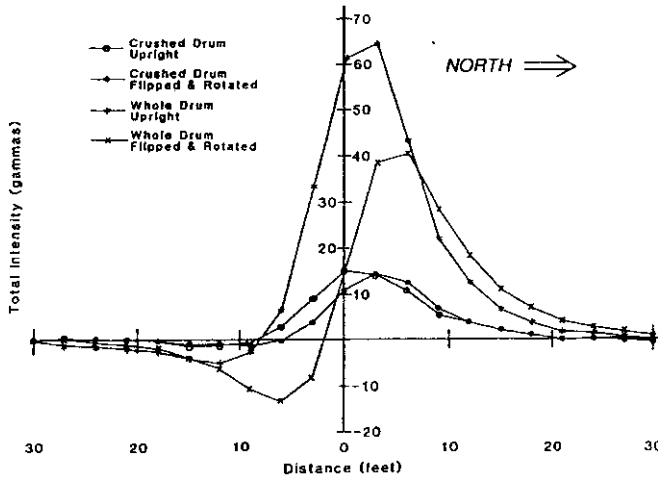


**Figure 5. North-south profiles beneath a suspended 55-gallon drum in its upright orientation and its flipped plus rotated orientation. The lower-amplitude profiles are for the same drum after it had been crushed to a 1.1 cubic foot drum-shaped mass.**

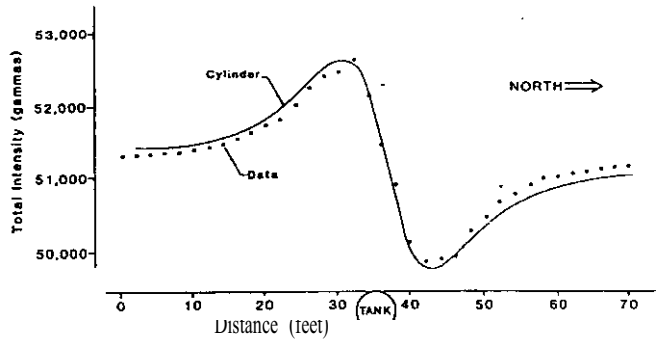


**Figure 6. Total-intensity anomaly due to an underground storage tank. The modeled anomaly is that due to an infinitely long cylinder with a horizontal magnetization of 2750 gammas per cubic foot.**

The first example is a single tank on a narrow land spit extending from the south shore of Lake Mead, Arizona. The tank had been part of a marine fuel dock until the facility was destroyed by high water and abandoned. There were no remaining buildings, power lines,

pipes or other sources of cultural noise.

Figure 6 is a profile normal to the long axis of this tank along with a matching model based on the actual tank diameter. The model has a uniform horizontal magnetization of 2750 gammas per unit volume. This net magnetization is the vector sum of induced plus remanent magnetization and cannot be resolved without reorienting the tank. One simple possibility is an induced magnetization of 5500 gammas per unit volume (k = 0.1) plus an upward remanent magnetization of 4763 gammas per unit volume.

The second example is a profile over two adjacent tanks located 22 feet to one side of a large vehicle maintenance garage. Figure 7 shows the observed data, an assumed linear regional, which may be due to the garage. and the residual anomaly along with the profile due to the indicated model. In this case, the entire anomaly might be due to induced magnetization in a single small body that is considerably deeper than the actual tanks. Note that the data did not resolve two tanks even though geometrically correct models of two magnetically independent tanks had dual-peaked anomalies. A possible explanation is that the inducing field within each tank is the sum of the earth's ambient field, the field due to the tank, and the field due to the adjacent tank. The tanks would then not be magnetically independent and the two-tank model would not apply.

## Field Surveys

### The Landfill

The first example is a survey of a 70-acre covered landfill in south-central Indiana. A 20-acre lake occupies the center of the site and a river flows along the northern and northeastern sides. The landfill had been used to dispose of approximately 40,000 drums of chemical wastes along with a variety of domestic and industrial refuse. The survey was conducted to better define the lateral extent of the landfill and, if possible. to locate clusters of drums.

Two survey methods were used. One was a reconnaissance survey with stations at 50-foot intervals along lines spaced 100 feet apart. The other was a series of more detailed north-south profiles with stations at 10- or 20-foot intervals. Both were conducted with GeoMetrics Model 856 total-intensity magnetometers.

Figure 8 is a contour map of the total intensity data from the reconnaissance survey. The dots are measurement stations and the contour interval is 1000 gammas. At this location, the ambient field is 56,200 gammas and the measured values range from 52,600 to 64.500 gammas, so the anomalous field ranges from 3600 to +8300 gammas. The reconnaissance survey clearly showed areas in the southeast corner and west-central side of the site that are magnetically smooth and are not believed to contain buried debris. The data contoured surprisingly well, considering that drums and metallic debris are exposed on the surface. At the relatively coarse 50- by 100-foot station spacing (necessitated by the size of the site and limited field time) many "single point anomalies" and ambiguities in the contours were anticipated.

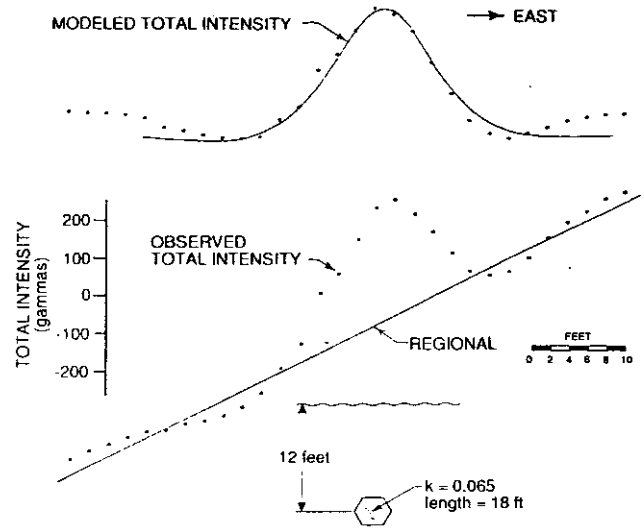


**Figure 7. Total-intensity anomaly due to two underground storage tanks. The magnetic data did not resolve the presence of two objects even though calculated models of two near-surface magnetically independent tanks produced dual-peaked anomalies.**

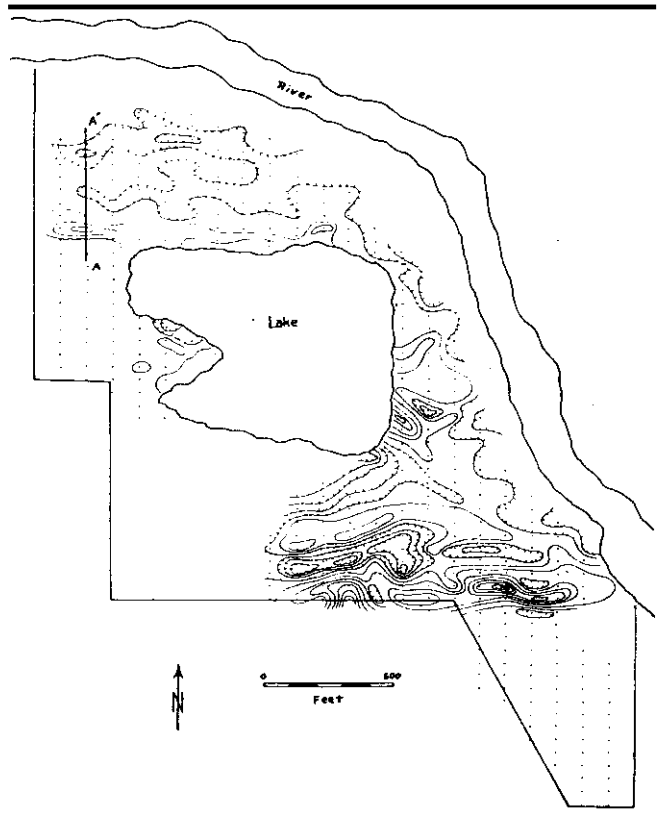


**Figure 8. Magnetic total intensity over a covered landfill in south-central Indiana. The contour interval is 1000 gammas and the dots are stations at which data were gathered. Profile A-A' is shown in Figure 9.**

The continuity of the contoured field may be due to demagnetization limiting and homogenizing the effective susceptibility of the landfill material. Figure 9 is a north-south profile along line A-A. Stations are at 10-foot intervals. Also shown is a simple model and modeled field configured to match the larger features in the observed data. The model is an east-west trending, infinitely long polygon with a uniform susceptibility of k = 024 (the Talwanii algorithm, e.g., Grant and West 1965). The horizontal scale is as shown, but there is a lOX vertical exaggeration in the model and its greatest

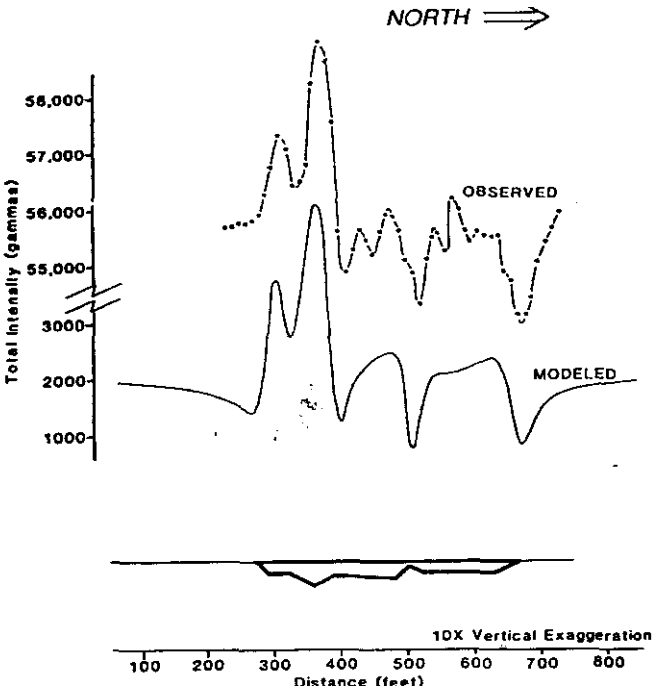


**Figure 9. Observed and modeled magnetic total intensity over a covered landfill. The modeled anomalies are due to variations in the configuration of the landfill material.**

thickness is only 5 feet. The important point is that the anomalies can be attributed to modest thickness variations in the layer. Comparable results were obtained with models having an irregular upper surface and a flat base. In contrast, Figure 10 shows the effect of induced magnetization in an assembledge of randomly located, randomly sized spheres. This modeled field is predominately positive and dominated by a few high-intensity narrow peaks due to the shallowest objects. The observed field at the landfill had broad anomalies with both positive and negative parts.

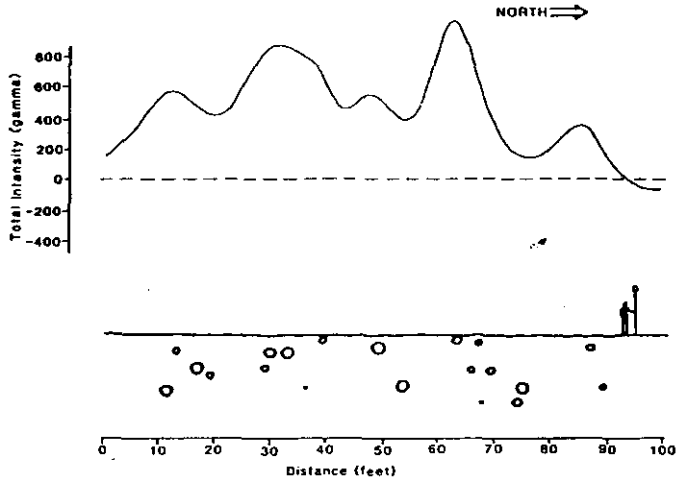


**Figure 10. A total-intensity magnetic model of an assembledge of randomly located, randomly sized spheres magnetized in the direction of the earth's field. The modeled field is dominated by a few narrow peaks due to the shallowest objects.**

### The Sludge Ponds

The next example is a survey of some abandoned sludge ponds on a 6-acre site south of Houston, Texas. The ponds had been used to dispose of broken slabs of reinforced concrete and had then been covered with earth. The survey objective was to locate areas where the slabs had been dumped so they could avoid when drilling ground water monitoring wells. It was thought that the steel reinforcing bars in the concrete

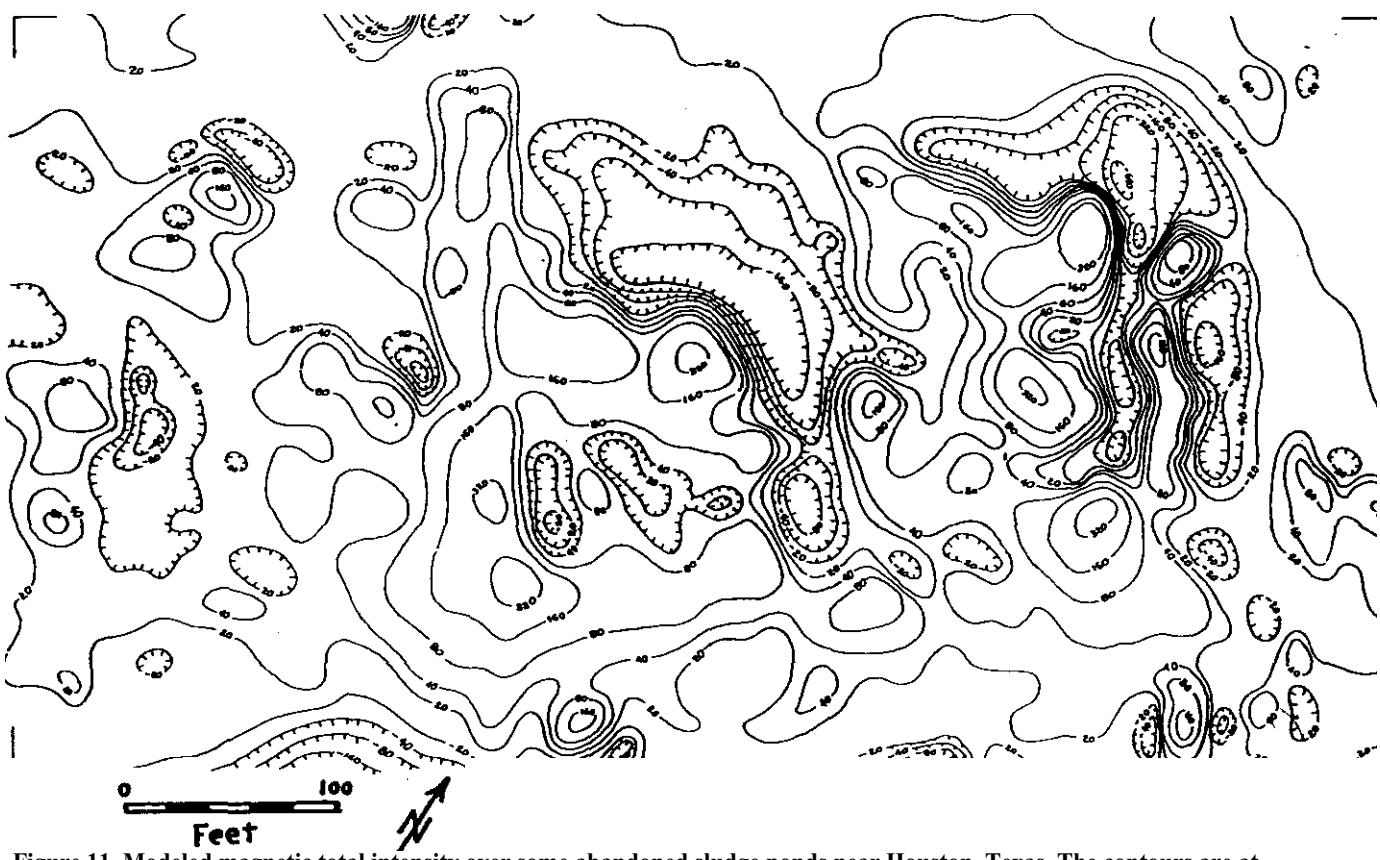


**Figure 11. Modeled magnetic total intensity over some abandoned sludge ponds near Houston, Texas. The contours are at 49800 ± 20, ± 40, ± 80, ±160, ± 320, ± 640 gammas and stations were on a 10- by 10- foot square g rid.**

would produce a detectable magnetic anomaly.

This survey was conducted with an OMNI-IV tie-line magnetometer system. Stations were established at 10-foot intervals along lines 10 feet apart and both the total intensity and its vertical gradient were recorded. The OMNI-IV monitors the quality of each reading and the data are reliable except in an 80-foot strip along the eastern side of the site where there is an overhead powerline. In this area about 20 percent of the readings were unreliable and were edited from the data.

Figure 11 is a contour map of the edited total intensity data. Values range from 49,150 to 50,350 gammas. The ambient field at this location is 49,800 gammas so the anomalies range from -650 to +550 gammas. The exponentially spaced contour intervals were used so that both subtle features in the relatively smooth areas and the shapes of the larger anomalies are displayed. This map along with a map of the vertical gradient sucessfully identified undisturbed areas in which the monitoring wells could be placed.

On Figure 11 there is a tendency for the magnetic highs to be flanked to the north by lows of comparable amplitude. As in the landfill survey, the effect could be modeled as thickness variations in a continuous layer. However, at this site, enough of the slab dumps (and anomalies) are sufficiently isolated to suggest a different interpretation. Figure 12 shows the total intensity anomaly due to a horizontally magnetized slab at a depth of 4 feet. For horizontal magnetization at the latitude of the site, the magnetic highs and lows are of comparable amplitude but for steeply plunging magnetization parallel to the ambient field, the highs are significantly larger than the lows. Demagnetization limits the effective susceptibility perpendicular to the surface of a slab or to the axis of a bar. However, it does not limit the susceptibility parallel to a thin slab or along the axis of a bar. Therefore, for flat-lying reinforced slabs, the horizontal component of induced magnetization is expected to be larger than the vertical component, which is consistent with our model.

Selecting station spacing and line separation involves a tradeoff between survey resolution and the amount of field work. If the distance between measurements is too large, the data will be uncertain by an amount comparable to the amplitude of the narrower anomalies; even if the measurements are precise. (This spatial-aliasing phenomena is similar to the temporal aliasing that occurs when a continuous time signal is digitized.) On the other hand, if the distance between measurements is too small, the time and cost of the survey may be prohibitive. For the survey over the sludge ponds, the relatively short 10- by 10-foot grid was selected because the nature of the signal was not known beforehand and the surveyor wanted to detect all significant anomalies.

To determine the maximum distance between stations that would have adequately resolved the field variations, the Fourier transformation was used on the total intensity data and then the resulting amplitude spectra (Figure 13) was smoothed and contoured. This map shows the relative amplitudes of the variations in magnetic total intensity as a function of their widths

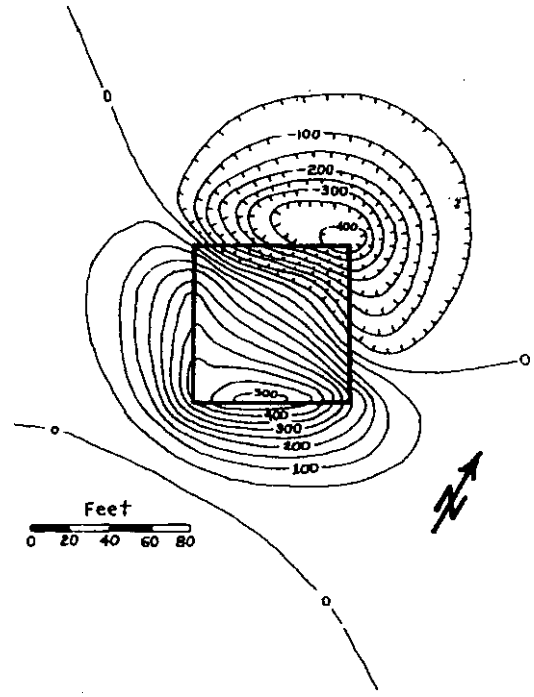


**Figure 12. Magnetic total intensity anomaly due to a 80- by 80- by 4-foot thick slab of material with a horizontal northerly magnetization of 1000 gammas per cubic foot. The contour interval is 50 gammas.**

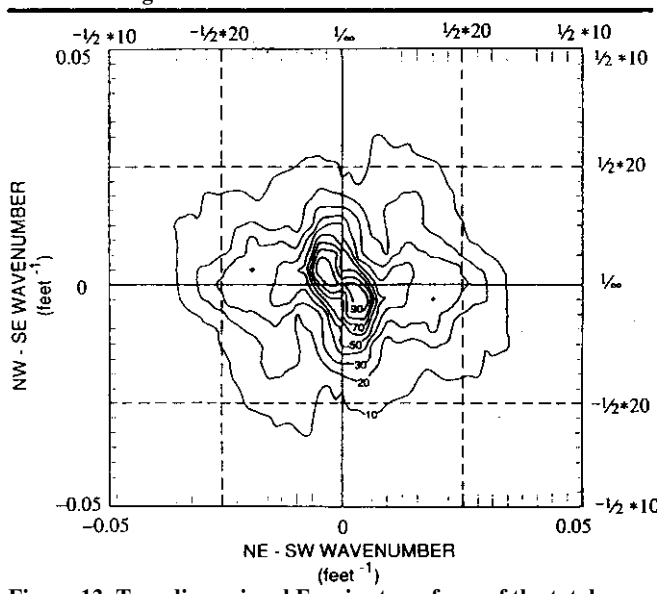


**Figure 13. Two-dimensional Fourier transform of the total intensity data in Figure 11. The contoured values are the moduli of the transform after they were smoothed by a nine-point unit matrix. The contour interval is 10 percent of the maximum value.**

and orientations. The graph axes are wave number or one-half the reciprocal wavelengths in the ENE-WSW and NNW-SSE directions of the survey grid. The contours are the moduli of the transform (an array of complex numbers) after they had been filtered or averaged with a nine-point unit matrix. The contour interval is 10 percent of the peak filtered value.

Note that almost all of the amplitude spectra are at wavenumbers less than 0.025 ft (0.5/20 ft). This implies that most features would be adequately resolved by a survey conducted on a 20-foot grid, assuming the data were reliable. Some data redundancy is desirable and it is more efficient to make closely spaced readings along

more widely separated lines than it is to make the same number of readings on a square grid. An optimum survey grid at this site might have stations at 10-foot intervals along lines no more than 30 feet apart. Contour maps constructed from alternate stations and lines (a 20- by 20-foot grid) and from every third line (a 10- by 30-foot grid) resolved all of the anomalies on the total-intensity map.

The highest peaks on the amplitude spectra occur at wave numbers near 0.005 ft (0.5/100 feet) and amplitudes are generally less that 50 percent of the peak value at wave numbers greater than about 0.01 ft (0.5/50 ft). This implies that the larger amplitude anomalies would have been detected by a survey on a 50-foot grid. A map constructed from every fifth line and station detected all the major anomalous areas but did not resolve the shapes of the anomalies.

## Summary

Magnetic surveys can be an important part of hazardous waste site investigations but the physical principles must be understood before the data are interpreted. In particular, these surveys often involve ferrous metals and effective susceptibility can be limited by demagnetization to a few tenths. The magnetic field variations will then be due to the configuration of the magnetized material rather than to local concentrations of metal.

The detectable anomaly due to an isolated steel drum has a width of about twice the distance between the drum and the magnetometer sensor. A survey to reliably detect single drums would have to be conducted with a station spacing and line separation less than this width. However, if a hazardous waste site contains sufficient disseminated metal for demagnetization to occur, the stronger anomalies can have dimensions comparable to the landfill cells. In this case, relatively coarse station spacings and line separations may be adequate.

## Acknowledgments

The landfill survey in south-central Indiana was conducted by Mike Gibbons and Aldo Mazzella for the U.S. Environmental Protection Agency. The drum study was conducted by the authors, also with support from the U.S. EPA. The study of underground storage tanks was part of a Boy Scout service project by Mike Barrows and the sludge pond survey was conducted by Jerry Robinson for the ENSR Corp. The contributions of all these individuals and agencies is gratefully acknowledged.

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## Biographical Sketches

***Larry Barrows received his M.S. and Ph.D. degrees in geophysics from the Colorado School of Mines in 1973 and 1978, respectively. He has worked as a systems engineer on Skylab remote-sensing experiments and as an exploration geophysicist in frontier areas of Alaska. Since 1979 he has specialized in geophysical surveying for ground water and hazardous waste site investigations, first as the project geophysicist on a radioactive waste disposal program and then as a research scientist for the U.S. EPA. In 1988 he joined Earth Science and Engineering Inc and LaCoste and Romberg Gravity Meters Inc (4807 Spicewood Springs Rd, Bldg. 2, Austin TX 78759). Current projects include using microgravity to detect solution conduits in karst terrains and using seismic groundroll to determine near-surface shear moduli.***

***Judith E. Rocchio is the future air resource specialist on the Stanislaus National Forest (1977 Greenley Rd, Sonora, CA 95370). She will obtain the position upon completion of her M.A. degree in air resource management at Colorado State University, Department of Natural Resources (1990). She was with Lockheed Engineering Management Services Co., Las Vegas, Nevada, prior to attending CSU where she was involved in several environmental monitoring programs and co-authored the paper with Dr. Barrows. From 1981 to 1986 Rocchio was a project geologist for Gower Oil Co. and Consolidation Coal Co., Denver, Colorado. She received her B.S. in geology (1981) from the University of Nevada, Las Vegas.***

**Magnetic Survey Anomaly Investigation Results – July 2007**

| Location # | Result |
|---|---|
| 1 | Unused USGS Caisson |
| 2 | 12" piece of rebar |
| 3 | Nail |
| 4 | Rock |
| 5 | Rock |
| 6 | 2' x 2' steel plate |
| 7 | Rock |
| 8 | Rock |
| 9 | Nail |
| 10 | Rock |
| 11 | Rock |
| 12 | Bolt |
| 13 | Rock |
| 14 | Nail |
| 15 | Wire |
| 16 | Steel roller |
| 17 | Bolt |
| 18 | Steel roller |
| 19 | Pipe |
| 20 | Steel plate |
| 21 | Rock |
| 22 | Rock |
| 23 | Bolt |
| 24 | Open end wrench |
| 25 | Steel roller |
| 26 | Nail |
| 27 | Bungee hooks |
| 28 | Bungee hook |

All items were excavated using a backhoe and isolated using a Schonstedt Magnetic Locator.

# ATTACHMENT 3

# SUPPLEMENTAL ENGINEERING CALCULATIONS

# SLOPE STABILITY VERIFICATION

AquAeTer

*optimizing environmental resources - water; air; earth*

# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: September 18, 2007

CALCULATION NUMBER: _____ Revision: Update per 2007 Design

**CALCULATION TITLE: Deep Seated Slope Stability Revision**

**DESCRIPTION OF CALCULATION:**

Calculation to re-evaluate the stability of the final cell 12 cover configuration for pseudo-static loading conditions considering revised surface soil thicknesses and waste cohesion values.

**REFERENCES USED:** Number of Reference Pages Attached: _____

1. Previous Calc: 1996 Calculation titled "Deep Seated Slope Stability – Final Configuration"
2. Modeling Program: WinStabl Version 2.40

**REVIEW COMMENTS:**

CALCULATION MADE BY: SLW DATE: 9/18/2007

CALCULATION CHECKED BY: CAB DATE: 9/18/2007

CALCULATION REVISED BY: _____ DATE: _____

CALCULATION REVIEWED BY: SLW DATE: 9/18/2007

## Purpose of Slope Stability Verification Calculation

**Loose Soil Layer Thickness.** Calculations and related information documenting the 1996 Design, as previously accepted by the NDEP, appear to include some inaccuracy in the description of the loose surface soil layer in the Trench 12 area. In various parts of the information, this layer is described as being as little as four and as much as 20 feet thick. The "Geotechnical Investigation for Cell 12" by Grant Environmental (July 1994) gives the loose surface soil layer as 4.0, 9.0, 4.0, and 8.0 feet thick on the south, east, north, and west sides of Trench 12, respectively. Considering these thickness values, which were determined by consideration of all deep boring data available in the Trench 12 area indicate that two general thickness conditions represent the loose surface soil layer – these are 5.0 feet thick and 10.0 feet thick. These two thicknesses are used in slope stability calculations done (in a manner similar to that used for the 1996 calculations) to determine the sensitivity of slope stability to certain soil properties.

**Soil and Waste Strength.** Stability analyses for the 1996 Design, as revised and later accepted by NDEP, indicate that the loose surface soil layer should be improved to achieve a cohesive strength of 1,000 PSF. Considering the thickness of that layer (i.e., from 5.0 to 10.0 feet) and the geometry of potential slope failures, the previous specification for surface material improvement could be too conservative. This revised calculation shows that the cohesion of reworked surface soil is not critical to achieving acceptable slope stability.

Waste properties appear to be more important to final cover slope stability than creating a small strong wedge in the surface soil layer. Also, some waste properties (cohesive strength and unit weight) considered in the 1996 Design calculations appear to be overly conservative with regard to slope stability.

- The assumed cohesive strength of waste is adjusted to 550 PSF, which is only slightly higher than the 500 PSF assumed for the 1996 Design calculations. The 1996 calculations provide justification (copied and included in this calculation from "Enclosure C to Attachment 1 of the December 1996 Response to NOD") for using hazardous waste cohesion values from 575 to 900 PSF. This minor adjustment in the assumed waste property is both justifiable and remains a conservative assumption.

- The unit weight of the upper portion (above ground level) of the hazardous waste that will be disposed in Trench 12 is adjusted to 100 PCF from the value of 115 PCF used for the 1996 Design calculations. The actual unit weight of waste disposed by US Ecology in Trench 11 is 96.3 PCF. Adjusting the waste weight to 100 PCF is justified by actual site waste disposal records.

## Slope Stability Analysis Method

The computer modeling program WinStabl, using the Modified Bishop Method of analysis, was used to assess slope stability when varying the thickness of the loose soil layer and the cohesive strength of the waste in the final Trench 12 configuration. The Modified Bishop Method also

was used for the slope stability analyses in the 1996 Design. The model accepts as input the material properties (principally, unit weight, cohesive strength, and angle of internal friction) and a set of coordinates defining the position of the materials in typical Trench 12 cross-sections. The model is then asked to find deep seated failure surface through the various layers. For these analyses, a pseudo-static condition is assumed to represent seismic loading. The output of the model is calculated factors of safety for the identified failure surface and materials.

**Analysis**

The following conditions were considered in this slope stability verification.

1. Excavation sidewall slopes with a 10-feet thick surface soil layer.
2. Final soil cover (closed Trench 12) with 5-feet thick improved surface soil wedge.
3. Final soil cover (closed Trench 12) with 10-feet thick improved surface soil wedge.

Excavation slopes with 10-feet thick surface soil layer

For excavation slope stability, the 10-feet thick layer of unimproved surface soil zone (loose soil, cohesion = 0 PSF) is the 'worst case condition'. Slope stability analyses considering failure surfaces within each of the soil types present in the Trench 12 subsurface, including the surface soil layer, show that that factors of safety against slope failure under pseudo-static loading (simulating design earthquake loads) are much greater than 1.0. Slope stability under the 'worst case' operating condition (i.e., fully excavated trench, no waste in place) is acceptable.

Final soil cover (closed Trench 12)

The influence of variations in the properties of the improved surface soil wedge at both 5.0 and 10.0 feet thickness are the conditions under which slopes in the waste fill and natural or improved surface soil must be stable. Various configurations of material properties and slope failure surfaces were evaluated to determine which properties are significant to slope stability and which properties, if any, should be improved on trench construction to achieve acceptable stability.

The following table lists the various conditions analyzed and the resulting factor of safety for the following slope conditions:

| Improved Surface Soil Wedge Thickness (feet) | Improved Surface Soil Wedge Cohesion (PSF) | Waste Cohesion (PSF) | Waste Weight (PCF) | Pseudo-Static Loading (g) | Factor of Safety |
|---|---|---|---|---|---|
| **5 feet** | | | | | |
| 5 | 0 | 500 | 115 | 0.42 | 0.94 |

| Improved Surface Soil Wedge Thickness (feet) | Improved Surface Soil Wedge Cohesion (PSF) | Waste Cohesion (PSF) | Waste Weight (PCF) | Pseudo-Static Loading (g) | Factor of Safety |
|---|---|---|---|---|---|
| 5 | 250 | 500 | 115 | 0.42 | 0.95 |
| 5 | 1000 | 500 | 115 | 0.42 | 0.99 |
| 5 | 250 | 550 | 115 | 0.42 | 0.98 |
| 5 | 500 | 550 | 115 | 0.42 | 0.99 |
| 5 | 250 | 600 | 115 | 0.42 | 1.00 |
| 5 | 500 | 600 | 115 | 0.42 | 1.02 |
| 5 | 250 | 500 | 100 | 0.42 | 0.99 |
| **5** | **250** | **550** | **100** | **0.42** | **1.02** |
| **10 feet** | | | | | |
| 10 | 0 | 500 | 115 | 0.42 | 0.98 |
| 10 | 250 | 500 | 115 | 0.42 | 1.00 |
| 10 | 250 | 550 | 115 | 0.42 | 1.02 |
| 10 | 250 | 600 | 115 | 0.42 | 1.05 |
| **10** | **250** | **550** | **100** | **0.42** | **1.04** |

PSF = pounds per square foot
PCF = pounds per cubic foot
**Bold** = final condition with acceptable strength and stability

**Results**

To be acceptable, the factors of safety against slope failure under pseudo-static loading conditions (i.e., 0.42 g, which simulates the maximum horizontal acceleration value with a 90 percent or greater probability of not being exceeded in 250 years, NAC 444.6793) should equal or exceed 1.0.

For the 5-feet thick surface soil layer, representing the north and south sides of Trench 12, the condition that meets or exceeds the slope stability requirement is a surface soil layer with a cohesion of 250 PSF or greater; a waste cohesion of 550 PSF or greater, and a waste weight of 100 PCF or less. When the waste weight of 100 PCF (approximately the same as the actual Trench 11 average disposed waste weight of 96.3 PCF) is considered, the surface soil cohesion needed is 250 PSF and waste cohesion needed is 550 PSF.

For the 10-feet thick surface soil layer, representing the east and west sides of Trench 12, the condition that meets or exceeds slope stability requirements is a surface soil layer with a cohesion of 250 PSF or greater, a waste cohesion of 550 PSF or greater, and a waste weight of

100 PCF or less. When the waste weight of 100 PCF (approximately the same as the actual Trench 11 average disposed waste weight of 96.3 PCF) is considered, the surface soil cohesion needed is 250 PSF and waste cohesion needed is 550 PSF.

In both sets of slope evaluations, acceptable slope stability is achieved with the surface soil layer cohesion at 250 PSF, a value shown by laboratory soil tests to be achievable with recompaction of the natural surface soil with little or no addition of fine materials. These analyses show that the Trench 12 slopes, during and after operations (i.e., initial excavation slopes and final cover slopes), are acceptably stable without improving the cohesive strength of the surface soil layer (wedge) to a value greater than 250 PSF.

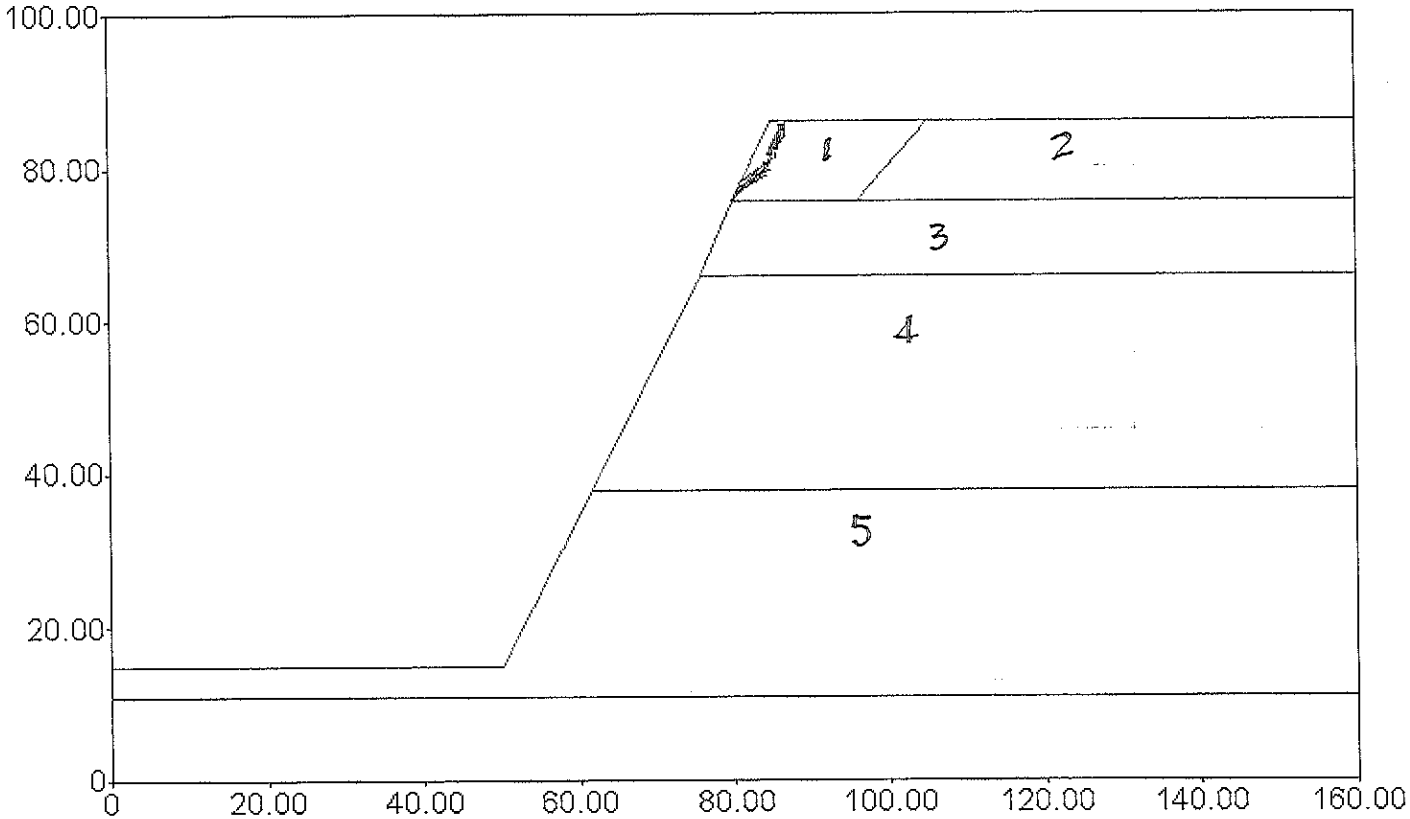
WIN STABL

MODEL RUNS

Typical excavation slope, with 0.42 g horizontal acceleration

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 250.00 | 35.00 |
| 2 | 120.00 | 120.00 | 0.00 | 35.00 |
| 3 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 4 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 5 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 6 | 120.00 | 120.00 | 4320.00 | 35.00 |

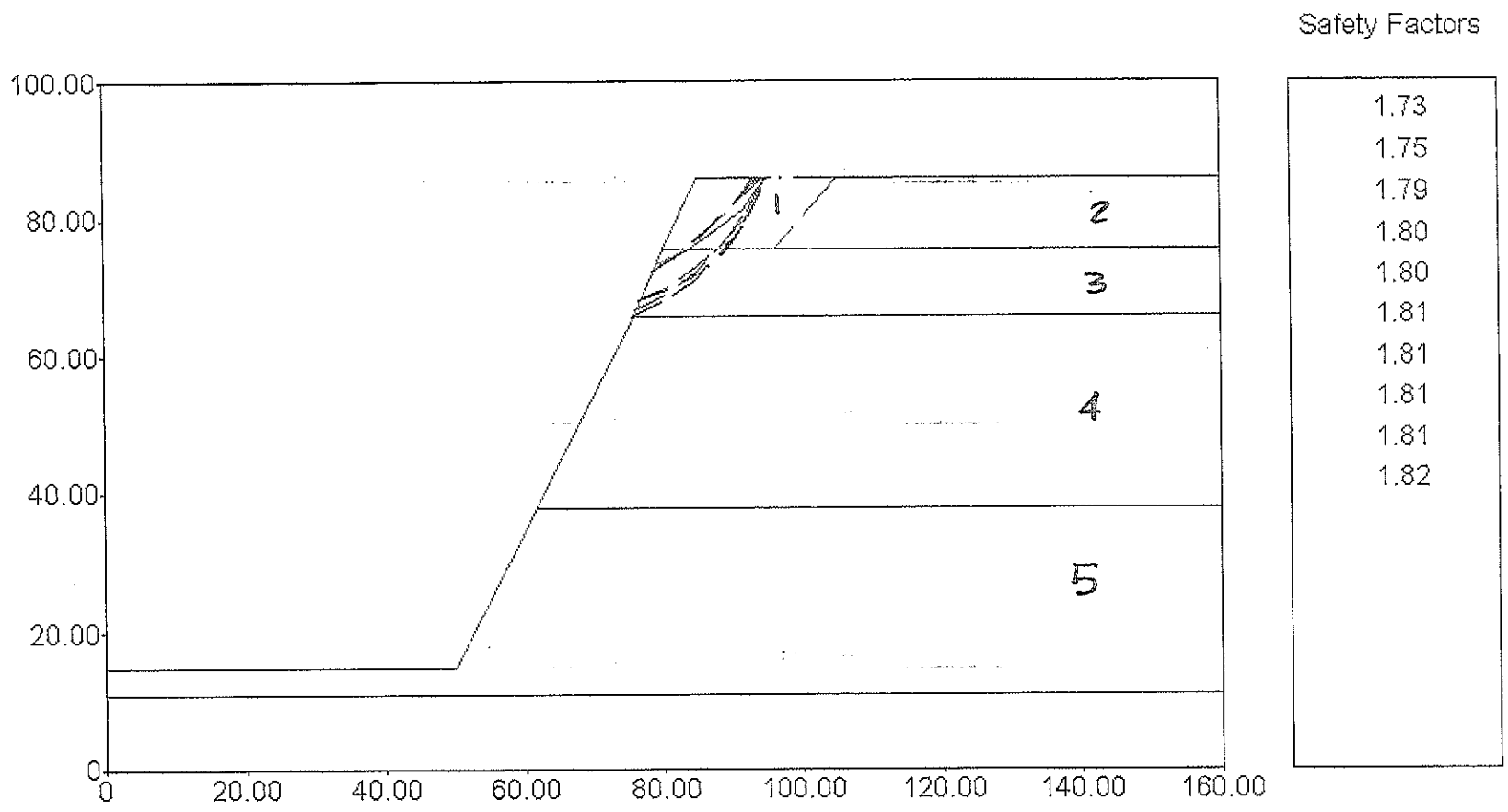
Excavation slope - Pseudo-Static Loading



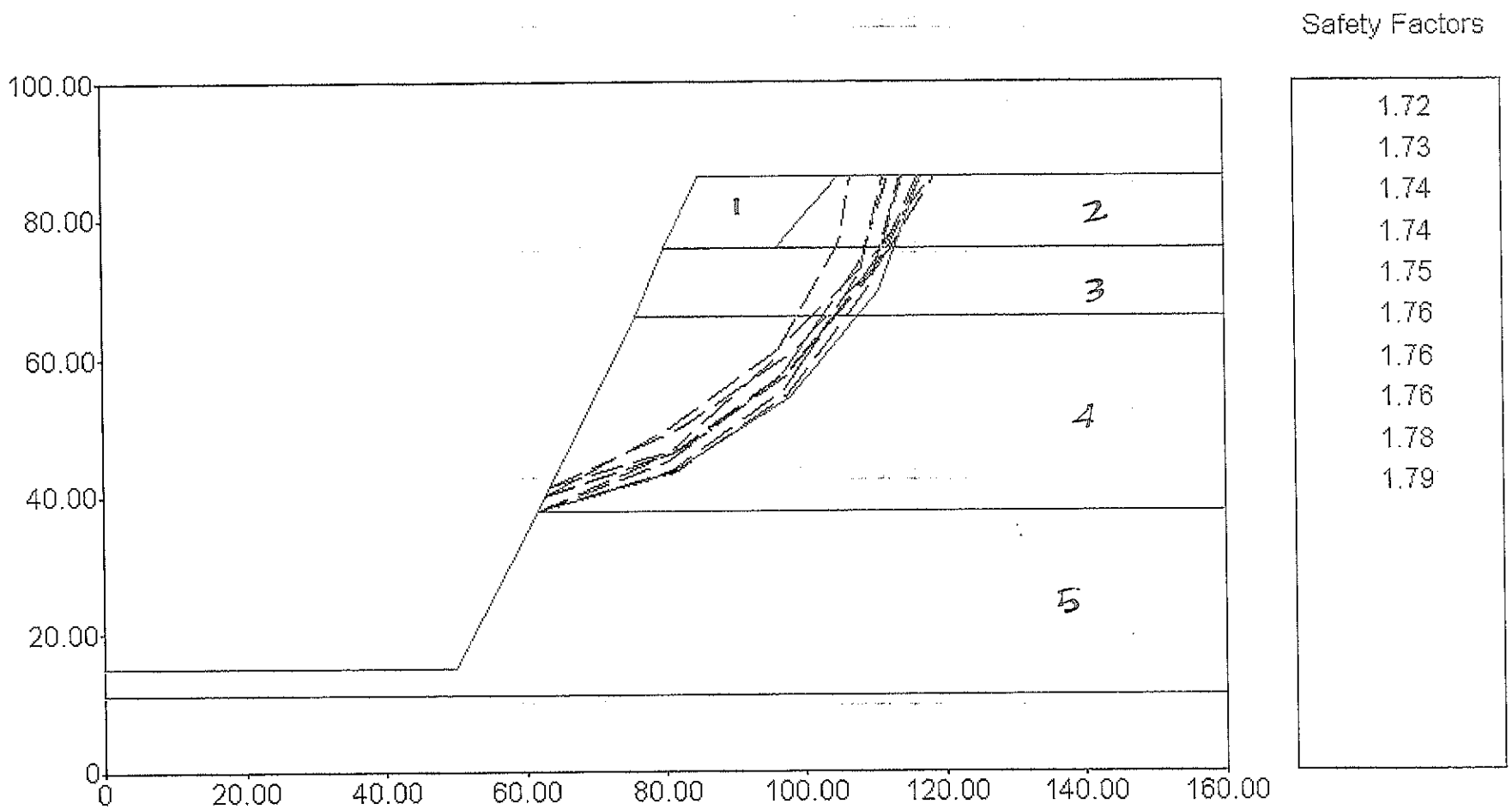

Safety Factors

1.64
1.66
1.69
1.75
1.78
1.78
1.79
1.81
1.83
1.84

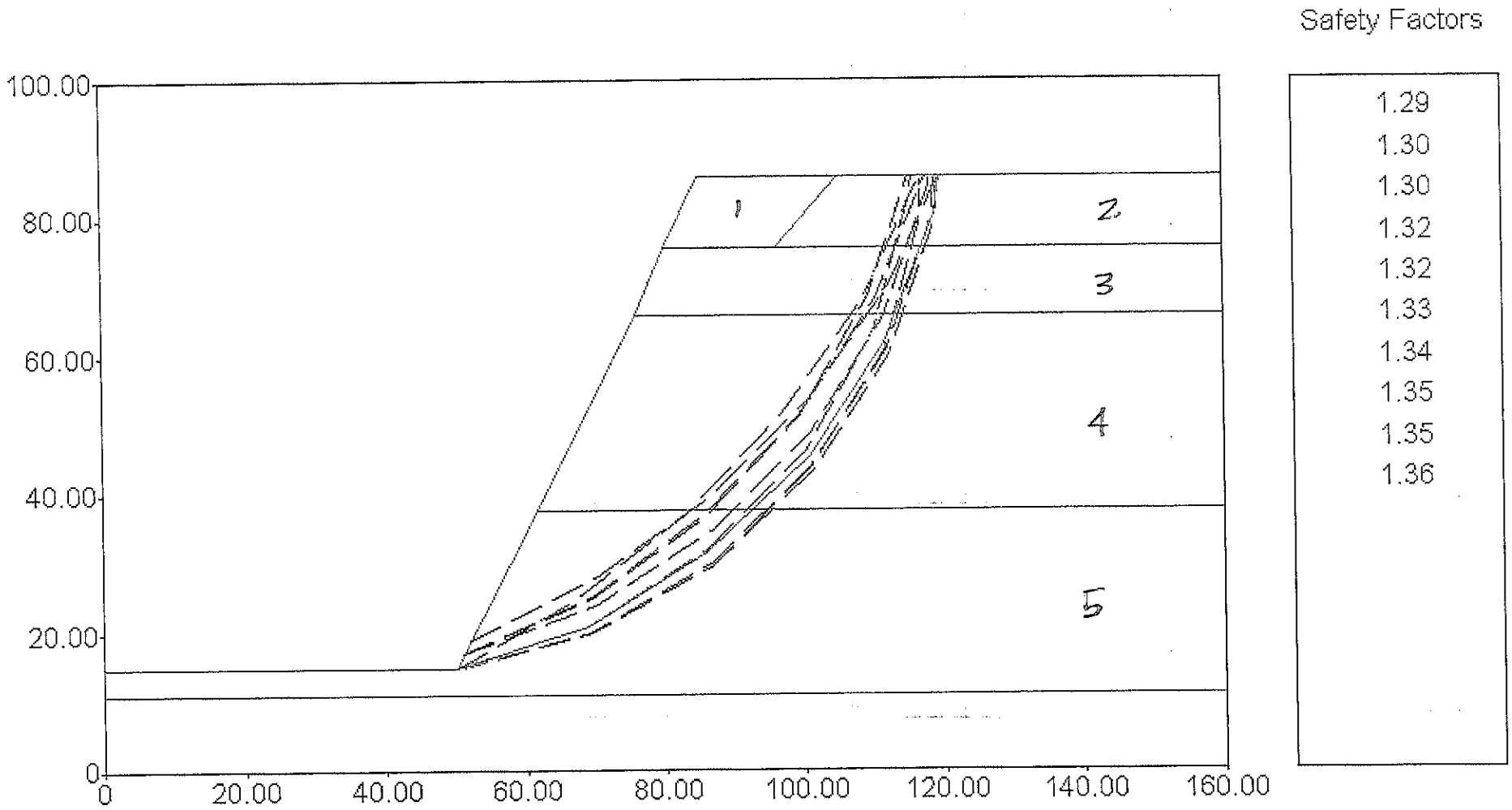
Typical excavation slope, with 0.42g horiz. acceleration



Typical excavation slope, with 0.42g horiz. acceleration



Typical excavation slope, with 0.42g horiz. acceleration



Profile.out
** PCSTABL6 **

by
Purdue University

modified by
Peter J. Bosscher
University of Wisconsin-Madison

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

PROBLEM DESCRIPTION

TYPICAL EXCAVATION WALL

BOUNDARY COORDINATES

7 Top Boundaries
13 Total Boundaries

| Boundary No. | X-Left (ft) | Y-Left (ft) | X-Right (ft) | Y-Right (ft) | Soil Type Below Bnd |
|---|---|---|---|---|---|
| 1 | 0.00 | 15.00 | 50.00 | 15.00 | 5 |
| 2 | 50.00 | 15.00 | 62.00 | 38.00 | 5 |
| 3 | 62.00 | 38.00 | 76.00 | 66.00 | 4 |
| 4 | 76.00 | 66.00 | 80.00 | 76.00 | 3 |
| 5 | 80.00 | 76.00 | 85.00 | 86.00 | 1 |
| 6 | 85.00 | 86.00 | 105.00 | 86.00 | 1 |
| 7 | 105.00 | 86.00 | 160.00 | 86.00 | 2 |
| 8 | 80.00 | 76.00 | 96.00 | 76.00 | 3 |
| 9 | 96.00 | 76.00 | 105.00 | 86.00 | 2 |
| 10 | 96.00 | 76.00 | 160.00 | 76.00 | 3 |
| 11 | 76.00 | 66.00 | 160.00 | 66.00 | 4 |
| 12 | 62.00 | 38.00 | 160.00 | 38.00 | 5 |
| 13 | 0.00 | 11.00 | 160.00 | 11.00 | 6 |

ISOTROPIC SOIL PARAMETERS

6 Type(s) of Soil

| Soil Type No. | Total Unit Wt. (pcf) | Saturated Unit Wt. (pcf) | Cohesion Intercept (psf) | Friction Angle (deg) | Pore Pressure Param. | Pressure Constant (psf) | Piez. Surface No. |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 120.0 | 120.0 | 250.0 | 35.0 | 0.00 | 0.0 | 0 |
| 2 | 120.0 | 120.0 | 0.0 | 35.0 | 0.00 | 0.0 | 0 |
| 3 | 120.0 | 120.0 | 1440.0 | 35.0 | 0.00 | 0.0 | 0 |
| 4 | 120.0 | 120.0 | 2880.0 | 35.0 | 0.00 | 0.0 | 0 |
| 5 | 120.0 | 120.0 | 2160.0 | 35.0 | 0.00 | 0.0 | 0 |
| 6 | 120.0 | 120.0 | 4320.0 | 35.0 | 0.00 | 0.0 | 0 |

A Horizontal Earthquake Loading Coefficient
Of0.420 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 psf

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Irregular Surfaces, Has Been Specified.

100 Trial Surfaces Have Been Generated.

10 Surfaces Initiate From Each Of 10 Points Equally Spaced
Along The Ground Surface Between X = 79.00 ft.
and X = 82.00 ft.

Each Surface Terminates Between X = 85.00 ft.
and X = 87.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y = 0.00 ft.

5.00 ft. Line Segments Define Each Trial Failure Surface.

Following Are Displayed The Ten Most Critical Of The Trial
Failure Surfaces Examined. They Are Ordered - Most Critical
First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.33 | 76.67 |
| 2 | 84.14 | 79.91 |
| 3 | 86.63 | 84.25 |
| 4 | 86.95 | 86.00 |

*** 1.639 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.67 | 77.33 |
| 2 | 84.66 | 80.34 |
| 3 | 86.68 | 84.92 |
| 4 | 86.93 | 86.00 |

*** 1.664 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.33 | 76.67 |
| 2 | 84.08 | 79.98 |
| 3 | 86.21 | 84.50 |
| 4 | 86.94 | 86.00 |

*** 1.693 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.33 | 76.67 |
| 2 | 84.62 | 79.24 |
| 3 | 85.86 | 84.09 |
| 4 | 86.83 | 86.00 |

*** 1.754 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.00 | 76.00 |
| 2 | 83.90 | 79.14 |
| 3 | 86.25 | 83.55 |

| | | |
|---|---|---|
| 4 | 86.36 | 86.00 |

*** 1.778 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.00 | 76.00 |
| 2 | 83.55 | 79.53 |
| 3 | 86.13 | 83.81 |
| 4 | 86.62 | 86.00 |

*** 1.778 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.33 | 76.67 |
| 2 | 84.43 | 79.54 |
| 3 | 85.91 | 84.31 |
| 4 | 86.34 | 86.00 |

*** 1.793 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.67 | 77.33 |
| 2 | 84.95 | 79.92 |
| 3 | 86.39 | 84.70 |
| 4 | 86.59 | 86.00 |

*** 1.812 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 81.00 | 78.00 |
| 2 | 85.00 | 81.01 |

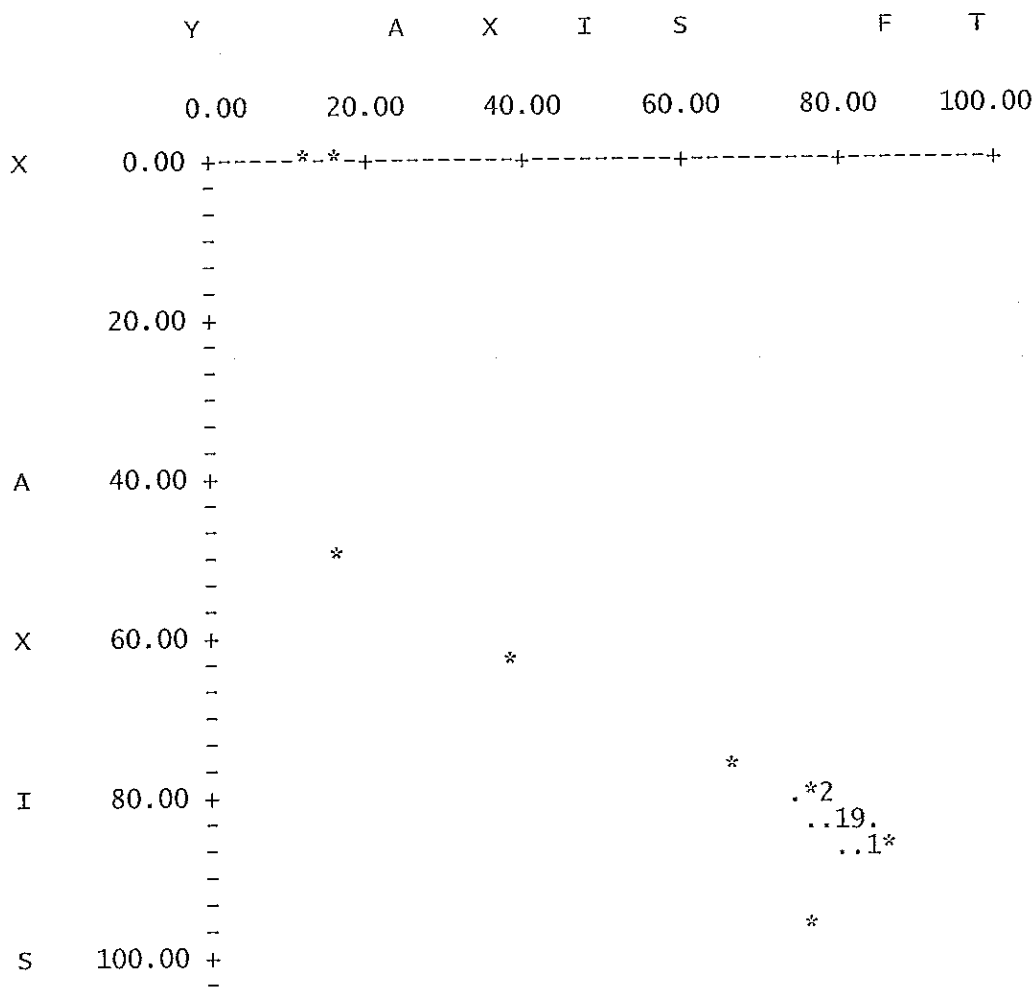
| | | |
|---|---|---|
| 3 | 86.78 | 85.68 |
| 4 | 86.80 | 86.00 |

*** 1.826 ***

Failure Surface Specified By 4 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 80.33 | 76.67 |
| 2 | 84.02 | 80.04 |
| 3 | 86.89 | 84.14 |
| 4 | 86.92 | 86.00 |

*** 1.842 ***



```
                                                                  *
                 -
                 -
                 -
                 -
       120.00 +
                 -
                 -
                 -
                 -
                 -
F      140.00 +
                 -
                 -
                 -
                 -
                 -
T      160.00 +     *             *             *    *    *
```

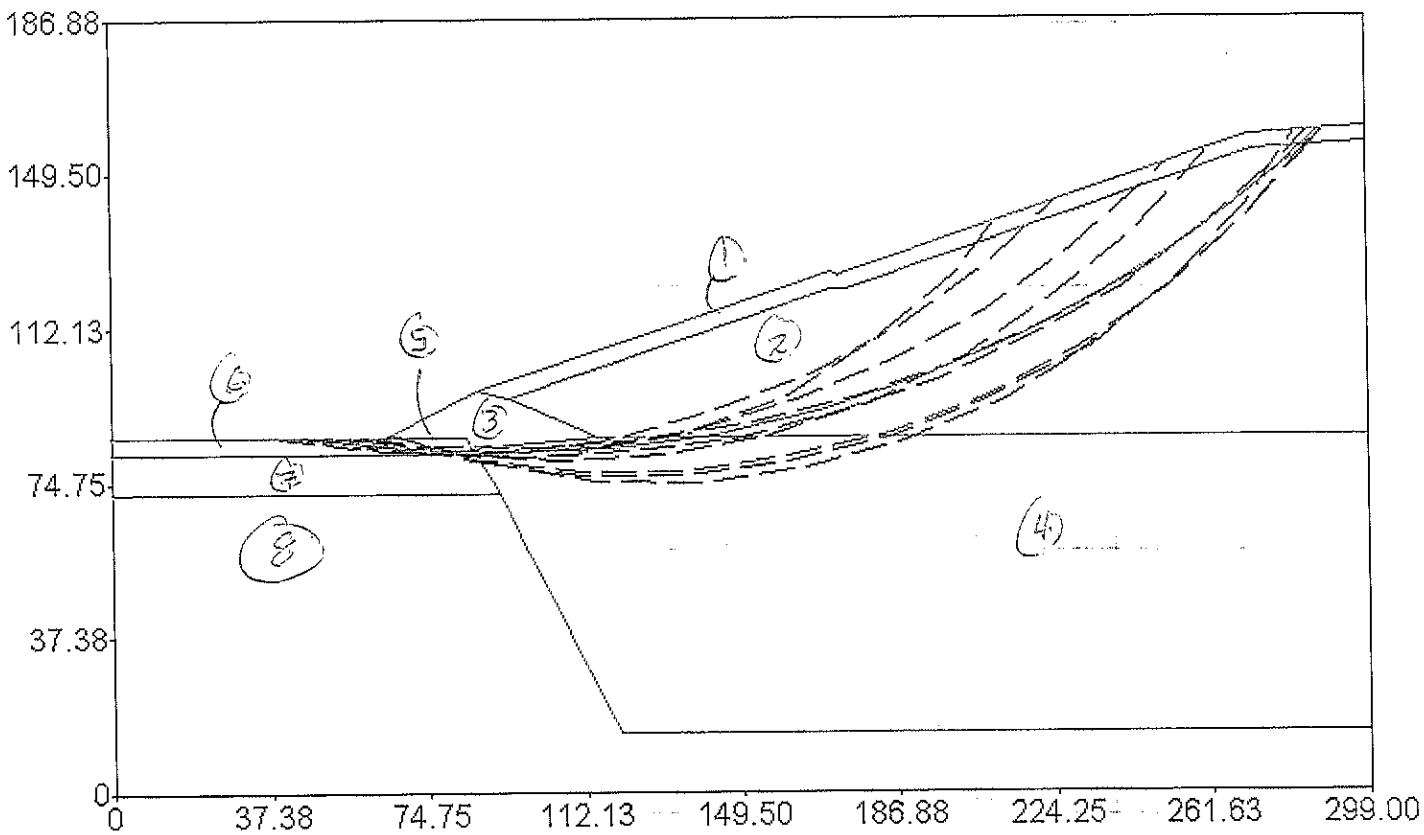
Final Cover Slope Stability for section with 5 feet of surface soil

Surface soil at C = 0 PSF (not recompacted)

Waste at C = 500 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 0.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

| |
|---|
| 0.94 |
| 0.94 |
| 0.95 |
| 0.98 |
| 0.98 |
| 0.98 |
| 0.99 |
| 1.01 |
| 1.02 |
| 1.04 |

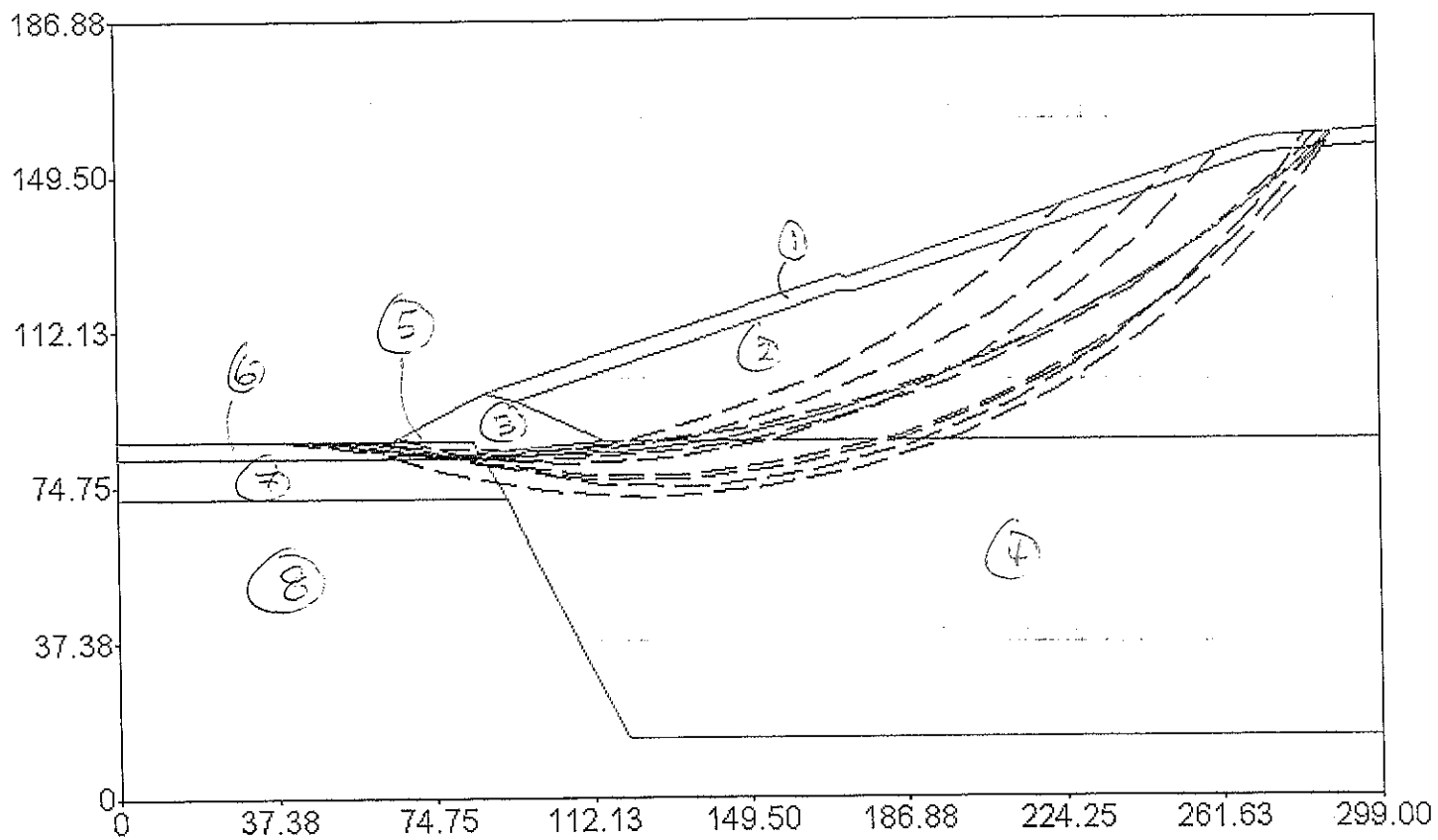
Final Cover Slope Stability for section with 5 feet of surface soil

Surface soil at C = 250 PSF (recompacted, no amendment)

Waste at C = 500 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotro, Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

0.95
0.95
0.97
0.99
1.00
1.00
1.00
1.03
1.04
1.05

Final Cover Slope Stability for section with 5 feet of surface soil.

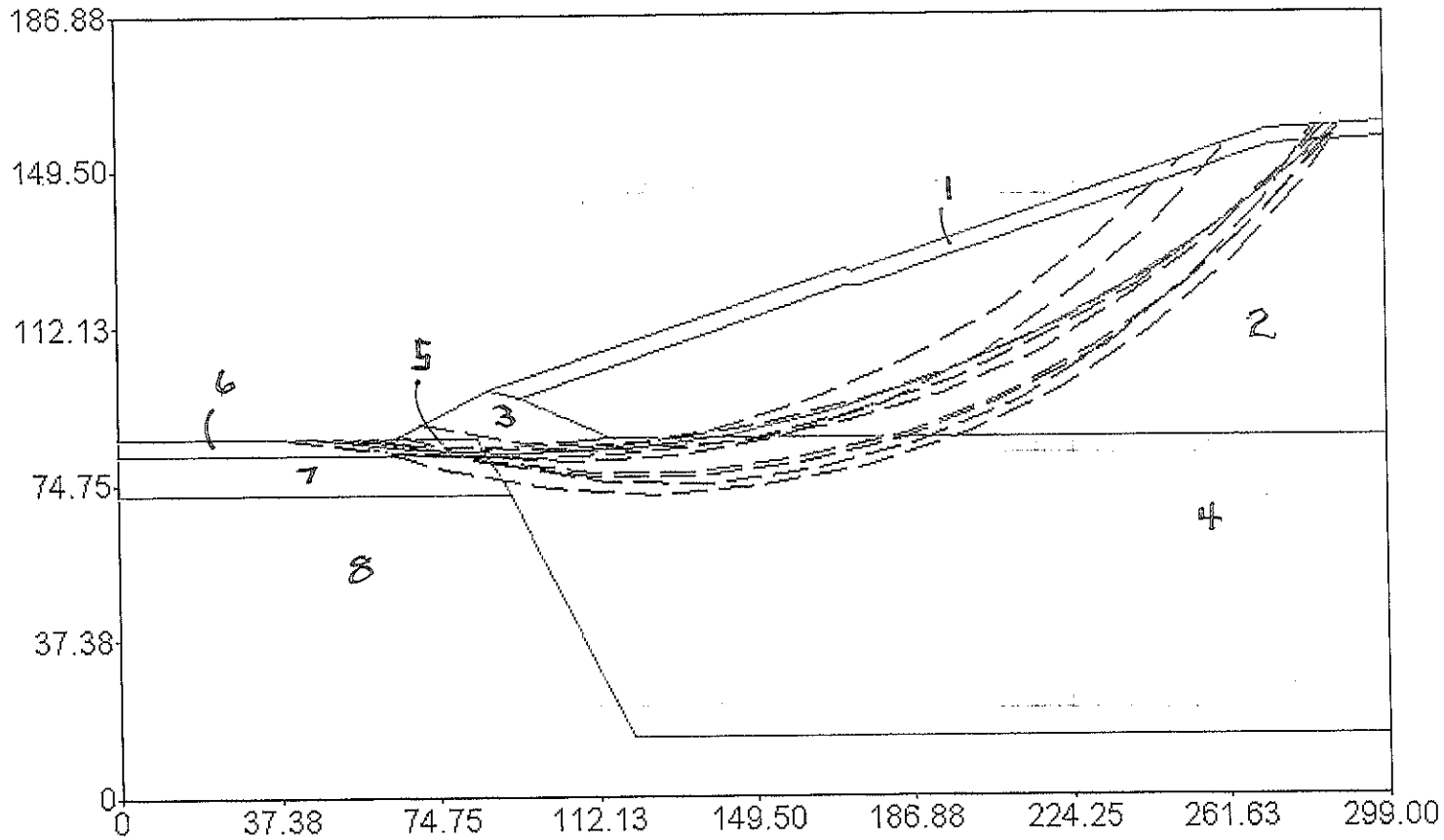
Surface soil at C = 1000 PSF (Recompacted, with additives)

Upper waste at 115 PCF weight, C = 500 PSF (cohesion)

Lower waste at 115 PCF weight, C = 500 PSF (cohesion

| | Moist Unit Weight | Saturated Unit Weight | Isotro Stren Intercept | sotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

0.99
1.00
1.01
1.03
1.04
1.05
1.05
1.05
1.06
1.07

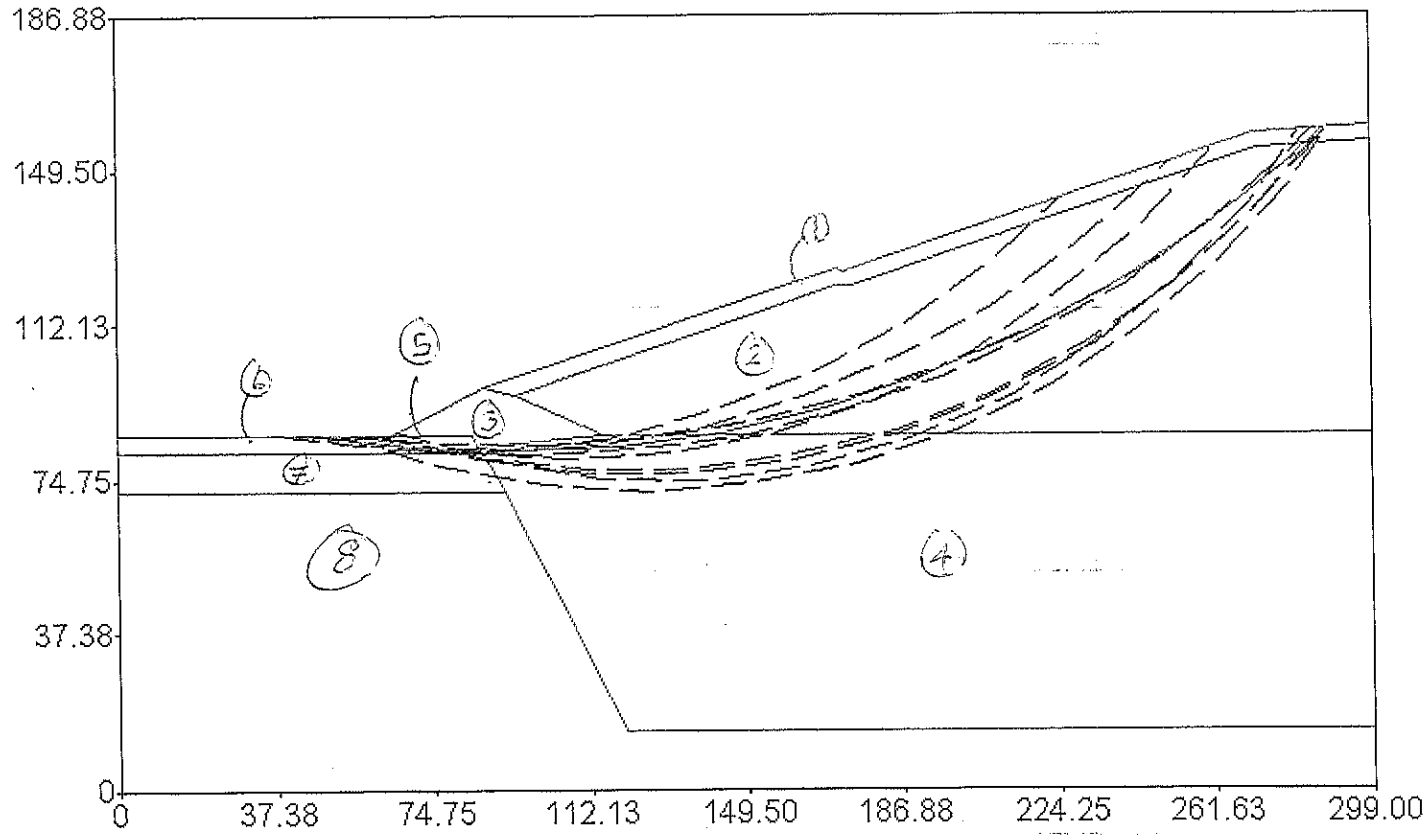
Final Cover Slope Stability for section with 5 feet of surface soil

Surface soil at C = 250 PSF (recompacted, no amendment)

Waste at C = 550 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropi Strengt. Intercept | tropic rength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 550.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 550.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

| |
|---|
| 0.98 |
| 0.98 |
| 1.00 |
| 1.01 |
| 1.02 |
| 1.02 |
| 1.03 |
| 1.05 |
| 1.07 |
| 1.07 |

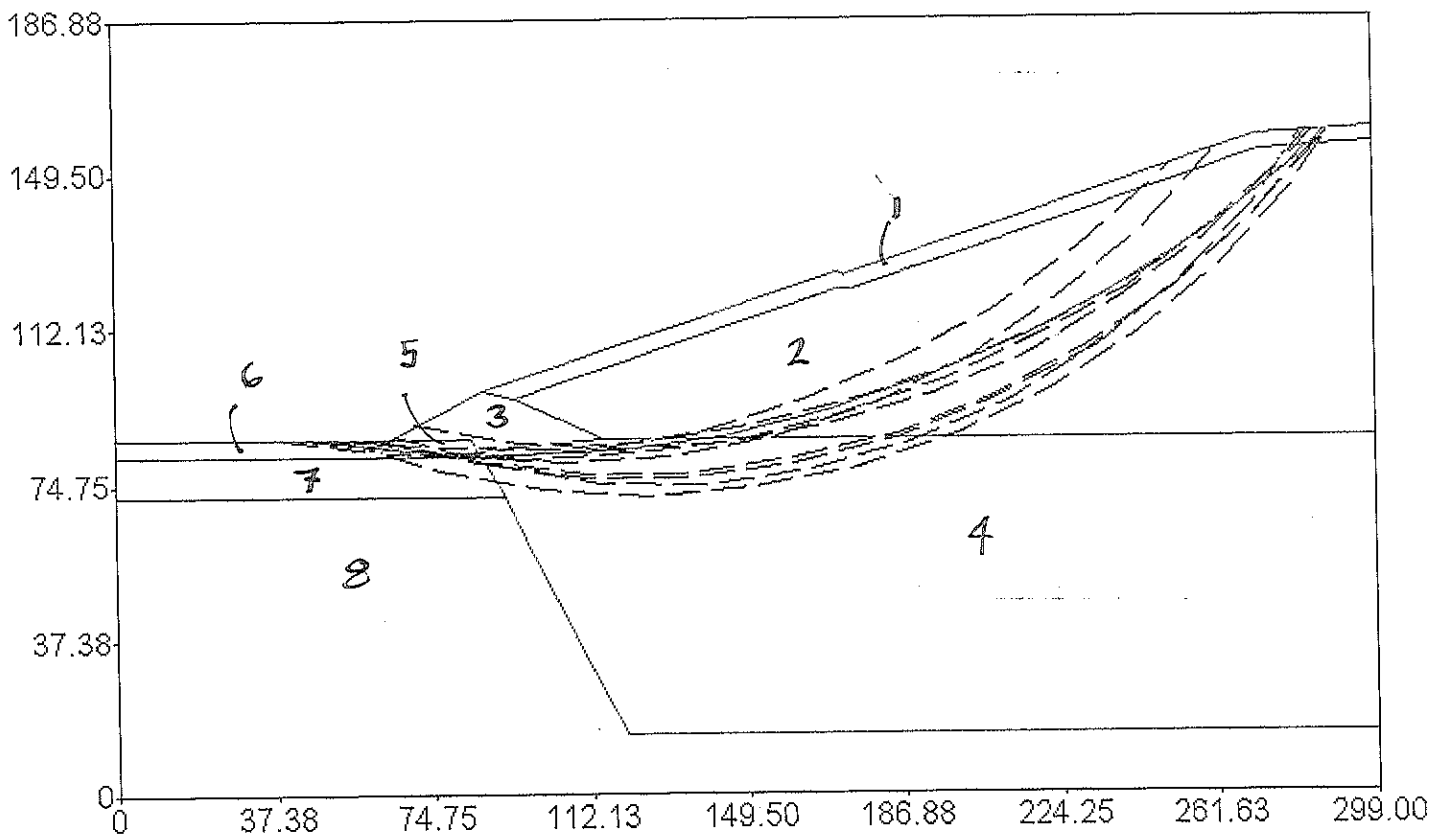
Final Cover Slope Stability for section with 5 feet of surface soil.

Surface soil at C = 500 (Recompacted, with additives)

Waste at 115 PCF weight, C = 550 PSF (cohesion)

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 550.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 550.00 | 27.00 |
| 5 | 120.00 | 120.00 | 500.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

0.99
0.99
1.01
1.02
1.04
1.04
1.04
1.06
1.07
1.09

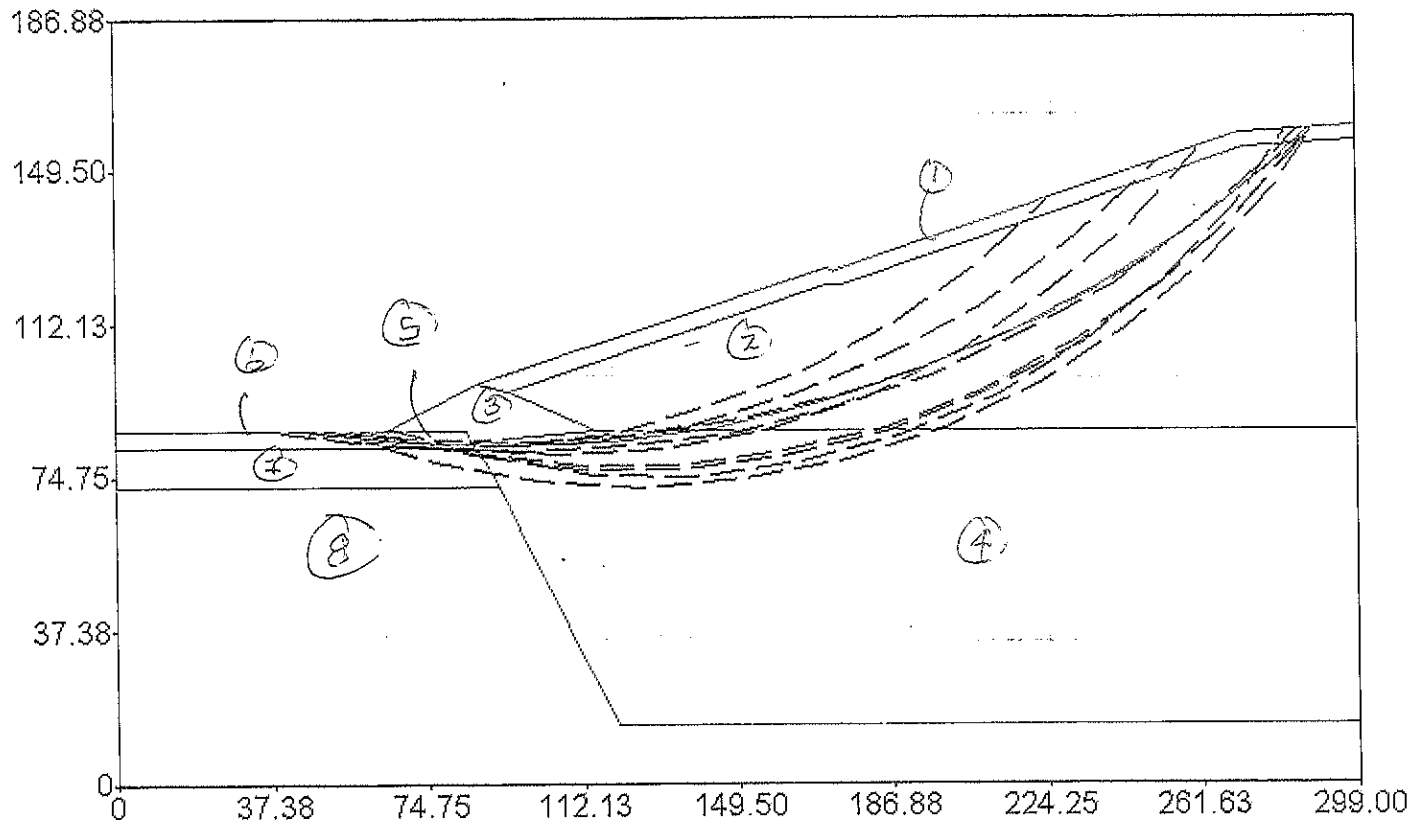
Final Cover Slope Stability for section with 5 feet of surface soil

Surface soil at C = 250 PSF (recompacted, with amendment)

Waste at C = 600 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 600.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 600.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

1.00
1.00
1.02
1.03
1.05
1.05
1.06
1.07
1.09
1.10

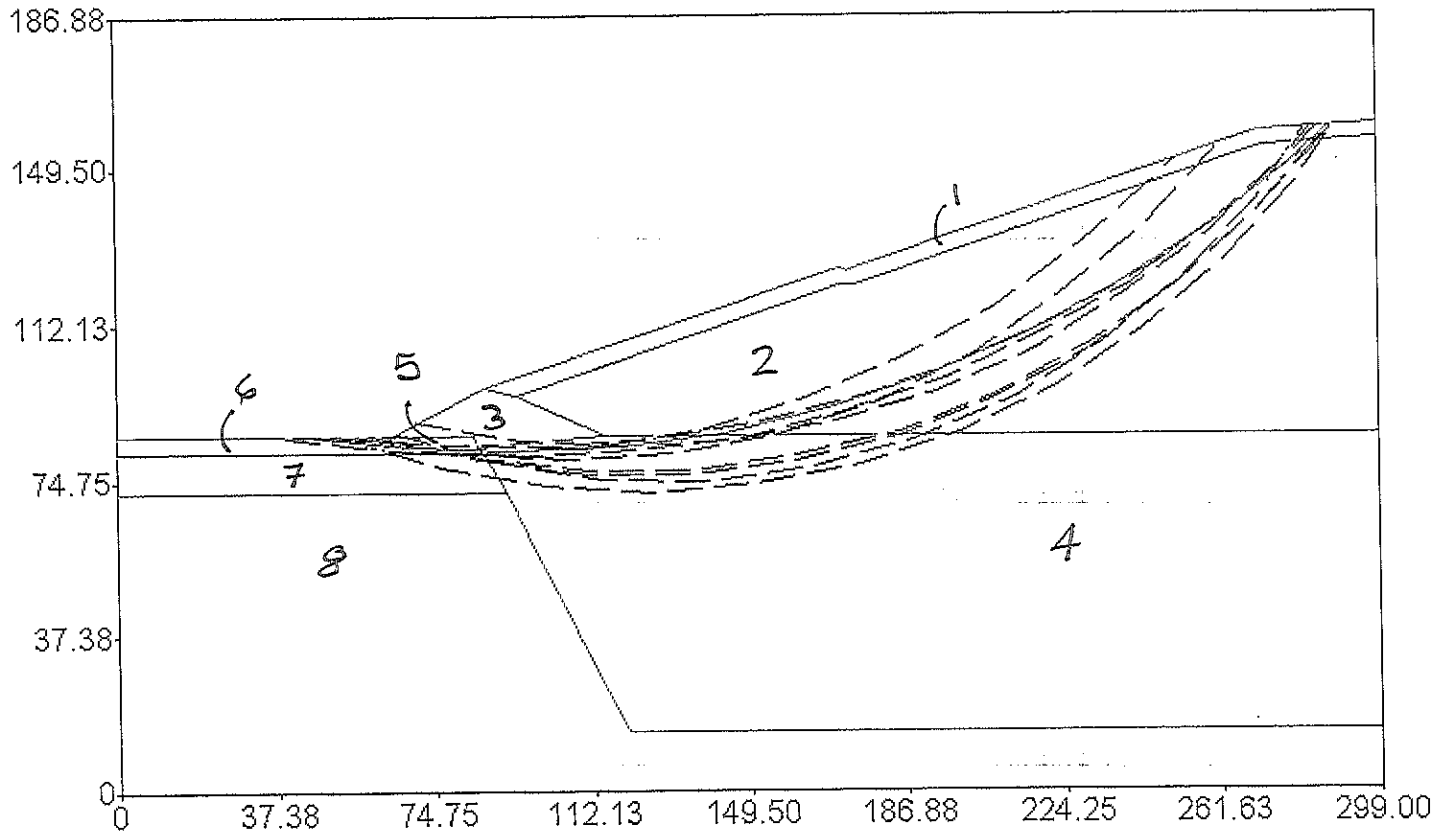
Final Cover Slope Stability for section with 5 feet of surface soil

Surface soil at C = 500 PSF (recompacted, with amendment)

Waste at C = 600 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 600.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 600.00 | 27.00 |
| 5 | 120.00 | 120.00 | 500.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

1.02
1.02
1.04
1.05
1.06
1.07
1.08
1.08
1.09
1.11

Final Cover Slope Stability for section with 5 feet of surface soil.

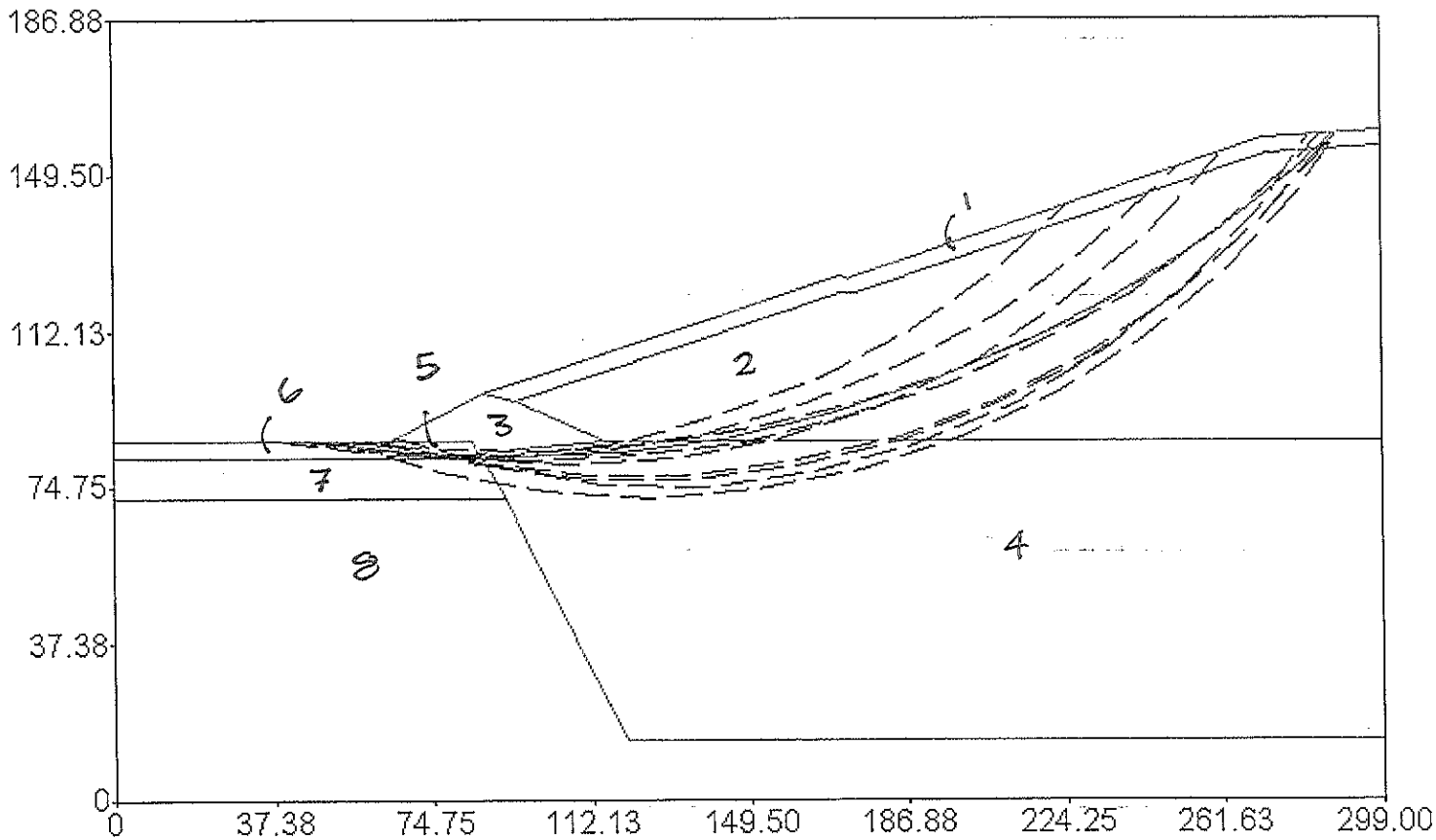
Surface soil at C = 250 PSF (Recompacted, no additives)

Upper waste at 100 PCF weight, C = 500 PSF (cohesion)

Lower waste at 115 PCF weight, C = 500 PSF (cohesion

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 100.00 | 100.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

0.99
0.99
1.01
1.03
1.04
1.04
1.04
1.07
1.08
1.10

Final Cover Slope Stability for section with 5 feet of surface soil.

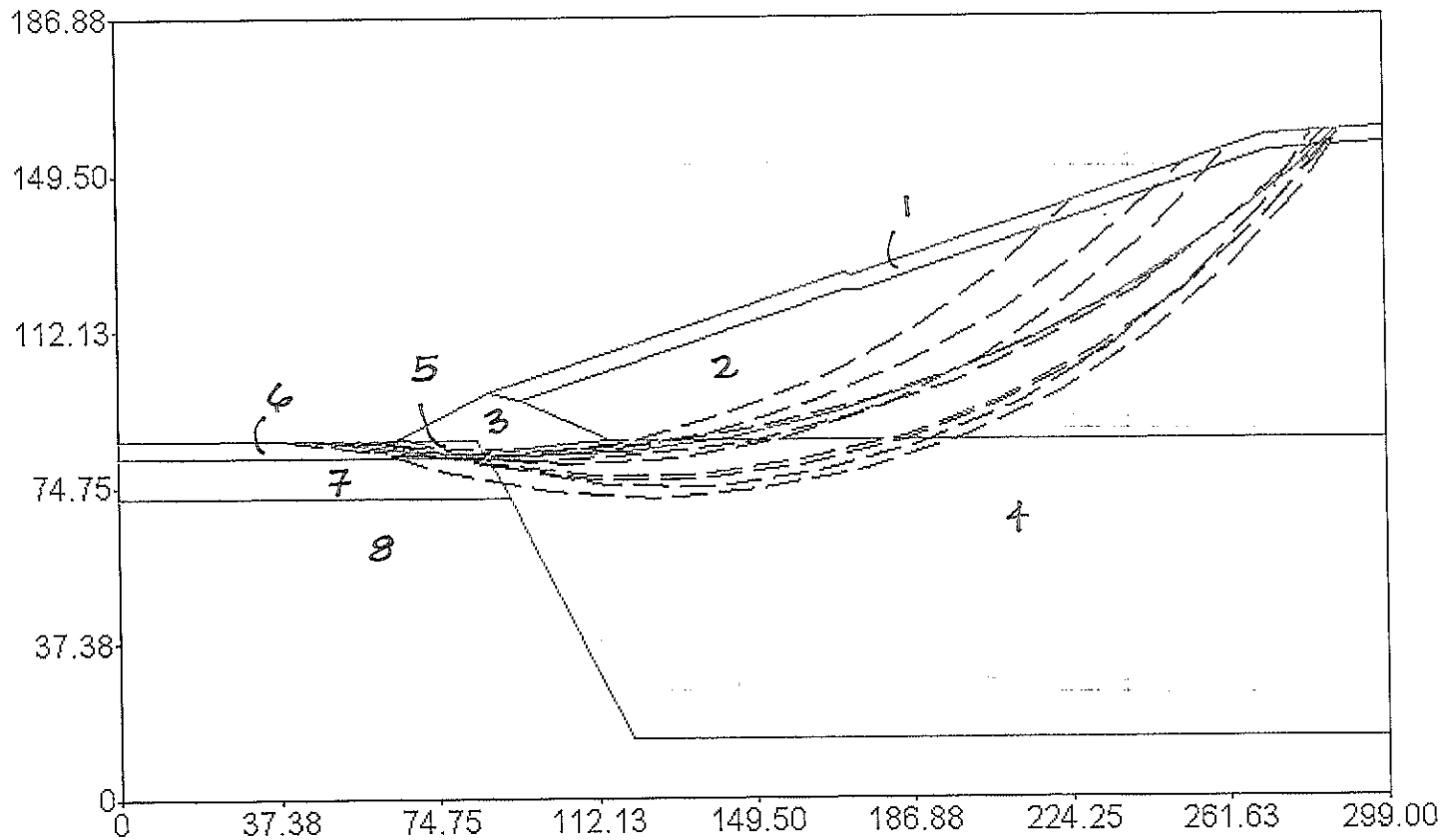
Surface soil at C = 250 PSF (Recompacted, no additives)

Upper waste at 100 PCF weight, C = 550 PSF (cohesion)

Lower waste at 115 PCF weight, C = 550 PSF (cohesion

| | Moist Unit Weight | Saturated Unit Weight | Isotr Stre Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 100.00 | 100.00 | 550.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 550.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer




Safety Factors

1.02
1.02
1.04
1.05
1.07
1.07
1.07
1.09
1.12
1.12

5 FEET SURFACE SOIL

FINAL RUN

Surface soil c = 250 psf

Waste $\gamma$ = 100 pcf

c = 550 psf

Profile.out
** PCSTABL6 **

by
Purdue University

modified by
Peter J. Bosscher
University of Wisconsin-Madison

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

PROBLEM DESCRIPTION  Pseudo-Static loading (0.42 g) for 5-ft thick surface soil layer

BOUNDARY COORDINATES

8 Top Boundaries
29 Total Boundaries

| Boundary No. | X-Left (ft) | Y-Left (ft) | X-Right (ft) | Y-Right (ft) | Soil Type Below Bnd |
|---|---|---|---|---|---|
| 1 | 0.00 | 86.00 | 65.00 | 86.00 | 6 |
| 2 | 65.00 | 86.00 | 87.00 | 97.00 | 3 |
| 3 | 87.00 | 97.00 | 171.00 | 126.00 | 1 |
| 4 | 171.00 | 126.00 | 172.00 | 126.00 | 1 |
| 5 | 172.00 | 126.00 | 173.50 | 125.00 | 1 |
| 6 | 173.50 | 125.00 | 175.00 | 126.00 | 1 |
| 7 | 175.00 | 126.00 | 271.00 | 158.00 | 1 |
| 8 | 271.00 | 158.00 | 299.00 | 160.00 | 1 |
| 9 | 87.00 | 97.00 | 95.00 | 95.50 | 3 |
| 10 | 95.00 | 95.50 | 171.00 | 122.00 | 2 |
| 11 | 171.00 | 122.00 | 172.00 | 122.00 | 2 |
| 12 | 172.00 | 122.00 | 173.50 | 121.00 | 2 |
| 13 | 173.50 | 121.00 | 175.00 | 122.00 | 2 |
| 14 | 175.00 | 122.00 | 272.00 | 154.50 | 2 |
| 15 | 272.00 | 154.50 | 299.00 | 156.00 | 2 |
| 16 | 95.00 | 95.50 | 116.00 | 86.00 | 3 |
| 17 | 116.00 | 86.00 | 299.00 | 86.00 | 4 |
| 18 | 65.00 | 86.00 | 85.00 | 86.00 | 5 |
| 19 | 85.00 | 86.00 | 86.00 | 83.00 | 5 |
| 20 | 86.00 | 83.00 | 116.00 | 86.00 | 4 |
| 21 | 86.00 | 83.00 | 87.00 | 81.00 | 5 |
| 22 | 87.00 | 81.00 | 92.00 | 72.00 | 7 |
| 23 | 92.00 | 72.00 | 97.00 | 62.00 | 8 |
| 24 | 97.00 | 62.00 | 120.00 | 14.00 | 8 |
| 25 | 120.00 | 14.00 | 299.00 | 14.00 | 8 |

| | | | | | |
|---|---|---|---|---|---|
| 26 | 65.00 | 86.00 | 70.00 | 81.00 | 6 |
| 27 | 70.00 | 81.00 | 87.00 | 81.00 | 7 |
| 28 | 0.00 | 81.00 | 70.00 | 81.00 | 7 |
| 29 | 0.00 | 72.00 | 92.00 | 72.00 | 8 |

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

| Soil Type No. | Total Unit Wt. (pcf) | Saturated Unit Wt. (pcf) | Cohesion Intercept (psf) | Friction Angle (deg) | Pore Pressure Param. | Pressure Constant (psf) | Piez. Surface No. |
|---|---|---|---|---|---|---|---|
| 1 | 120.0 | 120.0 | 0.0 | 35.0 | 0.00 | 0.0 | 0 |
| 2 | 100.0 | 100.0 | 550.0 | 27.0 | 0.00 | 0.0 | 0 |
| 3 | 120.0 | 120.0 | 1000.0 | 35.0 | 0.00 | 0.0 | 0 |
| 4 | 115.0 | 115.0 | 550.0 | 27.0 | 0.00 | 0.0 | 0 |
| 5 | 120.0 | 120.0 | 250.0 | 35.0 | 0.00 | 0.0 | 0 |
| 6 | 120.0 | 120.0 | 0.0 | 35.0 | 0.00 | 0.0 | 0 |
| 7 | 120.0 | 120.0 | 1440.0 | 35.0 | 0.00 | 0.0 | 0 |
| 8 | 120.0 | 120.0 | 2880.0 | 35.0 | 0.00 | 0.0 | 0 |
| 9 | 120.0 | 120.0 | 2160.0 | 35.0 | 0.00 | 0.0 | 0 |
| 10 | 120.0 | 120.0 | 4320.0 | 35.0 | 0.00 | 0.0 | 0 |

A Horizontal Earthquake Loading Coefficient
Of0.420 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 psf

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

100 Trial Surfaces Have Been Generated.

10 Surfaces Initiate From Each Of 10 Points Equally Spaced
Along The Ground Surface Between X = 40.00 ft.
and X = 80.00 ft.

Each Surface Terminates Between X = 150.00 ft.
and X = 290.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y = 70.00 ft.

25.00 ft. Line Segments Define Each Trial Failure Surface.

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 44.44 | 86.00 |
| 2 | 69.25 | 82.86 |
| 3 | 94.23 | 81.89 |
| 4 | 119.20 | 83.11 |
| 5 | 143.97 | 86.50 |
| 6 | 168.34 | 92.04 |
| 7 | 192.15 | 99.69 |
| 8 | 215.19 | 109.39 |
| 9 | 237.30 | 121.06 |
| 10 | 258.30 | 134.62 |
| 11 | 278.04 | 149.96 |
| 12 | 288.02 | 159.22 |

Circle Center At X = 92.8 ; Y = 368.0 and Radius, 286.1

*** 1.018 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 48.89 | 86.00 |
| 2 | 73.62 | 82.34 |
| 3 | 98.59 | 81.06 |
| 4 | 123.56 | 82.17 |
| 5 | 148.32 | 85.65 |
| 6 | 172.63 | 91.47 |
| 7 | 196.28 | 99.59 |
| 8 | 219.04 | 109.93 |
| 9 | 240.71 | 122.39 |
| 10 | 261.10 | 136.86 |
| 11 | 280.02 | 153.20 |
| 12 | 285.59 | 159.04 |

Circle Center At X = 99.5 ; Y = 342.9 and Radius, 261.9

*** 1.020 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 53.33 | 86.00 |
| 2 | 78.22 | 83.64 |
| 3 | 103.22 | 83.43 |
| 4 | 128.15 | 85.35 |
| 5 | 152.82 | 89.41 |
| 6 | 177.05 | 95.56 |
| 7 | 200.66 | 103.76 |
| 8 | 223.49 | 113.96 |
| 9 | 245.36 | 126.07 |
| 10 | 266.11 | 140.02 |
| 11 | 285.59 | 155.69 |
| 12 | 289.38 | 159.31 |

Circle Center At X = 93.2 ; Y = 374.9 and Radius, 291.6

*** 1.039 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 62.22 | 86.00 |
| 2 | 86.57 | 80.31 |
| 3 | 111.41 | 77.54 |
| 4 | 136.41 | 77.75 |
| 5 | 161.21 | 80.92 |
| 6 | 185.46 | 87.02 |
| 7 | 208.81 | 95.95 |
| 8 | 230.93 | 107.58 |
| 9 | 251.52 | 121.77 |
| 10 | 270.28 | 138.30 |
| 11 | 286.94 | 156.93 |
| 12 | 288.56 | 159.25 |

Circle Center At X = 122.2 ; Y = 287.5 and Radius, 210.2

*** 1.054 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 57.78 | 86.00 |
| 2 | 82.35 | 81.39 |
| 3 | 107.31 | 79.92 |
| 4 | 132.25 | 81.62 |
| 5 | 156.78 | 86.45 |
| 6 | 180.50 | 94.35 |

| | | |
|---|---|---|
| 7 | 203.03 | 105.17 |
| 8 | 224.02 | 118.76 |
| 9 | 243.12 | 134.89 |
| 10 | 260.03 | 153.30 |
| 11 | 261.00 | 154.67 |

Circle Center At X = 106.4 ; Y = 277.4 and Radius, 197.5

*** 1.065 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 62.22 | 86.00 |
| 2 | 86.46 | 79.87 |
| 3 | 111.27 | 76.77 |
| 4 | 136.27 | 76.73 |
| 5 | 161.08 | 79.76 |
| 6 | 185.34 | 85.82 |
| 7 | 208.67 | 94.81 |
| 8 | 230.71 | 106.59 |
| 9 | 251.15 | 120.99 |
| 10 | 269.66 | 137.80 |
| 11 | 285.97 | 156.74 |
| 12 | 287.59 | 159.19 |

Circle Center At X = 124.1 ; Y = 279.6 and Radius, 203.2

*** 1.068 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 40.00 | 86.00 |
| 2 | 64.75 | 82.45 |
| 3 | 89.73 | 81.58 |
| 4 | 114.67 | 83.39 |
| 5 | 139.26 | 87.85 |
| 6 | 163.24 | 94.93 |
| 7 | 186.32 | 104.53 |
| 8 | 208.24 | 116.55 |
| 9 | 228.75 | 130.85 |
| 10 | 247.61 | 147.27 |
| 11 | 251.54 | 151.51 |

Circle Center At X = 85.4 ; Y = 314.6 and Radius, 233.1

*** 1.071 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 66.67 | 86.83 |
| 2 | 90.58 | 79.55 |
| 3 | 115.28 | 75.67 |
| 4 | 140.28 | 75.25 |
| 5 | 165.09 | 78.32 |
| 6 | 189.23 | 84.82 |
| 7 | 212.23 | 94.60 |
| 8 | 233.65 | 107.50 |
| 9 | 253.07 | 123.24 |
| 10 | 270.11 | 141.54 |
| 11 | 282.18 | 158.80 |

Circle Center At X = 130.7 ; Y = 254.3 and Radius, 179.3

*** 1.094 ***

Failure Surface Specified By 9 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 44.44 | 86.00 |
| 2 | 69.23 | 82.74 |
| 3 | 94.23 | 82.62 |
| 4 | 119.05 | 85.65 |
| 5 | 143.28 | 91.78 |
| 6 | 166.56 | 100.90 |
| 7 | 188.50 | 112.89 |
| 8 | 208.76 | 127.54 |
| 9 | 224.89 | 142.63 |

Circle Center At X = 82.7 ; Y = 280.6 and Radius, 198.3

*** 1.115 ***

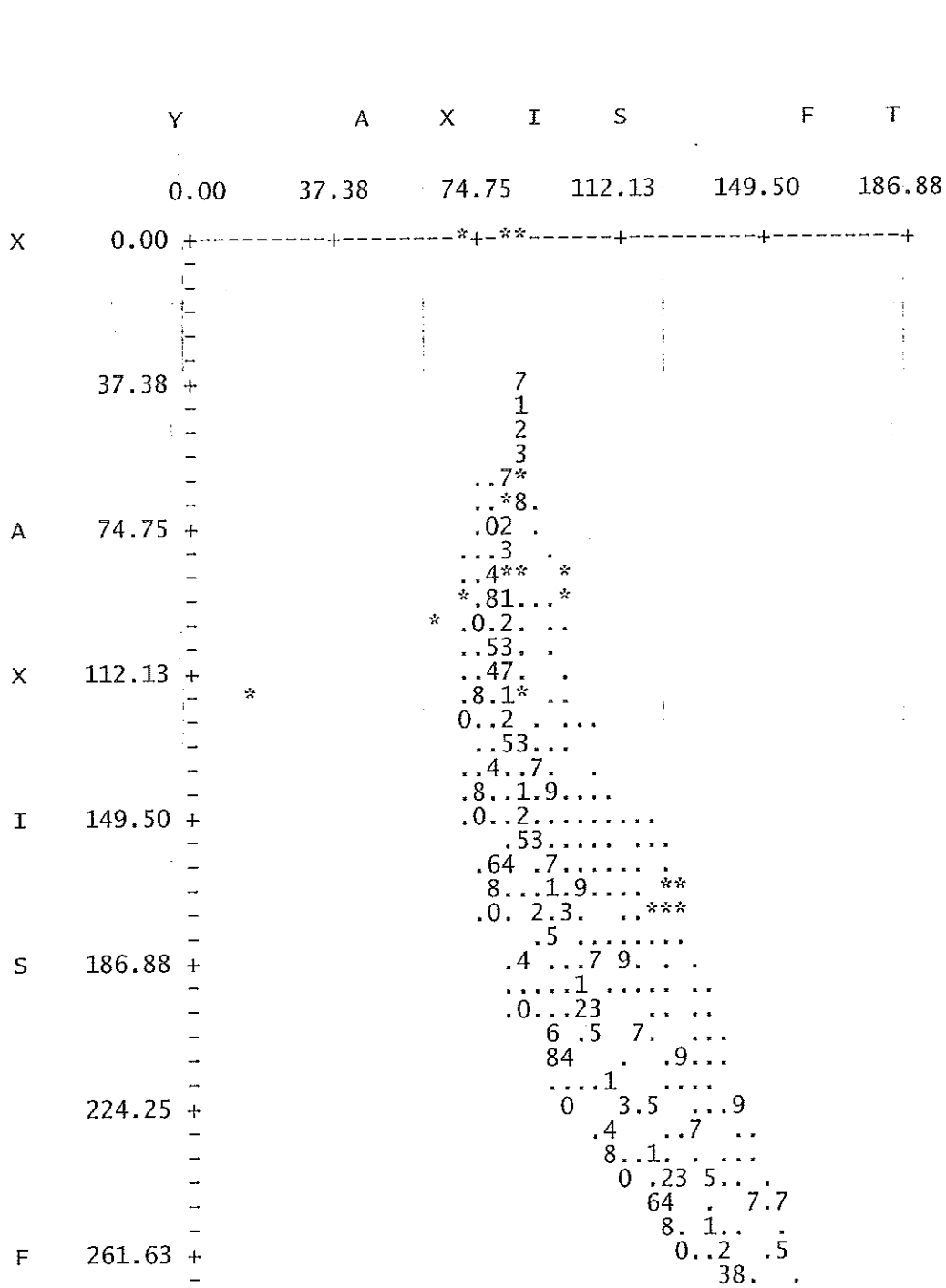
Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 53.33 | 86.00 |
| 2 | 77.13 | 78.33 |
| 3 | 101.70 | 73.72 |
| 4 | 126.66 | 72.24 |
| 5 | 151.60 | 73.92 |
| 6 | 176.13 | 78.73 |
| 7 | 199.86 | 86.59 |
| 8 | 222.42 | 97.38 |

| | | |
|---|---|---|
| 9 | 243.43 | 110.92 |
| 10 | 262.57 | 127.01 |
| 11 | 279.53 | 145.37 |
| 12 | 289.46 | 159.32 |

Circle Center At X = 125.9 ; Y = 270.2 and Radius, 198.0

*** 1.119 ***



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                 -                                          .. .**
                 -                                            0128
                 -                                                31
                 -                                                 .
T      299.00 +   *                  *                          **
```

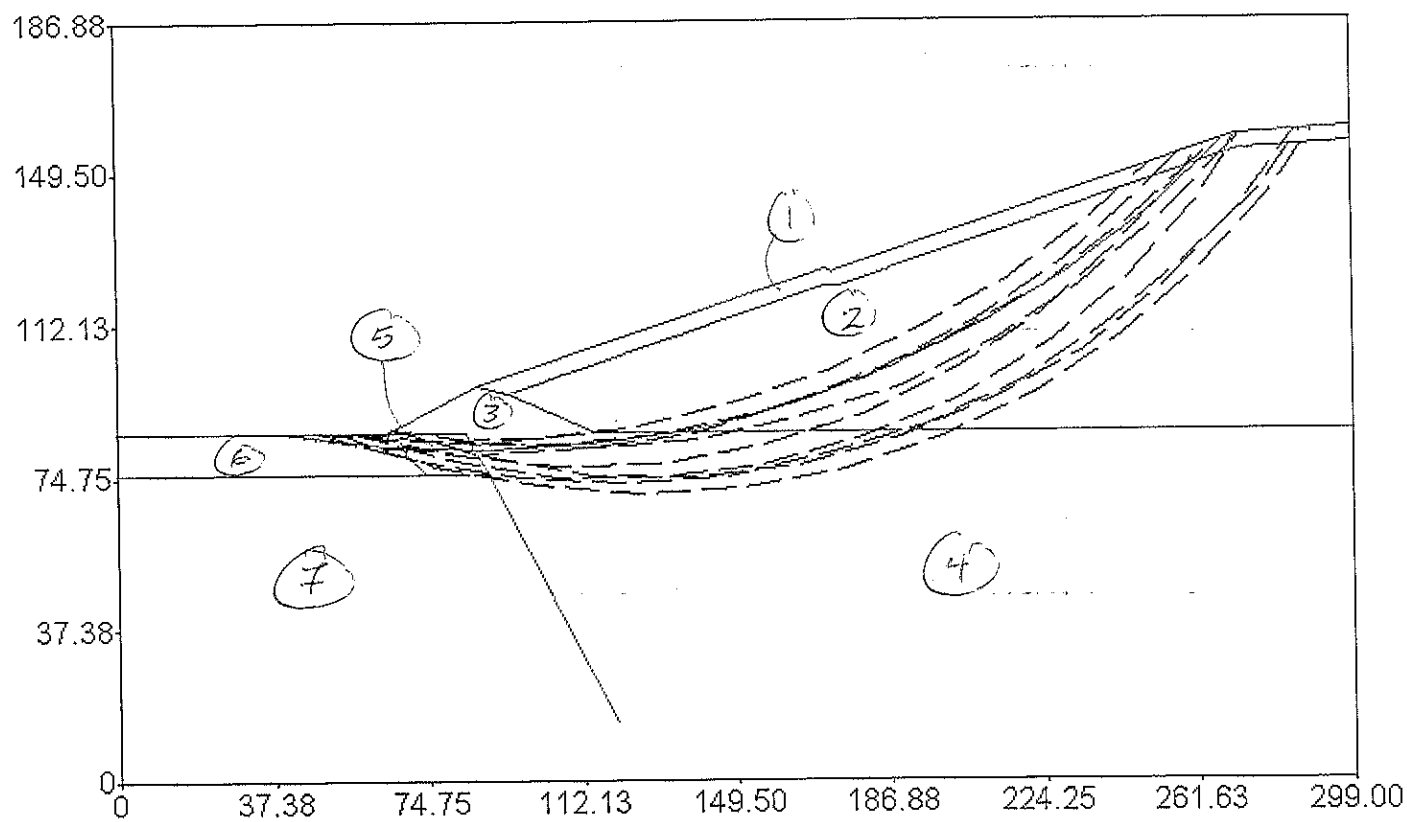
Final Cover Slope Stability for section with 10 feet of surface soil

Surface soil at C = 0 PSF (no recompaction)

Waste at C = 500 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | opic ngth Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 0.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g horiz accel) for 10 ft thick improved surface soil layer




Safety Factors

| |
|---|
| 0.98 |
| 0.98 |
| 0.99 |
| 1.00 |
| 1.00 |
| 1.00 |
| 1.01 |
| 1.01 |
| 1.03 |
| 1.03 |

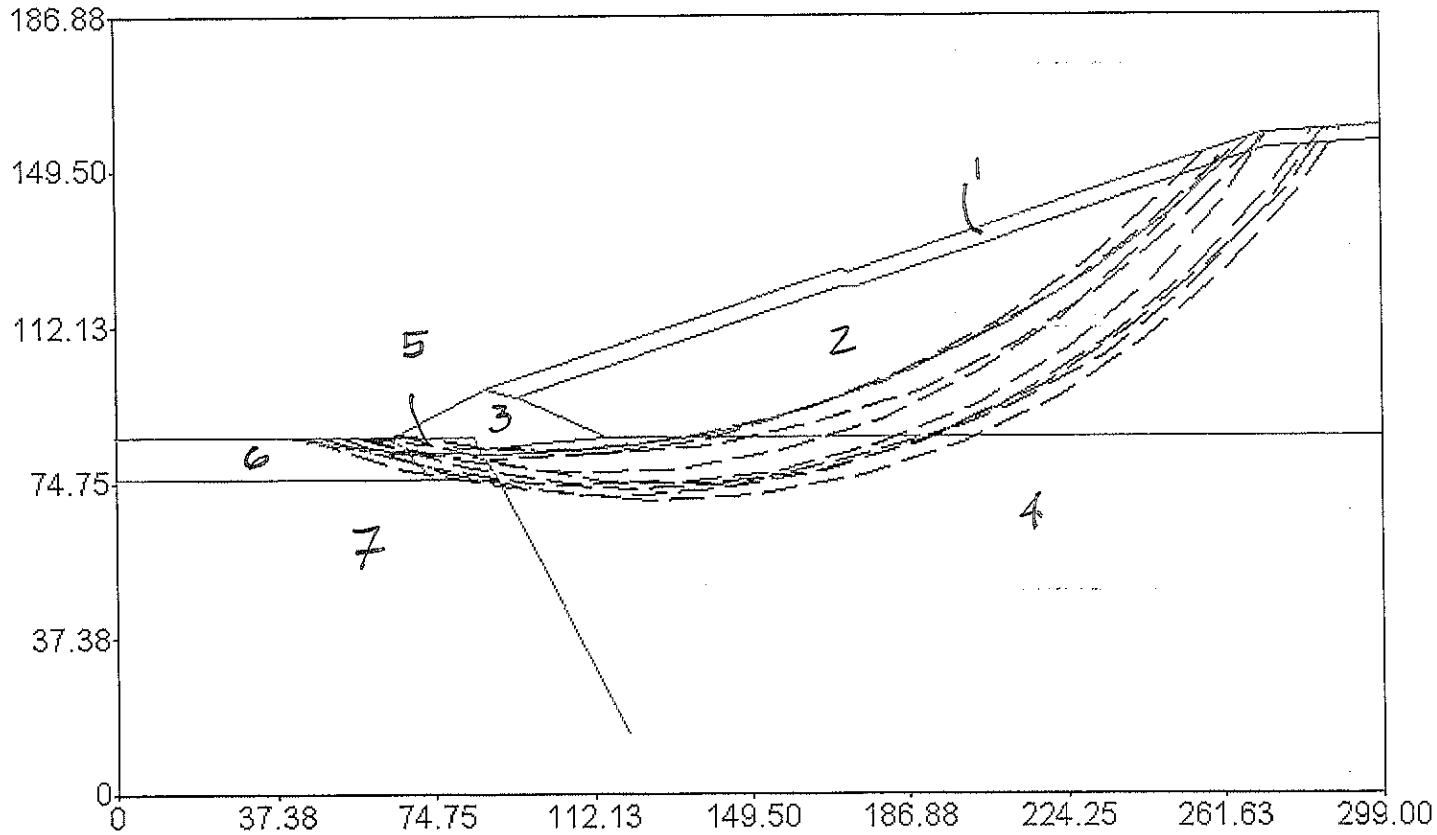
Final Cover Slope Stability for section with 10 feet of surface soil

Surface soil at C = 250 PSF (recompacted, no amendment)

Waste at C = 500 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 500.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 500.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g horiz accel) for 10 ft thick improved surface soil layer




Safety Factors

1.00
1.00
1.01
1.01
1.02
1.02
1.02
1.03
1.04
1.05

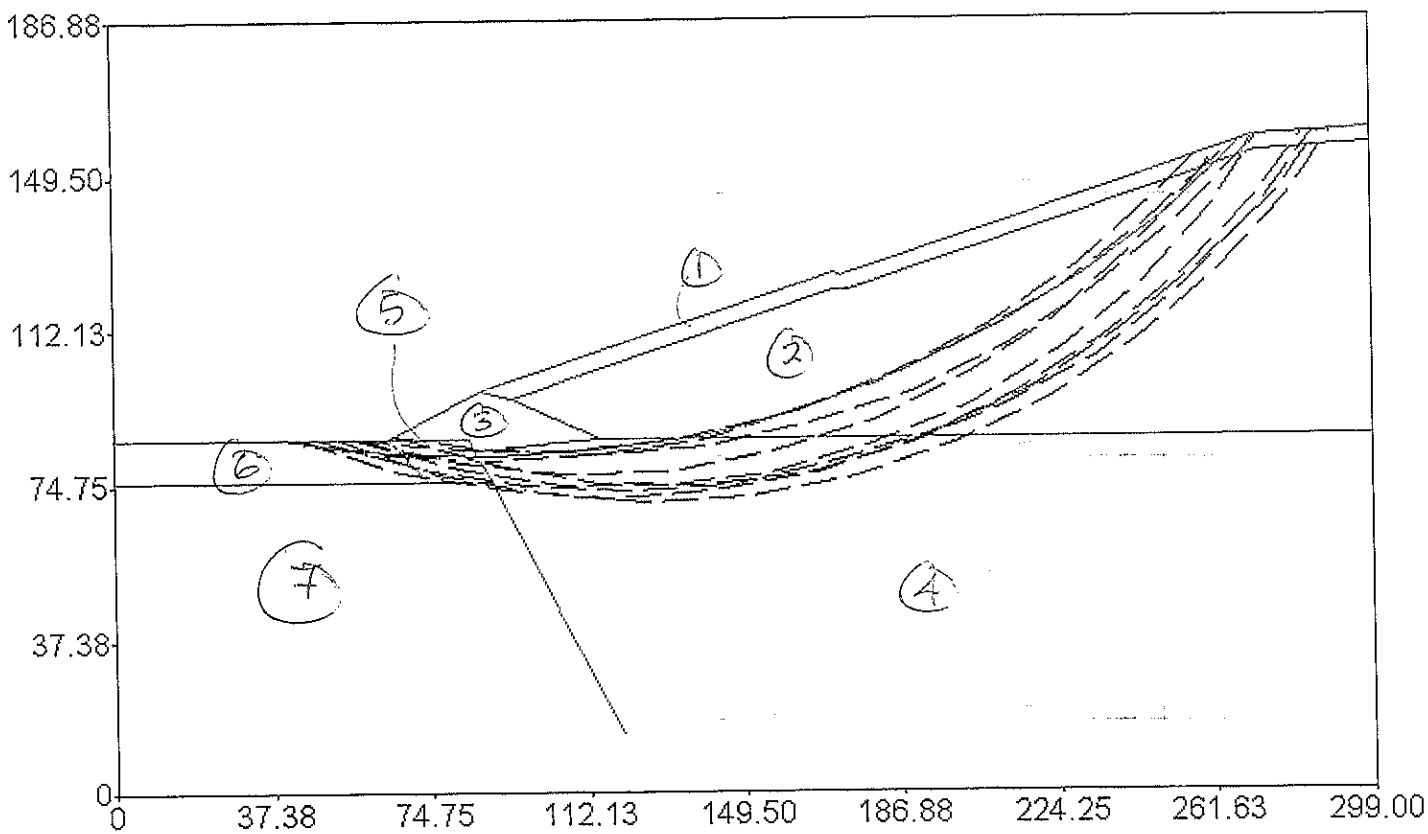
Final Cover Slope Stability for section with 10 feet of surface soil

Surface soil at C = 250 PSF (recompacted, no amendment)

Waste at C = 550 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 550.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 550.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g horiz accel) for 10 ft thick improved surface soil layer




Safety Factors

1.02
1.03
1.03
1.04
1.04
1.04
1.04
1.05
1.06
1.07

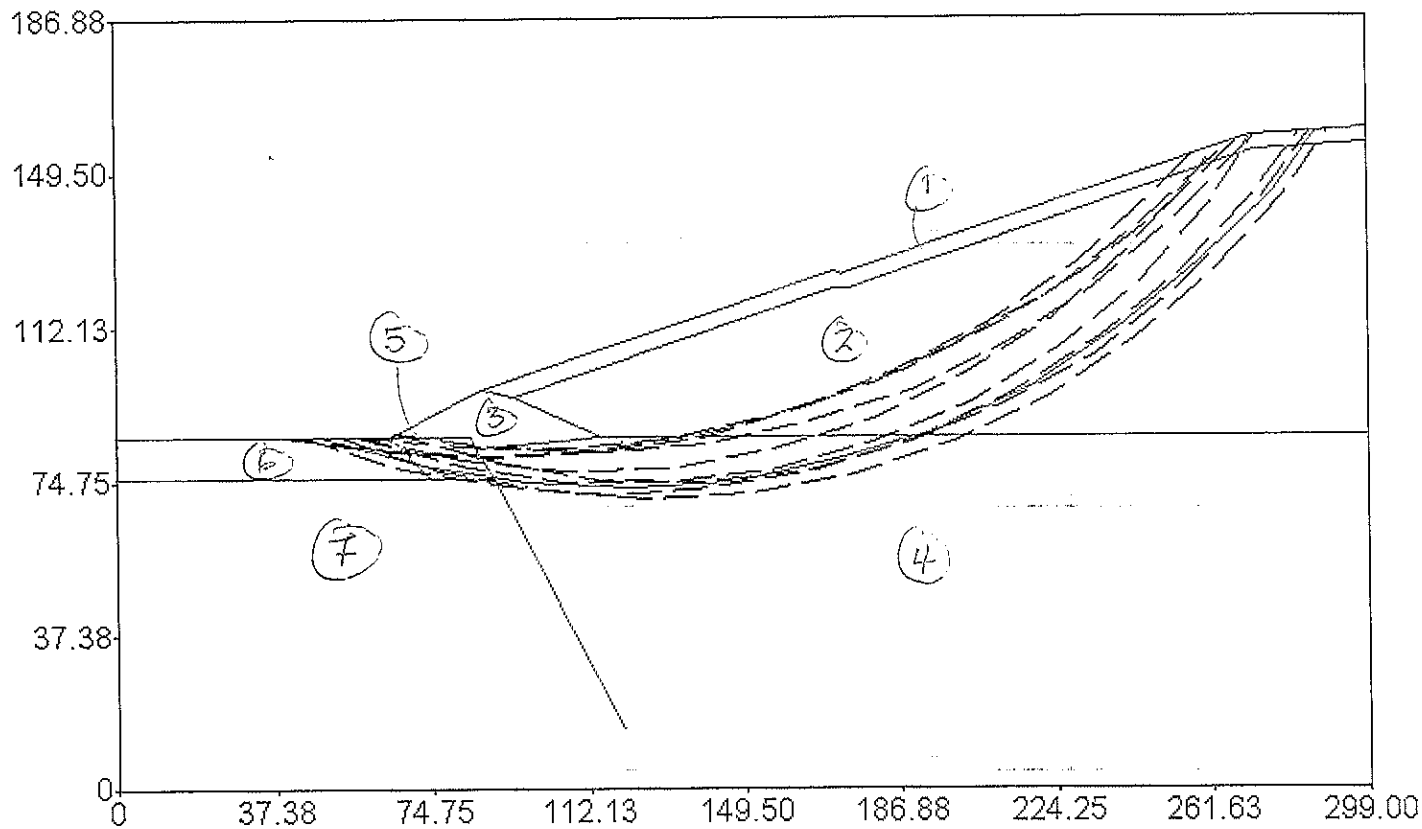
Final Cover Slope Stability for section with 10 feet of surface soil

Surface soil at C = 250 PSF (recompacted, no amendment)

Waste at C = 600 PSF

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 115.00 | 115.00 | 600.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 600.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 35.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-Static loading (0.42 g horiz accel) for 10 ft thick improved surface soil layer




Safety Factors

1.05
1.05
1.06
1.06
1.06
1.06
1.07
1.07
1.08
1.09

Final Cover Slope Stability for section with 10 feet of surface soil.

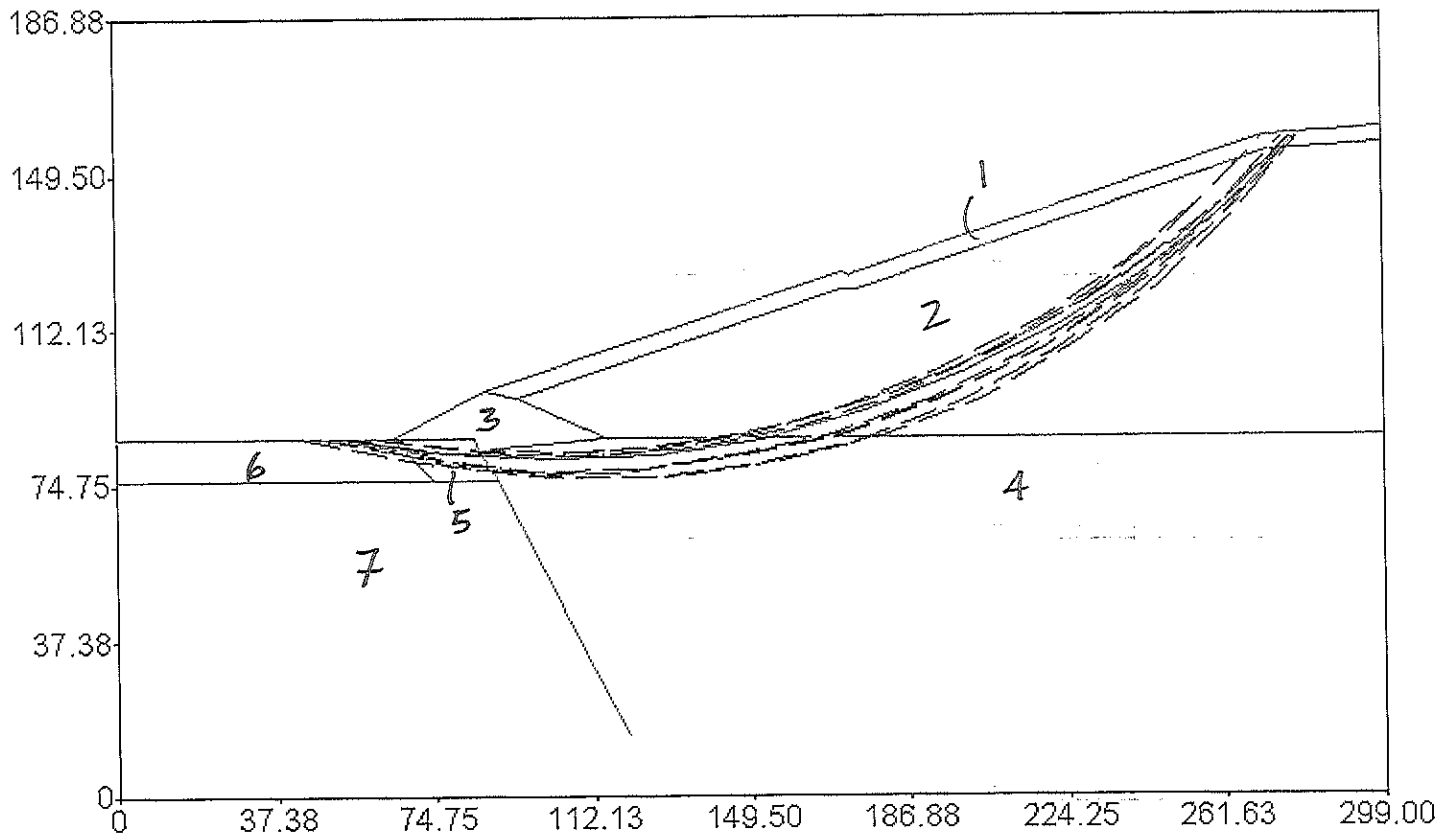
Surface soil at C = 250 (Recompacted, no additives)

Upper waste at 100 PCF weight, C = 550 PSF (cohesion)

Lower waste at 115 PCF weight, C = 550 PSF (cohesion

| | Moist Unit Weight | Saturated Unit Weight | Isotropic Strength Intercept | Isotropic Strength Angle |
|---|---|---|---|---|
| 1 | 120.00 | 120.00 | 0.00 | 35.00 |
| 2 | 100.00 | 100.00 | 550.00 | 27.00 |
| 3 | 120.00 | 120.00 | 1000.00 | 35.00 |
| 4 | 115.00 | 115.00 | 550.00 | 27.00 |
| 5 | 120.00 | 120.00 | 250.00 | 35.00 |
| 6 | 120.00 | 120.00 | 0.00 | 35.00 |
| 7 | 120.00 | 120.00 | 1440.00 | 35.00 |
| 8 | 120.00 | 120.00 | 2880.00 | 35.00 |
| 9 | 120.00 | 120.00 | 2160.00 | 27.00 |
| 10 | 120.00 | 120.00 | 4320.00 | 35.00 |

Pseudo-static loading (0.42 g horiz accel)




Safety Factors

1.04
1.04
1.05
1.05
1.05
1.06
1.06
1.06
1.06
1.06

10 FEET SURFACE SOIL

FINAL RUN

Surface soil C=250 psf
Waste $\gamma$=100 pcf
C= 550 psf

Profile.out
** PCSTABL6 **

by
Purdue University

modified by
Peter J. Bosscher
University of Wisconsin-Madison

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer's Method of Slices

PROBLEM DESCRIPTION Pseudo-static loading (0.42 g horiz acce
l)

BOUNDARY COORDINATES

8 Top Boundaries
24 Total Boundaries

| Boundary No. | X-Left (ft) | Y-Left (ft) | X-Right (ft) | Y-Right (ft) | Soil Type Below Bnd |
|---|---|---|---|---|---|
| 1 | 0.00 | 86.00 | 65.00 | 86.00 | 6 |
| 2 | 65.00 | 86.00 | 87.00 | 97.00 | 3 |
| 3 | 87.00 | 97.00 | 171.00 | 126.00 | 1 |
| 4 | 171.00 | 126.00 | 172.00 | 126.00 | 1 |
| 5 | 172.00 | 126.00 | 173.50 | 125.00 | 1 |
| 6 | 173.50 | 125.00 | 175.00 | 126.00 | 1 |
| 7 | 175.00 | 126.00 | 271.00 | 158.00 | 1 |
| 8 | 271.00 | 158.00 | 299.00 | 160.00 | 1 |
| 9 | 87.00 | 97.00 | 95.00 | 95.50 | 3 |
| 10 | 95.00 | 95.50 | 171.00 | 122.00 | 2 |
| 11 | 171.00 | 122.00 | 172.00 | 122.00 | 2 |
| 12 | 172.00 | 122.00 | 173.50 | 121.00 | 2 |
| 13 | 173.50 | 121.00 | 175.00 | 122.00 | 2 |
| 14 | 175.00 | 122.00 | 272.00 | 154.50 | 2 |
| 15 | 272.00 | 154.50 | 299.00 | 156.00 | 2 |
| 16 | 95.00 | 95.50 | 116.00 | 86.00 | 3 |
| 17 | 116.00 | 86.00 | 299.00 | 86.00 | 4 |
| 18 | 65.00 | 86.00 | 85.00 | 86.00 | 5 |
| 19 | 85.00 | 86.00 | 86.00 | 83.00 | 5 |
| 20 | 86.00 | 83.00 | 116.00 | 86.00 | 4 |
| 21 | 86.00 | 83.00 | 90.00 | 76.00 | 5 |
| 22 | 90.00 | 76.00 | 120.00 | 14.00 | 7 |
| 23 | 65.00 | 86.00 | 75.00 | 76.00 | 7 |
| 24 | 0.00 | 76.00 | 90.00 | 76.00 | 7 |

ISOTROPIC SOIL PARAMETERS

10 Type(s) of Soil

| Soil Type No. | Total Unit Wt. (pcf) | Saturated Unit Wt. (pcf) | Cohesion Intercept (psf) | Friction Angle (deg) | Pore Pressure Param. | Pressure Constant (psf) | Piez. Surface No. |
|---|---|---|---|---|---|---|---|
| 1 | 120.0 | 120.0 | 0.0 | 35.0 | 0.00 | 0.0 | 0 |
| 2 | 100.0 | 100.0 | 550.0 | 27.0 | 0.00 | 0.0 | 0 |
| 3 | 120.0 | 120.0 | 1000.0 | 35.0 | 0.00 | 0.0 | 0 |
| 4 | 115.0 | 115.0 | 550.0 | 27.0 | 0.00 | 0.0 | 0 |
| 5 | 120.0 | 120.0 | 250.0 | 35.0 | 0.00 | 0.0 | 0 |
| 6 | 120.0 | 120.0 | 0.0 | 35.0 | 0.00 | 0.0 | 0 |
| 7 | 120.0 | 120.0 | 1440.0 | 35.0 | 0.00 | 0.0 | 0 |
| 8 | 120.0 | 120.0 | 2880.0 | 35.0 | 0.00 | 0.0 | 0 |
| 9 | 120.0 | 120.0 | 2160.0 | 35.0 | 0.00 | 0.0 | 0 |
| 10 | 120.0 | 120.0 | 4320.0 | 35.0 | 0.00 | 0.0 | 0 |

A Horizontal Earthquake Loading Coefficient
Of0.420 Has Been Assigned

A Vertical Earthquake Loading Coefficient
Of0.000 Has Been Assigned

Cavitation Pressure = 0.0 psf

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

100 Trial Surfaces Have Been Generated.

10 Surfaces Initiate From Each Of 10 Points Equally Spaced
Along The Ground Surface Between X = 40.00 ft.
and X = 80.00 ft.

Each Surface Terminates Between X = 200.00 ft.
and X = 280.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y = 74.00 ft.

25.00 ft. Line Segments Define Each Trial Failure Surface.

Following Are Displayed The Ten Most Critical Of The Trial
Failure Surfaces Examined. They Are Ordered - Most Critical
First.

* * Safety Factors Are Calculated By The Modified Bishop Method * *

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 53.33 | 86.00 |
| 2 | 77.99 | 81.88 |
| 3 | 102.95 | 80.40 |
| 4 | 127.92 | 81.59 |
| 5 | 152.62 | 85.43 |
| 6 | 176.78 | 91.88 |
| 7 | 200.11 | 100.86 |
| 8 | 222.35 | 112.27 |
| 9 | 243.26 | 125.98 |
| 10 | 262.58 | 141.84 |
| 11 | 279.03 | 158.57 |

Circle Center At X = 104.3 ; Y = 315.0 and Radius, 234.6

*** 1.044 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 53.33 | 86.00 |
| 2 | 78.11 | 82.69 |
| 3 | 103.10 | 81.88 |
| 4 | 128.04 | 83.58 |
| 5 | 152.69 | 87.76 |
| 6 | 176.80 | 94.39 |
| 7 | 200.12 | 103.40 |
| 8 | 222.42 | 114.69 |
| 9 | 243.48 | 128.17 |
| 10 | 263.08 | 143.68 |
| 11 | 278.41 | 158.53 |

Circle Center At X = 98.7 ; Y = 331.3 and Radius, 249.4

*** 1.045 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 62.22 | 86.00 |
| 2 | 87.05 | 83.07 |

| | | |
|---|---|---|
| 3 | 112.05 | 82.73 |
| 4 | 136.95 | 85.00 |
| 5 | 161.47 | 89.84 |
| 6 | 185.36 | 97.20 |
| 7 | 208.36 | 107.00 |
| 8 | 230.22 | 119.14 |
| 9 | 250.69 | 133.49 |
| 10 | 269.56 | 149.88 |
| 11 | 277.58 | 158.47 |

Circle Center At X = 102.8 ; Y = 322.8 and Radius, 240.3

*** 1.049 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 48.89 | 86.00 |
| 2 | 73.32 | 80.67 |
| 3 | 98.18 | 78.12 |
| 4 | 123.18 | 78.37 |
| 5 | 148.00 | 81.43 |
| 6 | 172.31 | 87.25 |
| 7 | 195.82 | 95.76 |
| 8 | 218.22 | 106.86 |
| 9 | 239.24 | 120.39 |
| 10 | 258.60 | 136.20 |
| 11 | 276.07 | 154.09 |
| 12 | 279.59 | 158.61 |

Circle Center At X = 108.4 ; Y = 300.4 and Radius, 222.5

*** 1.051 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 48.89 | 86.00 |
| 2 | 73.33 | 80.73 |
| 3 | 98.20 | 78.24 |
| 4 | 123.20 | 78.57 |
| 5 | 148.00 | 81.70 |
| 6 | 172.30 | 87.61 |
| 7 | 195.77 | 96.21 |
| 8 | 218.13 | 107.39 |
| 9 | 239.08 | 121.03 |
| 10 | 258.37 | 136.93 |
| 11 | 275.75 | 154.90 |
| 12 | 278.56 | 158.54 |

Circle Center At X = 107.8 ; Y = 299.9 and Radius, 221.9

*** 1.053 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 48.89 | 86.00 |
| 2 | 73.59 | 82.15 |
| 3 | 98.56 | 80.95 |
| 4 | 123.52 | 82.39 |
| 5 | 148.19 | 86.47 |
| 6 | 172.28 | 93.14 |
| 7 | 195.53 | 102.33 |
| 8 | 217.68 | 113.93 |
| 9 | 238.47 | 127.81 |
| 10 | 257.68 | 143.81 |
| 11 | 271.47 | 158.03 |

Circle Center At X = 97.4 ; Y = 316.6 and Radius, 235.6

*** 1.059 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 62.22 | 86.00 |
| 2 | 86.94 | 82.23 |
| 3 | 111.92 | 81.38 |
| 4 | 136.84 | 83.45 |
| 5 | 161.34 | 88.41 |
| 6 | 185.09 | 96.20 |
| 7 | 207.77 | 106.72 |
| 8 | 229.07 | 119.81 |
| 9 | 248.70 | 135.30 |
| 10 | 266.38 | 152.98 |
| 11 | 270.11 | 157.70 |

Circle Center At X = 106.7 ; Y = 295.0 and Radius, 213.7

*** 1.060 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 44.44 | 86.00 |

| | | |
|---|---|---|
| 2 | 68.82 | 80.42 |
| 3 | 93.66 | 77.65 |
| 4 | 118.66 | 77.71 |
| 5 | 143.49 | 80.60 |
| 6 | 167.83 | 86.30 |
| 7 | 191.37 | 94.72 |
| 8 | 213.81 | 105.75 |
| 9 | 234.84 | 119.26 |
| 10 | 254.21 | 135.07 |
| 11 | 271.66 | 152.97 |
| 12 | 275.82 | 158.34 |

Circle Center At X = 105.6 ; Y = 297.3 and Radius, 220.0

*** 1.061 ***

Failure Surface Specified By 11 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 57.78 | 86.00 |
| 2 | 82.00 | 79.80 |
| 3 | 106.80 | 76.68 |
| 4 | 131.80 | 76.72 |
| 5 | 156.60 | 79.89 |
| 6 | 180.80 | 86.16 |
| 7 | 204.02 | 95.42 |
| 8 | 225.89 | 107.53 |
| 9 | 246.07 | 122.30 |
| 10 | 264.23 | 139.48 |
| 11 | 279.95 | 158.64 |

Circle Center At X = 119.0 ; Y = 274.7 and Radius, 198.4

*** 1.061 ***

Failure Surface Specified By 12 Coordinate Points

| Point No. | X-Surf (ft) | Y-Surf (ft) |
|---|---|---|
| 1 | 53.33 | 86.00 |
| 2 | 77.55 | 79.77 |
| 3 | 102.34 | 76.59 |
| 4 | 127.34 | 76.49 |
| 5 | 152.16 | 79.50 |
| 6 | 176.42 | 85.54 |
| 7 | 199.74 | 94.55 |
| 8 | 221.77 | 106.37 |
| 9 | 242.17 | 120.82 |
| 10 | 260.62 | 137.69 |
| 11 | 276.84 | 156.71 |
| 12 | 278.03 | 158.50 |

Circle Center At X = 115.6 ; Y = 277.8 and Radius, 201.7

*** 1.064 ***

```
          Y            A     X     I     S            F     T

          0.00      37.38     74.75    112.13    149.50    186.88

X       0.00 +---------+---------*--*------+---------+---------+
             -
             -
             -
             -
             -
       37.38 +                      .
             -                      8
             -                      4
             -                      1
             -                    ..*
             -                    .8..
A      74.75 +                   *04 .
             -                    91  .
             -                   *.**  *
             -                   .8....*
             -                   046. ..
             -                   .91..
X     112.13 +                   ..3.
             -   *               .8.*....
             -                   046.. . .
             -                   .91...
             -                    .73.   .
             -                   ..8.......
I     149.50 +                   .046......
             -                    9.1....
             -                     ..3..  ...
             -                    ..8.... ... **
             -                    . 4.1.....***
             -                     .9......
S     186.88 +                      . .3.......
             -                       .846......
             -                      ..0.12......
             -                        .9..3.... ...
             -                         ..8 .......
             -                         . .46.......
      224.25 +                         ..0912 ......
             -                             . 3.......
             -                             ..4.6.....
             -                             ..0.1... ..
             -                                9  3.. .
             -                                 ..856...
F     261.63 +                                 . 491....
             -                                      .377
             -                                       .**
             -                                         1
             -
             -
T     299.00 +                      *                  **
```

ENCLOSURE C

TO

ATTACHMENT 1

# WASTE CONTAINMENT SYSTEMS, WASTE STABILIZATION, AND LANDFILLS: DESIGN AND EVALUATION

HARI D. SHARMA, PH.D., P.E.
Chief Engineer and Director
EMCON Associates
San Jose, California

SANGEETA P. LEWIS, P.E.
Project Manager
$CH_2M$ Hill
Oakland, California

A Wiley-Interscience Publication
JOHN WILEY & SONS, INC.
New York / Chichester / Toronto / Brisbane / Singapore

1 kPa = 0.145 psi



TABLE 2.24 Strength Variation of Fly Ash and Mixtures of Fly Ash with Time

| Material | $q_u$ (kPa) 7 days | $q_u$ (kPa) 28 days |
|---|---|---|
| Michigan | $0.170 \times 10^3$ | $0.210 \times 10^3$ |
| New Jersey | $0.310 \times 10^3$ | $0.425 \times 10^3$ |
| UK | $0.550 \times 10^3$ | $0.660 \times 10^3$ |
| West Virginia | | |
| Ash A with 3% lime | $19.6 \times 10^3$ | $31.6 \times 10^3$ |
| Ash A with 3% cement | $7.4 \times 10^3$ | $12.8 \times 10^3$ |
| Ash B with 3% lime | $2.8 \times 10^3$ | $4.0 \times 10^3$ |
| Ash B with 3% cement | $3.2 \times 10^3$ | $8.0 \times 10^3$ |
| Lignite fly ash (fly ash 10%, sand 90%) | $2.6 \times 10^3$ | $4.6 \times 10^3$ |
| Lime:fly ash:FDG sludge | | |
| 6.3:43.7:50.0 | $3.3 \times 10^3$ | $5.5 \times 10^3$ |
| 2.5:55.8:41.7 | $3.0 \times 10^3$ | $4.0 \times 10^3$ |
| 0:41.2:58.8 | $0.3 \times 10^3$ | $0.4 \times 10^3$ |
| Fly ash:lime:cement:dredge waste | | |
| 4:0:0:96 | | 8 |
| 0:4:0:96 | | 10.5 |
| 0:0:4:96 | | 38 = 5.5 psi = 794 psf |
| 10:0:0:90 | | 10 |
| 0:10:0:90 | | 19 |
| 0:0:10:90 | | 78 = 11.3 psi = 1630 psf |

*Source:* Weis and Khera (1990). Reproduced by permission of Butterworth-Heinemann.

Oweis and Khera (1990) reviewed the results of strength tests performed by various investigators on mineral wastes. Evaluations indicated that addition of a small amount of lime or cement to fly ash may result in a strength increase. Table 2.23 summarizes strength properties of mineral wastes, and Table 2.24 presents strength variations of fly ash and mixtures of fly ash over time.

### 2.4.8 Compressibility

Compressibility of a municipal landfill is related to the settlement behavior of the landfill. However, unlike soils, the settlement behavior of a landfill is complex and can be influenced by various factors, such as movement of smaller particles into larger voids, chemical reactions, biodegradation of organics within the landfill, dissolving of soluble substances by percolating groundwater, creep, and changes in deformation properties with time (U.S. Dept. of the Navy, 1983; Sowers, 1968; Huitric 1981 and Fassett et al. 1994). Generally, it has been observed that a new landfill may settle up to 50 percent of its thickness or depth, while a closed landfill will settle between 15 and 20 percent of its total thickness after 10 to 15 years. Since landfill settlements vary significantly depending on specific waste types and

CORRESPONDENCE

TRC Environmental Solutions Inc.

21 Technology Drive
Irvine, California 92718
Telephone 714-727-9336
Facsimile 714-727-7399

October 18, 1996

Project No. 95-284

Catherine R. Pool, P.E.
State of Nevada
Division of Environmental Protection
RCRA Facilities Branch
Bureau of Waste Management
333 West Nye Lane
Carson City, NV 89710

Transmittal
Response to Notice of Deficiency (NOD)
Dated September 13, 1996

Dear Ms. Pool:

On behalf of U.S. Ecology, Inc., we are submitting the attached responses to comments received from the Nevada Division of Environmental Protection (NDEP) on the report entitled "Cell 12 Design Report, Volumes I and II", dated March 1996; supplemental information transmitted on Minimum Technology Requirements (MTR) dated April 4, 1996; and a letter from American Ecology Corporation to NDEP transmitted on July 9, 1996, regarding base liner configuration revisions.

The responses are intended to address the issues raised by NDEP. Calculation, Design Report, and Drawing, and Final Specifications and Construction Quality Assurance Plan documents will be submitted under separate cover. To assure that the revised and supplemental documents are developed to be consistent with NDEP's requirements, it is suggested that a meeting be scheduled at the earliest possible date to discuss the comment responses and resolve outstanding issues (if any). At the conclusion of that meeting, a schedule will be agreed to for submittal the above-mentioned documents.

If you have any questions, please call Zaki Naser at 702-553-2203.

Sincerely,

Scott M. Brown
Project Director

Richard D. Ellison, Ph.D., P.E.
President

SMB/RDE/GR:lmd
Enclosures

cc: Zaki Naser, U.S. Ecology, Inc.
Zia Qureshi, American Ecology Corporation
Miro Knezevic, TRC Environmental Solutions, Inc.

## RESPONSE TO COMMENT NO. 17 REGARDING WASTE STRENGTH

WASTE "C"

The strength of hazardous waste has recently been investigated as part of a comprehensive study at the Operating Industries, Inc. (OII) Landfill Superfund Site in Monterey Park, California[1]. Waste strengths from large-scale direct shear tests were measured to be $\phi = 31^\circ$ and c = 575 to 900 psf.

Supplemental slope stability analysis to be submitted under separate cover will use the previously assumed strength of $\phi = 27^\circ$ and c = 300 psf and also a value of $\phi = 31^\circ$ and c = 100 psf. Note that both of these values are less than the values measured at OII and are considered to be conservative.

## RESPONSE TO COMMENT NO. 18 REGARDING COHESION OF NATIVE SOILS

Calculations shown in Exhibit C.3 indicate that a cohesion value of 1,000 psf must be achieved from soil reinforcement in the upper 9 to 19 feet of the existing native cohesionless soils in order to meet stability requirements. Since it is a requirement of the design to perform soil reinforcement (see Sheets 006, Note 1 and 007, Note 4), specifications will require that this cohesion value be achieved.

## RESPONSE TO COMMENT NOS. 19 THROUGH 22 AND 25 REGARDING SLOPE STABILITY OF THE FINAL CONFIGURATION

Attachment A has been prepared to show how stability criteria is established for each type of temporary and permanent slope condition. Although it is general civil engineering practice to accept small amounts of permanent seismic induced deformation even for slippage planes along the liner system, Attachment A shows that a PSF of 1.0 or greater will be assumed at such critical potential failure surfaces. As a result, NDEP's requirement that the liner not be impacted due to a 0.42g earthquake will be adhered to.

Attachment A also discusses the criteria for less important failure surfaces, which do not have potential to damage the containment (liner) system. The maximum seismically induced permanent deformation for less important potential failure surfaces will be 6 inches. This amount of deformation is well within the range generally accepted in the landfill design practice as discussed in Seed and Bonaparte, 1992.

---

(1) New Cure Inc. Seismicity, Settlement and Slope Stability Work Plan, Reports 1 through 10, Operating Industries Inc. Landfill, Monterey Park, California, August 1996.

## Steve Wampler

**From:** Bob Marchand [BMARCHAND@usecology.com]
**Sent:** Thursday, September 27, 2007 10:56 AM
**To:** Steve Wampler
**Subject:** RE: Waste weight

Those numbers are included.

---

**From:** Steve Wampler [mailto:swampler@aquaeter.com]
**Sent:** Thursday, September 27, 2007 9:56 AM
**To:** Bob Marchand
**Subject:** RE: Waste weight

Are added materials, like clean soil (interim cover) or stabilization materials, included in the waste weight number? If not, in your opinion, is the amount those additives significant?

**Steve Wampler**
**AquAeTer, Inc. - Denver**
><>><>><>><>><>><>><>
swampler@aquaeter.com

**7340 East Caley Avenue, #200**
**Centennial, CO 80111**
==========
**303-771-9150 / 303-349-1638 (cell) / 303-771-8776 (fax)**
*If you are not the intended recipient of this electronic message, please advise the sender immediately by return e-mail and delete this message.*

---

**From:** Bob Marchand [mailto:BMARCHAND@usecology.com]
**Sent:** Thursday, September 27, 2007 10:51 AM
**To:** Steve Wampler
**Subject:** RE: Waste weight

Steve:
The number is based on weights received vs. volume consumed as confirmed by survey.
Bob

---

**From:** Steve Wampler [mailto:swampler@aquaeter.com]
**Sent:** Thursday, September 27, 2007 9:03 AM
**To:** Bob Marchand
**Subject:** RE: Waste weight

Bob, can you provide a simple explanation of how this number is determined. We've used it (actually 100 PCF) in our revised calculations and should include a source for the Trench 11 number.

**Steve Wampler**
**AquAeTer, Inc. - Denver**
><>><>><>><>><>><>><>
swampler@aquaeter.com

**7340 East Caley Avenue, #200**
**Centennial, CO 80111**

==========
303-771-9150 / 303-349-1638 (cell) / 303-771-8776 (fax)
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**From:** Bob Marchand [mailto:BMARCHAND@usecology.com]
**Sent:** Monday, September 17, 2007 4:56 PM
**To:** Steve Wampler
**Subject:** RE: Waste weight

Our current estimate is 96.3 lbs/cubic foot based on historic receipts.
Bob

---

**From:** Steve Wampler [mailto:swampler@aquaeter.com]
**Sent:** Monday, September 17, 2007 3:18 PM
**To:** Bob Marchand
**Subject:** Waste weight

Bob – in the previous calculations, a pretty heavy weight was used for waste – 115 lbs/cubic foot. If the waste was all soil, it'd probably be 120-125 PCF. If all concrete, of course, much higher. But, we're thinking your average waste weight in the whole cell – all of Trench 11 – probably is lower. We note that the heaviest upper end unit weight we've seen for solid and hazardous waste is about 110 PCF at a closed hazwaste landfill in S. California. Do you have any way to estimate waste unit weight in the cell, with interim cover, etc. ?

(it could be significant in slope stability calculations as the waste weight is the driver toward stability/instability)

**Steve Wampler**
**AquAeTer, Inc. - Denver**
**><>><>><>><>><>><>**
**swampler@aquaeter.com**
---
**7340 East Caley Avenue, #200**
**Centennial, CO 80111**
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# LINER STRESSES (SIDEWALL LINER MATERIALS)

AquAeTer

*optimizing environmental resources - water; air; earth*

## CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: August 13, 2007

CALCULATION NUMBER: 5 Revision:

**CALCULATION TITLE: Liner Stability on Trench 12 Side-Slopes**

**DESCRIPTION OF CALCULATION:**

Determine liner materials stability on Trench 12 0.5:1.0 slopes. This calculation supplements a previous (1996) design calculation to incorporate the properties of liner materials that are available in 2007

**REFERENCES USED:** Number of Reference Pages Attached:

Previous calc: 1996 calculation by TRW titled "Liner Stresses"

Previous calc: 1997 calculation by HWA environmental titled "Side Slope Friction Forces"

Liner member manufacturer specifications

Koerner, "Designing with Geosynthetics" 1998.

**REVIEW COMMENTS:**

CALCULATION MADE BY: APM DATE: August 13, 2007

CALCULATION CHECKED BY: CAB DATE: August 13, 2007

CALCULATION REVISED BY: DATE:

CALCULATION REVIEWED BY: SLW DATE: 8/27/2007

# CALCULATION
# LINER STABILITY – TRENCH 12 SIDE SLOPES

## Purpose of Calculation

Determine liner materials stability on Trench 12 0.5:1.0 slopes. Stability in this calculation refers to liner material strength and capacity to remain intact and functional under the loads that will be imposed by liner material weight (self weight of liner members and loading from overlying liner members) and resisted by liner strength and friction.

## Method

This calculation supplements two previous liner design calculations including TRC Environmental Solutions March 1996 and HMW Environmental in January 1997. This calculation incorporates the properties of liner materials that are available in 2007. The previous calculations were part of the 1996 Trench 12 design that received conditional approval from NDEP. As such, this supplemental calculation is done in the same manner as the 'approved' 1996 calculations (and January 1997 supplement) and is changed only where 2007 liner materials and properties differ from those considered in the 1996 design.

This calculation first compares the liner material specified in the 1996 design to materials currently available regarding liner weight and strength properties. The calculation secondly looks at the tension/elongation of the design slope liner system to predict if rupture or damage to the liner system could be caused by gravity, thermal expansion/contraction, wind uplift, seismic deformation, or waste settlement.

## Comparison of Liner Material Properties

The following tabulations compare the properties of liner system materials considered in the 1996 Trench 12 design and the properties of materials considered in the 2007 design.

**Table 1: Liner Properties Considered in 1996 Design**

| Liner Material (reference for product data) | Unit Weight (lbs/ft^2) | Self Weight* (lbs/ft) | Accumulated Weight (lbs/ft) |
|---|---|---|---|
| Non-woven Geotextile (Trevira Spunbond 1125) | 0.052 | 4.5 | 4.5 |
| Geonet (Poly-Net PN-3000) | 0.180 | 15.1 | 19.6 |
| 100-mil HDPE (Textured Hyperflex) smooth upper/textured lower | 0.54 | 45 | 65 |
| Geocomposite (Texnet TN 3002/1125) | 0.26 | 22 | 87 |
| 80-mil HDPE (Textured Hyperflex) textured upper/textured lower | 0.44 | 37 | 124 |
| GCL (Claymax 600 SP) | 1.22 | 85.7 | 210 |

Note:
* Self Weight = Unit Weight*Slope Length (Slope Length = 84 feet)

**Table 2: Liner Properties Considered in 2007 Design**

| Liner Material (reference for product data) | Unit Weight (lbs/ft^2) | Self Weight (lbs/ft) | Accumulated Weight (lbs/ft) |
|---|---|---|---|
| **Non-woven Geotextile (GSE NW10; GEO 1008002)** | 0.069 | 5.8 | 5.8 |
| **Geonet (GSE HyperNet XL4000N004)** | 0.17 | 14 | 20 |
| **80-mil HDPE (GSE HST 080G000 - textured on one side)** | 0.37 | 31 | 51 |
| **Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile)** | 0.25 | 21 | 72 |
| **60-mil HDPE (GSE HD 060G000 –textured both sides)** | 0.28 | 24 | 96 |
| **GCL (CETCO Bentomat DN)** | 1.22 | 103 | 198 |

The 2007 design geonet weight was obtained from a phone conversation with the manufacturer's technical representative. Geonets are not commonly measured for unit weight.

**Table2: Material Strengths**

| Material (reference for product data) | Yield Strength (lb/in) 1996 Design | Yield Strength (lb/in) 2007 Design |
|---|---|---|
| Geotextile | 150 | 140[1] |
| Geonet | 50 | 45 |
| 100-mil HDPE/80-mil HDPE | 240 | 168 |
| Geocomposite | Not Reported | 78[1] |
| 80-mil HDPE/60-mil HDPE | 192 | 126 |
| GCL | 37.5 | 50 |

1 Yield strength obtained in phone conversation with manufacturer's representative

This calculation analyzes strength for liner materials proposed for use in Trench 12 at US Ecology's Beatty, Nevada facility. Stresses and strains on liner materials are estimated from the self weight of the liners, thermal expansion, seismic deformation, and settlement of the waste fill. The total induced stress from these factors is compared to estimated allowable stresses on the liner materials from estimated factors of safety that are assumed to be conservative.

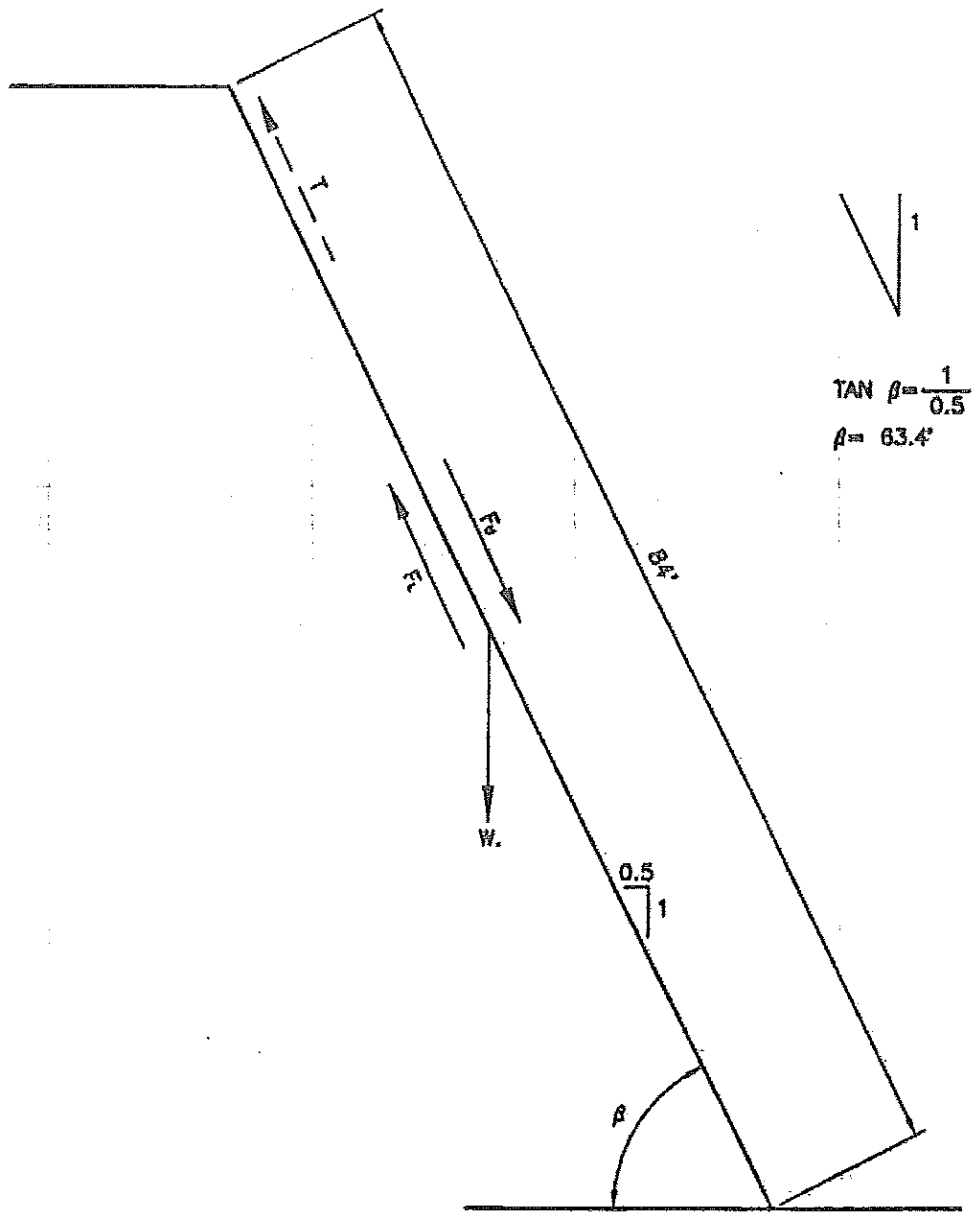
The liner materials will be placed on a 0.5:1 slope (an angle of 63.4° below horizontal). The trench will be 75 feet deep resulting in a slope length of 84 feet.

**Self Weight Forces on Liner Members and Tensile Loads**

Assuming stable slopes, the load due to gravity (tensile load) on the liners is due to self weight (shown in the tables above). The weight on the liner members accumulates for underlying liner members.

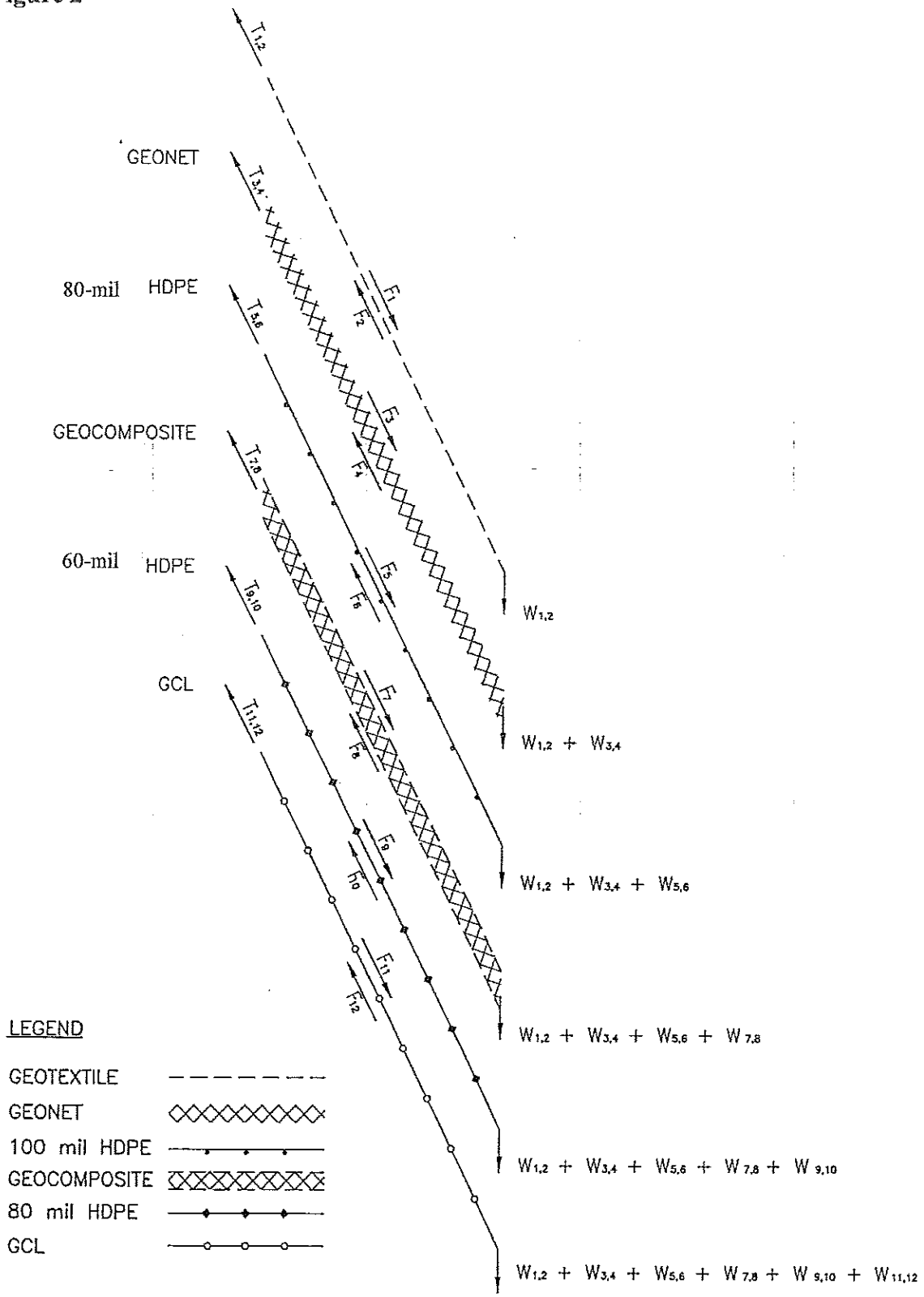
Self Weight = unit weight * slope length

**Figure 1**




FREE BODY DIAGRAM

**Figure 2**




EXPLODED VIEW OF THE SIDE SLOPE LINER SYSTEM

Self weight is the length of liner member (slope length = 84 feet) times the unit weight of the liner material, which is expressed in lbs per square feet. The unit weight of each liner material was obtained from specification sheets from liner member manufacturers. Tables 1 and 2 give the unit weight from the manufacturer, the self weight determined from the slope length of 84 feet for the 1996 design and 2007 design liner materials, and the accumulated weight accumulated for underlying liner members.

Friction forces acting on the upper side ($F_U$) of the liner and the forces acting on the lower side ($F_L$) of the liner were calculated using free body diagram analysis specific to runout calculations as shown in the 1996 TRW calculation and revisions provided in the 1997 HWA revision. $F_U$ equals the friction force acting on the upper side of the liner member. This friction ($F_U$) is part of the total force that is tending to cause liner member failure. $F_L$ is the component of the resultant force that resists failure as shown in Figure 1. $F_L$ was derived in the HMA Environmental January 1997 detailed explanation of friction force $F_L$.

$F_L = AW * \cos(B) * \tan(d)$
$F_U = F_L$ of liner component above

Where:
AW = accumulated weight of liner members
d = friction angle between liner components
B = slope angle (i.e. 63.4° below horizontal)

Accumulated weight (AW) is tabulated in Table 2. Slope angle (B) is the angle of the slope (63.4°). Friction angle (d) is the residual friction angle which is dependent on the liner materials that are in contact with each other. A graphical representation of the liner members with frictional forces is attached as Figure 2. The tensile load due to self weight (T) is calculated using the HMA Environmental January 1997 detailed explanation of friction forces.

$T = ((SW * \sin(B)) + F_U - F_L)/(12\text{inch}/1\text{foot})$

Where:
SW = self weight of liner members

The friction forces and tensile load for each liner member are calculated in Table 4. The residual friction angles were obtained from phone conversations with liner material technical representatives and the 1997 calculation done by HMA Environmental.

**Table 4: Tensile Load due to Self Weight**

| Liner Material (reference for product data) | d, Residual Friction Angle | $F_U$ (lb/ft) | $F_L$ (lb/ft) | T, Tensile Load Self Weight (lbs/in) |
|---|---|---|---|---|
| Non-woven Geotextile (GSE NW10; GEO 1008002) | 19 | 0 | 0.89 | 0.36 |
| Geonet (GSE HyperNet XL4000N004) | 8* | 0.89 | 1.26 | 1.03 |
| 80-mil HDPE (GSE HST 080G000 - textured on one side) | 21 | 1.26 | 8.79 | 1.69 |
| Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile) | 21 | 8.79 | 12.4 | 1.26 |
| 60-mil HDPE (GSE HD 060G000 –textured both sides) | 19 | 12.4 | 14.6 | 1.56 |
| GCL (CETCO Bentomat DN) | 36 | 14.6 | 64.2 | 3.49 |

* = Estimated from 1996 call to technical representative, no current reference.

The tensile load is given in lbs/in because the yield strength of the different liner members is expressed in lbs/in.

**Summary of Liner Member Strengths and Strains**

The following table summarizes the tensile strength at yield and percent strain at yield for each liner members. The tensile strength at yield is the strain at which the liner member deforms. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. The amount of elongation at yield also is known as the strain at yield and is reported as a percent. The information below was obtained from material specification sheets provided by the manufacturers.

**Table 3: Yield Strength and Strain**

| Liner Material (reference for product data) | Tensile Strength at Yield (lbs/in) | Strain at Yield (%) |
|---|---|---|
| Non-woven Geotextile (GSE NW10; GEO 1008002) | 140[1] | 50 |
| Geonet (GSE HyperNet XL4000N004) | 45 | 23[2] |
| 80-mil HDPE (GSE HST 080G000 - textured on one side) | 168 | 12 |
| Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile) | 78[1] | 50 |
| 60-mil HDPE (GSE HD 060G000 –textured both sides) | 126 | 12 |
| GCL (CETCO Bentomat DN) | 50 | 15 |

1 = Obtained from phone conversation with GSE Tech. representative, see phone log dated 7/19/2007.

2 = The percent strain at yield for geonets are not normally computed and not listed on data sheets. The value of 23% is taken from the textbook Designing with Geosynthetics by Robert Koerner, Chapter 4, pg. 340, Tensile Strength of Geonets. In phone conversations with technical representatives, they recommend using the yield properties of the non-woven geotextile for the geocomposite layer.

**Calculation of Strains**

Four strains are considered on the liner members including strain due to 1) self weight, 2) thermal expansion, 3) seismic deformation, 4) settlement of waste fill. The calculation of each strain is described below.

Strain due to self weight is calculated by comparing the percent strain at yield of each member to the tensile load due to self weight. For example:

(Tensile load due to self weight (lbs./in))/(Tensile strength at yield (lbs./in)) = (Strain due to self weight(%))/(Strain at yield (%)) where strain due to self weight is the unknown.

Rearranging the equation:
Strain due to self weight (%) = Tensile load due to self weight (lbs./in)/Tensile strength at yield (lbs./in)*Strain at yield (%).

Example using the 60-mil HDPE where

Tensile load due to self weight = 1.51 lbs./in
Tensile strength at yield = 126 lbs./in
Strain at yield = 12%

Therefore, Strain due to self weight for the 60-mil HDPE = $\frac{1.51 lbs./in}{126 lbs./in} * 12\% = 0.14\%$

Strain due to thermal expansion is considered only for HDPE Geomembranes and Geonets. From a conversation with a liner technical representative, the coefficient of linear thermal expansion is 0.00012 cm/cm*degC. A temperature variation of 40 degC was assumed in the 1997 HMA calculation, and is assumed here. Therefore; the strain due to thermal expansion is 0.00012 cm/cm*degC * 40 degC, or 0.5%.

Seismic deformation during waste placement is expected to be small. The 1997 HMA calculation references a document by US Ecology stating the strain from seismic deformation is around 0.2%. This strain will only act on the first two liner members because the liner system is designed to allow slippage between the second and third liner members (Geonet and 60-mil HDPE) and seismic strain is not expected to be transferred below that interface.

Strain from waste fill settlement also was considered. A US Ecology document was referenced, but not included in the 1997 HMA calculation estimating strain from waste fill settlement at less than 4%. Strain due to waste settlement will again only act on the first two liner members because of the design slippage between the second and third liner members.

Table 4 summarizes the strains on each liner member due to self weight, thermal expansion, seismic deformation, and settlement then totals the strains for each liner member.

**Total Tensile Load**

The total tensile load for each liner member is calculated by comparing the total strain calculated for the Trench 12 design to the strain at yield. For example:

(Tensile strength at yield (lbs./in))/(Total tensile strength at load (lbs./in)) = (Strain at yield(%))/(Strain at Load (%)) where total tensile strength at load is the unknown.

Rearranging the equation:
Total tensile strength at load (lbs./in) = Tensile strength at yield (lbs./in)/Strain at yield (5)*Strain at load (%).

Example using the 60-mil HDPE where:

Tensile strength at yield = 126 lbs./in
Strain at yield = 12%
Strain at load = 0.64%

Therefore, total tensile strength at load for the 60-mil HDPE = $\frac{126 lbs/in}{12\%} * 0.64\% = 6.7 lbs/in$

**Table 4: Stains and Total Tensile Loads on each Liner Member.**

| Liner Material (reference for product data) | T, Tensile Load Self Weight (lbs/in) | Strain due to Self Weight (%) | Strain due to Thermal Expansion (%) | Strain due to Seismic Deformation (%) | Strain due to Waste Settlement (%) | Total Strain (%) | Total Tensile Load (lbs/in) |
|---|---|---|---|---|---|---|---|
| Non-woven Geotextile (GSE NW10; GEO 1008002) | 0.36 | 0.13 | 0.0 | 0.2 | 4.0 | 4.3 | 12.1 |
| Geonet (GSE HyperNet XL4000N004) | 1.03 | 0.53 | 0.5 | 0.2 | 4.0 | 5.2 | 10.2 |
| 80-mil HDPE (GSE HST 080G000 - textured on one side) | 1.69 | 0.12 | 0.5 | 0.0 | 0.0 | 0.62 | 8.7 |
| Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile) | 1.26 | 0.81 | 0.0 | 0.0 | 0.0 | 0.81 | 1.3 |
| 60-mil HDPE (GSE HD 060G000 –textured both sides) | 1.56 | 0.15 | 0.5 | 0.0 | 0.0 | 0.65 | 6.8 |
| GCL (CETCO Bentomat DN) | 3.49 | 1.05 | 0.0 | 0.0 | 0.0 | 1.05 | 3.5 |

To avoid failure of any of the liner members, the calculated total tensile load for each liner member in the Trench 12 design must not exceed the tensile load at yield. Reducing factors also have been utilizes and therefore total tensile load for each liner member is compared to tensile load allowed (instead of tensile load at yield). The total allowable tensile load on each liner member is calculated by the following equation:

$$T_{allow} = T_{ultimate}/\text{Reducing Factor}$$

To avoid failure of any of the components, the allowable tensile load must exceed the total induced stress load.

**Geotextile**

The equation to calculate the reducing factor recommended for geotextile placement (Koerner, 1998) is as follows:

$$T_{allow} = T_{ultimate}\left(\frac{1}{RF_{ID} * RF_{CR} * RF_{CD} * RF_{BD}}\right)$$

Where
$T_{allow}$ = allowable tensile strength
$T_{ultimate}$ = ultimate tensile strength = tensile strength at yield

Where the maximum reducing factors for geotextiles used in a separation capacity (as given in Koerner 1998) are
$RF_{ID}$ = reduction factor for installation damage = 2.5
$RF_{CR}$ = reduction factor for creep = 2.5
$RF_{CD}$ = reduction factor for chemical degradation = 1.5
$RF_{BD}$ = reduction factor for biological degradation = 1.2

Inserting these values into the equation yields
$T_{allow} = T_{ultimate}/11.25$
For geotextile, $T_{ultimate}$ = 140 pounds/inch
$T_{allow}$ = 140/11.25 = 12.4 pounds/inch

As calculated above, total tensile load – 12.1 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**Geonet**

No reducing factors were available for geonets; therefore a reducing factor of 4 was used as done in the 1996 TRW calculation.
Inserting this reducing factor into the equation yields
$T_{allow} = T_{ultimate}/4.0$
For geonet, $T_{ultimate}$ = 45 pounds/inch, therefore
$T_{allow}$ = 45/4 = 11.25 pounds/inch

As calculated above, total tensile load = 10.2 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**HDPE**

**Upper HDPE**
HDPE reducing factor values range from 10 to 100 times (Koerner, 1998). While the 1996 TRC calculation used a reducing factor of 40 in their analysis, they also indicated that the value was extremely conservative. A reducing factor of 10 is used in this analysis.

For the upper 80 mil HDPE, $T_{ultimate}$ = 168 lbs/in, therefore
$T_{allow}$ = 168/10 = 16.8lbs/in

As calculated above, total tensile load = 8.7 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**Lower HDPE**
For the lower 60 mil HDPE, $T_{ultimate}$ = 126 lbs/in, therefore
$T_{allow}$ = 126/10 = 12.6 lbs/in

As calculated above, total tensile load = 6.7 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**Geocomposite**

No recommended reducing factors were available for geonets; therefore, a reducing factor of 4 was used as done in the 1996 TRW calculation.
Inserting this reducing factor into the equation yields
$T_{allow} = T_{ultimate}$ /4.0
For geonet, $T_{ultimate}$ = 78 pounds/inch, therefore
$T_{allow}$ = 78/4 = 19.5 pounds/inch

As calculated above, total tensile load = 1.3 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**GCL**

No recommended reducing factors were available for GCLs; therefore, a reducing factor of 10 was used as done in the 1996 TRW calculation.
Inserting this safety factor into the equation yields
$T_{allow} = T_{ultimate}$ /10
For GCL, $T_{ultimate}$ = 50 pounds/inch, therefore
$T_{allow}$ = 50/10 = 5.0 pounds/inch

As calculated above, total tensile load = 3.5 lbs/in
Since $T_{allow}$ > total tensile load, the material is safe from failure.

**Table 5: Tensile Load Comparison**

| Liner Material (reference for product data) | Tensile Strength at Yield (lbs/in) | Safety Factor | Tensile Load Allowed (lbs/in) | Total Tensile Load (lbs/in) |
|---|---|---|---|---|
| Non-woven Geotextile (GSE NW10; GEO 1008002) | 140 | 11.25 | 12.4 | 12.1 |
| Geonet (GSE HyperNet XL4000N004) | 45 | 4 | 11.3 | 10.2 |
| 80-mil HDPE (GSE HST 080G000 - textured on one side) | 168 | 10 | 16.8 | 8.7 |
| Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile) | 78 | 4 | 19.5 | 1.3 |
| 60-mil HDPE (GSE HD 060G000 –textured both sides) | 126 | 10 | 12.6 | 6.8 |
| GCL (CETCO Bentomat DN) | 50 | 10 | 5.0 | 3.5 |

## CONCLUSIONS

Liner material stability on Trench 12 side slopes of 0.5:1.0 were evaluated for liner material strength and capacity to remain intact and function under the loads that will be imposed by liner material weight (self weight of liner members and loading from overlying liner members) and resisted by liner strength and friction.

The materials proposed for the 2007 design were compared to materials proposed in 1996. Geotextiles do not report yield strength therefore a straight comparisons of the materials was not made. Proposed Geonets and GCLs have similar yield strength properties. 80-mil (primary) and 60-mil (secondary) HDPE liners are proposed for the 2007 design and haves lower yield strength then the 1996 design using 100-mil (primary) and 80-mil (secondary) HDPE; however, the respective unit weights are less, resulting in lower total accumulated weight and lower yield strength requirements.

Four strains were considered on the liner members including strain due to 1) self weight, 2) thermal expansion, 3) seismic deformation, 4) settlement of waste fill. Stains on individual members were summed as a total strain of the liner system. The total strain was compared to the manufacturer's technical specification strains at yield. A reduction factor (conservative safety factor) was used with the manufacturer's data. None of the 2007 liner member's calculated strains exceed the stain at yield provided in technical specifications.

SLOPE
LINER
MEMBERS

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# Product Data Sheet

## GSE Nonwoven Geotextile

GSE Nonwoven Geotextiles is a family of polypropylene, staple fiber, nonwoven, needlepunched geotextiles. Manufactured using an advanced manufacturing and quality system, these products are the most uniform and consistent nonwoven, needlepunched geotextile currently available in the industry. GSE combines a fiber selection and approval system with in-line quality control and a state-of-the-art laboratory to ensure that every roll shipped meets customer specifications. The company has performed extensive performance testing to evaluate suitability of its nonwovens for various applications. GSE Nonwoven Geotextiles are available in a range of weights to meet your specific project needs. *These product specifications meet or exceed GRI GT12, GRI GT13 and AASHTO M288.*

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | NW4 | NW6 | NW8 | NW10 | NW12 | NW16 |
|---|---|---|---|---|---|---|---|---|
| Product Code | | | GEO 0408002 | GEO 0608002 | GEO 0808002 | GEO 1008002 | GEO 1208002 | GEO 1608002 |
| AASHTO M288 Class | | | 3 | 2 | 1 | >1 | >>1 | >>>1 |
| Mass per Unit Area, oz/yd² (g/m²) | ASTM D 5261 | 90,000 ft² | 4 (135) | 6 (200) | 8 (270) | 10 (335) | 12 (405) | 16 (540) |
| Thickness | ASTM D 5199 | 1/90,000 ft² | 45 mil | 70 mil | 80 mil | ~~100 mil~~ | 110 mil | 155 mil |
| Grab Tensile Strength, lb (N) | ASTM D 4632 | 90,000 ft² | 120 (530) | 170 (755) | 220 (975) | 260 (1,155) | 320 (1,420) | 390 (1,735) |
| Grab Elongation, % | ASTM D 4632 | 90,000 ft² | 50 | 50 | 50 | 50 | 50 | 50 |
| Puncture Strength, lb (N) | ASTM D 4833 | 90,000 ft² | 60 (265) | 90 (395) | 120 (525) | 165 (725) | 190 (835) | 240 (1,055) |
| Trapezoidal Tear Strength, lb (N) | ASTM D 4533 | 90,000 ft² | 50 (220) | 70 (310) | 95 (420) | 100 (445) | 125 (555) | 150 (665) |
| Apparent Opening Size, Sieve No. (mm) | ASTM D 4751 | 540,000 ft² | 70 (0.212) | 70 (0.212) | 80 (0.180) | 100 (0.150) | 100 (0.150) | 100 (0.150) |
| Permittivity, sec⁻¹ | ASTM D 4491 | 540,000 ft² | 1.50 | 1.50 | 1.50 | 1.20 | 0.80 | 0.70 |
| Permeability, cm/sec | ASTM D 4491 | 540,000 ft² | 0.22 | 0.30 | 0.30 | 0.30 | 0.29 | 0.27 |
| Water Flow Rate, gpm/ft² (l/min/m²) | ASTM D 4491 | 540,000 ft² | 120 (4,885) | 110 (4,480) | 110 (4,480) | 85 (3,460) | 60 (2,440) | 50 (2,035) |
| UV Resistance (% retained after 500 hours) | ASTM D 4355 | per formulation | 70 | 70 | 70 | 70 | 70 | 70 |
| Roll Length[1], ft (m) | | | 600 (182) | 600 (182) | 600 (182) | 300 (91) | 300 (91) | 300 (91) |
| Roll Width[1], ft (m) | | | 15 (4.6) | 15 (4.6) | 15 (4.6) | 15 (4.6) | 15 (4.6) | 15 (4.6) |
| Roll Area, ft² (m²) | | | 9,000 (836) | 9,000 (836) | 9,000 (836) | 4,500 (418) | 4,500 (418) | 4,500 (418) |

**NOTES:**

- The property values listed are in weaker principal direction. All values listed are Minimum Average Roll Values (MARV) except apparent opening size in mm and UV resistance. Apparent opening size (mm) is a Maximum Average Roll Value. UV is a typical value.
- [1]Roll lengths and widths have a tolerance of ±1%.

YIELD STRENGTH ≥ 140 lbs/in FROM PHONE CONVERSATION w/ MANF. REP. SEE ATTACHED PHONE LOG

$\frac{335g}{M^2} = \frac{0.052\ lbs}{ft^2}$

DS037 NW R03/15/06

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| North America | GSE Lining Technology, Inc. | Houston, Texas | 800 435 2008 | 281 443 8564 | Fax: 281 230 8650 |
| South America | GSE Lining Technology Chile S.A. | Santiago, Chile | | 56 2 595 4200 | Fax: 56 2 595 4290 |
| Asia Pacific | GSE Lining Technology Company Limited | Bangkok, Thailand | | 66 2 937 0091 | Fax: 66 2 937 0097 |
| Europe & Africa | GSE Lining Technology GmbH | Hamburg, Germany | | 49 40 767420 | Fax: 49 40 7674234 |
| Middle East | GSE Lining Technology-Egypt | The 6th of October City, Egypt | | 202 2 828 8888 | Fax: 202 2 828 8889 |

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# TELEPHONE CONVERSATION AND MEETING RECORD

(X) Telephone call

(__) Meeting at _____

Date: 7/19/2007

Time: 8:45

Persons Involved (*note who initiated the conversation*)

(__)
Name: Jimmy Youngblood
of: GSE

(__)
Name: Adam Musulin
of: **AquAeTer, Inc.**

Telephone No: (281) 230-2523

Project Number: 073113

Conversation Subject: Geotextile Grab Tensile Strength

The Product Data Sheet from GSE for a non-woven geotextile reports the grab tensile strength in lbs. For the pupose of our liner calculation we would like the strength reported in lbs/in. APM spoke to Mr. Youngblood about the possibility of getting a number in lbs/in. The test method for geotextiles is ASTM D 4632, which reports the strength as a force (lbs.) on a 4-inch piece of fabric. Mr. Youngblood stated that you do not want to just divide the force number by the 4-inches of fabric used because the grips used in the test are not 4-inches wide.

Mr. Youngblood then provided some data for a wide width tensile strength test. For the 6 oz/yd^2 geotextile the wide width tensile strength was 78 lbs/in. For the 4 oz/yd^2 geotextile the wide width tensile strength was 72 lbs/in. Mr Youngblood stated that these numbers are averages of a few tests and not true specifications and are not garunteed to be met in the specifications. This is why these numbers are not reported on the product data sheets. Safety factors are used in the calculation to compensate for the uncertainty.

10 oz/yd² = 140 lbs/in

8 oz/yd² = 100 lbs/in

12 oz/yds² = 175 lbs/in

16 oz/yds² → 260 lbs/in

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GSE STANDARD PRODUCTS

# Product Data Sheet

## GSE HyperNet, HF, HS and UF Geonet

GSE HyperNet geonets are synthetic drainage materials manufactured from a premium grade high density polyethylene (HDPE) resin. The structure of the HyperNet geonet is formed specifically to transmit fluids uniformly under a variety of field conditions. HDPE resins are inert to chemicals encountered in most of the civil and environmental applications where these materials are used. GSE geonets are formulated to be resistant to ultraviolet light for time periods necessary to complete installation. GSE HyperNet geonets are available in standard, HF, HS, and UF varieties.

The table below provides index physical, mechanical and hydraulic characteristics of GSE geonets. Contact GSE for information regarding performance of these products under site-specific load, gradient, and boundary conditions.

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM AVERAGE ROLL VALUE[b] | | | |
|---|---|---|---|---|---|---|
| | | | HyperNet | HyperNet HF | HyperNet HS | HyperNet UF |
| Product Code | | | XL4000N004 | XL5000N004 | XL7000N004 | XL8000N004 |
| Transmissivity[a], gal/min/ft ($m^2$/sec) | ASTM D 4716 | 1/540,000 $ft^2$ | 9.66 (2 x $10^{-3}$) | 14.49 (3 x $10^{-3}$) | 28.98 (6 x $10^{-3}$) | 38.64 (8 x $10^{-3}$) |
| Thickness, mil (mm) | ASTM D 5199 | 1/50,000 $ft^2$ | 200 (5) | 250 (6.3) | 275 (7) | 300 (7.6) |
| Density, g/$cm^3$ | ASTM D 1505 | 1/50,000 $ft^2$ | 0.94 | 0.94 | 0.94 | 0.94 |
| Tensile Strength (MD), lb/in (N/mm) | ASTM D 5035 | 1/50,000 $ft^2$ | 45 (7.9) | 55 (9.6) | 65 (11.5) | 75 (13.3) |
| Carbon Black Content, % | ASTM D 1603, modified | 1/50,000 $ft^2$ | 2.0 | 2.0 | 2.0 | 2.0 |
| Roll Width[c], ft (m) | | | 15 (4.6) | 15 (4.6) | 15 (4.6) | 15 (4.6) |
| Roll Length[c], ft (m) | | | 300 (91) | 250 (76) | 220 (67) | 200 (60) |
| Roll Area, $ft^2$ ($m^2$) | | | 4,500 (418) | 3,750 (348) | 3,300 (305) | 3,000 (278) |

**NOTES:**

- [a]Gradient of 0.1, normal load of 10,000 psf, water at 70° F (20° C), between steel plates for 15 minutes.
- [b]These are MARV values that are based on the cumulative results of specimens tested by GSE.
- [c]Roll widths and lengths have a tolerance of ±1%.

GEONET UNIT WEIGHT PROVIDED BY MANUFACTURER REP DURING PHONE CONVERSATION = 0.17 $\frac{lbs}{ft^2}$

DS017 HyperNet R01/13/06

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# Product Data Sheet

GSE STANDARD PRODUCTS

## GSE HD Textured (Single-Sided)

GSE HD Textured is the textured version of GSE HD. It is a high quality, high density polyethylene (HDPE) geomembrane with one or two coextruded, textured surfaces, and consisting of approximately 97.5% polyethylene, 2.5% carbon black and trace amounts of antioxidants and heat stabilizers; no other additives, fillers or extenders are used. The resin used is specially formulated, virgin polyethylene and is designed specifically for flexible geomembrane applications. GSE HD Textured has excellent resistance to UV radiation and is suitable for exposed conditions. This product allows projects with greater slopes to be designed since frictional characteristics are enhanced. *These product specifications meet or exceed GRI GM13.*

$\frac{0.94g}{cm^3} = \frac{0.0021\ lbs}{cm^3} \cdot \frac{0.193cm\ THICK}{1} = \frac{4.0\times10^{-4}\ lbs}{cm^2}$ OR $\frac{0.37\ lbs}{ft^2}$

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM VALUE | | | |
|---|---|---|---|---|---|---|
| **Product Code** | | | HST 040G000 | HST 060G000 | HST 080G000 | HST 100G000 |
| Thickness, (minimum average) mil (mm) | ASTM D 5994 | every roll | 38 (0.96) | 57 (1.45) | 76 (1.93) | 95 (2.41) |
| Lowest individual for 8 out of 10 values | | | 36 (0.91) | 54 (1.40) | 72 (1.80) | 90 (2.30) |
| Lowest individual for any of the 10 values | | | 34 (0.86) | 51 (1.30) | 68 (1.73) | 85 (2.16) |
| Density, g/cm³ | ASTM D 1505 | 200,000 lb | 0.94 | 0.94 | 0.94 | 0.94 |
| Tensile Properties (each direction)[1] | ASTM D 6693, Type IV | 20,000 lb | | | | |
| Strength at Break, lb/in-width (N/mm) | Dumbell, 2 ipm | | 60 (11) | 90 (16) | 120(21) | 150 (27) |
| Strength at Yield, lb/in-width (N/mm) | | | 84 (15) | 126 (22) | 168 (29) | 210 (37) |
| Elongation at Break, % | G.L. = 2.0 in (51 mm) | | 100 | 100 | 100 | 100 |
| Elongation at Yield, % | G.L. = 1.3 in (33 mm) | | 12 | 12 | 12 | 12 |
| Tear Resistance, lb (N) | ASTM D 1004 | 45,000 lb | 28 (125) | 42 (187) | 56 (249) | 70 (311) |
| Puncture Resistance, lb (N) | ASTM D 4833 | 45,000 lb | 60 (267) | 90 (400) | 120 (534) | 150 (667) |
| Carbon Black Content, % | ASTM D 1603 | 20,000 lb | 2.0 | 2.0 | 2.0 | 2.0 |
| Carbon Black Dispersion | ASTM D 5596 | 45,000 lb | +Note 1 | +Note 1 | +Note 1 | +Note 1 |
| Asperity Height | GRI GM 12 | second roll | +Note 2 | +Note 2 | +Note 2 | +Note 2 |
| Notched Constant Tensile Load[2], hr | ASTM D 5397, Appendix | 200,000 lb | 300 | 300 | 300 | 300 |
| **REFERENCE PROPERTY** | **TEST METHOD** | **FREQUENCY** | **NOMINAL VALUE** | | | |
| Oxidative Induction Time, min | ASTM D 3895, 200° C; $O_2$, 1 atm | 200,000 lb | >100 | >100 | >100 | >100 |
| Roll Length[3] (approximate), ft (m) | Standard Textured | | 650 (198) | 420 (128) | 320 (98) | 250 (76) |
| Roll Width[3], ft (m) | | | 22.5 (6.9) | 22.5 (6.9) | 22.5 (6.9) | 22.5 (6.9) |
| Roll Area, ft² (m²) | | | 14,625 (1,359) | 9,450 (878) | 7,200 (669) | 5,625 (523) |

**NOTES:**

- +Note 1: Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.
- +Note 2: 10 mil average. 8 of 10 readings ≥7 mils. Lowest individual ≥ 5 mils.
- GSE HD Standard Textured is available in rolls weighing about 3,000 lb (1,360 kg).
- [1]The combination of stress concentrations due to coextrusion texture geometry and the small specimen size results in large variation of test results. Therefore, these tensile properties are minimum average values.
- [2]NCTL for HD Textured is conducted on representative smooth membrane samples.
- All GSE geomembranes have dimensional stability of ±2% when tested with ASTM D 1204 and LTB of <-77° C when tested with ASTM D 746.
- [3]Roll lengths and widths have a tolerance of ± 1%.

DS006s HDtextss R03/09/06

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GSE STANDARD PRODUCTS

# Product Data Sheet

## GSE FabriNet Geocomposite (Double-Sided)

GSE FabriNet geocomposite consists of GSE HyperNet geonet heat-laminated on both sides with a GSE nonwoven needlepunched geotextile. GSE HyperNet is a 200 mil thick geonet manufactured from a premium grade high density polyethylene resin. For the purpose of lamination to geonets, GSE nonwoven needlepunched geotextiles are available in mass per unit area range of 6 oz/yd² (200 g/m²) to 16 oz/yd² (540 g/m²). GSE FabriNet geocomposites are designed and formulated to perform drainage function under a range of anticipated site loads, gradients and boundary conditions. Index properties for the product are provided in the table below. Please contact GSE for further information regarding performance under site-specific conditions.

### *Product Specifications*

YIELD STRENGTH VALUE ON ATTACHED PHANG LOG

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM AVERAGE ROLL VALUE[a] | | |
|---|---|---|---|---|---|
| **Geocomposite** | | | 6 oz/yd² | 8 oz/yd² | 10 oz/yd² |
| Product Code | | | F420600 60S | F420800 80S | F421000 100S |
| Transmissivity[b], gal/min/ft (m²/sec) | ASTM D 4716 | 1/540,000 ft² | 0.48 (1 x $10^{-4}$) | 0.48 (1 x $10^{-4}$) | 0.43 (9 x $10^{-5}$) |
| Ply Adhesion, lb/in (g/cm) | ASTM D 7005 | 1/50,000 ft² | 1.0 (178) | 1.0 (178) | 1.0 (178) |
| Roll Width[c], ft (m) | | | 14.5 (4.4) | 14.5 (4.4) | 14.5 (4.4) |
| Roll Length[c], ft (m) | | | 230 (70.1) | 200 (60.9) | 190 (58.0) |
| Roll Area, ft² (m²) | | | 3,335 (310) | 2,900 (269) | 2,755 (256) |
| **Geonet core[d]** | | | | | |
| Transmissivity,[b] gal/min/ft (m²/sec) | ASTM D 4716 | | 9.66 (2 x $10^{-3}$) | 9.66 (2 x $10^{-3}$) | 9.66 (2 x $10^{-3}$) |
| Thickness, mil (mm) | ASTM D 5199 | 1/50,000 ft² | 200 (5) | 200 (5) | 200 (5) |
| Density, g/cm³ | ASTM D 1505 | 1/50,000 ft² | 0.94 | 0.94 | 0.94 |
| Tensile Strength (MD), lb/in (N/mm) | ASTM D 5035 | 1/50,000 ft² | 45 (7.9) | 45 (7.9) | 45 (7.9) |
| Carbon Black Content, % | ASTM D 1603 | 1/50,000 ft² | 2.0 | 2.0 | 2.0 |
| **Geotextile (prior to lamination)[d,e]** | | | | | |
| Mass per Unit Area, oz/yd² (g/m²) | ASTM D 5261 | 1/90,000 ft² | 6 (200) | 8 (270) | 10 (335) |
| Grab Tensile, lb (N) | ASTM D 4632 | 1/90,000 ft² | 170 (755) | 220 (975) | 260 (1,155) |
| Puncture Strength, lb (N) | ASTM D 4833 | 1/90,000 ft² | 90 (395) | 120 (525) | 165 (725) |
| AOS, US sieve (mm) | ASTM D 4751 | 1/540,000 ft² | 70 (0.212) | 80 (0.180) | 100 (0.150) |
| Permittivity, (sec⁻¹) | ASTM D 4491 | 1/540,000 ft² | 1.5 | 1.5 | 1.2 |
| Flow Rate, gpm/ft² (lpm/m²) | ASTM D 4491 | 1/540,000 ft² | 110 (4,480) | 110 (4,480) | 85 (3,460) |
| UV Resistance, % retained | ASTM D 4355 (after 500 hours) | once per formulation | 70 | 70 | 70 |

**NOTES:**

- [a]These are MARV values that are based on the cumulative results of specimens tested and determined by GSE. AOS in mm is a maximum average roll value.
- [b]Gradient of 0.1, normal load of 10,000 psf, water at 70° F between steel plates for 15 minutes.
- [c]Roll widths and lengths have a tolerance of ±1%.
- [d]Component properties prior to lamination.
- [e]Refer to geotextile product data sheet for additional specifications.

2 LAYER OF GEOTEXTILE @ 200 g/m² OR 0.08 lbs/ft²
+ PREVIOUSLY CALCULATED GEONET UNIT WEIGHT
OF 0.17 lbs/ft² = 0.25 lbs/ft²

DS018 Fabrinet R01/13/06

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# Product Data Sheet

GSE STANDARD PRODUCTS

## GSE HD Textured

GSE HD Textured is the textured version of GSE HD. It is a high quality, high density polyethylene (HDPE) geomembrane with one or two coextruded, textured surfaces, and consisting of approximately 97.5% polyethylene, 2.5% carbon black and trace amounts of antioxidants and heat stabilizers; no other additives, fillers or extenders are used. The resin used is specially formulated, virgin polyethylene and is designed specifically for flexible geomembrane applications. GSE HD Textured has excellent resistance to UV radiation and is suitable for exposed conditions. This product allows projects with greater slopes to be designed since frictional characteristics are enhanced. *These product specifications meet or exceed GRI GM13.* $0.94\frac{g}{cm^3} = 0.0021\frac{lbs}{cm^3} \cdot \frac{0.145\,cm\ THICK}{1} = 3.0\times10^{-4}\frac{lbs}{cm^2}$ OR $0.28\frac{lbs}{ft^2}$

***Product Specifications***

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM VALUE | | | | |
|---|---|---|---|---|---|---|---|
| **Product Code** | | | HDT 030G000 | HDT 040G000 | HDT 060G000 | HDT 080G000 | HDT 100G000 |
| Thickness, (minimum average) mil (mm) | ASTM D 5994 | every roll | 29 (0.73) | 38 (0.96) | 57 (1.45) | 76 (1.93) | 95 (2.41) |
| Lowest individual for 8 out of 10 values | | | 27 (0.69) | 36 (0.91) | 54 (1.40) | 72 (1.80) | 90 (2.30) |
| Lowest individual for any of the 10 values | | | 26 (0.66) | 34 (0.86) | 51 (1.30) | 68 (1.73) | 85 (2.16) |
| Density, g/cm³ | ASTM D 1505 | 200,000 lb | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 |
| Tensile Properties (each direction)[1] | ASTM D 6693, Type IV | 20,000 lb | | | | | |
| Strength at Break, lb/in-width (N/mm) | Dumbell, 2 ipm | | 45 (8) | 60 (11) | 90 (16) | 120(21) | 150 (27) |
| Strength at Yield, lb/in-width (N/mm) | | | 63 (11) | 84 (15) | 126 (22) | 168 (29) | 210 (37) |
| Elongation at Break, % | G.L. = 2.0 in (51 mm) | | 100 | 100 | 100 | 100 | 100 |
| Elongation at Yield, % | G.L. = 1.3 in (33 mm) | | 12 | 12 | 12 | 12 | 12 |
| Tear Resistance, lb (N) | ASTM D 1004 | 45,000 lb | 21 (93) | 28 (125) | 42 (187) | 56 (249) | 70 (311) |
| Puncture Resistance, lb (N) | ASTM D 4833 | 45,000 lb | 45 (200) | 60 (267) | 90 (400) | 120 (534) | 150 (667) |
| Carbon Black Content, % | ASTM D 1603 | 20,000 lb | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Carbon Black Dispersion | ASTM D 5596 | 45,000 lb | +Note 1 | +Note 1 | +Note 1 | +Note 1 | +Note 1 |
| Asperity Height | GRI GM 12 | second roll | +Note 2 | +Note 2 | +Note 2 | +Note 2 | +Note 2 |
| Notched Constant Tensile Load[2], hr | ASTM D 5397, Appendix | 200,000 lb | 300 | 300 | 300 | 300 | 300 |
| **REFERENCE PROPERTY** | **TEST METHOD** | **FREQUENCY** | **NOMINAL VALUE** | | | | |
| Oxidative Induction Time, min | ASTM D 3895, 200° C; $O_2$, 1 atm | 200,000 lb | >100 | >100 | >100 | >100 | >100 |
| Roll Length[3] (approximate), ft (m) | Standard Textured | | 830 (253) | 700 (213) | 520 (158) | 400 (122) | 330 (101) |
| Roll Width[3], ft (m) | | | 22.5 (6.9) | 22.5 (6.9) | 22.5 (6.9) | 22.5 (6.9) | 22.5 (6.9) |
| Roll Area, ft² (m²) | | | 18,674 (1,735) | 15,750 (1,463) | 11,700 (1,087) | 9,000 (836) | 7,425 (690) |

**NOTES:**

- +Note 1: Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.
- +Note 2: 10 mil average. 8 of 10 readings ≥7 mils. Lowest individual ≥ 5 mils.
- GSE HD Standard Textured is available in rolls weighing about 4,000 lb (1,800 kg).
- [1]The combination of stress concentrations due to coextrusion texture geometry and the small specimen size results in large variation of test results. Therefore, these tensile properties are minimum average values.
- [2]NCTL for HD Textured is conducted on representative smooth membrane samples.
- All GSE geomembranes have dimensional stability of ±2% when tested with ASTM D 1204 and ITB of <-77° C when tested with ASTM D 746.
- [3]Roll lengths and widths have a tolerance of ± 1%.

DS006 HDtext R03/09/06

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CETCO® LINING TECHNOLOGIES

# Bentomat® & Claymax® Panel & Roll Specifications

UNIT WEIGHT $\frac{2650 \text{ lbs}}{2175 \text{ ft}^2} = 1.22 \text{ lb/ft}^2$

## Panel Specifications

| PRODUCTS | DIMENSIONS Width x Length | AREA | EFFECTIVE AREA |
|---|---|---|---|
| BENTOMAT® ST | 15 ft x 150 ft (4.6 m x 45.7 m) | 2,250 ft² (209 m²) | 2,145 ft² (200 m²) |
| BENTOMAT SDN | 14.5 ft x 150 ft (4.4 m x 45.7 m) | 2,175 ft² (202 m²) | 2,071 ft² (193 m²) |
| BENTOMAT DN | 14.5 ft x 150 ft (4.4 m x 45.7 m) | 2,175 ft² (202 m²) | 2,071 ft² (193 m²) |
| BENTOMAT YSDN | 14.5 ft x 200 ft (4.4 m x 60.9 m) | 2,900 ft² (270 m²) | 2,771 ft² (258 m²) |
| BENTOMAT CL Lovell, WY Plant | 15 ft x 150 ft (4.6 m x 45.7 m) | 2,250 ft² (209 m²) | 2,145 ft² (200 m²) |
| BENTOMAT CL Fairmount, GA Plant | 14.5 ft x 150 ft (4.4 m x 45.7 m) | 2,175 ft² (202 m²) | 2,071 ft² (193 m²) |
| BENTOMAT CLT | 15 ft x 150 ft (4.6 m x 45.7 m) | 2,250 ft² (209 m²) | 2,145 ft² (200 m²) |
| CLAYMAX® 200R | 15 ft x 150 ft (4.6 m x 45.7 m) | 2,250 ft² (209 m²) | 2,145 ft² (200 m²) |
| CLAYMAX 600CL Lovell, WY Plant | 15 ft x 150 ft (4.6 m x 45.7 m) | 2,250 ft² (209 m²) | 2,145 ft² (200 m²) |
| CLAYMAX 600CL Fairmount, GA Plant | 14.5 ft x 150 ft (4.4 m x 45.7 m) | 2,175 ft² (202 m²) | 2,071 ft² (193 m²) |

## Roll Specifications

| PRODUCTS | DIMENSIONS Length x Diameter (Avg.) | NOMINAL WEIGHT | ROLLS / TRUCKLOAD |
|---|---|---|---|
| BENTOMAT ST | 16 ft x 24 in (4.9 m x 610 mm) | 2,600 lbs (1180 kg) | 16 rolls per truckload |
| BENTOMAT SDN | 16 ft x 24 in (4.9 m x 610 mm) | 2,650 lbs (1200 kg) | 15 rolls per truckload |
| BENTOMAT DN | 16 ft x 24 in (4.9 m x 610 mm) | 2,650 lbs (1200 kg) | 15 rolls per truckload |
| BENTOMAT YSDN | 15 ft x 24 in (4.6 m x 600 mm) | 2,500 lbs (1133 kg) | 17 rolls per truckload |
| BENTOMAT CL | 16 ft x 24 in (4.9 m x 610 mm) | 2,650 lbs (1200 kg) | 15 rolls per truckload |
| BENTOMAT CLT | 16 ft x 26 in (4.9 m x 660 mm) | 2,950 lbs (1340 kg) | 15 rolls per truckload |
| CLAYMAX 200R | 16 ft x 20 in (4.9 m x 510 mm) | 2,750 lbs (1250 kg) | 15 rolls per truckload |
| CLAYMAX 600CL | 16 ft x 20 in (4.9 m x 510 mm) | 2,825 lbs (1250 kg) | 15 rolls per truckload |

**Unloading and handling equipment for all GCL products:**

- Spreader bar and core pipe: Spreader bar 17 ft (5.2 m) long; core pipe 20 ft (6.1 m) long, nominal pipe size, XXH.
- Core Pipe for Bentomat YSDN: 16 ft (4.9 m); O.D. = 3.5 in (90 mm)
- A solid 3.5 in. (90 mm) O.D. x 14.5 ft (4.4 m) solid steel pipe stinger attachment for a forklift.
- Slings: 2 Polyester slings are required, approximately 12 ft (3.7 m) long x 2 in (50 mm) wide each.
- Vehicle needed: Front end loader or forklift (are typical).

**Standard Roll Specifications:**

- Packaging: U.V. resistant polyethylene sleeve.

CETCO® LINING TECHNOLOGIES
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CETCO LINING TECHNOLOGIES

Certified Properties

# BENTOMAT® DN CERTIFIED PROPERTIES

| MATERIAL PROPERTY | TEST METHOD | TEST FREQUENCY $ft^2(m^2)$ | REQUIRED VALUES |
|---|---|---|---|
| Bentonite Swell Index[1] | ASTM D 5890 | 1 per 50 tonnes | 24 mL/2g min. |
| Bentonite Fluid Loss[1] | ASTM D 5891 | 1 per 50 tonnes | 18 mL max. |
| Bentonite Mass/Area[2] | ASTM D 5993 | 40,000 $ft^2$ (4,000 $m^2$) | 0.75 $lb/ft^2$ (3.6 $kg/m^2$) min |
| GCL Grab Strength[3] | ASTM D 6768 | 200,000 $ft^2$ (20,000 $m^2$) | 50 lbs/in (88 N/cm) MARV |
| GCL Peel Strength[3] | ASTM D 6496 | 40,000 $ft^2$ (4,000 $m^2$) | 3.5 lbs/in (6.1 N/cm) min |
| GCL Index Flux[4] | ASTM D 5887 | Weekly | $1 \times 10^{-8}$ $m^3/m^2/sec$ max |
| GCL Hydraulic Conductivity[4] | ASTM D 5887 | Weekly | $5 \times 10^{-9}$ cm/sec max |
| GCL Hydrated Internal Shear Strength[5] | ASTM D 5321<br>ASTM D 6243 | Periodic | 500 psf (24 kPa) typ @ 200 psf |

***Bentomat DN is a reinforced GCL consisting of a layer of sodium bentonite between two nonwoven geotextiles, which are needlepunched together.***

**Notes**

[1] Bentonite property tests performed at a bentonite processing facility before shipment to CETCO's GCL production facilities.

[2] Bentonite mass/area reported at 0 percent moisture content.

[3] All tensile strength testing is performed in the machine direction using ASTM D 6768. All peel strength testing is performed using ASTM D 6496. Upon request, tensile and peel results can be reported per modified ASTM D 4632 using 4 inch grips.

[4] Index flux and permeability testing with deaired distilled/deionized water at 80 psi (551kPa) cell pressure, 77 psi (531 kPa) headwater pressure and 75 psi (517 kPa) tailwater pressure. Reported value is equivalent to 925 gal/acre/day. This flux value is equivalent to a permeability of $5 \times 10^{-9}$ cm/sec for typical GCL thickness. Actual flux values vary with field condition pressures. The last 20 weekly values prior the end of the production date of the supplied GCL may be provided.

[5] Peak values measured at 200 psf (10 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

*CETCO has developed an edge enhancement system that eliminates the need to use additional granular sodium bentonite within the overlap area of the seams. We call this edge enhancement, SuperGroove™, and it comes standard on both longitudinal edges of Bentomat® DN. It should be noted that SuperGroove™ does not appear on the end-of-roll overlaps and recommend the continued use of supplemental bentonite for all end-of-roll seams.*

CETCO® LINING TECHNOLOGIES

1500 W. Shure Drive Arlington Heights, IL 60004 USA 800.527.9948 Fax 847.577.5571
For the most up-to-date information please visit our website, www.cetco.com
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REFERENCE

KOERNER 1998

Fourth Edition

# Designing with Geosynthetics

Robert M. Koerner, Ph.D., P.E.

H. L. Bowman Professor of Civil Engineering,
Drexel University and Director, Geosynthetic
Research Institute

PRENTICE HALL
Upper Saddle River, New Jersey 07458

properties will sort out into their respective categories and uses, but most organizations are looking at the complete collection of tests as they were presented here.

Table 2.10 is a summary table of geotextile properties. The rapidly changing market and its demands make it difficult to give accurate values, but for typical commercially available geotextiles, Table 2.10 gives the range of current values. For the specific values of specific types of geotextiles, the respective manufacturers should be consulted.

## 2.4 ALLOWABLE VERSUS ULTIMATE GEOTEXTILE PROPERTIES

It is important to recognize that many of the preceding geotextile test properties represent idealized conditions and therefore result in the maximum possible numeric values when used directly in design; that is, they result in upper-bound values. In the design-by-function concept described in Section 2.1.3, the factor of safety was formulated around an allowable test value (Eqs. 2.2a and 2.2b). Thus, most laboratory test values cannot generally be used directly; they must be suitably modified for the in situ conditions. This could be done directly in the test procedure, for example, by conducting a completely simulated performance test; but in most cases this simply is not possible. Simulating installation damage, performing long-term creep testing, using site-specific liquids, reproducing in situ pore-water stresses, providing complete stress state modeling, and so on, are generally not feasible. To account for such differences between the laboratory measured test value and the desired performance value, two approaches can be taken:

1. Use an extremely high factor of safety at the end of a problem.
2. Use reduction factors on the laboratory-generated test value to make it into a site-specific allowable value.

The latter alternative of *reduction factors*‡ will be used in this book. By doing this, the usual value of the factor of safety can be used in the final analysis. Our approach will be to refer to the general laboratory-obtained value as an *ultimate* value and to modify it by reduction factors to an *allowable* value.

### 2.4.1 Strength-Related Problems

For problems dealing with geotextile strength, such as in separation and reinforcement applications, the formulation of the allowable values takes the following form. Typical values for reduction factors are given in Table 2.11. Note that these values, however, must be tempered by the site-specific considerations. If the laboratory test includes the mechanism listed, it appears in the equation as a value of 1.0.

$$T_{\text{allow}} = T_{\text{ult}}\left(\frac{1}{\text{RF}_{ID} \times \text{RF}_{CR} \times \text{RF}_{CD} \times \text{RF}_{BD}}\right) \tag{2.24a}$$

$$T_{\text{allow}} = T_{\text{ult}}\left(\frac{1}{\Pi\text{RF}}\right) \tag{2.24b}$$

‡In previous editions of this book, reduction factors were called partial factors of safety. This edition is changed to reflect the current trend in agency specifications and the more appropriate terminology.

TABLE 2.10 TYPICAL RANGE OF PROPERTIES FOR CURRENTLY AVAILABLE GEOTEXTILES

| | |
|---|---|
| **Physical Properties** | |
| Specific gravity | 0.9–1.7 |
| Mass per unit area | 135–1000 g/m$^2$ |
| Thickness | 0.25–7.5 mm |
| Stiffness | nil to 25,000 mg-cm |
| **Mechanical Properties** | |
| Compressibility | nil to high |
| Tensile strength (grab) | 0.45–4.5 kN |
| Tensile strength (wide width) | 9–180 kN/m |
| Confined tensile strength | 18–180 kN/m |
| Seam strength | 50–100% of tensile |
| Cyclic fatigue strength | 50–100% of tensile |
| Burst strength | 350–5200 kPa |
| Tear strength | 90–1300 N |
| Impact strength | 14–200 J |
| Puncture strength | 45–450 N |
| Friction behavior | 60–100% of soil friction |
| Pullout behavior | 50–100% of geotextile strength |
| **Hydraulic Properties** | |
| Porosity (nonwovens) | 50–95% |
| Percent open area (wovens) | nil to 36% |
| Apparent opening size (sieve size) | 2.0 to 0.075 mm (#10 to #200) |
| Permittivity | 0.02–2.2 s$^{-1}$ |
| Permittivity under load | 0.01–3.0 s$^{-1}$ |
| Transmissivity | 0.01 to 2.0 $\times$ 10$^{-3}$ m$^2$/min |
| Soil retention: turbidity curtains | m.b.e. |
| Soil retention: silt fences | m.b.e. |
| **Endurance Properties** | |
| Installation damage | 0–70% of fabric strength |
| Creep response | g.n.p if < 40% strength is being used |
| Confined creep response | g.n.p. if < 50% strength is being used |
| Stress relaxation | g.n.p. if < 40% strength is being used |
| Abrasion | 50–100% of geotextile strength |
| Long-term clogging | m.b.e. for critical conditions |
| Gradient ratio clogging | m.b.e. for critical conditions |
| Hydraulic conductivity ratio | 0.4–0.8 appear to be acceptable |
| **Degradation Properties** | |
| Temperature degradation | high temperature accelerates degradation |
| Oxidative degradation | m.b.e. for long service lifetimes |
| Hydrolysis degradation | m.b.e. for long service lifetimes |
| Chemical degradation | g.n.p. unless aggressive chemicals |
| Ratioactive degradation | g.n.p. |
| Biological degradation | g.n.p. |
| Sunlight (UV) degradation | major problem unless protected |
| Synergistic effects | m.b.e. |
| General aging | actual record to date is excellent |

Abbreviations: m.b.e.—must be evaluated; g.n.p.—generally no problem.

TABLE 2.11 RECOMMENDED REDUCTION FACTOR VALUES FOR USE IN EQ. (2.24a)

| Application Area | Range of Reduction Factors | | | |
|---|---|---|---|---|
| | Installation Damage | Creep* | Chemical Degradation | Biological Degradation |
| Separation | 1.1 to 2.5 | 1.5 to 2.5 | 1.0 to 1.5 | 1.0 to 1.2 |
| Cushioning | 1.1 to 2.0 | 1.2 to 1.5 | 1.0 to 2.0 | 1.0 to 1.2 |
| Unpaved roads | 1.1 to 2.0 | 1.5 to 2.5 | 1.0 to 1.5 | 1.0 to 1.2 |
| Walls | 1.1 to 2.0 | 2.0 to 4.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| Embankments | 1.1 to 2.0 | 2.0 to 3.5 | 1.0 to 1.5 | 1.0 to 1.3 |
| Bearing capacity | 1.1 to 2.0 | 2.0 to 4.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| Slope stabilization | 1.1 to 1.5 | 2.0 to 3.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| Pavement overlays | 1.1 to 1.5 | 1.0 to 2.0 | 1.0 to 1.5 | 1.0 to 1.1 |
| Railroads (filter/sep.) | 1.5 to 3.0 | 1.0 to 1.5 | 1.5 to 2.0 | 1.0 to 1.2 |
| Flexible forms | 1.1 to 1.5 | 1.5 to 3.0 | 1.0 to 1.5 | 1.0 to 1.1 |
| Silt fences | 1.1 to 1.5 | 1.5 to 2.5 | 1.0 to 1.5 | 1.0 to 1.1 |

*The low end of the range refers to applications which have relatively short service lifetimes and/or situations where creep deformations are not critical to the overall system performance.

where

$T_{allow}$ = allowable tensile strength,
$T_{ult}$ = ultimate tensile strength,
$RF_{ID}$ = reduction factor for installation damage,
$RF_{CR}$ = reduction factor for creep,
$RF_{CD}$ = reduction factor for chemical degradation,
$RF_{BD}$ = reduction factor for biological degradation, and
$\Pi RF$ = value of cumulative reduction factors.

Note that Eq. (2.24a) could have included additional site-specific terms, such as reduction factors for seams and intentionally made holes. It also could have been formulated with fractional multipliers (values $\leq 1.0$) placed in the numerator of the equation or on the opposite side of the equation, as with the *load-factor design method*. It has been put in this form following other studies (e.g., Voskamp and Risseeuw [63]). While the equation indicates tensile strength, it can be applied to burst strength, tear strength, puncture strength, impact strength, and so on.

### 2.4.2 Flow-Related Problems

For problems dealing with flow through or within a geotextile, such as filtration and drainage applications, the formulation of the allowable values takes the following form. Typical values for reduction factors are given in Table 2.12. Note that these values must be tempered by the site-specific conditions, as in Section 2.4.1. If the laboratory test includes the mechanism listed, it appears in the equation as a value of 1.0.

$$q_{allow} = q_{ult}\left(\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right) \tag{2.25a}$$

1996

LINER STRESS CALCULATION

# C.5 LINER STRESSES

# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner Stresses Sheet No. 0 of 20

Chkd. By WS Date 3/7/96 Proj. No. 95-284

LINER STRESSES

US ECOLOGY HAZARDOUS WASTE LANDFILL

BEATTY, NV



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner stresses Sheet No. 1 of 20
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## 1.0 PURPOSE

Evaluate tension/elongation of the design slope liner system to prevent rupture or damage to liner system due to gravity, thermal expansion/contraction, wind uplift, seismic deformation, and waste settlement.

## 2.0 APPROACH

The following causes of liner stresses are considered:

- Load due to gravity
- Thermal expansion/contraction
- wind uplift
- Seismic deformation
- Settlement of waste fill

<u>Load Due To Gravity</u> (Assume stable slopes)

Gravity load is calculated as follows:

$$T_1 = W \sin\theta + F_u - F_L$$

where $W$ = weight of liner component.

$\theta$ = slope angle [63.4° FOR 0.5:1 (H:V) slope]

$F_u$ = Friction Force above the liner component.

$F_L$ = Friction Force below the liner component.



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Strain caused by self weight is denoted as $\varepsilon_1$.

## Thermal Expansion/Contraction

Thermal expansion is considered for HDPE geomembrane and geonet. A coefficient of linear thermal expansion of $1.2 \times 10^{-4}$ cm/cm-°c is selected (See Ref. 3). Assume a temperature variation of 40°c (Ref. 4), the induced thermal strain is

$$\varepsilon_2 = 1.2 \times 10^{-4} \times 40 \fallingdotseq 0.5\%$$

## Wind Uplift

Sand bags and suction devices will be used to hold down the liner system during installation and waste placement. As a result, wind uplift will be balanced by sand bags and suction devices and will not generate stresses in liner system.

## Seismic Deformation

Seismic deformation during waste placement will be small (less than 1.6", see Ref. 13). Consider a slope length of 84', seismic deformation is $\fallingdotseq 0.2\%$, which will generate negligible stresses.

$$\Rightarrow \quad \varepsilon_3 = 0.2\%$$

Although negligible, this strain is included in the calculation for completeness. This strain will not occur below Interface No. 3, See Figure 1 and discussions below.



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Settlement of Waste fill

From Ref. 8, waste fill settlement will be less than 4% which includes settlements during waste placement and after closure of landfill. Waste fill settlement will induce upto 4% strains in the upper layers (non-woven geotextile and geonet) of the liner system, see Figure 1.

The liner system is designed such that slippage will occur between geonet and the smooth side of HDPE membrane (i.e., slippage will occur at Interface No. 3).

As a result, waste fill settlement will not affect the liner system below Interface No. 3. (Similarly, strain induced by seismic deformation will not be transferred below this interface.)

Induced Stresses

The overall strains caused by the above factors are added and the corresponding liner component stresses are determined from stress-strain curves or the elastic (secant) modulus of the material.

Allowable Stresses of Geotextile

The geotextile is used for separation purposes and the following partial factors of safety are used to calculate allowable tensile stress:

$$T_{allow} = T_{ult} \left( \frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}} \right) \qquad \text{(Ref. 10)}$$

where $FS_{ID} = 2.5$, $FS_{CR} = 1.2$, $FS_{CD} = 1.5$, and $FS_{BD} = 1.2$.



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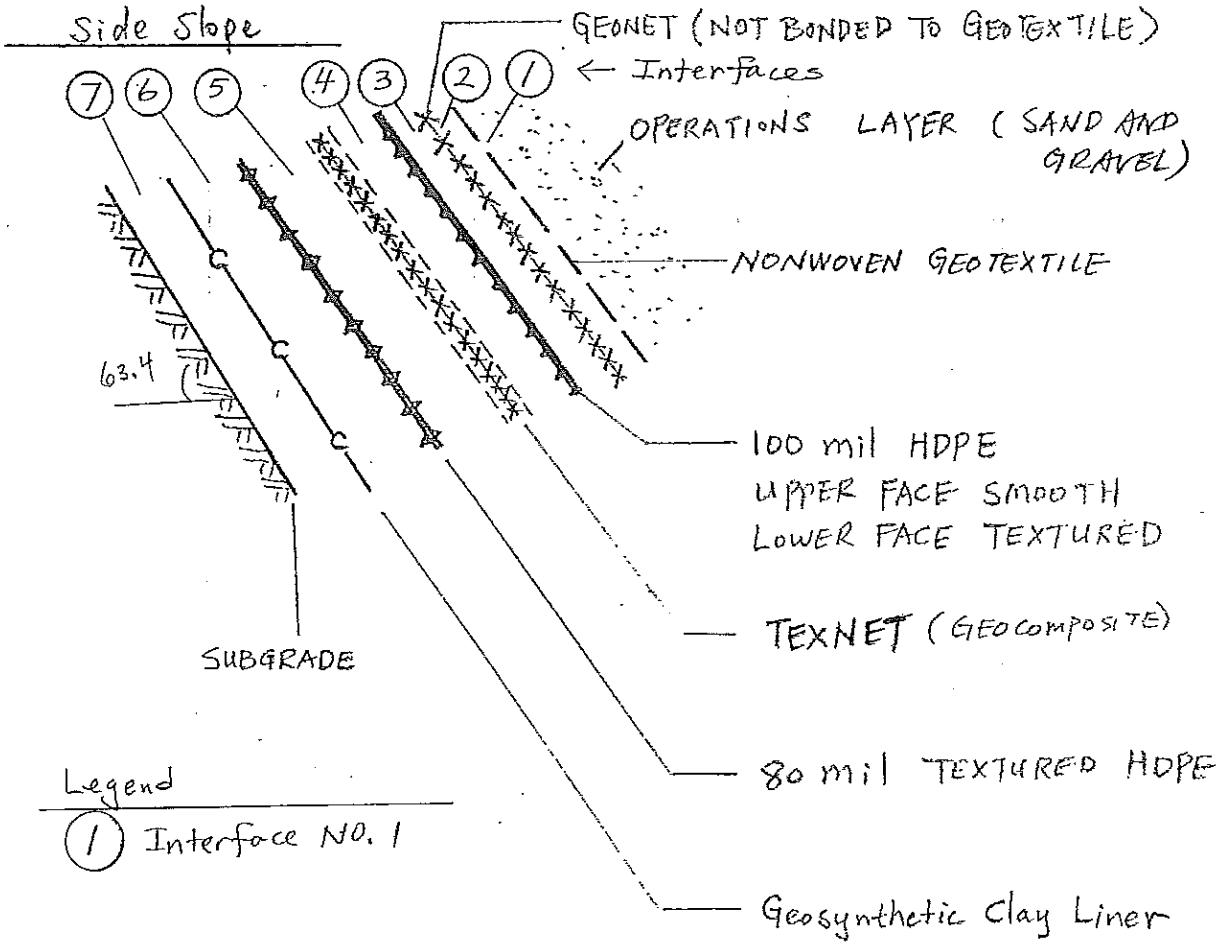
Design Profile:




Legend
(1) Interface NO. 1

Figure 1 Side Slope Liner System

Note: See Tables 1, 2, and 3 for material properties of liner components.



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Ref (10) 6/20



TABLE 2.12 RECOMMENDED PARTIAL FACTOR OF SAFETY VALUES FOR USE IN EQUATION 2.18

| Application area | Various partial factors of safety | | | |
|---|---|---|---|---|
| | Installation damage | Creep* | Chemical degradation | Biological degradation |
| separation | 1.1 to 2.5 | 1.0 to 1.2 | 1.0 to 1.5 | 1.0 to 1.2 |
| cushioning | 1.1 to 2.0 | 1.2 to 1.5 | 1.0 to 2.0 | 1.0 to 1.2 |
| unpaved roads | 1.1 to 2.0 | 1.5 to 2.5 | 1.0 to 1.5 | 1.0 to 1.2 |
| walls | 1.1 to 2.0 | 2.0 to 4.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| embankments | 1.1 to 2.0 | 2.0 to 3.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| bearing capacity | 1.1 to 2.0 | 2.0 to 4.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| slope stabilization | 1.1 to 1.5 | 1.5 to 2.0 | 1.0 to 1.5 | 1.0 to 1.3 |
| pavement overlays | 1.1 to 1.5 | 1.0 to 1.2 | 1.0 to 1.5 | 1.0 to 1.1 |
| railroads | 1.5 to 3.0 | 1.0 to 1.5 | 1.5 to 2.0 | 1.0 to 1.2 |
| flexible forms | 1.1 to 1.5 | 1.5 to 3.0 | 1.0 to 1.5 | 1.0 to 1.1 |
| silt fences | 1.1 to 1.5 | 1.5 to 2.5 | 1.0 to 1.5 | 1.0 to 1.1 |

*The low end of the range refers to results that have been compensated for creep in the performance of the tests.

$$T_{\text{allow}} = T_{\text{ult}} \left( \frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}} \right) \tag{2.18}$$

where

$T_{\text{allow}}$ = the allowable tensile strength,
$T_{\text{ult}}$ = the ultimate tensile strength,
$FS_{ID}$ = the factor of safety for installation damage,
$FS_{CR}$ = the factor of safety for creep,
$FS_{CD}$ = the factor of safety for chemical degradation, and
$FS_{BD}$ = the factor of safety for biological degradation.

Note that this equation could just as well have been formulated as fractional multipliers ($\leq 1.0$) and placed in the numerator of the equation. It is placed in this form because other studies have done likewise (e.g., Voskamp and Risseeuw [37]). While the equation indicates tensile strength, it can equally well be applied to burst strength, tear strength, puncture strength, seam strength, etc.

*For problems dealing with flow through or within a geotextile,* the formulation takes the following form with typical values given in Table 2.13. Note that these values must be tempered with site-specific conditions as was the case with the previous table.

$$q_{\text{allow}} = q_{\text{ult}} \left( \frac{1}{FS_{SCB} \times FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC}} \right) \tag{2.19}$$

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allowable Stresses of Geotextile

$\therefore$ Tallow = Tult / (2.5 × 1.2 × 1.5 × 1.2) , Tult = 150 lbs/in.

= 150/5.4 = 27.8 lbs/in

Allowable Stresses of Geonet

To avoid rupture of geonet, a factor of safety of 4 is used to calculate allowable stresses in geonet.

Tallow = Tult/4

= 50/4 = 12.5 lbs/in , Tult = 50 lbs/in

allowable Stresses of HDPE

To avoid rupture of HDPE, a factor of safety of 40 is used (See Ref. 10) to calculate allowable stresses in geomembrane. This factor of safety is considered very conservative.

Tallow = Tult/40

where Tult = 500 lbs/in for 100-mil HDPE and 400 lbs/in for 80-mil HDPE (see Ref. 11)

For 100-mil HDPE,
Tallow = 500/40 = 12.5 lbs/in

For 80-mil HDPE
Tallow = 400/40 = 10 lbs/in

allowable Stresses of Geocomposite

The geocomposite is composed of a geonet heat bonded to non-woven geotextile on both the upper and lower face of the geonet. As a result, the allowable stresses can be significantly higher than a single layer of geotextile or a geonet. For convenience, the allowable stresses of a geotextile can be used conservatively as the allowable stress of the geocomposite.



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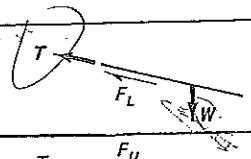
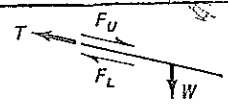
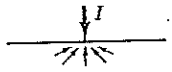
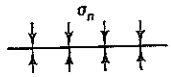
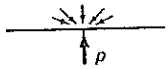
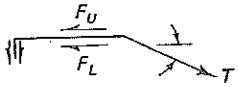
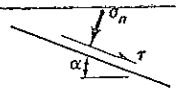
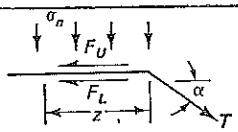
Ref (10) 8/20



**TABLE 5.17 VARIOUS DESIGN MODELS FOR GEOMEMBRANES IN WASTE DISPOSAL SITUATIONS (REF: KOERNER AND RICHARDSON, 48)**

| Problem | Liner stress | Free body diagram | Required properties: Geomembrane | Required properties: Landfill | Typical factor of safety |
|---|---|---|---|---|---|
| 1. liner self weight | tensile |   | $G, t, \sigma_{allow}, \delta_L$ | $\beta, H$ | 10 to 100 |
| 2. weight of filling | tensile |   | $t, \sigma_{allow}, \delta_U, \delta_L$ | $\beta, h, \gamma, H$ | 0.5 to 10 |
| 3. impact during construction | impact |   | $I$ | $d, w$ | 0.1 to 5 |
| 4. weight of landfill | compression |   | $\sigma_{allow}$ | $\gamma, H$ | 10 to 50 |
| 5. puncture | puncture |   | $\sigma_p$ | $\gamma, H, P, A_p$ | 0.5 to 10 |
| 6. anchorage | tensile |   | $t, \sigma_{allow}, \delta_U, \delta_L$ | $\beta, \gamma, \phi$ | 0.7 to 5 |
| 7. settlement of landfill | shear |   | $\tau, \delta_U$ | $\beta, \gamma, H$ | 10 to 100 |
| 8. subsidence under landfill | tensile |   | $t, \sigma_{allow}, \delta_U, \delta_L, \chi$ | $\alpha, \gamma, H$ | 0.3 to 10 |

Notes:

Geomembrane properties

- $G$ = specific gravity
- $t$ = thickness
- $\sigma_{allow}$ = allowable stress (yield or break)
- $\tau$ = shear stress
- $I$ = impact energy
- $\sigma_p$ = puncture stress
- $\delta_U$ = friction with material above
- $\delta_L$ = friction with material below
- $\chi$ = mobilization distance

Landfill properties

- $\beta$ = slope angle
- $H$ = height
- $\gamma$ = unit weight
- $h$ = lift height
- $\alpha$ = subsidence angle
- $\phi$ = friction angle
- $d$ = drop height
- $W$ = weight
- $p$ = puncture force
- $A_p$ = puncture area

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For this analysis, an allowable stress of 27.8 lbs/in is used for geocomposite.

Allowable stresses of GCL

To avoid rupture of GCL, a conservative factor of safety of 10 is used in this calculation.

$$T_{allow} = T_{ult}/10 = 45/10 = 4.5 \text{ lbs/in}$$

3.0 Calculations (see Tables 1, 2, and 3)



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Chkd. By WJ Date 3/7/96 3.0 Calculations Proj. No. 95-284

Table 1

| COMPONENT | UNIT WEIGHT (lbs/ft²) | Tensile Load Due To Self Wt (lbs/in) (2) | Strain Due To Self Weight, $\varepsilon_1$ (%) | Strain Due To Thermal Expansion $\varepsilon_2$ (%) | Strain Due To Seismic Deformation $\varepsilon_3$ (%) | Strain Due To Settlement of Waste Fill $\varepsilon_4$ (%) | Total Strain $\varepsilon_T$ (%) | Total Induced Stresses (lbs/in) | Tult (lbs/in) | Tyield (lbs/in) | Tallow (lbs/in) | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-Woven GEOTEXTILE (TREVIRA SPUNBOND 1125) | 0.052 | 0.3 | 0 (7) | 0.5 | 0.2 | 4 | 4.7 | 12 (3) | 150 | NR (1) | 27.8 | 9 |
| GEONET (POLY-NET PN 300) | 0.18 | 1.1 | 0.51 (4) | 0.5 | 0.2 | 4 | 5.2 | 11.3 (4) | NA (9) | 50 (8) | 12.5 | 10, 14 |
| 100-MIL HDPE (Textured Hyperflex) | 0.54 | 2.6 | 0.16 (5) | 0.5 | 0 | 0 | 0.66 | 10.6 (5) | 500 | 240 | 12.5 | 11 |
| GEOCOMPOSITE (TEXTNET TN3002/1125) | 0.26 | 1.3 | 0 (7) | 0 | 0 | 0 | 0 | 0 | 150 | NR | 27.8 | 9 |
| 80-MIL HDPE (Textured Hyperflex) | 0.44 | 2.6 | 0.2 (5) | 0.5 | 0 | 0 | 0.7 | 9 (5) | 400 | 192 | 10 | 11 |
| GCL (CLAYMAX 500SP) | 1.2 | 2.4 | 0.8 (6) | 0 | 0 | 0 | 0.8 | 2.4 (6) | NA | 45 (10) | 4.5 | 2 |

NOTES

(1) "NR" represents Not Reported. Stress-strain curve does not indicate a pronounced yield point.

(2) See Calculations in Table 2.

(3) See stress-strain curve, Ref 9.

(4) Calculated using an assumed elongation at yield of about 23% (Ref. 10)

(5) Calculated using a tensile elongation at yield of 15% (Ref. 11)

(6) Calculated using tensile elongation at rupture of 15% (Ref. 2)

(7) See Stress-strain curve attached (Ref 9).

(8) Ref. 14

(9) Not Available.

(10) Calculated using the GCL grab strength of 180 lbs (Ref. 2) devided by the width (4") of the test specimen, 180/4 = 45 lbs/in.



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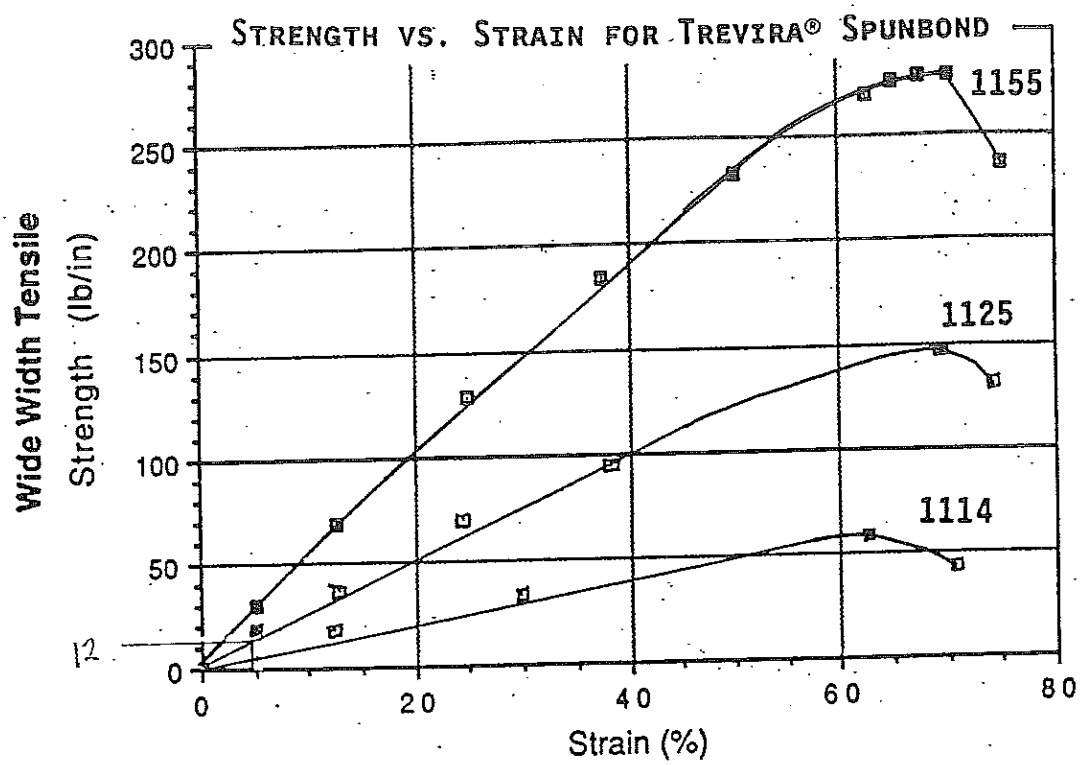
Ref. 9

TREVIRA SPUNBOND

## ~~TABLE 1:~~ STRENGTH CHARACTERISTICS OF TREVIRA® SPUNBOND GEOTEXTILES

| | CBR Puncture Strength (lb) | CBR Puncture Elongation (in) | Measured Wide Width Tensile (lb/ft) | | | Measured Wide Width Strain % | | |
|---|---|---|---|---|---|---|---|---|
| | | | Machine | Cross-M | Average | Machine | Cross-M | Average |
| Trevira 1114 | 341 | 1.9 | 674 | 529 | 602 | 63% | 61% | 62% |
| Trevira 1125 | 701 | 1.95 | 1770 | 1450 | 1610 | 69% | 70% | 70% |
| Trevira 1155 | 1420 | 1.99 | 3360 | 2670 | 3015 | 68% | 77% | 73% |




## ~~FIGURE 1:~~ WIDE WIDTH TENSILE STRENGTH/STRAIN CURVES FOR TREVIRA® SPUNBOND GEOTEXTILES (MACHINE DIRECTION)

Ref (10)

12/20



## 4.1 GEONET PROPERTIES AND TEST METHODS

Since the primary function of a geonet is to convey liquid within the plane of its structure, the in-plane hydraulic flow rate, or transmissivity, is of major importance. However, other features, which may influence this value over the service lifetime of the geonet, are also of importance. Thus a number of properties will be presented in this section.

### 4.1.1 Physical Properties

The primary physical property needed to characterize a geonet is its thickness, which can be determined using ASTM D1777. In this test, it is recommended that geotextile thickness be measured under a normal pressure of 42 lb./ft.$^2$ (2.0 kPa). There are no current guidelines for geonets. The pressures used in obtaining the values listed in Table 4.1 are not known, but it should be noted that geonets are not nearly as sensitive to thickness variation under normal pressure as are geotextiles.

Mass per unit area can be determined using ASTM D1910. For a 200-mil (5.1-mm)-thick, extruded, solid-rib geonet, the mass per unit area is usually in the range of 20 to 30 oz./yd.$^2$ (680 to 1020 g/m$^2$). It is not a design property per se, but it is informative from a manufacturer's point of view.

Other physical properties such as rib dimensions, planar angles made by the intersecting ribs, vertical angles made at the juncture point, aperture size and shape, color, hardness, etc., can be measured directly and are relatively straightforward to obtain.

### 4.1.2 Mechanical Properties

A number of strength aspects of geonets are important to consider.

#### 4.1.2.1 Tensile Strength

The wide-strip tensile properties of geonets are sometimes called for in various specifications. Using ASTM D4595 which uses a test specimen 8.0 in.(200 mm) in width by 4.0 in. (100 mm) in length, the curves of Figure 4.4 resulted for a 200-mil(5.1-mm) thick solid-rib geonet in the machine and cross machine directions. Note the differences in behavior, suggesting that there is a preferential direction in strength between the machine and cross-machine directions. If site-specific conditions warrant a high-strength direction, the geonet should be oriented with its machine direction positioned accordingly. Also to be noted is that geonets do indeed possess a measurable tensile strength. For the solid-rib geonet illustrated in Figure 4.1 and shown in Figure 4.4, the average of a series of wide-strip tensile tests gave the following information:

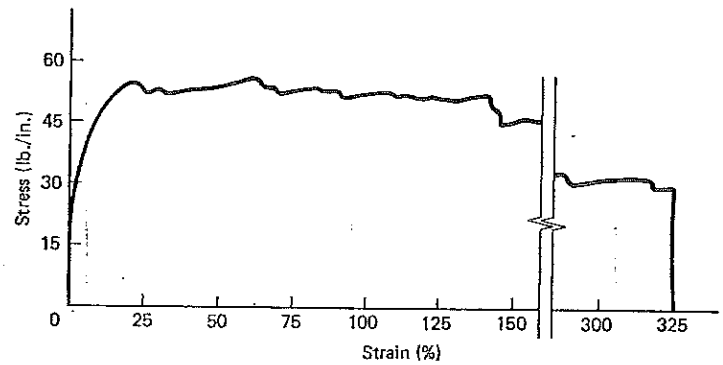
- machine direction:
  Peak strength = 680 lb./ft. (120 kN/m) = 680/12 lb./in = 56.7 lbs/in
  Strain at peak = 23%
  Strain at failure = 290%

Ref (10)

13/20.



- cross-machine direction:
  Peak strength = 390 lb./ft. (68 kN/m)
  Strain at peak = 170%
  Strain at failure = 240%



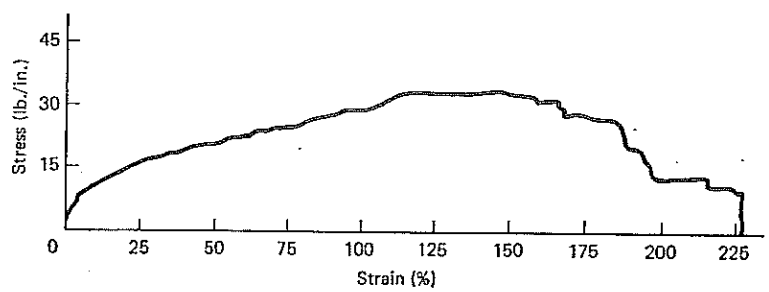




**Figure 4.4.** Tensile strength behavior of a 200-mil (5.1-mm) solid-rib extruded geonet. Upper curve, machine direction; lower curve, cross-machine direction.

### 4.1.2.2 Compressive Strength

Of greater importance than the above described in-plane tensile strength of geonets is the cross-plane compressive strength. This is due to the influence that compressive yielding or collapse has on the ability of the geonet to conduct liquid within its open spaces. There are a number of approaches to measuring a geonet's compressive strength, and the ASTM has a task commitee working on the topic. Using 6.0-in. (150-mm)-square test specimens normally loaded under a constant strain rate load of 0.002 in./min. (= 0.05 mm/min.), the curves of Figure 4.5 resulted. The upper figure illustrates deformation behavior to applied normal stress, while the lower figure presents strain versus applied normal stress. Here it is seen that both the foamed rib extruded geonet and the solid rib extruded geonet are initially very stiff but begin to deform at approximately 15,000 lb./ft.$^2$ (≅ 720 kPa). The solid extruded ribs deform into the valleys created by their intersecting

# HDPE DRAINAGE NET — GEOTEXTILE GEOCOMPOSITE 14/20

## Recommended TEX-NET® Specifications

Ref. (14)

## 1. DESCRIPTION

These specifications describe a high density polyethylene (HDPE) drainage net - geotextile geocomposite. The supply and installation of this material shall be in strict accordance with these specifications and contract drawings.

## 2. MATERIALS AND PRODUCT CONSTRUCTION

The geocomposite drainage material shall be TEX-NET® by Fluid Systems, Inc. and shall meet or exceed the following criteria:

### 2.01

Drainage net shall be manufactured by extruding two sets of strands to form a three (3) dimensional structure to provide planar water flow.

The drainage net shall contain stabilizers to prevent ultraviolet light degradation.

### 2.02

The drainage net shall be POLY-NET® PN-3000 or approved equal. In addition to the material properties listed above, the drainage net shall conform to the following properties detailed in the table below.

**POLY-NET® PN-3000**

| PROPERTY | TEST METHOD | UNIT | QUALIFIER | VALUE |
|---|---|---|---|---|
| POLYMER DENSITY | ASTM D-1505 | g/cm³ | range | .937 ± .002 |
| POLYMER MELT INDEX | ASTM D-1238 | g/10 min | maximum | 1.0 |
| CARBON BLACK CONTENT | ASTM D-1603 | % | range | 2–3% |
| NOMINAL THICKNESS | ASTM D-1777 | inches | range | 0.220 ± 0.022 |
| NOMINAL MASS PER UNIT AREA | ASTM D-3776 | lbs/1000 ft² | range | 180 ± 18 |
| TRANSMISSIVITY at 15,000 psf | *ASTM D-4716 | m²/sec | minimum | $1 \times 10^{-3}$ |
| TENSILE STRENGTH MACHINE DIRECTION | ASTM D-1682 | lbs/in | range | 50 ± 10 |

*Per ASTM D4716-87. The transmissivity was measured using water @ 20°C (68°F) with a gradient of one, between two steel plates, after one hour. Value may vary, based on dimensions of the transmissivity specimen and specific laboratory.

### 2.03

The geotextile filter fabric shall meet or exceed the following:

**TREVIRA® 1120 OR EQUAL MEETING THE PROPERTIES LISTED BELOW**

| FABRIC PROPERTY | UNIT | TEST METHOD | *MINIMUM REQUIREMENT |
|---|---|---|---|
| FABRIC WEIGHT | oz/yd² | ASTM D-3776 | 5.7 |
| THICKNESS, t | mils | ASTM D-1777 | 75 |
| GRAB STRENGTH | lbs | ASTM D-4632 | 160 |
| GRAB ELONGATION | % | ASTM D-4632 | 60 |
| TRAPEZOID TEAR STRENGTH | lbs | ASTM D-4533 | 60 |
| PUNCTURE RESISTANCE | lbs | ASTM D-4833 | 80 |
| MULLEN BURST STRENGTH | psi | ASTM D-3786 | 275 |
| WATER FLOW RATE | gpm/ft² | ASTM D-4491 | 130 |
| PERMITTIVITY, Ψ | sec⁻¹ | ASTM D-4491 | 1.74 |
| PERMEABILITY, k = Ψ t | cm/sec | ASTM D-4491 | .33 |
| AOS | Sieve Size mm | ASTM D-4751 | 70 .210 |

*These minimum values represent minimum test values determined from Q.C. testing on all lots produced in 1989.

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Ref (11) 15/20

# FrictionFlex® Textured HyperFlex® Lining Material

SLT's FrictionFlex patented texturing process provides the industry's leading textured liners. Uniquely produced from a specially formulated virgin HDPE geomembrane resin, FrictionFlex has outstanding chemical resistance, mechanical properties, environmental stress crack resistance, dimensional stability and thermal aging characteristics. HyperFlex, textured with the FrictionFlex process, contains approximately 97.5% polymer and 2.5% carbon black, anti-oxidants and heat stabilizers, and contains no additives, fillers or extenders. SLT textured liners have excellent resistance to UV radiation and are suitable for exposed conditions.

| PROPERTY | TEST METHOD | NOMINAL VALUES | | | |
|---|---|---|---|---|---|
| Thickness, mils | ASTM D751/374/1593 | 40 | 60 | 80 | 100 |
| Density (g/cc) | ASTM D792/1505 | 0.944 | 0.944 | 0.944 | 0.944 |
| Melt Flow Index (g/10 minutes) | ASTM D1238-E | ≤ 1.0 | ≤ 1.0 | ≤ 1.0 | ≤ 1.0 |
| Tensile Properties Either Direction | ASTM D638 Type IV Dumbell, 2 ipm Gauge length per N.S.F. Std. 54 | | | | |
| Tensile Strength at Break (lbs/in, width) | | 200 | 300 | 400 | 500 |
| Tensile Strength at Yield (lbs/in, width) | | 96 | 144 | 192 | 240 |
| Elongation at Break (percent) | | 600 | 600 | 600 | 600 |
| Elongation at Yield (percent) | | 15 | 15 | 15 | 15 |
| Tear Resistance Initiation (lbs) | ASTM D1004 Die C | 33 | 50 | 66 | 83 |
| Low Temperature Brittleness | ASTM D746 B | <-120°F | <-120°F | <-120°F | <-120°F |
| Dimensional Stability Each Direction (percent) | ASTM D1204 248°F 1 hr. | ± 1 | ± 1 | ± 1 | ± 1 |
| Ozone Resistance | ASTM D1149 7 days 100 ppm 104°F | No Cracks | No Cracks | No Cracks | No Cracks |
| Environmental Stress Crack Resistance (hrs) | ASTM D1693 Cond. C | >2000 | > 2000 | > 2000 | > 2000 |
| Puncture Resistance (lbs) | FTMS 101C Method 2065 | 60 | 90 | 120 | 150 |
| Water Absorption (percent weight change) | ASTM D570 | <0.01 | <0.01 | <0.01 | <0.01 |
| Moisture Vapor Transmission (g/m²day) | ASTM E96 | <0.001 | <0.001 | <0.0009 | <0.00085 |
| Oxidative Induction Time (minutes) Pure $O_2$ at 1 Atmosphere | ASTM D3895 200°C | 100 | 100 | 100 | 100 |
| Tensile Impact Strength (ft-lbs/in²) | ASTM D1822 | 381 | 381 | 381 | 381 |
| Carbon Black Content (percent) | ASTM D1603 | 2-3 | 2-3 | 2-3 | 2-3 |
| Carbon Black Dispersion | ASTM D3015 | A1/A2 | A1/A2 | A1/A2 | A1/A2 |

SLT FrictionFlex is available in 24-foot widths and up to 8,000 lb. rolls. Special length rolls and other material thicknesses are available upon request.

*This data is provided for informational purposes only and is not intended as a warranty or guarantee. SLT assumes no liability in connection with the use of this data.*

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**North American Headquarters:**
**SLT North America, Inc.**
200 South Trade Center Parkway
Conroe, Texas 77385
Phone 713-350-1813
Fax 409-273-2266

**European Headquarters:**
**SLT Lining Technology GmbH**
Buxtehuder Strasse 112
D-21073 Hamburg
Germany
Phone 49-40-767-420
Fax 49-40-767-4233

**Australian Headquarters:**
**SLT Advanced Lining Technology Pty. Ltd.**
24 Regent Crescent
Moorebank, New South Wales
Australia 2170
Phone 61-2-821-2977
Fax 61-2-821-3611

**Far East Headquarters:**
**SLT Lining Technology (Far East) Pte., Ltd.**
182 Tagore Ln.
Singapore 2678
Phone 65-459-2466
Fax 65-459-4366

# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner Stresses Sheet No. 17 of 20

Chkd. By MB Date 3/7/96 Proj. No. 95-284

Table 2

| material | Self weight (1) (lb/ft) | Accumulated weight (lb/ft) | $F_u$ (2) (lb/ft) | $F_L$ (2) (lb/ft) | Tensile Load Due To Gravity (3) (lbs/ft) |
|---|---|---|---|---|---|
| Geotextile | 4.4 | 4.4 | 0 | 0.7 | 0.3 |
| Geonet | 15.1 | 19.5 | 0.7 | 1.2 | 1.1 |
| 100-mil HDPE | 45.4 | 63.9 | 1.2 | 11 | 2.6 |
| Geocomposite | 21.8 | 85.7 | 11 | 14.7 | 1.3 |
| 80-mil HDPE | 37 | 122.7 | 14.7 | 16.8 | 2.6 |
| GCL | 100.8 | 223.5 | 16.8 | 78.2 | 2.4 |

NOTES

(1) Self Weight = unit weight (in lbs/ft$^2$) * Slope Length
Slope Length = 84 feet.
unit weight is listed in Table 1.

(2) Friction Forces ($F_u$ & $F_L$) are calculated as follows:

$$F = \text{Accumulated Wt.} \times \cos 63.4 \times \tan \delta$$

where $\delta$ = residual interface friction angle (see Table 3).

(3) Tensile Load Due To Gravity (in lbs/ft) = (Self Wt. * $\sin 63.4 + F_u - F_L$)/12"



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner stresses Sheet No. 18 of 20

Chkd. By WB Date 3/7/96 Proj. No. 95-284

Table 3

| Interface No. | Residual Friction angle (degree) | Reference |
|---|---|---|
| 2 | 19 | 1 |
| 3 | 8 | 1 |
| 4 | 21 | 1 |
| 5 | 21 | 1 |
| 6 | 17 | 2 |
| 7 | 38 | 2 |



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4.0 CONCLUSIONS

1. The outer layers of the liner system will withstand the relatively large strains (up to ≈ 4.7%) primarily caused by waste fill settlement. Settlement induced stresses will occur gradually as the waste fill is being placed. This slow loading process will allow the upper materials (geotextile and geonet) to deform without inducing significant stresses. The calculated stresses are conservative and are within the allowable limits. This slow load application, creep relaxation of stresses should be measured in the laboratory to verify design parameters (see item 6).

2. The design slip plane between geonet and the smooth side of the 100-mil HDPE will prevent the settlement induced strains (and stresses) from being transferred to the lower layers of the liner system.

3. Self weight of liner components are not an issue. Up to one percent of strain can occur in the GCL material. The calculated stress in GCL is less than the allowable stress.

4. Thermal stresses are negligible. Based on our experience, we do not expect wrinkles to occur in the liner system when textured HDPE is used. However, in case minor wrinkles do occur, care should be taken to avoid placing fill (soil or waste) over wrinkles such that thermal stresses (and strains) are "locked in" and thus could accumulate from the bottom to the top.

5. Wind uplift is balanced by using sand bags and suction devices, and are not included in the liner stress calculations.

6. Actual materials used in construction should be tested for stress-strain properties and interface shear strength parameters.



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By JH Date 2/9/96 Subject Tension / Elongation Sheet No. 20 of 20
Chkd. By WB Date 2/19/96 Proj. No. 95-284

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LINER STRESS CALCULATION REVISION

HMA environmental

SUBJECT US Ecology Beatty, NV
Side Slope Friction Forces

DESIGNER J. Ellison

CHECKER R.G. Spear

AEP NO. 023801

SHEET 1 OF 10

DATE 1-28-97

DATE 1-29-97

PROFESSIONAL ENGINEER STATE OF NEVADA GARY R. HORWITCH CIVIL No. 12401

all sheets

I. INTRODUCTION

The Purpose of this calculation is to provide detailed explanation of how friction forces $F_L$ (as outlined in Cell 12 Design Report, p. 18) are calculated.

The free body diagram shown in Figure 1 identify forces present in the overall system. Figure 2 shows an exploded view of the interactive forces resulting from the components of the liner system.

LINER SYSTEM COMPONENTS ARE AS FOLLOWS:

1. Geotextile (Trevira Spunbound 1125)
2. Geonet (Poly-Net PN-3000)
3. 100 mil HDPE (Textured Hyperflex)
   smooth upper face
   textured lower face
4. Geocomposite (Texnet TN 3002/1125)
5. 80 mil HDPE (Textured Hyperflex)
   textured upper and lower faces
6. GCL (Claymax 600 SP)

DEFINITIONS:

$T$ = Tensile Force
$W$ = Weight of Liner Component
$F_U$ = Upper Face Friction Force
$F_L$ = Lower Face Friction Force
$\beta$ = Slope Angle
$\delta$ = Friction Angle Between Liner Components

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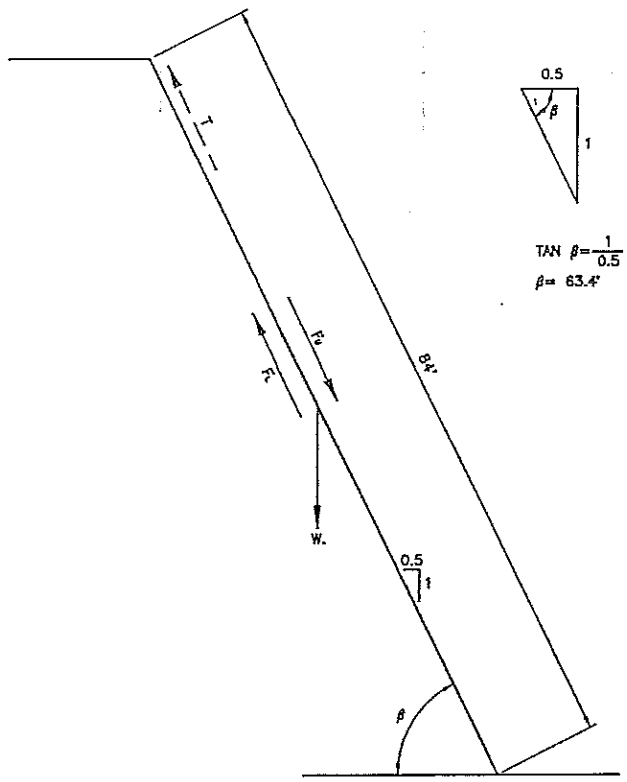
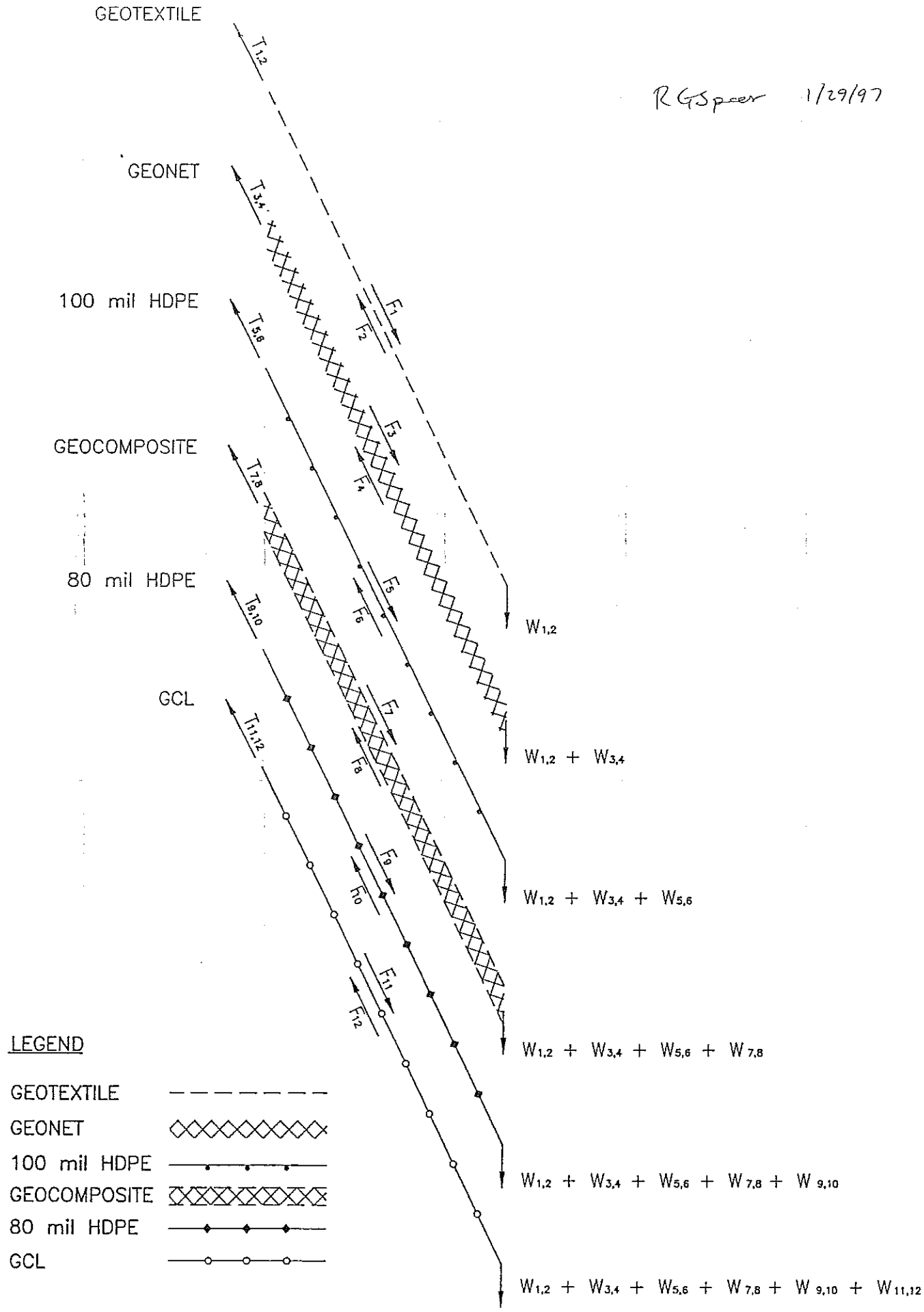



FREE BODY DIAGRAM

FIGURE 1

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EXPLODED VIEW OF THE SIDE SLOPE LINER SYSTEM

FIGURE 2

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Side Slope Friction Forces — SHEET 4 OF 10
DESIGNER J. Ellison — DATE 1-28-97
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SUM FORCES IN THE HORIZONTAL DIRECTION

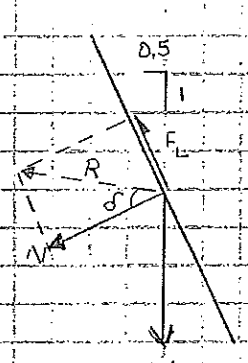
$\Sigma F_H = 0$ Orient Horizontal Axis Along Slope

$$T + F_L = W \sin \beta + F_U$$

$$T = W \sin \beta + F_U - F_L$$

SUM FORCES IN THE VERTICAL DIRECTION

$\Sigma F_V = 0$ Orient Vertical Axis Perpendicular To THe Slope (Further detail must be shown in order to completely develop this equation) (Eshbach's Handbook of Engineering Fundamentals, 4th edition, Byron O. Tapley)




$F_L$, friction force, is a component of the resultant force that opposes motion.
N, normal force, is always normal or perpendicular to the plane of motion.
$\delta$ is the friction angle

$\Sigma F_V = 0$ : Normal force, $N = W \cos \beta$

$$\tan \delta = \frac{F_L}{N} \quad \therefore \quad N = \frac{F_L}{\tan \delta}$$

Substitute for the Normal force, N

$$\frac{F_L}{\tan \delta} = W \cos \beta$$

$$F_L = W \cos \beta \tan \delta$$

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SUBJECT US Ecology Beatty, NV — Side Slope Friction Forces
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Therefore $\Sigma F_H = 0 \quad T = W \sin\beta + F_U - F_L$

$\Sigma F_V = 0 \quad F_L = W \cos\beta \tan\delta$

The following equations are utilized to determine friction forces within the liner system:

(1) SELF WEIGHT = UNIT WEIGHT · SLOPE LENGTH

(2) $F_L = \text{WEIGHT}_{accumulated} \cdot \cos\beta \cdot \tan\delta$

(3) $T = \left[(\text{SELF WEIGHT} \cdot \sin\beta) + F_U - F_L\right] / 12$

| COMPONENT | UNIT WEIGHT (lbs/ft²) | INTERFACE | RESIDUAL FRICTION ANGLE (degrees) |
|---|---|---|---|
| Geotextile | 0.052 | Geotextile/Geonet | 19 |
| Geonet | 0.180 | Geonet/100 mil HDPE | 12 |
| 100 mil HDPE | 0.54 | 100 mil HDPE -to- Geocomposite | 26 |
| Geocomposite | 0.26 | Geocomposite -to- 80 mil HDPE | 26 |
| 80 mil HDPE | 0.44 | 80 mil HDPE/GCL | 19 |
| GCL | 1.02 | GCL/Soil | 36 |

All friction angle values are based upon information received from SLT, NSC, and CETCO geosynthetics representatives. Values used in the original calculation are conservative. Typical residual friction angle values are included in Enclosure No. 1.

This calculation is prior to slippage of the smooth face of the 100 mil HDPE liner

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AEP NO 023801
SHEET 6 OF 10
DESIGNER J. Ellison — DATE 1-28-97
CHECKER RG Spear — DATE 1-29-97

SLOPE LENGTH = 84 ft

(1) Geotextile / Geonet Interface:

1. Self Weight = $0.052\ lb/ft^2\ (84\ ft) = 4.37\ lb/ft$

2. $F_1 \cong 0$ (since soil deforms as it moves along liner)

$F_2 = W_{accumulated} \cdot \cos\beta \cdot \tan\delta$

$F_2 = (4.37\ lb/ft) \cos 63.4^\circ \tan 19^\circ$

$F_2 = 0.67\ lb/ft$

3. $T_{1,2} = \left[(4.37\ lb/ft) \sin 63.4^\circ + 0 - 0.67\ lb/ft\right] / 12\ in/1\ ft$

$T_{1,2} = 0.27\ lb/in$

(2) Geonet / 100 mil HDPE Interface:

1. Self Weight = $0.18\ lb/ft^2\ (84\ ft) = 15.12\ lb/ft$

2. $F_2 = F_3 \therefore F_3 = 0.67\ lb/ft$

$F_4 = (4.37 + 15.12) \cos 63.4^\circ \tan 12^\circ$

$F_4 = 1.85\ lb/ft$

3. $T_{3,4} = (15.12 \sin 63.4^\circ + 0.7 - 1.85) / 12$

$T_{3,4} = 1.03\ lb/in$

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Side Slope Friction Forces — SHEET 7 OF 10
DESIGNER J. Ellison — DATE 1-28-97
CHECKER R G Speer — DATE 1-29-97

(3) 100 mil HDPE / Geocomposite :

1. Self Weight = $0.54\ lb/ft^2 (84\ ft) = 45.36\ lb/ft$

2. $F_4 = F_5 \quad \therefore \quad F_5 = 1.85\ lb/ft$

$F_6 = (4.37 + 15.12 + 45.36) \cos 63.4° \tan 26°$

$F_6 = 14.16\ lb/ft$

3. $T_{5,6} = (45.36 \sin 63.4° + 1.85 - 14.16)/12$

$T_{5,6} = 2.35\ lb/in$

(4) Geocomposite / 80 mil HDPE

1. Self Weight = $0.26\ lb/ft^2 (84\ ft) = 21.84\ lb/ft$

2. $F_6 = F_7 \quad \therefore \quad F_7 = 14.16\ lb/ft$

$F_8 = (4.37 + 15.12 + 45.36 + 21.84) \cos 63.4° \tan 26°$

$F_8 = 18.93\ lb/ft$

3. $T_{7,8} = (21.84 \sin 63.4° + 14.16 - 18.93)/12$

$T_{7,8} = 1.23\ lb/in$

HMA environmental

SUBJECT U.S Ecology Beatty, NV
Side-Slope Friction Forces
DESIGNER J. Ellison
CHECKER RGSpear

AEP NO. 023801
SHEET 8 OF 10
DATE 1-28-97
DATE 1-29-97

(5) 80 mil HDPE/GCL

1. Self Weight = $0.44\ lb/ft^2 (84\ ft) = 36.96\ lb/ft$

2. $F_8 = F_9 \therefore F_9 = 18.93\ lb/ft$

$F_{10} = (4.37 + 15.12 + 45.36 + 21.84 + 36.96) \cos 63.4° \tan 19°$

$F_{10} = 19.06\ lb/ft$

3. $T_{9,10} = (36.96 \sin 63.4° + 18.93 - 19.06)/12$

$T_{9,10} = 2.74\ lb/in$

(6) GCL/Soil

GCL - Claymax 600 SP bentonite weight = $0.75\ lb/ft^2$ @ 0% moisture
The industry standard reports bentonite weight = $0.95\ lb/ft^2$ @ 20 moisture, this value is conservative considering the very dry climate of Nevada ∴ Bentonite = $0.95\ lb/ft^2$

Upper geosynthetic = $3.2\ oz/yd^2 \left(\frac{1\ lb}{16\ oz}\right)\left(\frac{yd^2}{9\ ft^2}\right) = 0.022\ lb/ft^2$

Lower geosynthetic = $6.6\ oz/yd^2 \left(\frac{1\ lb}{16\ oz}\right)\left(\frac{yd^2}{9\ ft^2}\right) = 0.046\ lb/ft^2$

Weight = $0.95 + 0.022 + 0.046 = 1.02\ lb/ft^2$

1. Self Weight = $1.02\ lb/ft^2 (84\ ft) = 85.7\ lb/ft$

2. $F_{10} = F_{11} \therefore F_{11} = 19.06\ lb/ft$

$F_{12} = (4.37 + 15.12 + 45.36 + 21.84 + 36.96 + 85.7) \cos 63.4° \tan 36°$

$F_{12} = 68.10\ lb/ft$

3. $T_{11,12} = (85.7 \sin 63.4° + 19.06 - 68.10)/12$

$T_{11,12} = 2.30\ lb/in$

HMA environmental

SUBJECT US Ecology Beatty, NV
Side Slope Friction Forces
DESIGNER J. Ellison
CHECKER RGSpear

AEP NO. 023801
SHEET 9 OF 10
DATE 1-28-97
DATE 1-29-97

The following table summarizes forces in tabular form. These forces are very similar to the liner forces calculated in the Cell 12 Design Report included in Enclosure 2. Please note that this condition is prior to loading and waste settlement. Once settlement occurs, slippage will take place at the 100 mil HDPE (smooth) face and the geonet. Available material data sheets are included in Enclosure No. 3.

| TABLE OF DERIVED FRICTIONAL FORCES PRIOR TO SLIPPAGE | | | | | | |
|---|---|---|---|---|---|---|
| MATERIAL | UNIT WEIGHT ($lb/ft^2$) | SELF WEIGHT (lb/ft) | ACCUMULATED WEIGHT (lb/ft) | $F_U$ (lb/ft) | $F_L$ (lb/ft) | TENSILE LOAD DUE TO GRAVITY (lb/in) |
| Geotextile (Trevira Spunbond 1125) | 0.052 | 4.37 | 4.37 | $F_1 = 0$ | $F_2 = 0.67$ | 0.27 |
| Geonet ( Poly-Net PN-3000) | 0.180 | 15.12 | 19.49 | $F_3 = 0.67$ | $F_4 = 1.85$ | 1.03 |
| 100 mil HDPE (Textured Hyperflex) | 0.54 | 45.36 | 64.85 | $F_5 = 1.85$ | $F_6 = 14.16$ | 2.35 |
| Geocomposite (Texnet TN 3002/1125) | 0.26 | 21.84 | 86.69 | $F_7 = 14.16$ | $F_8 = 18.93$ | 1.23 |
| 80 mil HDPE (Textured Hyperflex) | 0.44 | 36.96 | 123.65 | $F_9 = 18.93$ | $F_{10} = 19.06$ | 2.74 |
| GCL (Claymax 600 SP) | 1.02 | 85.7 | 209.35 | $F_{11} = 19.06$ | $F_{12} = 68.10$ | 2.30 |

RG Spear 1-26-97

# ANCHOR TRENCH STRESSES

AquAeTer

*optimizing environmental resources - water; air; earth*

# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: August 15, 2007

CALCULATION NUMBER: C.6 Revision: Update per 2007 Design

**CALCULATION TITLE: Anchor Trench**

**DESCRIPTION OF CALCULATION:**

Calculation to determine if 1996 trench design dimensions are sufficient for 2007 proposed liner members

**REFERENCES USED:** Number of Reference Pages Attached:

1. Previous calc: 1996 calculation titled Anchor Trench"
2. Selected pages from 2007 Calculation - Liner Stability on Trench 12 Side-Slopes dated August 13, 2007

**REVIEW COMMENTS:**

CALCULATION MADE BY: CAB DATE: 8/22/2007

CALCULATION CHECKED BY: SLW DATE: 8/22/2007

CALCULATION REVISED BY: CAB DATE: 8/27/07

CALCULATION REVIEWED BY: SLW DATE: 8/22/2007

## Purpose of Calculation

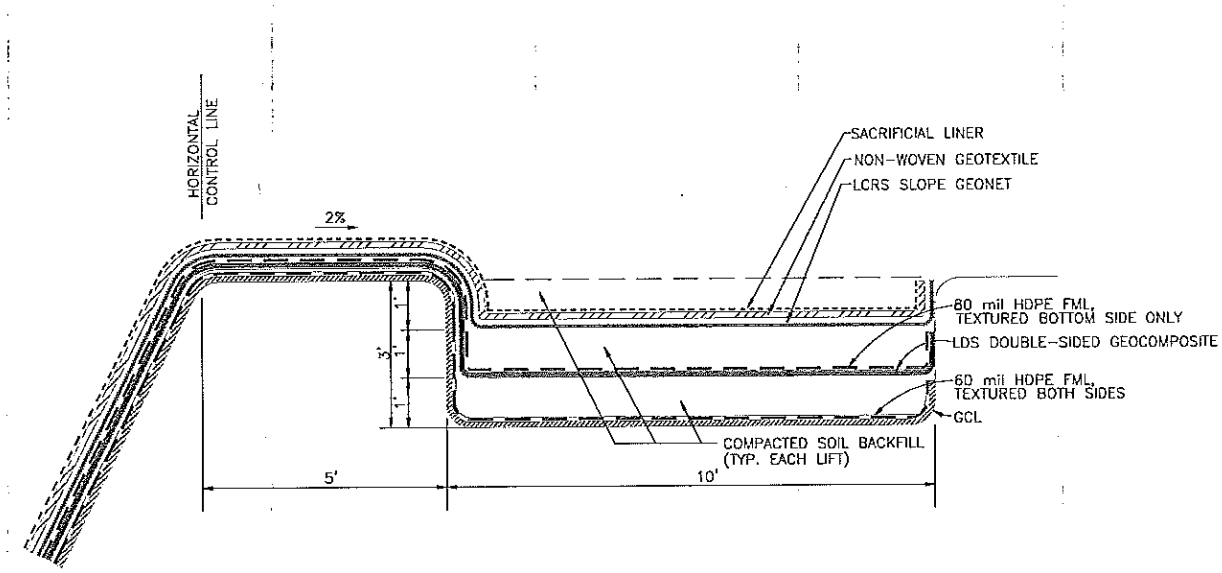
Verify that the 1996 anchor trench calculation to determine trench dimensions is applicable for liner members proposed in the 2007 design.

## Method

- Compare total liner stresses (tensile loads) of 2007 liner members and 1996 liner members.
- Compare yield strengths of 2007 liner members and 1996 liner members.

## Approach

The anchor trench is designed to withstand the total stresses of the liner side slope members. The anchor trench has the following configuration.




Total induced liner stresses due to gravity load, thermal expansion/contraction, seismic deformation, and settlement of waste fill in the 2007 design and detailed in the Liner Stresses Calculation done by AAT, August 13, 2007 was compared to stresses evaluated in the 1996 design as shown in the table below. These are the stresses considered normal during construction and operation of the landfill trench. The members are combined in zones. Zone 1 includes the upper geotextile and LCRS geonet, Zone 2 includes the primary geomembrane and LDS geocomposite, and Zone 3 includes the secondary geomembrane and GCL. A safety factor of 4 is used for the minimum required anchor capacity as was done in the 1996 calculation.

| Zone | Material | Total Induced Liner Stresses (lbs/in) 1996 Design | Zone Stresses (lbs/in) 1996 Design | Zone Stress with x4 FS (lbs/in) 1996 Design | Total Induced Liner Stresses (lbs/in) 2007 Design | Zone Stresses (lbs/in) 2007 Design | Zone Stress with x4 FS (lbs/in) 1996 Design |
|---|---|---|---|---|---|---|---|
| 1 | Geotextile | 12 | 23.3 | 93.2 | 12.1 | 22.3 | 89.2 |
| | Geonet | 11.3 | | | 10.2 | | |
| 2 | 100-mil HDPE/80-mil HDPE | 10.6 | 10.6 | 42.4 | 8.7 | 10.0 | 40.0 |
| | Geocomposite | 0 | | | 1.3 | | |
| 3 | 80-mil HDPE/60-mil HDPE | 9 | 11.4 | 45.6 | 6.8 | 10.3 | 41.2 |
| | GCL | 2.4 | | | 3.5 | | |

Since all of the zone stresses in the 2007 design are less than the 1996 design, the anchor trench design as presented in the 1996 design prevents pull-out.

The anchor trench capacity also is designed to exceed the yield strength of the stronger material in each zone such that the liner members will yield before being pulled out in the event of unforeseen incident. Localized liner member failure is preferred over pull-out at trenches. Localized liner member failures should be more easily repairable than an anchor trench pull-out.

Yield strengths were compared in the table below.

| Zone | Material (reference for product data) | Yield Strength (lb/in) 1996 Design | Strongest Yield per Zone (lbs/in) 1996 Design | Yield Strength (lb/in) 2007 Design | Strongest Yield per Zone (lbs/in) 1996 Design |
|---|---|---|---|---|---|
| 1 | Geotextile | 150 | 150 | 140 | 140 |
| | Geonet | 50 | | 45 | |
| 2 | 100-mil HDPE/80-mil HDPE | 240 | 240 | 168 | 168 |
| | Geocomposite | Not Reported | | 78[1] | |
| 3 | 80-mil HDPE/60-mil HDPE | 192 | 192 | 126 | 126 |
| | GCL | 37.5 | | 50 | |

Comparison in each zone shows that all yield strengths are highest in the 1996 design; therefore, using the 1996 anchor trench design is sufficiently conservative relative to anchor trench pull-out.

**Results**

Total liner stresses (by zone) for 2007 liner members are all less than those considered for 1996 liner members; therefore, the 1996 anchor trench design is sufficiently conservative for use in the 2007 design update.

Yield strengths (by zone) for 2007 liner members are all less than 1996 liner members; therefore, liner members should yield prior to being pulled out of the anchor trench. The 1996 anchor trench design is sufficiently conservative for use in the 2007 design update.

REFERENCE

2007 LINER STRESSES

APPLICABLE PAGES

**Table 2: Liner Properties Considered in 2007 Design**

| Liner Material (reference for product data) | Unit Weight (lbs/ft^2) | Self Weight (lbs/ft) | Accumulated Weight (lbs/ft) |
|---|---|---|---|
| **Non-woven Geotextile (GSE NW10; GEO 1008002)** | 0.069 | 5.8 | 5.8 |
| **Geonet (GSE HyperNet XL4000N004)** | 0.17 | 14 | 20 |
| **80-mil HDPE (GSE HST 080G000 - textured on one side)** | 0.37 | 31 | 51 |
| **Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile)** | 0.25 | 21 | 72 |
| **60-mil HDPE (GSE HD 060G000 –textured both sides)** | 0.28 | 24 | 96 |
| **GCL (CETCO Bentomat DN)** | 1.22 | 103 | 198 |

The 2007 design Geonet and weight was obtained from a phone conversation with the manufacturer's technical representative. Geonets are not commonly measured for unit weight.

**Table2: Material Strengths**

| Material (reference for product data) | Yield Strength (lb/in) 1996 Design | Yield Strength (lb/in) 2007 Design |
|---|---|---|
| Geotextile | 150 | 140[1] |
| Geonet | 50 | 45 |
| 100-mil HDPE/80-mil HDPE | 240 | 168 |
| Geocomposite | Not Reported | 78[1] |
| 80-mil HDPE/60-mil HDPE | 192 | 126 |
| GCL | 37.5 | 50 |

1 Yield strength obtained in phone conversation with manufacturer's representative

This calculation analyzes strength for liner materials proposed for use in Trench 12 at US Ecology's Beatty, Nevada facility. Stresses and strains on liner materials are estimated from the self weight of the liners, thermal expansion, seismic deformation, and settlement of the waste fill. The total induced stress from these factors is compared to estimated allowable stresses on the liner materials from estimated factors of safety that are assumed to be conservative.

The liner materials will be placed on a 0.5:1 slope (an angle of 63.4° below horizontal). The trench will be 75 feet deep resulting in a slope length of 84 feet.

**Self Weight Forces on Liner Members and Tensile Loads**

Assuming stable slopes, the load due to gravity (tensile load) on the liners is due to self weight (shown in the tables above). The weight on the liner members accumulates for underlying liner members.

Self Weight = unit weight * slope length

**Table 4: Stains and Total Tensile Loads on each Liner Member.**

| Liner Material (reference for product data) | T, Tensile Load Self Weight (lbs/in) | Strain due to Self Weight (%) | Strain due to Thermal Expansion (%) | Strain due to Seismic Deformation (%) | Strain due to Waste Settlement (%) | Total Strain (%) | Total Tensile Load (lbs/in) | 1996 Total Tensile Load (lbs/in) |
|---|---|---|---|---|---|---|---|---|
| Non-woven Geotextile (GSE NW10; GEO 1008002) | 0.36 | 0.13 | 0.0 | 0.2 | 4.0 | 4.3 | 12.1 | 12 |
| Geonet (GSE HyperNet XL4000N004) | 1.03 | 0.53 | 0.5 | 0.2 | 4.0 | 5.2 | 10.2 | 11.3 |
| 80-mil HDPE (GSE HST 080G000 - textured on one side) | 1.69 | 0.12 | 0.5 | 0.0 | 0.0 | 0.62 | 8.7 | 10.6 |
| Double-sided Geocomposite (GSE Fabrinet with double sided 6 ounce/yd$^2$ geotextile) | 1.26 | 0.81 | 0.0 | 0.0 | 0.0 | 0.81 | 1.3 | Ø |
| 60-mil HDPE (GSE HD 060G000 –textured both sides) | 1.56 | 0.15 | 0.5 | 0.0 | 0.0 | 0.65 | 6.8 | 9 |
| GCL (CETCO Bentomat DN) | 3.49 | 1.05 | 0.0 | 0.0 | 0.0 | 1.05 | 3.5 | 2.4 |

REFERENCE

1996 ANCHOR TRENCH CALCULATION

# C.6 ANCHOR TRENCH

# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/11/96 Subject Anchor Trench Sheet No. 0 of

Chkd. By HB Date 2/19/96 Proj. No. 95-284

ANCHOR TRENCH DESIGN

US ECOLOGY

BEATTY, NV



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/11/96 Subject Anchor Trench Sheet No. 1 of 10

Chkd. By RB Date 2/14/96 Proj. No. 95-284

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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/16/96 Subject Anchor Trench Sheet No. 2 of 10

Chkd. By WB Date 2/19/96 Proj. No. 95-284

1.0 Purpose Determine required trench dimensions.

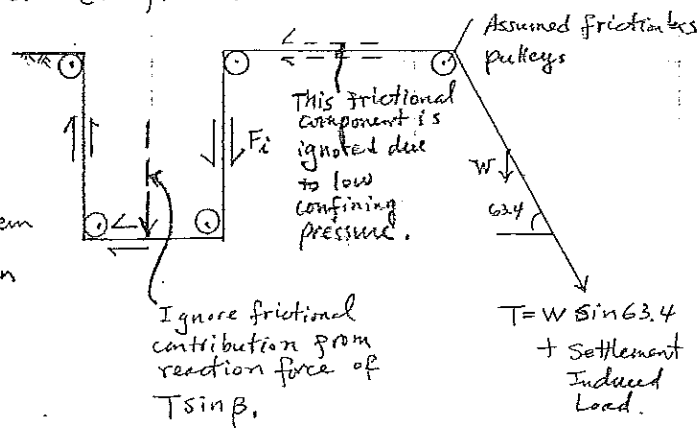
2.0 Approach

- Assume tension in liner system is taken by the sum of frictional resistance in anchor trench.

- From the model shown below, frictionless pulleys are assumed at angle points to simplify the analysis (Ref. 5).

- Downdrag Load
  T = Liner Stresses (Ref. 12)

- $F_i$ = resistance along soil/liner system interfaces (see Fig. 1 for design geometry).




MODEL

- Trench sizes are selected such that

$$\Sigma F_i \geq T \cdot F.S.$$

where F.S. is a factor of safety selected to be 4.

- The integrity of the liner components are checked in Ref. 12 with sufficient factor of safety against rupture.

- A 30-mil sacraficial HDPE membrane will be placed over the non-woven geotextile (see Figure 1) and will be anchored in Zone 1. However, this sacraficial membrane will pose very minor load. The unit weight is 0.11 lbs/ft², or 9.24 lbs/ft for 84-ft-long, 1-ft-wide strip. The downdrag load is

$$T = W \sin 63.4 = 9.24 \times \sin 63.4 = 8.26 \text{ lbs/ft} \doteq 0.7 \text{ lbs/in.}$$

Because of the negligibe load and embedment length of 10 feet, the layer will be adequately anchored.



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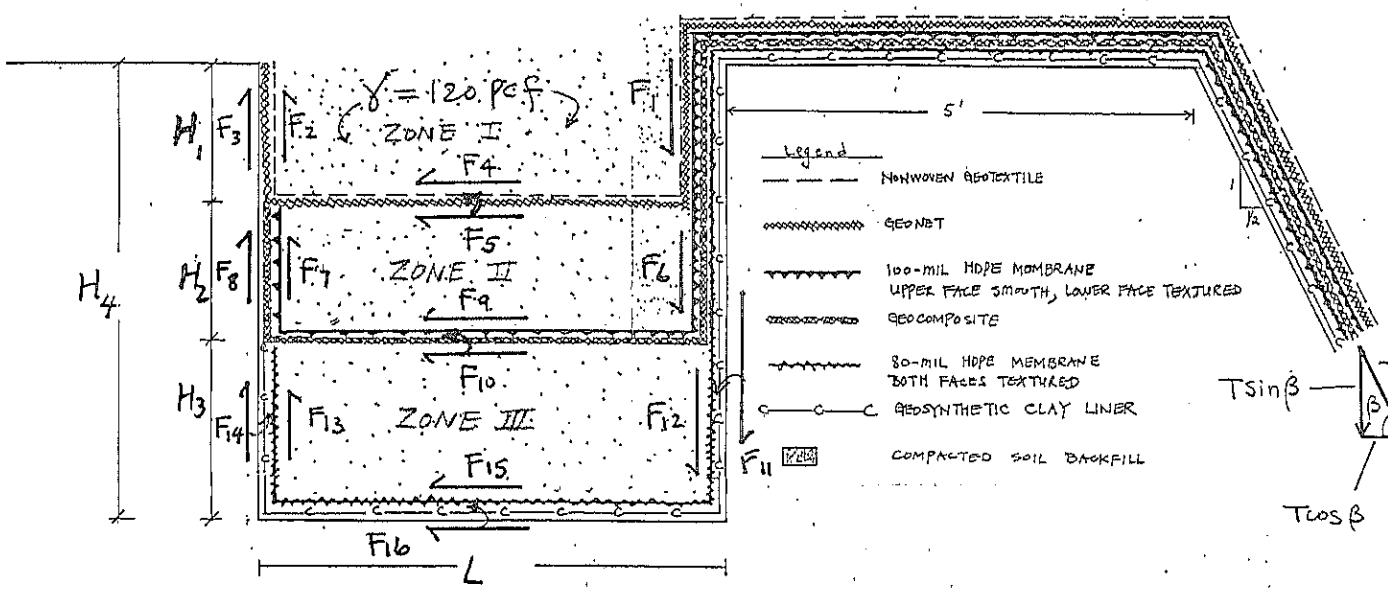
By JH Date 2/11/96 Subject ANCHOR TRENCH Sheet No. 3 of 10

Chkd. By WB Date 2/18/96 Figure Proj. No. 95-284

Figure 1




$L = 10'$

$H_1 = 1'$

$H_2 = 1'$

$H_3 = 1'$

$H_4 = 3'$

Vertical Frictional Component $= \frac{1}{2}\gamma H_i^2 K_o \tan\delta + a H_i$

Horizontal Frictional Component $= (\sigma_v \tan\delta + a) L$

$\delta$ = interface friction angle

$a$ = interface adhesion

$\sigma_v$ = vertical stress due to overburden.

3/10

# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/16/96 Subject Anchor Trench Sheet No. 4 of 10

Chkd. By WB Date 2/19/96 Proj. No. 75-284

2.0 Approach (cont'd)

- From Ref. 12, the total induced liner stresses due to gravity load, thermal expansion/contraction, seismic deformation, and settlement of waste fill are as follows for the liner components:

| Liner Components | Liner stresses (lbs/") | |
|---|---|---|
| geotextile | 12 | Zone 1 |
| geonet | 11.3 | |
| 100-mil HDPE | 10.6 | Zone 2 |
| Geocomposite | 0 | |
| 80-mil HDPE | 9 | Zone 3 |
| GCL | 2.4 | |

Let anchor capacity be at least 4 times the total liner stresses in each zone.

| Zone | Total Liner stresses (lbs/") | Minimum Required Anchor Capacity (lbs/") |
|---|---|---|
| 1 | 12+11.3 = 23.3 | 23.3×4 = 93.2 |
| 2 | 10.6 | 10.6×4 = 42.4 |
| 3 | 9+2.4 = 11.4 | 11.4×4 = 45.6 |

The anchor capacity is also designed to exceed the yield strength of the stronger material in each zone such that the liner components will yield before being pulled out.

# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/11/96 Subject Anchor Trench Sheet No. 5 of 10

Chkd. By WB Date 2/19/96 Proj. No. 95-284

3.0 Calculations

Zone 1, Geotextile and Geonet Anchor Length

Min. Required anchor capacity is 93.2 lbs/ft

or

$93.2 \times 12 = 1118.4$ lbs/ft

From Figure 1, $\Sigma F_i = F_1 + F_2 + F_3 + F_4 + F_5$

where $F_1 = F_2$ = Frictional resistance between sand and geotextile

$= \frac{1}{2} \gamma H_1^2 K_o \tan 21 + 25 H_1$ ($K_o = 0.5$ assumed, $\gamma = 120$ pcf)

$= 11.5 H_1^2 + 25 H_1$

$F_3$ = Frictional resistance between geonet and sand

$= \frac{1}{2} \gamma H_1^2 K_o \tan 30$

$= 17.3 H_1^2$

$F_4$ = Frictional resistance between geotextile and sand

$= (\gamma H_1 \tan 21 + 25) L$

$= (46 H_1 + 25) L$

$F_5$ = Frictional resistance between geotextile and geonet

$= (\gamma H_1 \tan 19 + 65) L = (41.3 H_1 + 65) L$

Let $H_1 = 1'$, $L = 10' \Rightarrow \Sigma F_i = (2 \times 36.5) + 17.3 + 710 + 1063 = 1863$ lbs/ft $> 1118$ lbs/ft (O.K.)

The yield strength of Trevira 1125 is 150 lbs/in $= 1800$ lbs/ft. $< 1863$ lbs/ft (O.K.)



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/18/96 Subject Anchor Trench Sheet No. 6 of 10

Chkd. By WB Date 3/5/96 Proj. No. 95-284

Zone 2 100 mil HDPE and Geocomposite Anchor Length

Min. Required anchor capacity is 42.4 lbs/" or

$42.4 \times 12 = 509$ lbs/ft

From Figure 1, $\Sigma F_i = F_6 + F_7 + F_8 + F_9 + F_{10}$

where $F_6 = F_7 =$ Friction resistance between sand and smooth side of HDPE.

$= \frac{1}{2}\gamma\left(H_1 + \frac{H_2}{2}\right)^2 K_o \tan 18$

$= 9.75\left(1 + \frac{H_2}{2}\right)^2$

$F_8 = \frac{1}{2}\gamma\left(H_1 + \frac{H_2}{2}\right)^2 K_o \tan 21 + a H_2$ (Geocomposite / Sand)

$= 11.5\left(1 + \frac{H_2}{2}\right)^2 + 25 H_2$

$F_9 = \gamma(H_1 + H_2)\tan 18 \cdot L$ (smooth HDPE / sand)

$= 39(1 + H_2)L$

$F_{10} = [\gamma(H_1 + H_2)\tan 7 + 280] \cdot L$

$= [14.7(1 + H_2) + 280]L$

Let $H_2 = 1'$, $L = 10'$

$\Rightarrow \Sigma F_i = 22 \times 2 + 51 + 780 + 3094 = 3969 \gg 509$ lbs/ft, O.K.

The yield strength of the 100-mil HDPE is 240* lbs/" = 2880 lbs/ft which is less than the anchor capacity, O.K.

* From Ref. 4



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/18/96 Subject Anchor Trench Sheet No. 7 of 10

Chkd. By WB Date 2/19/96 Proj. No. 95-284

Zone 3 80 mil HDPE and GCL

min. Required anchor capacity is 45.6 lbs/ft

or $45.6 \times 12 = 547$ lbs/ft.

From Figure 1, $\Sigma F_i = F_{11} + F_{12} + \cdots + F_{16}$

where $F_{11}$ = GCL internal shear strength

$$= \frac{1}{2}\gamma\left(\frac{2+H_3}{2}\right)^2 K_o \tan 5 + 550\cdot(2+H_3)$$

$$= 2.6\left(\frac{2+H_3}{2}\right)^2 + 550(2+H_3)$$

$$F_{12} = F_{13} = \frac{1}{2}\gamma\left(2+\frac{H_3}{2}\right)^2 K_o \tan 26 \qquad \text{(textured HDPE/Sand)}$$

$$= 14.6\left(2+\frac{H_3}{2}\right)^2$$

$$F_{14} = \frac{1}{2}\gamma\left(2+\frac{H_3}{2}\right)^2 K_o \tan 5 + 550\, H_3 \qquad \text{(GCL Internal)}$$

$$= 2.6\left(2+\frac{H_3}{2}\right)^2 + 550\, H_3$$

$$F_{15} = \gamma(2+H_3)\tan 26 \cdot L \qquad \text{(textured HDPE/Sand)}$$

$$= 58.5(2+H_3)L$$

$$F_{16} = [\gamma(2+H_3)\tan 5 + 550]L \qquad \text{(GCL internal)}$$

$$= [10.5(2+H_3)+550]L$$

Let $H_3 = 1'$, $L = 10'$ $\Rightarrow \Sigma F_i = 1656 + 2\times 32 + 566 + 1755 + 5815$

$= 9856$ lbs/ft $\gg$ 547 lbs/ft, O.K.

The yield strength of the 80-mil HDPE is 192 lbs/in (Ref. 4) which is $192 \times 12 = 2304$ lbs/ft. ($\ll$ 9856 lbs/ft, O.K.)



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# ENVIRONMENTAL SOLUTIONS, INC.

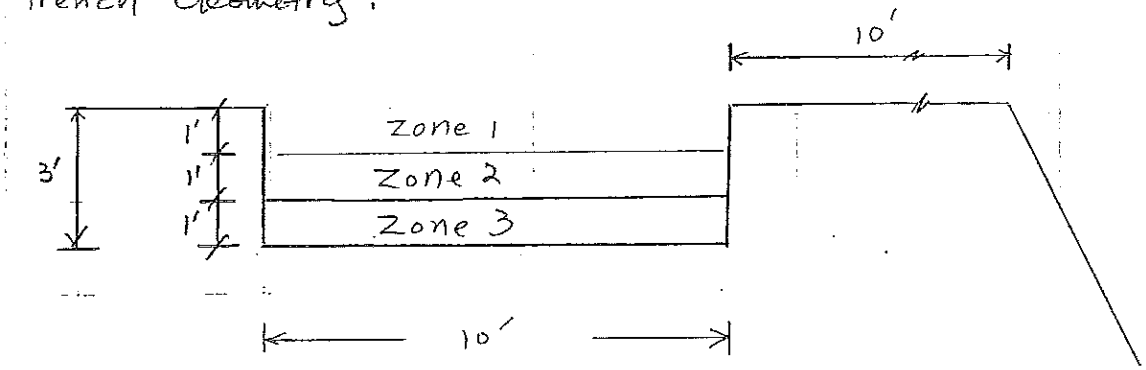
By JH Date 2/18/96 Subject Anchor Trench Sheet No. 8 of 10

Chkd. By KB Date 2/19/96 Proj. No. 95-284

4.0 Summary

- 10' wide trench is required to accomodate the downdrag load from zone 1. The anchor trench is designed such that the liner components will yield before being pulled out.

- Anchor Trench Geometry:




- Design interface, friction angle, adhesion, and equations are summarized in Table 1.

- Actual materials used in construction should be tested to obtain stress-strain properties and interface shear strength parameters.

- a 30-mil sacraficial HDPE membrane will be placed over the non-woven geotextile and will be anchored in Zone 1. Considering the negligible load applied to the anchor trench by the weight of this membrane, the inclusion of this sacraficial membrane in the anchor trench will have no effect to trench dimensions.



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/11/96 Subject Anchor Trench Sheet No. 9 of 10

Chkd. By WB Date 2/19/96 Table 1 Proj. No. 95-284

| Friction Force No. | Interface | Interface Friction angle (degree) | Interface Adhesion (PSF) | Reference No. | Equation (1),(2) |
|---|---|---|---|---|---|
| $F_1, F_2$ | Geotextile / Sand | 21 | 25 | 1 | $11.5\,H_1^2 + 25\,H_1$ |
| $F_3$ | Geonet / Sand | 30 | 0 | Assumed | $17.3\,H_1^2$ |
| $F_4$ | Geotextile / Sand | 21 | 25 | 1 | $(46\,H_1 + 25)\,L$ |
| $F_5$ | Geotextile / geonet | 19 | 65 | 1 | $(41.3\,H_1 + 65)\,L$ |
| $F_6, F_7$ | Smooth HDPE / Sand | 18 | 0 | 2 | $9.75\,(1 + \frac{H_2}{2})^2$ |
| $F_8$ | Geocomposite / Sand | 21 | 25 | 1 | $11.5\,(1 + \frac{H_2}{2})^2 + 25\,H_2$ |
| $F_9$ | Smooth HDPE / Sand | 18 | 0 | 2 | $39\,(1 + H_2)\,L$ |
| $F_{10}$ | Textured HDPE / Geocomposite | 7 | 280 | 1 | $[14.7\,(1 + H_2) + 280]\,L$ |
| $F_{11}$ | GCL internal | 5 | 550 | 9, 10 | $2.6\,(\frac{3 + H_3}{2})^2 + 550\,(3 + H_3)$ |
| $F_{12}, F_{13}$ | Textured HDPE / Sand | 26 | 0 | 4 | $14.6\,(3 + \frac{H_3}{2})^2$ |
| $F_{14}$ | GCL internal | 5 | 550 | 9, 10 | $2.6\,(3 + \frac{H_3}{2})^2 + 550\,H_3$ |
| $F_{15}$ | Textured HDPE / Sand | 26 | 0 | 4 | $58.5\,(3 + H_3)\,L$ |
| $F_{16}$ | GCL internal (4) | 5 | 550 | 9, 10 | $[10.5\,(3 + H_3) + 550] \cdot L$ |

Notes: (1) From Ref. 5 $\Rightarrow T = \Sigma F_i$ (3) $a$ = adhesion, $\delta$ = friction angle.

(2) $H_i$ = Depth of Embedment, $L$ = Trench Width. (4) Assumed shearing occur at internal face of GCL.



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# ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 2/11/96 Subject _____ Sheet No. 10 of 10

Chkd. By WB Date 2/19/96 _____ Proj. No. 95-284

5.0 References


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# LCRS INFILTRATION RATE

AquAeTer

*optimizing environmental resources - water; air; earth*

# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: August 6, 2007

CALCULATION NUMBER: C.8 Revision: Update per 2007 Design

**CALCULATION TITLE: LCRS Infiltration Rates**

**DESCRIPTION OF CALCULATION: LCRS Infiltration Rates**

Determine infiltration rates into the Trench 12 Leachate Collection/Recovery System (LCRS) by same method used for previously approved calculation (1996) done for same purpose. Design change necessitating calculation update are 1) change in area of Trench 12 bottom, and 2) change in approach to managing all precipitation inside Trench 12 after first waste is disposed. All precipitation collected inside the cell, whether from floors or sidewalls, is to be considered leachate.

**REFERENCES USED:** Number of Reference Pages Attached:

Previous calc: 1996 calculation titled "LCRS Flow Capacity and Pump Sizing"

Design drawing (2007) for Trench 12

**REVIEW COMMENTS:**

CALCULATION MADE BY: SLW DATE: 8/6/2007

CALCULATION CHECKED BY: CAB DATE: 8/7/2007

CALCULATION REVISED BY: CAB DATE: 8/27/07

CALCULATION REVIEWED BY: SLW DATE: 8/7/2007

## Purpose of Calculation

Determine the potential flow rate into the LCRS sump(s)

## Method

- Leachate: per discussions between USEN and NDEP (May 23, 2007 meeting), it was agreed that after the first waste is placed all precipitation collected inside Trench 12 must be managed as leachate.

- The sidewall liner design will include an upper (sacrificial) HDPE layer whose function will be to protect the liner components from direct exposure to solar UV radiation (and potential material deterioration from long-term UV exposure) and possibly to reduce the temperate change range in liner materials. That HDPE layer also will prevent direct entry of precipitation into the leachate collection member (geonet) of the liner system, instead routing all incident precipitation onto the cell floor.

- All incident precipitation (falling on the cell floor and sidewalls) will infiltrate into disposed waste and (ultimately) to the LCRS.

- The design storm is the 25-year, 24-hr storm, when is approximately 2.0 inches, based on Figure 28, NOAA Atlas 2, Volume VII.

- NOTE – precipitation that falls and collects within cell areas under construction (i.e., before waste placement) is not leachate, and can be managed by other means appropriate to stormwater management. Management of such stormwater is not the subject of this calculation.

## Calculation Steps

Precipitation

1. The critical period (i.e., when the greatest flow is likely to occur) for sizing the leachate collection system is directly after placement of the two-feet thick layer of select waste over the bottom of the cell. Infiltration likely will reach the LCRS most quickly (after precipitation) and with least loss (i.e., moisture retention within waste) at this point.

2. The attached figure shows the configuration of the three phases (cells) and corresponding LCRS sumps of Trench 12, designated Phases 1, 2, and 3 and Sumps 12A, 12B, and 12C. The horizontal area (foot print) of the three phases, as determined in a separate calculation, is as follows.

| Phases | LCRS Sump | Floor Area (sq ft) | Sidewall Area\| (sq ft) | Total Area (acres) | Design Precipitation* (acre-feet) |
|---|---|---|---|---|---|
| 1 | 12A | 149,149 | 44,492 | 4.45 | 0.74 |
| 2 | 12B | 122,425 | 28,055 | 3.45 | 0.58 |
| 3 | 12C | 93,409 | 48,410 | 3.26 | 0.54 |

* = Design Precipitation = Area (acres) x (2/12 feet)

Infiltration into the LCRS

1. No allowance is made for evaporation, so all precipitation is routed through the disposed waste (30 inches (2.5 feet) of selected waste).

2. Sandy soil is assumed to comprise the select soil layer. In the Engineering Documentation for the USEPA Help model, important properties of typical sandy soil types are provided. Conservatively, the most permeable of the sandy soil types is considered in this calculation.

| | |
|---|---|
| Soil type (Unified Soil Classification System) | SM |
| Hydraulic conductivity | 5.2 x 10-4 cm/sec |
| Porosity | 0.473 |
| Field capacity | 0.222 |
| Wilting point | 0.104 |

3. For cell 12A, total precipitation, and total water available for infiltration, is 0.74 acre-feet. It is necessary to determine if saturated or unsaturated flow conditions will control infiltration through the waste. It is assumed that the soil layer contains, at most, sufficient moisture to be a field capacity (i.e., no gravity drainage occurs). A unit volume (1 ft x 1 ft x 2.5 ft thick) of the SM soil layer has available pore space (based above properties) of:

$$2.5 \text{ cu ft} \times 7.48 \text{ gallons/cu ft} \times (0.473 - 0.22) = 4.73 \text{ gallons}$$

4. The rate at which the 0.74 ac-ft (i.e., 2" over full 4.45 ac Phase 1 footprint) design storm saturates the 1 ft x 1 ft unit volume of soil on the 3.42 ac cell floor during a 24 hour period is:

0.74 ac-ft / 3.42 ac X 7.48 gal/cu ft X 1 day / 1440 min = 1.12 x 10-3 gal/min for each 1 ft x 1 ft unit volume

If the design storm occurs when the soil layer already is near Field Capacity (i.e., maximum moisture content without drainage), what fraction of the remaining air-filled porosity is filled by the design storm?

Porosity, $\phi$ = 0.473 or 47.3% of 30 inches = 14.19 inches

FC = 0.222 or 22.2% of 30 inches = 6.66 inches

Remaining air space before storm = 14.19 – 6.66 = 7.53 inches

Design storm = 2 inches over the full 4.45 acres of Phase 12A, which, when all precipitation falling on the 44,492 sq ft (1.02 ac) of the Phase 12A side slopes is routed to the cell floor, is equivalent to 2.6 inches over the 149,149 sq ft (3.42 ac) cell floor. 2.6 inches is less than 7.53 inches, so the design storm does not fully saturate the select waste layer unit volume. The combination of FC and design storm moisture results in the following water-filled geometery in the unit volume:

6.66" + 2.6" = 9.26", or 9.26" / 14.19" = 65% of available air space

This is a volumetric moisture content of:

0.222 + 2.6" / 30" = 0.222 + 0.087 = 0.309

Assuming that drainage does not begin during the design storm, 65% of the total air space is saturated following the storm. Since 65% is less than 100%, unsaturated flow controls drainage from the unit volume of soil (1 ft x 1 ft x 2.5 ft thick select waste layer) following the design storm.

Laminar flow through a porous medium is estimated by d'Arcy's Law, or

Q = Kia

Where,

Q = flow (typical unit is cu ft / min

K = hydraulic conductivity (typical unit is ft / min)

i = gradient (feet / feet or unit-less)

a = area through which flow occurs (square feet)

for unsaturated flow, unsaturated hydraulic conductivity (Ku) replaces K

5. For the unsaturated flow through the select waste layer,

   K = 5.2 x 10-4 cm/sec or 1.02 x 10-3 ft / min

   i = 2.5 ft / 2.5 ft = 1.0

   a = 1 sq ft

6. Unsaturated hydraulic conductivity is estimated by Campbell's equation (Engineering Documentation for the USEPA Help model):

   $Ku = Ks\ [(\theta - \theta r) / (\phi - \theta r)]^{**}[3 + (2 / \lambda)]$

   Where

   $Ku$ = unsaturated hydraulic conductivity, cm/sec
   $Ks$ = saturated hydraulic conductivity, cm/sec
   $\theta$ = actual volumetric water content, vol/vol
   $\theta r$ = residual volumetric water content, vol/vol
   $\phi$ = total porosity, vol/vol
   $\lambda$ = pore-size distribution index, dimensionless

7. The residual water content, $\theta r$, is the amount of water remaining in the soil pores under infinite capillary suction. Residual water content is estimated by Rawls (Help documentation) as follows.

   $$\theta r = 0.014 + 0.25\ X\ Wilting\ Point,\ where\ WP \geq 0.04$$

   In this case, WP = 0.104 and is $\geq$ 0.04 and the equation is applicable. The residual water content is:

   $$\theta r = 0.014 + 0.25\ X\ 0.104 = 0.040$$

8. As discussed in the Help documentation reference, residual water content and pore-size distribution index, $\lambda$, are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces).

$$(\theta - \theta r) / (\phi - \theta r) = (\psi b / \psi)^{**}\lambda$$

Where
$\psi$ = capillary pressure, bars
$\psi b$ = bubbling pressure, bars

9. This equation is solved assuming that the volumetric water content is the field capacity at 0.33 bars of capillary suction, $\psi$, and equal to the wilting point at 15 bars capillary suction, $\psi b$. Solving the two equation for the values assumed for the site soil provides the following results.

| Constants | Variables |
|---|---|
| $\theta r$ = 0.040 | Field capacity = 0.222 @ $\psi$ = 0.33 |
| $\phi$ = 0.473 | Wilting point = 0.104 @ $\psi$ = 15 |

Two equations in two unknowns solved on next page, results are:

$\psi b$ = 0.013

$\lambda$ = 0.270

10. Assuming drainage does not start during the design storm, the volumetric water content following the storm is:

$$\theta = \text{Field Capacity} + 2.6" / 30"$$

$$\theta = 0.222 + 0.087$$

$$= 0.309$$

11. Based on the preceding, the unsaturated hydraulic conductivity is calculated as follows using Campbell's equation.

$$Ku = Ks\ [(\theta - \theta r) / (\phi - \theta r)]^{**}[3 + (2 / \lambda)]$$

$$Ku = 1.02 \times 10\text{-}3 * [(0.309–0.040) / (0.473–0.040)]^{**}[3 + (2 / 0.27)]$$

$$= 7.10 \times 10\text{-}6 \text{ ft/min}$$

12. Conservatively using a unit hydraulic gradient and assuming no evaporation, the rate at which infiltration drains through and from the 2.5 feet thick select soil layer into the LCRS per unit area (1 sq ft) is:

$$Q = Ku * i * A$$

$$Q = (7.10 \times 10\text{-}6 \text{ ft / min})(1.0)(1.0 \text{ sq ft})$$

$$= 7.10 \times 10\text{-}6 \text{ cu ft / min per square foot area}$$

$$= 5.31 \times 10\text{-}5 \text{ gal/ min per square foot area}$$

Drainage over the entire 3.42 acre area of the Phase 1 floor is:

$$Q = (5.31 \text{ gal} \times 10\text{-}5 \text{ gal / sq ft – min}) \text{ X } 3.42 \text{ acre X } 43{,}560 \text{ sq ft / acre}$$

$$Q = 7.9 \text{ gallons per minute}$$

The calculation was repeated for cells 12B and 12C. The results of the analyses are provided in the attached table.

**Calculation result**

When the 2.5-feet thick select waste layer, before placement of any additional waste, is subject to the 2-inch design storm, the resulting infiltration into the LCRS drainage net is dependent on unsaturated flow conditions and result in the following flow.

| Cell | Infiltration (gal/min/cell) |
|---|---|
| 12A | 7.9 |
| 12B | 5.4 |
| 12C | 8.6 |

**Infiltration Into the LCRS**

| Cell | Floor (ft2) | Sidewalls (ft2) | Design Storm (in) | Design Storm Precip to Floor (in) | Vol Water Content After Storm % | Ku (cm/sec) | Ku (ft/min) | $q$ ($ft^3/min/ft^2$) | $q$ ($gal/min/ft^2$) | $q$ (gal/min/cell) |
|---|---|---|---|---|---|---|---|---|---|---|
| 12A | 149,149 | 44,492 | 2 | 2.60 | 0.309 | 3.61E-06 | 7.10E-06 | 7.10E-06 | 5.31E-05 | 7.9 |
| 12B | 122,425 | 28,055 | 2 | 2.46 | 0.304 | 3.01E-06 | 5.93E-06 | 5.93E-06 | 4.43E-05 | 5.4 |
| 12C | 93,409 | 48,410 | 2 | 3.04 | 0.323 | 6.27E-06 | 1.23E-05 | 1.23E-05 | 9.23E-05 | 8.6 |

Variables

| | | k (cm/sec) | Porosity % | FC % | WP % | $\Psi b$ | $\lambda$ | $\theta r$ | $i$ | A ($ft^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil Type | SM | 5.20E-04 | 0.473 | 0.222 | 0.104 | 0.013 | 0.27 | 0.04 | 1 | 1 |

$A = \Psi_b \qquad B = \lambda$

$$\left(\frac{A}{0.33}\right)^B = 0.42 \qquad \left(\frac{A}{15}\right)^B = 0.15$$

$$B \log A - B \log 0.33 = \log 0.42$$
$$B \log A - B \log 15 = \log 0.15$$

$$B \log A = \log 0.42 + B \log 0.33$$
$$B \log A = \log 0.15 + B \log 15$$

$$\log 0.42 + B \log 0.33 = \log 0.15 + B \log 15$$
$$B \log 0.33 - B \log 15 = \log 0.15 - \log 0.42$$
$$B (\log 0.33 - \log 15) = \log 0.15 - \log 0.42$$

$$B = \frac{\log 0.15 - \log 0.42}{\log 0.33 - \log 15} = \frac{-0.447}{-1.658} = 0.27$$

$$(0.27) \log A = \log 0.42 + (0.27) \log 0.33$$

$$\log A = \frac{-0.507}{+0.27} = -1.877$$

$$A = 10^{-1.877} = 0.013$$

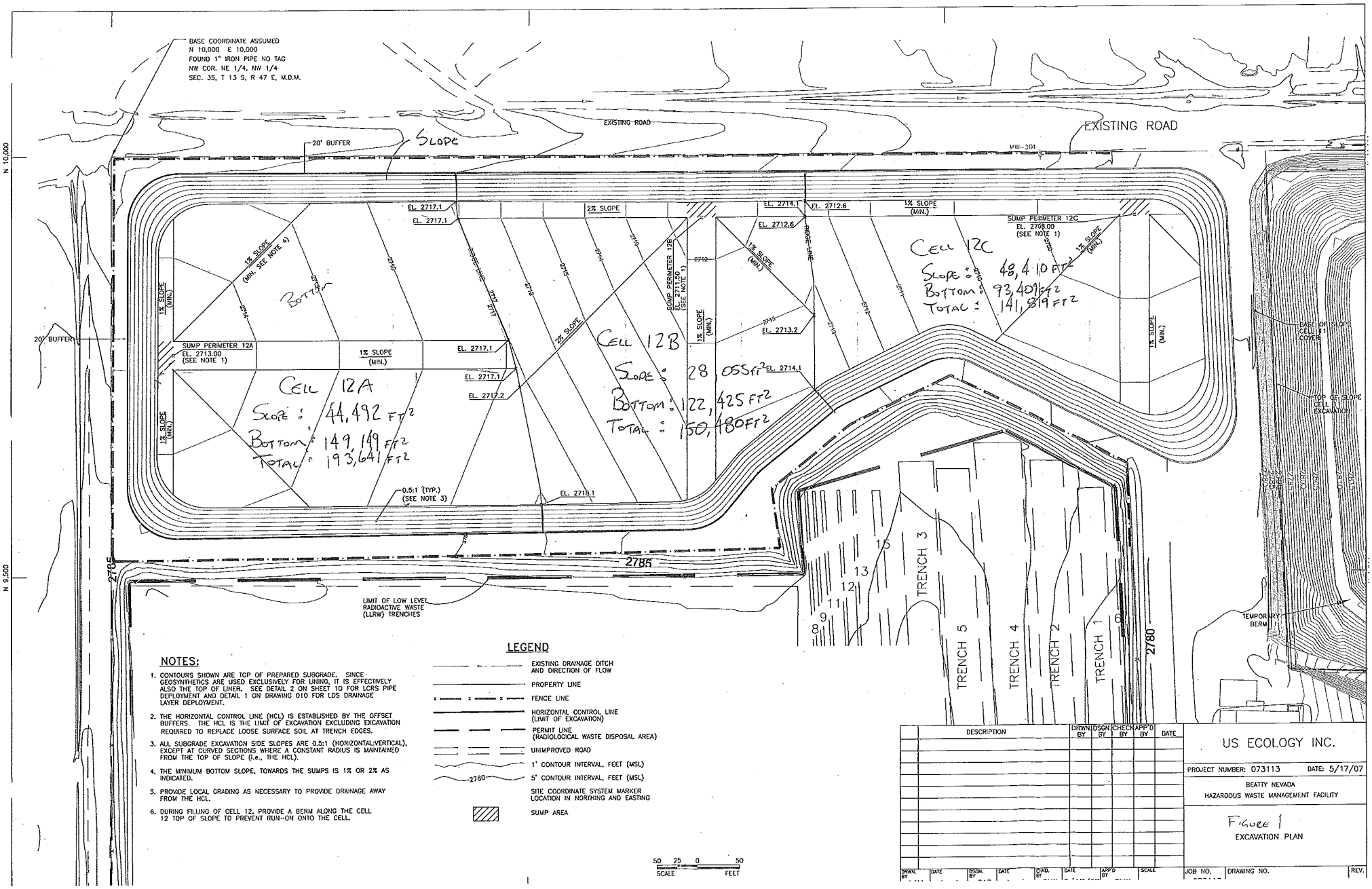
$\Psi_b = 0.013$

$\lambda = 0.27$

REFERENCE

AREAS FROM

2007 DESIGN DRAWINGS




## NOTES:

1. CONTOURS SHOWN ARE TOP OF PREPARED SUBGRADE. SINCE GEOSYNTHETICS ARE USED EXCLUSIVELY FOR LINING, IT IS EFFECTIVELY ALSO THE TOP OF LINER. SEE DETAIL 2 ON SHEET 10 FOR LCRS PIPE DEPLOYMENT AND DETAIL 1 ON DRAWING 010 FOR LDS DRAINAGE LAYER DEPLOYMENT.
2. THE HORIZONTAL CONTROL LINE (HCL) IS ESTABLISHED BY THE OFFSET BUFFERS. THE HCL IS THE LIMIT OF EXCAVATION EXCLUDING EXCAVATION REQUIRED TO REPLACE LOOSE SURFACE SOIL AT TRENCH EDGES.
3. ALL SUBGRADE EXCAVATION SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e., THE HCL).
4. THE MINIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1% OR 2% AS INDICATED.
5. PROVIDE LOCAL GRADING AS NECESSARY TO PROVIDE DRAINAGE AWAY FROM THE HCL.
6. DURING FILLING OF CELL 12, PROVIDE A BERM ALONG THE CELL 12 TOP OF SLOPE TO PREVENT RUN-ON ONTO THE CELL.

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- PROPERTY LINE
- FENCE LINE
- HORIZONTAL CONTROL LINE (LIMIT OF EXCAVATION)
- PERMIT LINE (RADIOLOGICAL WASTE DISPOSAL AREA)
- UNIMPROVED ROAD
- 1' CONTOUR INTERVAL, FEET (MSL)
- 2780 — 5' CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- SUMP AREA

50 25 0 50
SCALE FEET

| DESCRIPTION | DRWN. BY | DSGN. BY | CHECK BY | APP'D BY | DATE |
|---|---|---|---|---|---|
| | | | | | |

US ECOLOGY INC.

PROJECT NUMBER: 073113 DATE: 5/17/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

FIGURE 1
EXCAVATION PLAN

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
|---|---|---|---|---|---|---|---|---|---|---|

REFERENCE

HELP MODEL SOIL VALUES

# THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

*ENGINEERING DOCUMENTATION FOR VERSION 3*

by

Paul R. Schroeder, Tamsen S. Dozier, Paul A. Zappi,
Bruce M. McEnroe, John W. Sjostrom and R. Lee Peyton
Environmental Laboratory
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, MS 39180-6199

Interagency Agreement No. DW21931425

Project Officer

Robert E. Landreth
Waste Minimization, Destruction and Disposal Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

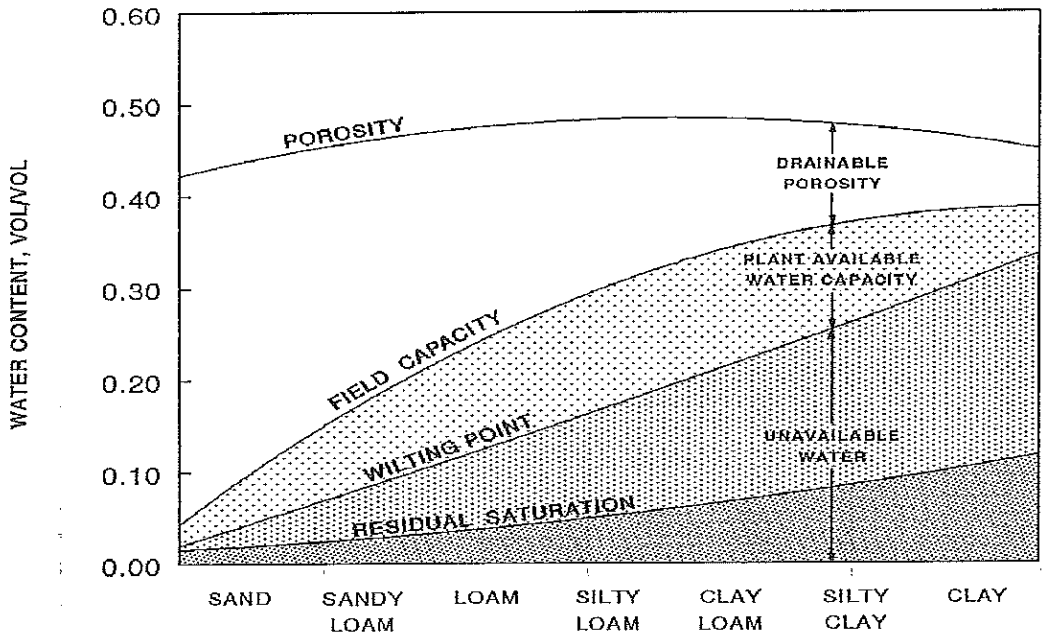



Figure 2. Relation Among Moisture Retention Parameters and Soil Texture Class

are not specified, the program assumes values near the steady-state values (allowing no long-term change in moisture storage) and runs a year of simulation to initialize the moisture contents closer to steady state. The soil water contents at the end of this year are substituted as the initial values for the simulation period. The program then runs the complete simulation, starting again from the beginning of the first year of data. The results of the volumetric water content initialization period are not reported in the output.

### 3.3.2 Unsaturated Hydraulic Conductivity

Darcy's constant of proportionality governing flow through porous media is known quantitatively as hydraulic conductivity or coefficient of permeability and qualitatively as permeability. Hydraulic conductivity is a function of media properties, such as particle size, void ratio, composition, fabric, degree of saturation, and the kinematic viscosity of the fluid moving through the media. The HELP program uses the saturated and unsaturated hydraulic conductivities of soil and waste layers to compute vertical drainage, lateral drainage and soil liner percolation. The vapor diffusivity for geomembranes is specified as a saturated hydraulic conductivity to compute leakage through geomembranes by vapor diffusion.

### *Saturated Hydraulic Conductivity*

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

### *Unsaturated Hydraulic Conductivity*

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

$$K_u = K_s \left[ \frac{\theta - \theta_r}{\phi - \theta_r} \right]^{3+\left(\frac{2}{\lambda}\right)} \tag{5}$$

where

$K_u$ = unsaturated hydraulic conductivity, cm/sec

$K_s$ = saturated hydraulic conductivity, cm/sec

$\theta$ = actual volumetric water content, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\phi$ = total porosity, vol/vol

$\lambda$ = pore-size distribution index, dimensionless

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & \text{for } WP \geq 0.04 \\ 0.6\,WP & \text{for } WP < 0.04 \end{cases} \tag{6}$$

where

$WP$ = volumetric wilting point, vol/vol

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \tag{7}$$

where

$\psi$ = capillary pressure, bars

$\psi_b$ = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retention and matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions).

The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

### 3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

| Soil Texture Class | | | Total Porosity vol/vol | Field Capacity vol/vol | Wilting Point vol/vol | Saturated Hydraulic Conductivity cm/sec |
|---|---|---|---|---|---|---|
| HELP | USDA | USCS | | | | |
| 1 | CoS | SP | 0.417 | 0.045 | 0.018 | $1.0 \times 10^{-2}$ |
| 2 | S | SW | 0.437 | 0.062 | 0.024 | $5.8 \times 10^{-3}$ |
| 3 | FS | SW | 0.457 | 0.083 | 0.033 | $3.1 \times 10^{-3}$ |
| 4 | LS | SM | 0.437 | 0.105 | 0.047 | $1.7 \times 10^{-3}$ |
| 5 | LFS | SM | 0.457 | 0.131 | 0.058 | $1.0 \times 10^{-3}$ |
| 6 | SL | SM | 0.453 | 0.190 | 0.085 | $7.2 \times 10^{-4}$ |
| 7 | FSL | SM | 0.473 | 0.222 | 0.104 | $5.2 \times 10^{-4}$ |
| 8 | L | ML | 0.463 | 0.232 | 0.116 | $3.7 \times 10^{-4}$ |
| 9 | SiL | ML | 0.501 | 0.284 | 0.135 | $1.9 \times 10^{-4}$ |
| 10 | SCL | SC | 0.398 | 0.244 | 0.136 | $1.2 \times 10^{-4}$ |
| 11 | CL | CL | 0.464 | 0.310 | 0.187 | $6.4 \times 10^{-5}$ |
| 12 | SiCL | CL | 0.471 | 0.342 | 0.210 | $4.2 \times 10^{-5}$ |
| 13 | SC | SC | 0.430 | 0.321 | 0.221 | $3.3 \times 10^{-5}$ |
| 14 | SiC | CH | 0.479 | 0.371 | 0.251 | $2.5 \times 10^{-5}$ |
| 15 | C | CH | 0.475 | 0.378 | 0.251 | $2.5 \times 10^{-5}$ |
| 21 | G | GP | 0.397 | 0.032 | 0.013 | $3.0 \times 10^{-1}$ |

$a$ = constant representing the effects of various fluid constants and gravity, 21 $cm^3/sec$

$\phi$ = total porosity, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\psi_b$ = bubbling pressure, cm

$\lambda$ = pore-size distribution index, dimensionless

A more detailed explanation of Equation 11 can be found in Appendix A of the HELP program Version 3 User's Guide and the cited references.

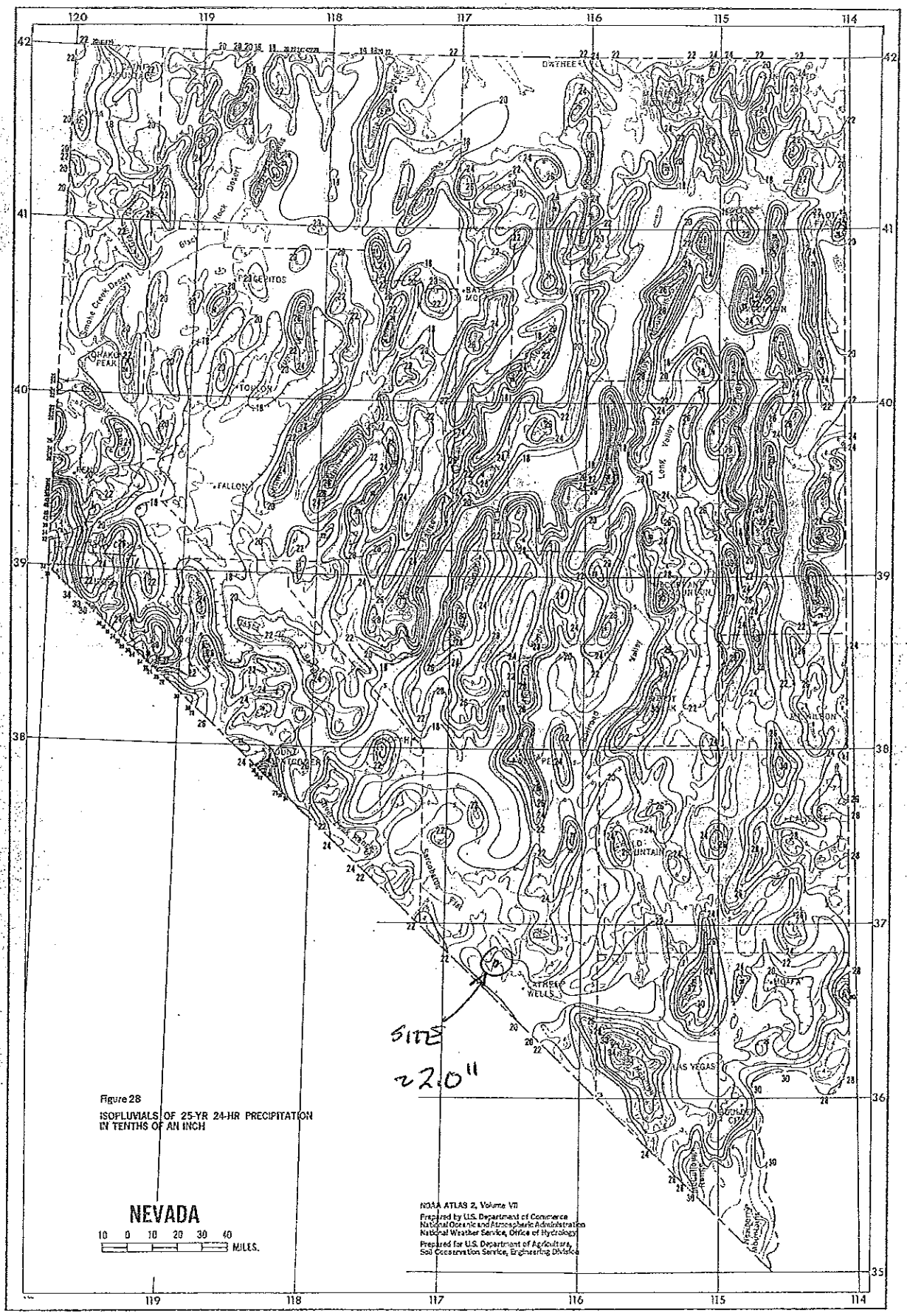



Figure 28

ISOPLUVIALS OF 25-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

NEVADA

10 0 10 20 30 40 MILES.

NOAA ATLAS 2, Volume VII

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

REFERENCE

1996 DESIGN CALCULATION

# Environmental Solutions, Inc.

By: RVH Date:2/22/96 Beatty Landfill-Cell 12 Page No. 1
Chk'd By: EC Date: 3/8/96 American Ecology Corporation Project No. 95-284

## LCRS Flow Capacity and Pump Sizing

**Purpose:**

1. Determine the potential flow rate into the leachate collection and removal sumps.

2. Size the flow elements (geonets, pipes, and gravel) and pumps to handle the projected flows.

3 Determine most effective method and pump requirements for run-off flows

**Method:**

1. Identify flow sources. The single largest source of liquid entering the sumps will be from infiltration when the cell has been completed but only the 2 foot thick select waste layer has been placed.

2. The design will assume the 25 year-24 hour storm event occurs just after placement of the select waste layer.

3. An infiltration factor will be selected.

4. The quantity of run-off will be calculated. Methods for handling run-off (which shall be considered hazardous waste) will be identified.

5. The quantity of infiltration, and the resultant flow to the sumps will be calculated. The sump flow elements will be sized to handle that flow. Pumps capable of evacuating that flow from the sumps will be identified.

**Summary**

1. 25 Year-24 Hour storm yields 2 inches of precipitation

2. Infiltration flow is controlled by unsaturated flow.

3. The maximum LCRS flow is 2 gallons per minute.

4. The geonet has insufficient capacity for the maximum infiltration flow and must be supplemented by 3 inch diameter slotted pipes (see layout in Figure 3).

5. In run-off systems must be able to store up to171,000 gallons of water, or be capable of pumping up to 100 gpm, if only a nominal impoundment is desired.

6. The maximum requirement for out of cell capacity is 300,000 gallons, assuming no measures to reduce contact between precipitation and waste are utilized.

**Analysis:**

Hydrology

1. The critical period for sizing the leachate collection system (i.e., when the greatest flow is likely to occur) is directly after placement of the 2 foot thick layer of select

waste over the bottom. The quantity of infiltration reaching the LCRS through the waste will be the greatest at this point, although all water touching the waste will be considered leachate. During the construction period precipitation will be impounded within the cell, removed and discharged to the existing channels.

2. Figure 1 shows the configuration of Cell 12. Each phase of the cell is indicated along with slope, bottom, and total catchment areas. Cell 12C includes the top deck area where Cell 12 adjoins Cell 11.

3. The 25 year-24 hour storm yields 2 inches of precipitation (Reference 1A). The working deck is assumed to be well compacted by heavy equipment running over its surface, yielding a relatively high run-off curve number. Since the characteristics of the waste soil are unknown at this time assume soil group B (Reference 1A) and an SCS RCN of 85 (Ref 2A). Further assume run-off from the slopes (with the sacrificial liner) is intercepted and directed to run-off collection tanks/ponds. Table 1, below, shows the distribution for precipitation falling on the floor only:

Table 1

| Cell | Area (ac) | Precipitation (ac-ft) | Run-off (ac-ft) | Infiltration (ac-ft) |
|---|---|---|---|---|
| 12A | 2.36 | 0.39 | 0.16 | 0.24 |
| 12B | 1.81 | 0.30 | 0.12 | 0.18 |
| 12C | 1.46 | 0.24 | 0.10 | 0.15 |

LCRS Infiltration:

1. No allowance is made for evaporation, and all infiltration will be routed through the LCRS system. This provides a conservative total volume for the system design.

2. Sandy soils, assumed to comprise the 2 foot protective layer, have a wide range of porosities and moisture retention values. Typical values are taken from the HELP model literature (Reference 3A) as being conservative representations of this soil. The values are:

| | |
|---|---|
| Soil Type | SC |
| Hydraulic Conductivity | $1.2 \times 10^{-4}$ cm/s |
| Porosity | 0.398 |
| Field Capacity | 0.244 |
| Wilting Point | 0.136 |

3. For the largest infiltration case, Cell 12A, there is 0.24 ac-ft, or nearly 80,000 gallons, of infiltration. It is necessary to determine whether saturated or unsaturated flow conditions control drainage into the LCRS. It is assumed that the soil layer contains, at most, sufficient moisture to be at field capacity (i.e., no gravity drainage is initially occuring within the soil). A 2 foot thick layer of soil of unit area therefore has an available pore space of approximately:

$$2\,ft^3 \times 7.48\frac{gal}{ft^3} \times (0.398 - 0.244) = {}^{2.3gal}\!/_{ft^2}$$

## LCRS Flow Capacity and Pump Sizing

4. The rate at which the storm saturates the soil layer is given by:

$$0.24\text{ac}-\text{ft}\times\frac{1}{2.36\text{ac}}\times 7.48\frac{\text{gal}}{\text{ft}^3}\times\frac{1\text{day}}{1440\text{min}}\cong\frac{1\text{gal}}{1850\text{min}}$$

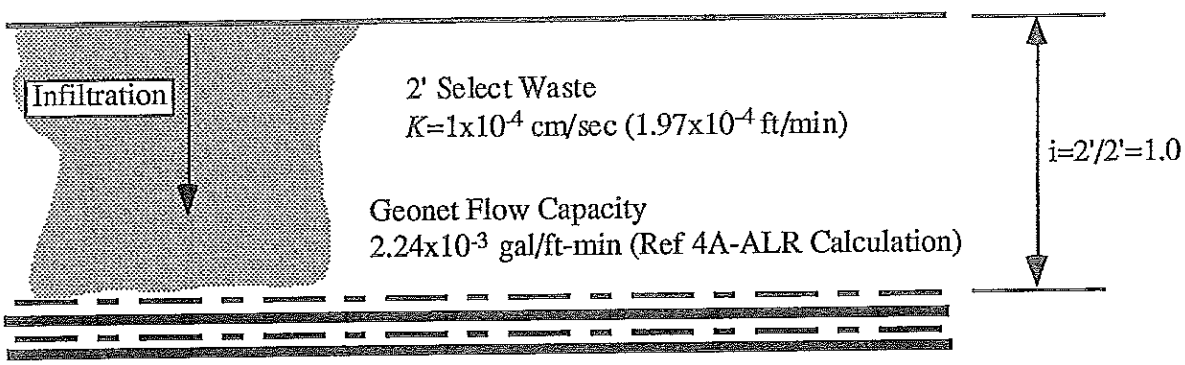
It would require nearly three days of steady rain at this rate to saturate the 2 foot soil layer assuming no simultaneous drainage occured. Conversely, only 34 percent of the available pore space is filled. Therefore unsaturated flow controls drainage from the 2 foot soil layer. Laminar flow through a porous media is estimated by:

$$Q = Kia \qquad (1)$$

| Where: | | |
|---|---|---|
| | $Q$ | Flow ($ft^3$/min) |
| | $K$ | Hydraulic Conductivity (ft/min) |
| | i | gradient |
| | a | flow area ($ft^2$) |

for the unsaturated case unsaturated hydraulic conductivity, $K_u$, replaces $K$.

5. The unit flow parameters are shown in Figure 2 below:




6 Unsaturated hydraulic conductivity is estimated by Campbell's equation (Reference 3B), definitions for the terms are found in the reference:

$$K_u = K_s\left(\frac{\Theta-\Theta_r}{\phi-\Theta_r}\right)^{3+(\frac{2}{\lambda})}$$

7. The residual water content, $\Theta_r$, is the amount of water remaining in the soil pores under infinite capillary suction. Residual water content is calculated by Rawls (Reference 3C) as follows:

$$\Theta_r = 0.014+.25WP; WP \geq 0.04$$

## LCRS Flow Capacity and Pump Sizing

Where WP is wilting point, which for the designated soil is 0.136>0.04. Therefore the equation is applicable. The residual water content is then:

$$\Theta_r = 0.048$$

8. As discussed in the reference, residual water content and the pore-size distribution index, $\lambda$, are constants in the Brooks-Corey equation relating volumetric content to matrix potential (capillary pressure and adsorptive forces, Reference 3D):

$$\frac{\Theta - \Theta_r}{\phi - \Theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda}$$

9. This equation is solved assuming the volumetric water content is the field capacity, at 0.33 bars of capillary suction, $\psi$, and then the wilting point, at 15 bars capillary suction. Solving simutaneously yields both the pore size distribution index and bubbling pressure. Solving for the values assumed for the site soil yields the following:

**Constants:**

| | |
|---|---|
| $\Theta r$ | 0.048 |
| $\phi$ | 0.398 |

| **Variables** | $\Theta$ | $\psi$ | $\Theta-\Theta r/\phi-\Theta r$ | $(\psi b/\psi)\lambda$ |
|---|---|---|---|---|
| Field Capacity | 0.244 | 0.33 | 0.56 | 0.56 |
| Wilting Point | 0.136 | 15 | 0.25 | 0.25 |

**Solved Values**

| | |
|---|---|
| $\psi b$ | 0.021 |
| $\lambda$ | 0.210 |

10. Since only 34 percent of the available pore space was filled by infiltration the volumetric water content is:

$$\Theta = FC + 0.34(\phi - FC)$$
$$\Theta = 0.244 + 0.34(0.398 - 0.244)$$
$$\Theta = 0.296$$

11. Based on this calculation the unsaturated hydraulic conductivity is calculated from the following using Campbell's equation:

$$K_u = 1\times10^{-4}\,\frac{\text{cm}}{\text{sec}}\left(\frac{0.296-0.048}{0.398-.048}\right)^{\left(3+\left(\frac{2}{0.210}\right)\right)}$$

$$K_u = 1.361\times10^{-6}\,\frac{\text{cm}}{\text{sec}} = 2.68\times10^{-6}\,\frac{\text{ft}}{\text{min}}$$

## LCRS Flow Capacity and Pump Sizing

12. Conservatively using a unit hydraulic gradient and assuming no evaporation, the rate at which the infiltration drains from the 2 foot layer into a unit area of the LCRS is:

$$q = \left(2.68\times10^{-6}\frac{\text{ft}}{\text{min}}\right)(1.0) = 2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}$$

$$q = 2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}\left(7.48\frac{\text{gal}}{\text{ft}^3}\right) = 2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}$$

Drainage over the entire 2.36 acre cell is then:

$$Q = \left(2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}\right)(2.36\text{ac})\left(\frac{43{,}560\text{ft}^2}{\text{ac}}\right)$$

$$Q = \frac{2.06\text{gal}}{\text{min}}$$

13. To accomodate this flow into the LCRS the geonet must have a minimum perimeter of $2.06/2.24\text{x}10^{-3}$=919 feet. Since providing this much flow capacity with geocomposite alone is infeasible a pipe system will be provided to improve drainage characteristics into the LCRS sumps.

14. A single 3 inch diameter corrugated polyethylene pipe (manning n=0.015) at a slope of 1 percent has a flow capacity of approximately 34 gallons per minute (Reference 5A). This is more than sufficient to accomodate the maximum LCRS flow into the sump. As shown in Figure 3, the pipes will be located in along the grade breaks of the bottom with lateral lines located every 100 feet along the grade break length. The basis for the layout is described below.

15. From the manufacturer's literature 3" diameter pipe comes with slots providing 1.44 $\text{in}^2$ (Reference 5B) of flow area per foot. The orifice equation (Reference 6A) is used to estimate flow into the pipe per foot of length. The orifice equation is as follows:

$$Q = CA\sqrt{2gH}$$

The coefficient C=0.6, g=32.2ft/$s^2$, and H is assumed to be 1 inch. The calculation is therefore:

$$Q = (0.6)(1.44\text{in}^2)\left(\frac{1\text{ft}^2}{144\text{in}^2}\right)\sqrt{2\left(\frac{32.2\text{ft}}{\text{sec}^2}\right)(1\text{in})\left(\frac{1\text{ft}}{12\text{in}}\right)}$$

$$Q = \frac{0.014\text{ft}^3}{\text{sec}}\left(\frac{7.48\text{gal}}{\text{ft}^3}\right)\left(\frac{60\text{sec}}{\text{min}}\right) = 6.2\text{gpm}$$

LCRS Flow Capacity and Pump Sizing

Since this is substantially more than the maximum estimated flow rate, the spacing of laterals is controlled by the flow capacity of the geocomposite. As stated above the geocomposite can accomodate $2.24 \times 10^{-3}$ gpm per foot of width. Since water percolates into the geocomposite at the rate of 2.00x10-5 gpm per square foot the lateral spacing is calculated as follows:

$$L = \left(2.24 \times 10^{-3} \frac{\text{gal}}{\text{min} - \text{ft}}\right)\left(\frac{\text{min} - \text{ft}^2}{2.00 \times 10^{-5} \text{gal}}\right)$$

$$L = 111\text{ft}$$

Use 100 foot spacing for lateral pipes.

16. The LCRS sump is configured as shown in Figure 4. Beginning at the 10 percent slope the sump is filled with clean 1" diameter (nom.) drain rock. To assure unimpeded drainage into the riser the 3" diameter lines will be continued until adjacent to the riser.

17 The LCRS pump must be capable of lifting the leachate vertically approximately 100 feet, the maximum depth of fill above the sump. Head losses in the discharge line are expected to be minimal, allow 5 feet of loss. Minor losses are anticipated to be no more than 20 percent of the subtotaled loss, or approximately 21 feet. Total estimated dynamic head (TDH) is therefore:

$$TDH = 100ft + 5ft + 21ft = 126ft$$

18. Using a factor of safety of 4 for the pump capacity yields 8 gallons per minute. A Protec recipricating pump, Model No. RP-2, with variable speed electric control is recommended (See Reference 7).

Surface Run-Off:

1. During the critical period when waste filling has just started the greatest quantity of run-off is generated by Cell 12A. Approximately 0.16 acre-feet (53,000 gallons) of precipitation runs off the cell bottom. Since the slopes are covered by a sacrificial liner, no infiltration occurs at those surfaces and run-off is equal to the direct precipitation. Since Cell 12A has the largest slope area it is the conservative case. If a gutter system is not used another 0.19 acre-feet (61,000 gallons) runs off the slopes. Handling of run-off is an operational consideration. However, two methods are likely 1) directing the run-off to a temporary lined pond; 2) transferring the liquid to a holding tank.

2. If run-off is directed to a temporary holding pond it must have a capacity of:

(53,000 gal+61,000 gal)(1.5)=171,000 gal

LCRS Flow Capacity and Pump Sizing

The value 1.5 is a factor of safety to assure adequate containment capacity. The volume of a regular type pond (frustrum of a pyramid) is found by the following formula (Reference 8A):

$$V = \frac{1}{3}h\left(A_{top} + A_{bot} + \sqrt{A_{top}A_{bot}}\right)$$

Assuming a depth of 5 feet, 80 foot sides, and 2:1 slopes yields a volume of

$$V = \frac{1}{3}(5)\left((80)^2 + (80-20)^2 + \sqrt{(80)^2(80-20)^2}\right)$$

$$V = 24{,}667\text{ft}^3\left(\frac{7.48\text{gal}}{\text{ft}^3}\right) = 185{,}000\text{gal} > 171{,}000\text{gal}$$

During the initial fill stages the bottom of the cell will slope towards the sump. The most likly location for a storage pond would be in the adjacent cell area. A pump system, as described below, would be necessary until the sufficient waste has been deposited to create the desired grade.

3. In the event alternative 2 is chosen a suitable pump must be specified. The peak flow into the sump, or other run-off collection area, can be estimated by the SCS unit hydrograph method (Reference 2B) where:

$$Q_p = \frac{484A}{T_R}$$

Total catchment area, A, is shown in Figure 1 to be 3.49 acres ($5.45\text{x}10^{-3}$ mi$^2$). A factor of 484 is used, which is likely conservative given the generally flat nature of the catchment slope.$T_R$ is the rising time and is calculated by the following relationship (Reference 2C):

$$T_R = \frac{D}{2} + t_p$$

The duration of the storm event, D, is 24 hours. The lag time, $t_p$, is found by the following equation (Reference 2D):

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}}$$

The catchment length, l, is found from Figure 1 to be approximately 450 feet (Cell 12A, east to west). The average catchment slope is 1 percent. The factor S is calculated from the SCS curve number, previously identified as 85. The relationship is
(Reference 2E):

LCRS Flow Capacity and Pump Sizing

$$S = \left(\frac{1000}{CN}\right) - 10 = \left(\frac{1000}{85}\right) - 10 = 1.76$$

This implies the lag time is:

$$t_p = \frac{(450)^{0.8}(1.76+1)^{0.7}}{1900(1)^{0.5}} = 0.14\text{hrs}$$

Given that result, the rising time is calculated to be:

$$T_R = \frac{24}{2} + 0.14 = 12.14\text{hrs}$$

and the peak flow is then:

$$Q_p = \frac{484(5.45\times10^{-3}\text{mi}^2)}{12.14} = 0.22\text{cfs}\left(\frac{449\text{gpm}}{\text{cfs}}\right) = 98\text{gpm}$$

4. To successfully transfer the accumulated water without undo ponding, and thus greater infiltration into the LCRS, a small impoundment ( e.g., 10,000-20,000 gallons) and a high capacity pump (e.g. 100 gpm) are required. The pump must be capable of generating sufficient head to lift the water out of the cell and into the desired holding facility. It is assumed the landfill operations staff will size the impoundment and select the necessary pump if this alternative is selected.

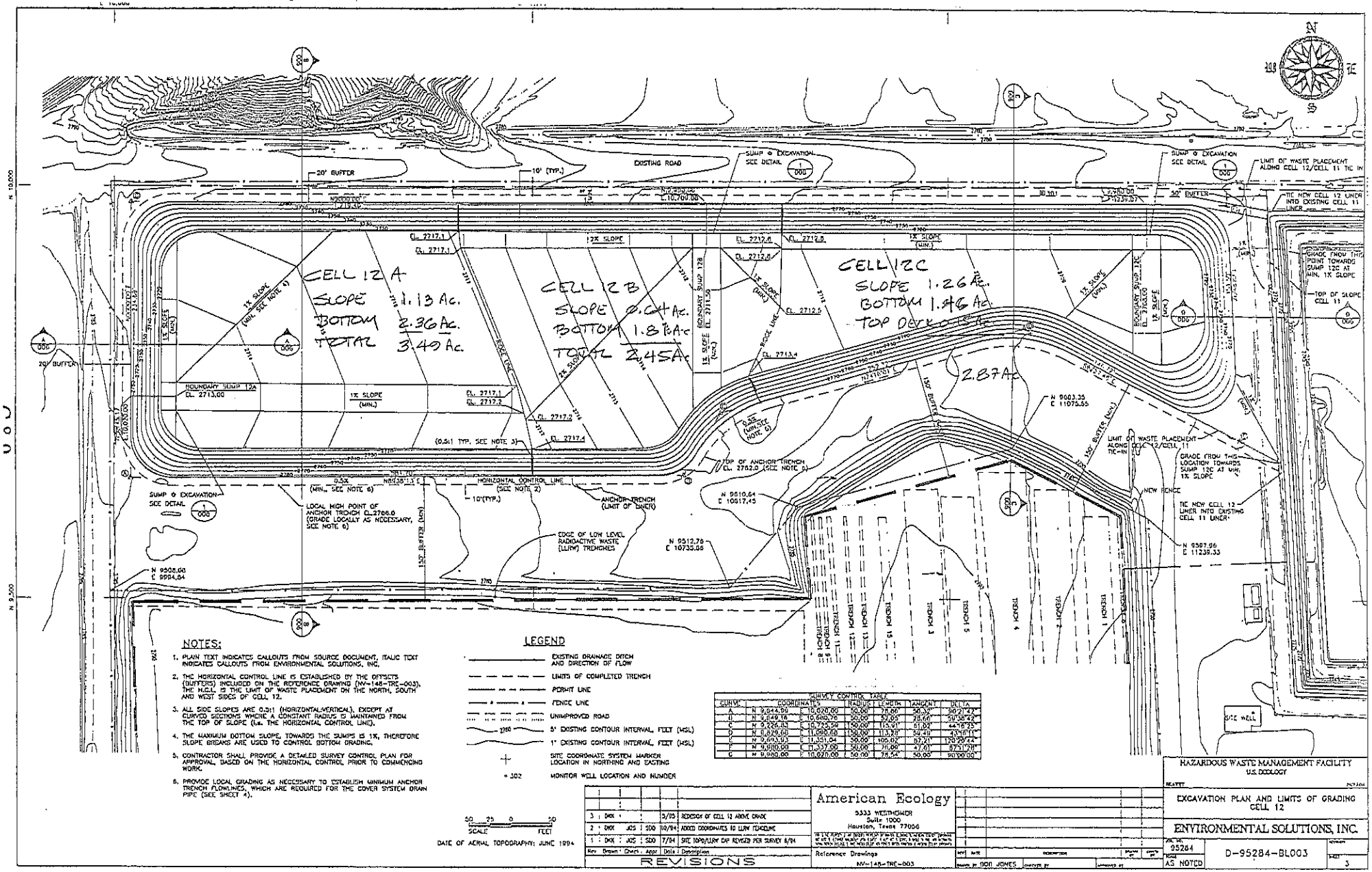
5. Construction of the starter berms, buttress fills and cover system will begin once waste filling is within 3 feet of the top of the excavation slope. The maximum waste area of (8.9 acres) within the horizontal control line (Figure 1) is potentially exposed to precipitation. As a conservative estimate it is assumed no exposure reduction measures are implemented, and the maximum run-off volume is contact water (i.e., has contacted waste).

6. The maximum volume of contact run-off is 198,282 gallons. The three foot freeboard around the facility is sufficient to contain this liquid on the surface of the fill. Should it be necessary to transfer the water out of the cell approximately 300,000 gallons of capacity is required (with a 50 percent factor of safety).

~85'
1 : 0.5 = MIDHEIGHT PERIMETER (MHP)

85' x MHP = SLOPE AREA

SHEET 9 OF 11




## NOTES:

1. PLAIN TEXT INDICATES CALLOUTS FROM SOURCE DOCUMENT, ITALIC TEXT INDICATES CALLOUTS FROM ENVIRONMENTAL SOLUTIONS, INC.
2. THE HORIZONTAL CONTROL LINE IS ESTABLISHED BY THE OFFSETS (BUFFERS) INCLUDED ON THE REFERENCE DRAWING (NV-148-TRC-003). THE H.C.L. IS THE LIMIT OF WASTE PLACEMENT ON THE NORTH, SOUTH AND WEST SIDES OF CELL 12.
3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
4. THE MAXIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1%, THEREFORE SLOPE BREAKS ARE USED TO CONTROL BOTTOM GRADING.
5. CONTRACTOR SHALL PROVIDE A DETAILED SURVEY CONTROL PLAN FOR APPROVAL, BASED ON THE HORIZONTAL CONTROL PRIOR TO COMMENCING WORK.
6. PROVIDE LOCAL GRADING AS NECESSARY TO ESTABLISH MINIMUM ANCHOR TRENCH FLOWLINES, WHICH ARE REQUIRED FOR THE COVER SYSTEM DRAIN PIPE (SEE SHEET 4).

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- MONITOR WELL LOCATION AND NUMBER

SURVEY CONTROL TABLE

| CURVE | COORDINATES | RADIUS | LENGTH | TANGENT | DELTA |
|---|---|---|---|---|---|
| A | N 9,844.90 E 10,620.00 | 50.00 | 78.66 | 50.35 | 90°21'42" |
| B | N 9,849.16 E 10,680.70 | 50.00 | 50.00 | 26.76 | 50°38'24" |
| C | N 9,226.83 E 10,725.58 | 150.00 | 115.91 | 61.02 | 44°18'25" |
| D | N 9,829.60 E 11,080.00 | 150.00 | 113.78 | 59.49 | 43°18'11" |
| E | N 9,693.93 E 11,351.04 | 50.00 | 105.02 | 57.21 | 120°29'44" |
| F | N 9,900.00 E 11,337.00 | 50.00 | 76.00 | 47.01 | 87°11'00" |
| G | N 9,880.00 E 10,970.00 | 50.00 | 78.54 | 50.00 | 90°00'00" |

50 25 0 50
SCALE FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

| Rev | Drawn | Check | Appr | Date | Description |
|---|---|---|---|---|---|
| 3 | DKK | | | 3/95 | REDUCTION OF CELL 12 ABOVE GRADE |
| 2 | DKK | JCS | SDO | 10/94 | ADDED COORDINATES TO LLRW TRENCHES |
| 1 | DKK | JCS | SDO | 7/94 | SITE TOPO/LLRW CAP REVISED PER SURVEY 6/94 |

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NV-148-TRC-003

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. DOE/DOGY

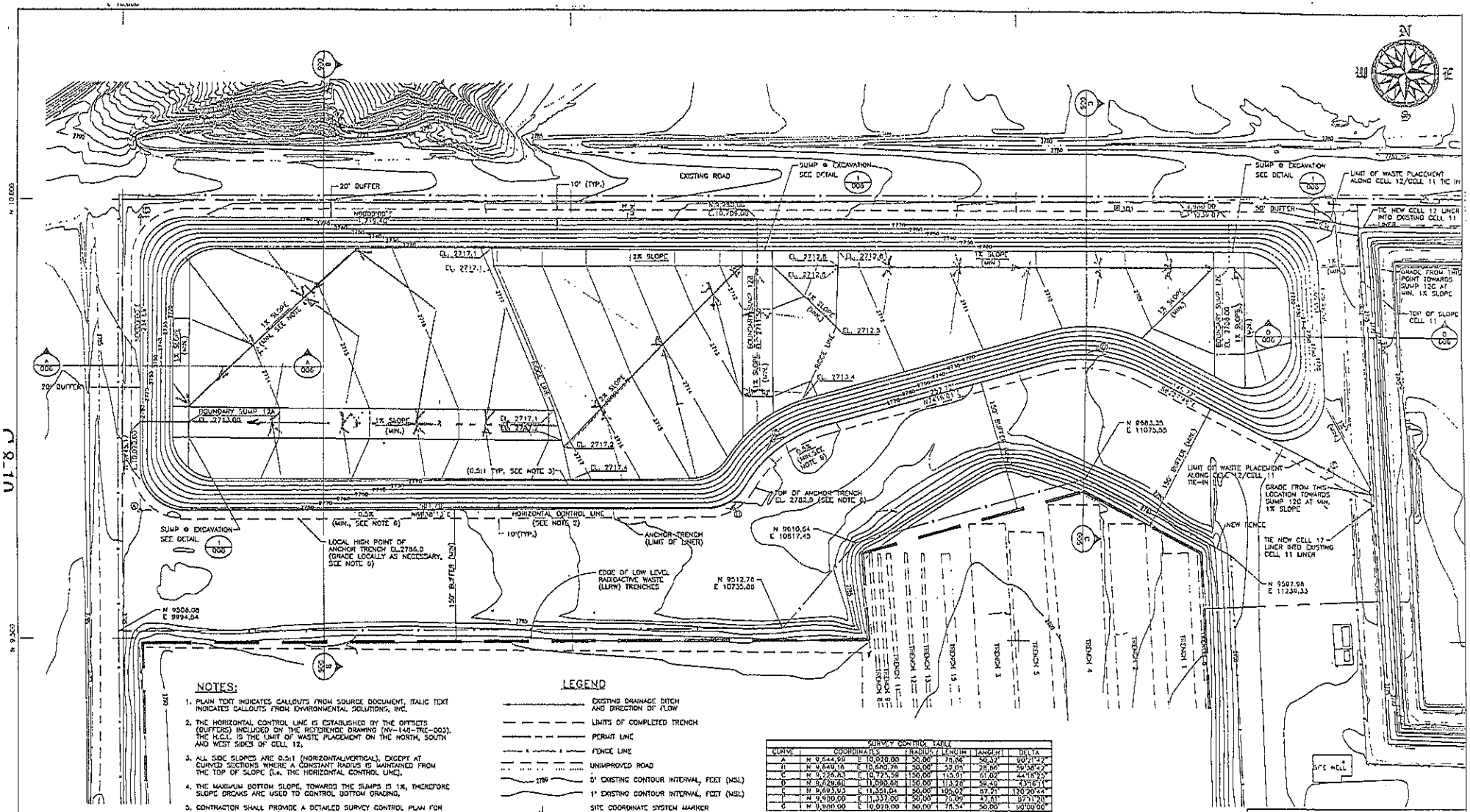
EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

JOB NO. 95264
SCALE AS NOTED
D-95284-BL003
SHEET 3

Figure 1

SHEET 10 of 11

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3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
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6. PROVIDE LOCAL GRADING AS NECESSARY TO ESTABLISH MINIMUM ANCHOR TRENCH FLOWLINES, WHICH ARE REQUIRED FOR THE COVER SYSTEM DRAIN PIPE (SEE SHEET 4).

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 2780 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- ● 302 MONITOR WELL LOCATION AND NUMBER

SURVEY CONTROL TABLE

| CURVE | COORDINATES | | RADIUS | LENGTH | ANGLE | DELTA |
|---|---|---|---|---|---|---|
| A | N 9,644.98 | E 10,920.00 | 50.00' | 78.54' | 90°00'00" | 90°01'42" |
| B | N 9,849.18 | E 10,660.78 | 50.00' | 59.83' | 70.00' | 59°58'42" |
| C | N 9,636.83 | E 10,725.59 | 150.00' | 113.91' | 61.02' | 44°18'29" |
| D | N 9,629.00 | E 11,098.04 | 150.00' | 113.28' | 59.40' | 43°16'11" |
| E | N 9,693.53 | E 11,351.04 | 50.00' | 105.02' | 57.21' | 120°30'44" |
| F | N 9,900.00 | E 11,337.00 | 50.00' | 77.09' | 47.61' | 89°31'28" |
| G | N 9,900.00 | E 10,920.00 | 50.00' | 78.54' | 50.00' | 90°00'00" |

SCALE 50 25 0 50 FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

| Rev | Drawn / Check | Appr | Date | Description |
|---|---|---|---|---|
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REVISIONS

American Ecology
8333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NV-146-TRE-003

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY

EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

JOB NO. 95284
SCALE AS NOTED
D-95284-BL003
SHEET 3

FIGURE 3

# ENVIRONMENTAL SOLUTIONS, INC.

By RVH Date 1/20/96 Subject BEATTY LANDFILL-CELL 2 Sheet No. 11 of 11

Chkd. By LMG Date 1/23/96 AMERICAN ECOLOGY CORP. Proj. No. 95-284

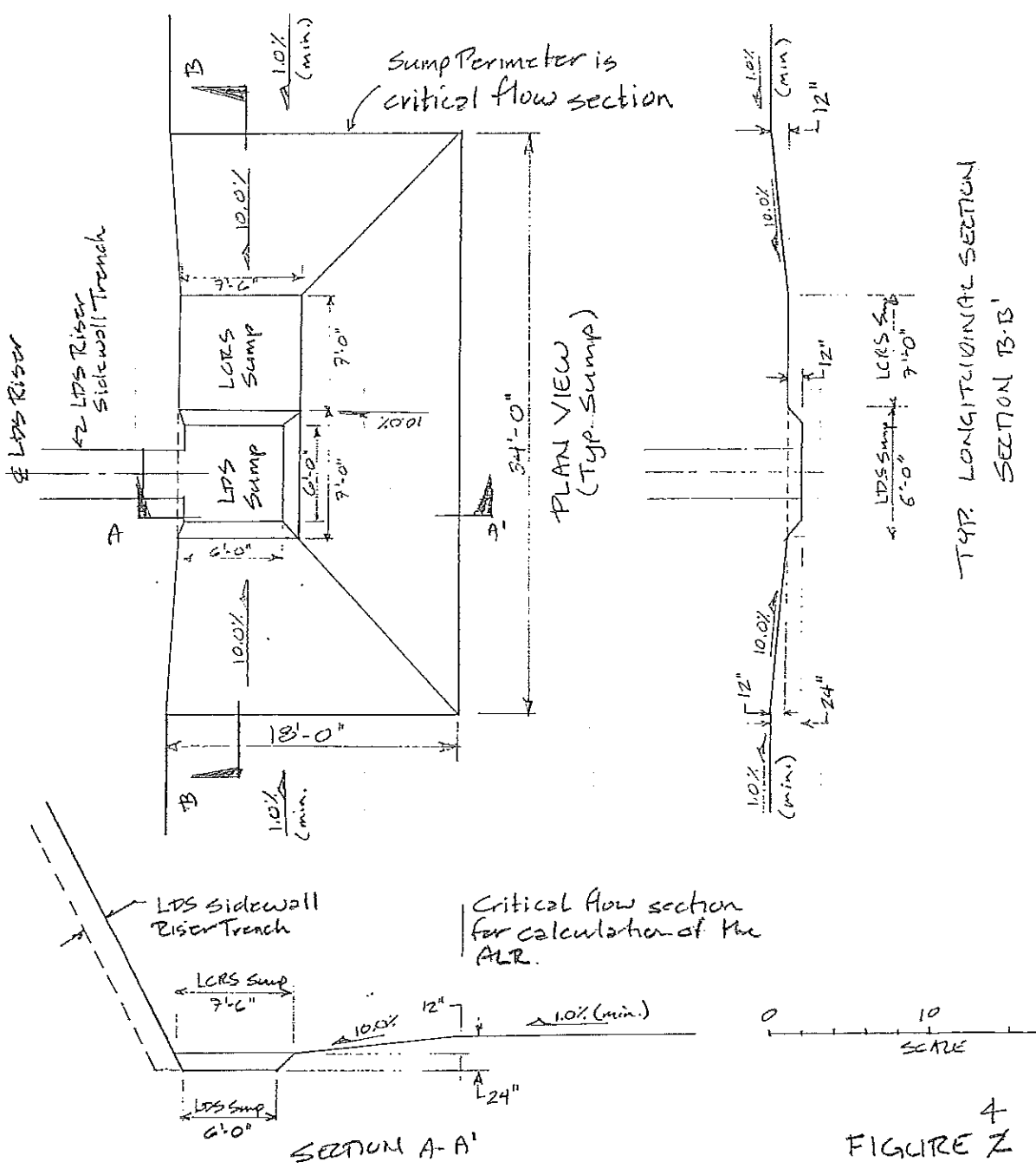


FIGURE 4

TYPICAL SUMP GEOMETRY

Notes:

1) Liner elements & riser pipes not shown for clarity.



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REF 1

# SECTION IV.D

# LANDFILL REPORT

US ECOLOGY, INC.

BEATTY, NEVADA

REF 1

# APPENDIX D

# DRAINAGE DIVERSION DITCHES

# DESIGN CALCULATIONS

## BEATTY RUN-ON CONTROL SYSTEM DESIGN

### Drainage Area Characteristics:

1. Drainage area = 1.7 sq. mi.
2. Max. flow length ($\ell$) = 21,650 ft.
3. Avg. land slope ($\gamma$) = $^{160}/(3.87)\ (5280) = 0.0078 = 0.78\%$
4. Sandy soil, barren land. SCS classifies soils as predominantly hydrological group B with some group A. Therefore, use soil group B and SCS Pasture/Range class with poor hydrologic condition.
5. Use AMC II for worst case.
6. SCS runoff curve No. (RCN) = 79 to account for steps 4 and 5

### Compute Time of Concentration (Tc):

$$\text{LAG (L)} = \frac{(\ell)^{.8}\ (S+1)^{.7}}{1900\ (\gamma)^{.5}}$$

$$S = \frac{1000}{RCN} - 10 = \frac{1000}{79} - 10 = 2.66$$

$$L = \frac{(21{,}650)^{.8}\ (3.66)^{.7}}{1900\ (0.78)^{.5}} = 4.35 \text{ hrs.}$$

$$Tc = {}^{L}/0.6 = \frac{4.35}{0.6} = 7.25 \text{ hrs.}$$

### Compute Excess Rainfall (Q):

25-yr, 24-hr storm = 2.0 in.

(From NOAA, Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume VII - Nevada)

Q = 0.52 in. for RCN = 79

### Compute Peak Flow for 25-yr, 24-hr Rainfall:

Ref: SCS ENGR-20 (Rev. 2)

PK = (D.A.) (Q) (CSM)

CSM = 83 for Tc = 6 hrs, $T_t$ = 0 hrs.
CSM = 72 for Tc = 7.25 hrs by interpolation
CSM = 66 for Tc = 8 hrs, $T_t$ = 0 hrs.

Peak flow = (1.7) (0.52) (72) = 63.65 CFS .06 cfs/sec

# Hydrology and Floodplain Analysis

Philip B. Bedient • Wayne C. Huber

REF 2.

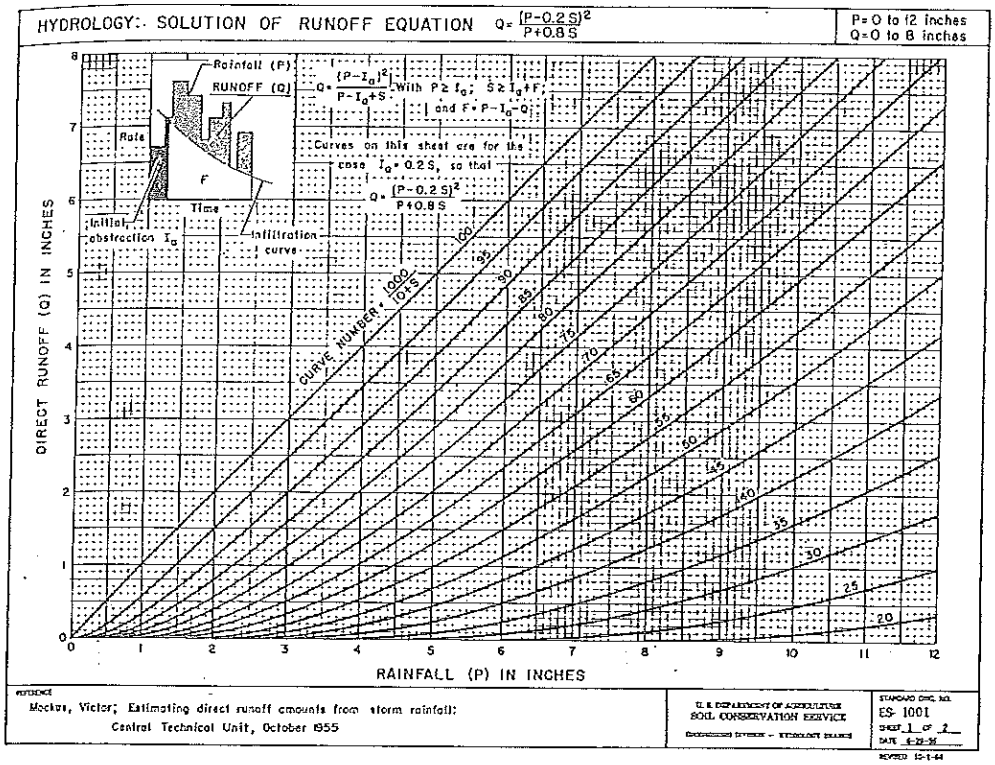



FIGURE 2.14

**Graphical solution of rainfall-runoff equation.**

EXAMPLE 2.8

**SCS UNIT HYDROGRAPH**

For the watershed of Example 2.7, develop a unit hydrograph using the SCS method. The watershed consists of meadows in good condition with soil group D. The average slope in the watershed is 100 ft/mi. Assume the same duration of rainfall as found in Example 2.7. Sketch the resulting hydrograph.

SOLUTION

Equation (2.18) gives the following relationship for $t_p$:

$$t_p = \frac{\ell^{0.8}(S+1)^{0.7}}{1900y^{1/2}}.$$

From Table 2.1, the SCS curve number is found to be 78. Therefore,

Since this is a small watershed,

$$T_b \approx 4t_p = 4(8.6) \text{ hr}$$

$$\boxed{T_b = 34.4 \text{ hr.}}$$

And the duration of rainfall

$$D = t_p/5.5$$
$$= 8.6/5.5 \text{ hr}$$

$$\boxed{D = 1.6 \text{ hr.}}$$

## SCS Method

The method developed by the Soil Conservation Service (SCS, 1957) is based on a **dimensionless hydrograph**, developed from a large number of unit hydrographs ranging in size and geographic location. The hydrograph is represented as a simple triangle (Fig. 2.13), with rainfall duration $D$ (hr), time of rise $T_R$ (hr), time of fall $B$(hr), and peak flow $Q_p$ (cfs). The volume of direct runoff is

$$\text{Vol} = \frac{Q_p T_R}{2} + \frac{Q_p B}{2}, \qquad \text{or}$$

$$Q_p = \frac{2 \text{ Vol}}{T_R + B} \tag{2.14}$$

From a review of a large number of hydrographs, it was found that

$$B = 1.67\, T_R. \tag{2.15}$$

Therefore, Eq. (2.14) becomes, for 1.0 in. of rainfall excess,

$$Q_p = \frac{0.75 \text{ Vol}}{T_R}$$
$$= \frac{(0.75)(640)A(1.008)}{T_R}$$
$$= \frac{484A}{T_R}, \qquad \text{REF 23} \tag{2.16}$$

where

$A$ = area of basin (sq mi),

$T_R$ = time of rise (hr).

Capece et al. (1984) found that a factor as low as 10–50 holds for flat, high-water-table watersheds rather than the value 484 presented here. Thus, care must be used when applying this method.

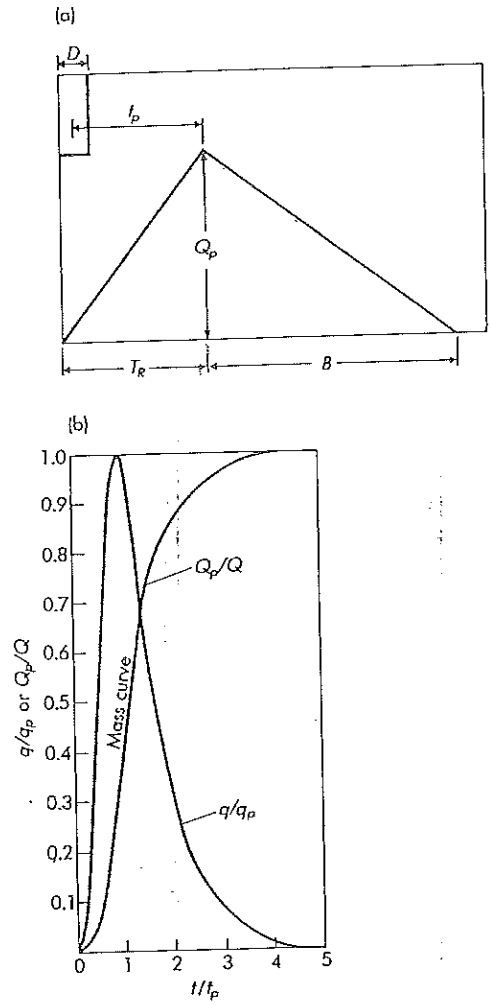



FIGURE 2.13
**(a) SCS triangular unit hydrograph. (b) SCS dimensionless unit hydrograph (SCS, 1964).**

From Fig. 2.13 it can be shown that

$$T_R = D/2 + t_p, \qquad (2.17)$$

REF 2C

where

$D$ = rainfall duration (hr),

$t_p$ = lag time from centroid of rainfall to $Q_p$ (hr).

Lag time $t_p$ is estimated from any one of several empirical equations used by the SCS, such as

$$t_p = \frac{\ell^{0.8}(S+1)^{0.7}}{1900y^{0.5}}, \quad \text{REF 20} \tag{2.18}$$

where

$t_p$ = lag time (hr),
$\ell$ = length to divide (ft),
$y$ = average watershed slope (%),
$S = 1000/\text{CN} - 10$,
CN = curve number for various soil/land use (see Table 2.1).

The SCS dimensionless unit hydrograph can be used to develop a curved hydrograph, using the same $t_p$ and $Q_p$ as the triangular hydrograph in Fig. 2.13.

Soil Conservation Service (1964) runoff estimates assume a relationship between accumulated total storm rainfall $P$, runoff $Q$, and infiltration plus initial abstraction $(F + I_a)$. It is assumed that

$$F/S = Q/P_e, \tag{2.19}$$

where $F$ is infiltration occurring after runoff begins, $S$ is **potential abstraction**, $Q$ is direct runoff in in., and $P_e$ is effective storm runoff $(P - I_a)$. With $F = (P_e - Q)$ and $P_e = (P - I_a) = (P - 0.2S)$ based on data from small watersheds,

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}. \tag{2.20}$$

The SCS method uses the **runoff curve number** CN, which is related to storage by

$$\text{CN} = 1000/(S + 10), \quad \text{REF 26} \tag{2.21}$$

where potential abstraction $S$ (in.) becomes

$$S = (1000/\text{CN}) - 10. \tag{2.22}$$

Figure 2.14 presents the SCS solution in graphical form for a range of CNs and rainfall amounts. Runoff curve numbers for selected land uses are presented in Table 2.1. The hydrologic soil group varies from A for sandy, well-drained soils to D for clayey, poorly drained soils. The SCS report *Urban Hydrology for Small Watersheds* (1986) provides a simple graphical and tabular procedure for determining peak flows for urban areas. Example 2.8 illustrates the SCS UH method.

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-94/168b
September 1994

3
REF

EPA

# The Hydrologic Evaluation of Landfill Performance (HELP) Model

## Engineering Documentation for Version 3

REF 8A
3

TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

| Soil Texture Class | | | Total Porosity vol/vol | Field Capacity vol/vol | Wilting Point vol/vol | Saturated Hydraulic Conductivity cm/sec |
|---|---|---|---|---|---|---|
| HELP | USDA | USCS | | | | |
| 1 | CoS | SP | 0.417 | 0.045 | 0.018 | $1.0 \times 10^{-2}$ |
| 2 | S | SW | 0.437 | 0.062 | 0.024 | $5.8 \times 10^{-3}$ |
| 3 | FS | SW | 0.457 | 0.083 | 0.033 | $3.1 \times 10^{-3}$ |
| 4 | LS | SM | 0.437 | 0.105 | 0.047 | $1.7 \times 10^{-3}$ |
| 5 | LFS | SM | 0.457 | 0.131 | 0.058 | $1.0 \times 10^{-3}$ |
| 6 | SL | SM | 0.453 | 0.190 | 0.085 | $7.2 \times 10^{-4}$ |
| 7 | FSL | SM | 0.473 | 0.222 | 0.104 | $5.2 \times 10^{-4}$ |
| 8 | L | ML | 0.463 | 0.232 | 0.116 | $3.7 \times 10^{-4}$ |
| 9 | SiL | ML | 0.501 | 0.284 | 0.135 | $1.9 \times 10^{-4}$ |
| 10 | SCL | SC | 0.398 | 0.244 | 0.136 | $1.2 \times 10^{-4}$ |
| 11 | CL | CL | 0.464 | 0.310 | 0.187 | $6.4 \times 10^{-5}$ |
| 12 | SiCL | CL | 0.471 | 0.342 | 0.210 | $4.2 \times 10^{-5}$ |
| 13 | SC | SC | 0.430 | 0.321 | 0.221 | $3.3 \times 10^{-5}$ |
| 14 | SiC | CH | 0.479 | 0.371 | 0.251 | $2.5 \times 10^{-5}$ |
| 15 | C | CH | 0.475 | 0.378 | 0.251 | $2.5 \times 10^{-5}$ |
| 21 | G | GP | 0.397 | 0.032 | 0.013 | $3.0 \times 10^{-1}$ |

$a$ = constant representing the effects of various fluid constants and gravity, 21 $cm^3/sec$

$\phi$ = total porosity, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\psi_b$ = bubbling pressure, cm

$\lambda$ = pore-size distribution index, dimensionless

A more detailed explanation of Equation 11 can be found in Appendix A of the HELP program Version 3 User's Guide and the cited references.

*Saturated Hydraulic Conductivity*

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

*Unsaturated Hydraulic Conductivity*

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

RCF 2B 3

$$K_u = K_s \left[ \frac{\theta - \theta_r}{\phi - \theta_r} \right]^{3 + \left(\frac{2}{\lambda}\right)} \tag{5}$$

where

| | | |
|---|---|---|
| $K_u$ | = | unsaturated hydraulic conductivity, cm/sec |
| $K_s$ | = | saturated hydraulic conductivity, cm/sec |
| $\theta$ | = | actual volumetric water content, vol/vol |
| $\theta_r$ | = | residual volumetric water content, vol/vol |
| $\phi$ | = | total porosity, vol/vol |
| $\lambda$ | = | pore-size distribution index, dimensionless |

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

RCF 2C 3

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & \text{for } WP \geq 0.04 \\ 0.6\,WP & \text{for } WP < 0.04 \end{cases} \tag{6}$$

where

| | | |
|---|---|---|
| $WP$ | = | volumetric wilting point, vol/vol |

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

REF 2D

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \tag{7}$$

where

$\psi$ = capillary pressure, bars

$\psi_b$ = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retention and matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions).

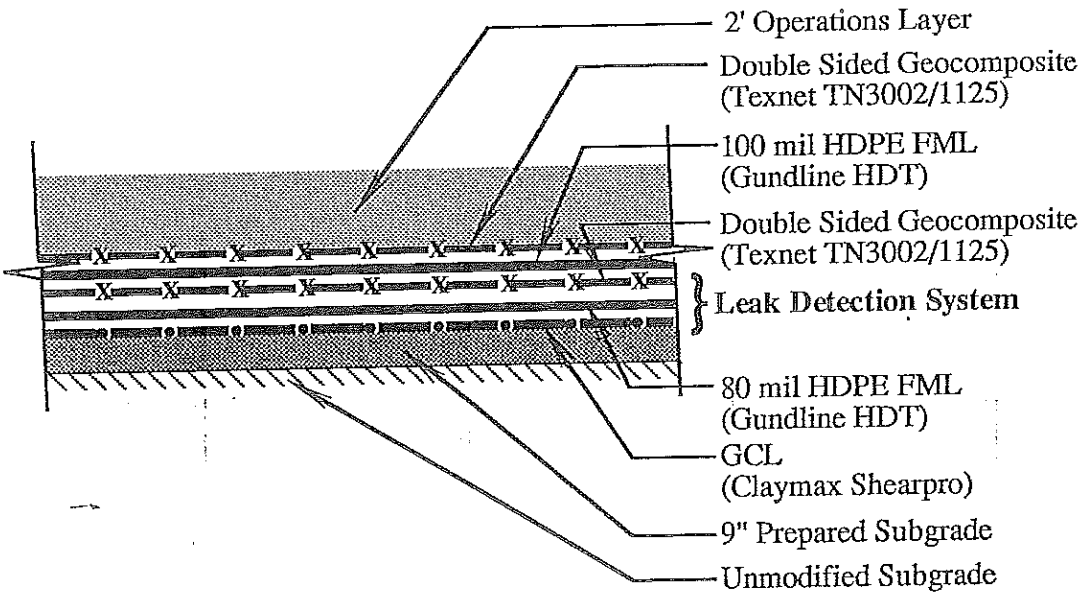
The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

### 3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

Figure 1




2. The sump locations are shown on Figure 2 (Attached). There are three sumps proposed for Cell 12. The typical geometry is shown in Figure 3 (Attached).

Flow Capacities

1. The following flow elements will be used in the LDS

   - Double sided geocomposite (Texnet TN3002/1125)
   - Geonet (Polynet PN3000)-used in the sump areas if additional flow capacity is required.
   - Gravel (clean, poorly graded, nominal 3/4" diameter)-used in the sump proper only.

2. The double sided geocomposite is used in the slope liner LDS as well as in the bottom liner as shown in Figure 1. A continuous strip of geocomposite will be used for each system. Therefore flow within the LDS will be controlled by the minimum bottom slope.

3. Flow within the geosynthetics is calculated using Darcy's Equation (which assumes laminar flow within the net) as follows (Reference 2A):

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

$$q = \Theta_{eff} i \qquad (1)$$

Where:

$q$ = flow per unit width

$\Theta_{eff}$ = effective transmissivity

$i$ = hydraulic gradient

Flow within the gravel also uses Darcy's formula, however, transmissivity is replaced with hydraulic conductivity and the thickness of the flow area.

4. Effective transmissivity for the geosynthetics is calculated by applying several safety factors to the published transmissivity value. The following formula (Reference 2B) is used for that calculation, definitions are provided in the attached reference:

$$\Theta_{eff} = \frac{\Theta}{(FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC})} \qquad (2)$$

5. The following table shows the unit flow capacity for the geosynthetic elements and the gravel based on the applicable transmissivity, or hydraulic conductivities, hydraulic gradients, and safety factors:

**Table 1**

| Flow Element | Q | $FS_{CR}$ | $FSI_N$ | $FS_{CC}$ | $FS_{BC}$ | $Q_{eff}$[1] | $i$ | q | q |
|---|---|---|---|---|---|---|---|---|---|
| Units: | m2/s | NA | NA | NA | NA | m2/s | NA | m3/m-s | gal/ft-day |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.01 | 4.66E-07 | 3.24 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.01 | 4.23E-06 | 29.45 |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.1 | 4.66E-06 | 32.39 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.1 | 4.23E-05 | 294.47 |

Transmissivity values are provided by the manufacturer (Reference 3A and 3B). Safety factors are taken from the literature and are attached (Reference 2C). Flow capacities are shown at hydraulic gradients of 1 percent and 10 percent for the nominal cell bottom slope and the minimum sump slope, respectively. Since the gravel is used only within the minimum sump boundaries around the riser pipes, flow capacities are calculated for the geosynthethics only.

Controlling Section

1. As shown in Figure 3 there are two potentially controlling sections: 1) the 7'x7' LDS perimeter; and 2) the perimeter at the grade break between the 1 and 10 percent slopes. In the controlling sections multiple layers of geocomposite or geonet alone may be used to provide sufficient flow capacity.

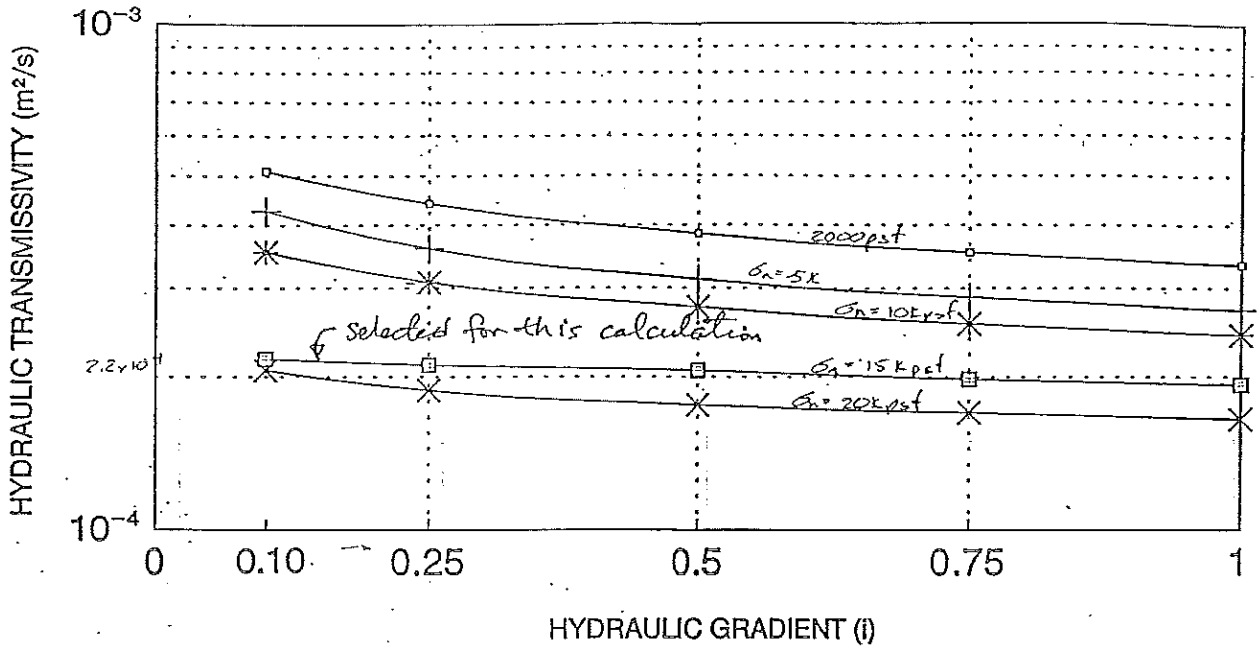
[1] The effective transmissivity of the geocomposite (using the factors of safety listed in Table 1) still exceeds the minimum transmissivity requirement ($3 \times 10^{-5}$ $m^2/s$) of 40 CFR § 264.301(c)(3)(ii).

Attachment B

REF 3A
φ

# TEX-NET TN3002/1125

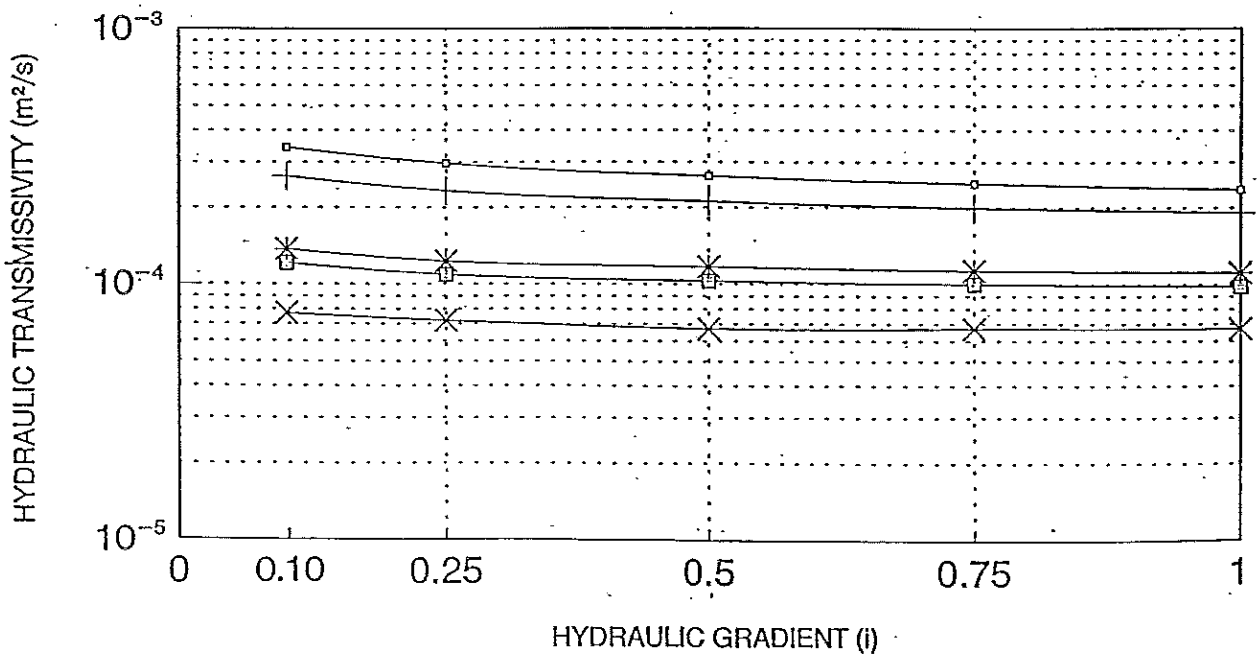
plate/FRICTION SEAL/TN3002/1125/FRICTION SEAL/plate




- 2000 psf
- 5000 psf
- 10000 psf
- 15000 psf
- 20000 psf

# TEX-NET TN3002CN/1125

plate/FRICTION SEAL/TN3002CN/1125/FRICTION SEAL/plate



REF # 5

# ADS SPECIFIER MANUAL

ADVANCED DRAINAGE SYSTEMS, INC.

ADVANCED DRAINAGE SYSTEMS, II

TABLE 7

CIRCULAR PIPE FLOW CAPACITY
Full Flow (cubic feet per second)

Mannings "n"= 0.015

| Dia. (in.) | *Conv. Factor | % Slope (feet per 100 feet) 0.02 | 0.05 | 0.10 | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.0 | 2.5 | 5.0 | 10.0 | 20.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | (c.f.s.) | | | | | | | | |
| 3 | 0.766 | 0.011 | 0.017 | 0.024 | 0.034 | 0.045 | 0.054 | 0.066 | 0.077 | 0.086 | 0.09 | 0.10 | 0.11 | 0.12 | 0.17 | 0.24 | 0.34 |
| 4 | 1.649 | 0.023 | 0.037 | 0.052 | 0.074 | 0.098 | 0.117 | 0.143 | 0.165 | 0.184 | 0.20 | 0.22 | 0.23 | 0.26 | 0.37 | 0.52 | 0.74 |
| 5 | 2.991 | 0.042 | 0.067 | 0.095 | 0.134 | 0.177 | 0.211 | 0.259 | 0.299 | 0.334 | 0.37 | 0.40 | 0.42 | 0.47 | 0.67 | 0.95 | 1.34 |
| 6 | 4.863 | 0.069 | 0.109 | 0.154 | 0.217 | 0.288 | 0.344 | 0.421 | 0.486 | 0.544 | 0.60 | 0.64 | 0.69 | 0.77 | 1.09 | 1.54 | 2.17 |
| 8 | 10.473 | 0.148 | 0.234 | 0.331 | 0.468 | 0.620 | 0.741 | 0.907 | 1.047 | 1.171 | 1.28 | 1.39 | 1.48 | 1.66 | 2.34 | 3.31 | 4.68 |
| 10 | 18.99 | 0.27 | 0.42 | 0.60 | 0.85 | 1.12 | 1.34 | 1.64 | 1.90 | 2.12 | 2.33 | 2.51 | 2.69 | 3.00 | 4.25 | 6.00 | 8.49 |
| 12 | 30.88 | 0.44 | 0.69 | 0.98 | 1.38 | 1.83 | 2.18 | 2.67 | 3.09 | 3.45 | 3.78 | 4.08 | 4.37 | 4.88 | 6.90 | 9.76 | 13.81 |
| 15 | 55.98 | 0.79 | 1.25 | 1.77 | 2.50 | 3.31 | 3.96 | 4.85 | 5.60 | 6.26 | 6.86 | 7.41 | 7.92 | 8.85 | 12.52 | 17.70 | 25.04 |
| 18 | 91.04 | 1.29 | 2.04 | 2.88 | 4.07 | 5.39 | 6.44 | 7.88 | 9.10 | 10.18 | 11.15 | 12.04 | 12.87 | 14.39 | 20.36 | 28.79 | 40.71 |
| 21 | 137.32 | 1.94 | 3.07 | 4.34 | 6.14 | 8.12 | 9.71 | 11.89 | 13.73 | 15.35 | 16.82 | 18.17 | 19.42 | 21.71 | 30.71 | 43.43 | 61.41 |
| 24 | 196.06 | 2.77 | 4.38 | 6.20 | 8.77 | 11.60 | 13.86 | 16.98 | 19.61 | 21.92 | 24.01 | 25.94 | 27.73 | 31.00 | 43.84 | 62.00 | 87.68 |
| 27 | 268.41 | 3.80 | 6.00 | 8.49 | 12.00 | 15.88 | 18.98 | 23.24 | 26.84 | 30.01 | 32.87 | 35.51 | 37.96 | 42.44 | 60.0 | 84.9 | 120.0 |
| 30 | 355.48 | 5.03 | 7.95 | 11.24 | 15.90 | 21.03 | 25.14 | 30.79 | 35.55 | 39.74 | 43.54 | 47.03 | 50.27 | 56.21 | 79.5 | 112.4 | 159.0 |
| 36 | 578.05 | 8.17 | 12.93 | 18.28 | 25.85 | 34.20 | 40.87 | 50.06 | 57.81 | 64.63 | 70.80 | 76.47 | 81.75 | 91.40 | 129.3 | 182.8 | 258.5 |
| 42 | 872.0 | 12.33 | 19.50 | 27.57 | 38.99 | 51.6 | 61.7 | 75.5 | 87.2 | 97.5 | 106.8 | 115.3 | 123.3 | 137.9 | 195.0 | 275.7 | 389.9 |
| 48 | 1244.9 | 17.61 | 27.84 | 39.37 | 55.67 | 73.6 | 88.0 | 107.8 | 124.5 | 139.2 | 152.5 | 164.7 | 176.1 | 196.8 | 278.4 | 393.7 | 556.7 |

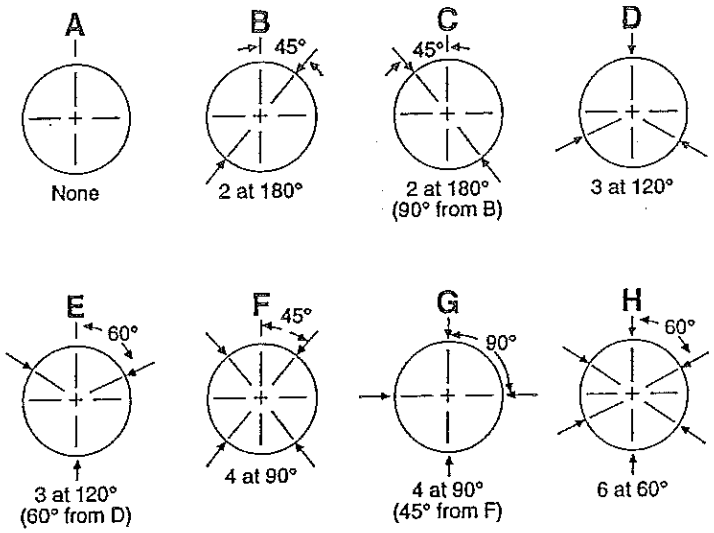
* Conveyance Factor = (1.486 x R2/3 x A) / n

REF 5B

# ADVANCED DRAINAGE SYSTEMS, INC.
## "FACT SHEET"
## STANDARD PIPE PERFORATIONS
## 3-24" I.D. SINGLE WALL PIPE

| Nominal I.D. | Perforation Type | Slot Length or Diameter (Max.) | Slot Width (Max.) | Nominal Water Inlet Area (Sq. In./Ft.) | Perforation Configuration |
|---|---|---|---|---|---|
| 3 | Slot | 1.25 | 0.125 | 1.44 | AF |
| 4 | Slot | 1.25 | 0.125 | 2.01 | AH |
| 5 | Slot | 1.57 | 0.125 | 2.01 | AH |
| 6 | Slot | 1.88 | 0.125 | 2.01 | AH |
| 8 | Slot | 2.50 | 0.125 | 1.57 | AD |
| 10 | Slot | 2.50 | 0.125 | 1.26 | AD |
| 12 | Slot | 2.50 | 0.125 | 3.38 | H |
| 15 | Slot | 2.50 | 0.125 | 1.58 | H |
| 18 | Circular | 0.375 | — | 1.58 | H |
| 24 | Circular | 0.375 | — | 1.58 | 11" Centers |

PERFORATION CONFIGURATIONS



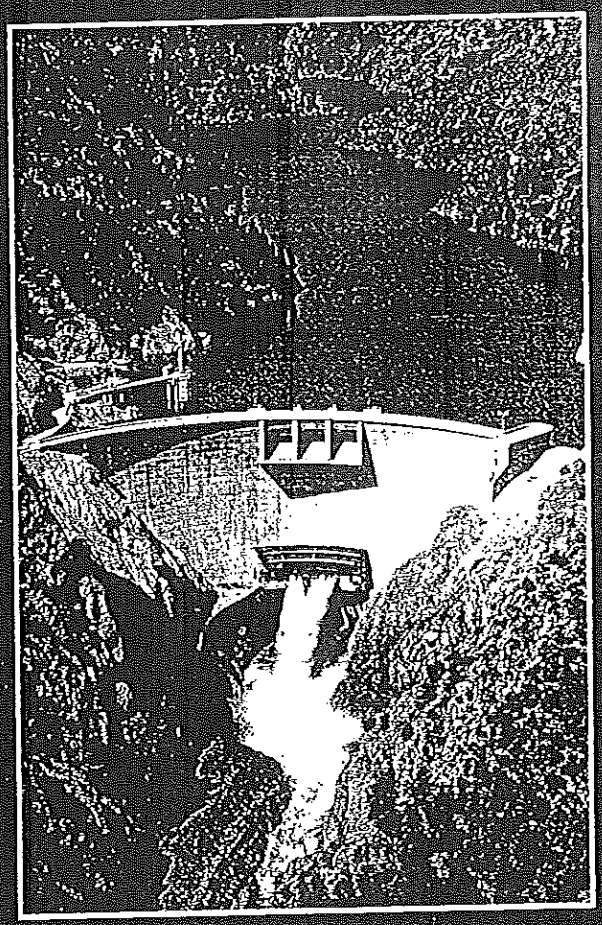

NOTE 1
ADS pipe is perforated for water entry with slots or circular perforations. The perforations are uniformly spaced along the length and circumference of the pipe.

NOTE 2
Unless otherwise specified, ADS pipe is manufactured to comply with the perforation requirements specified in the following industry standards: ASTM F405, ASTM F667, AASHTO M252, AASHTO M294, and SCS Code 606.

Issued: March 15, 1991

RET # 4

# DAVIS' HANDBOOK OF APPLIED HYDRAULICS



FOURTH EDITION

Vincent J. Zipparro
Hans Hasen

REF 8A

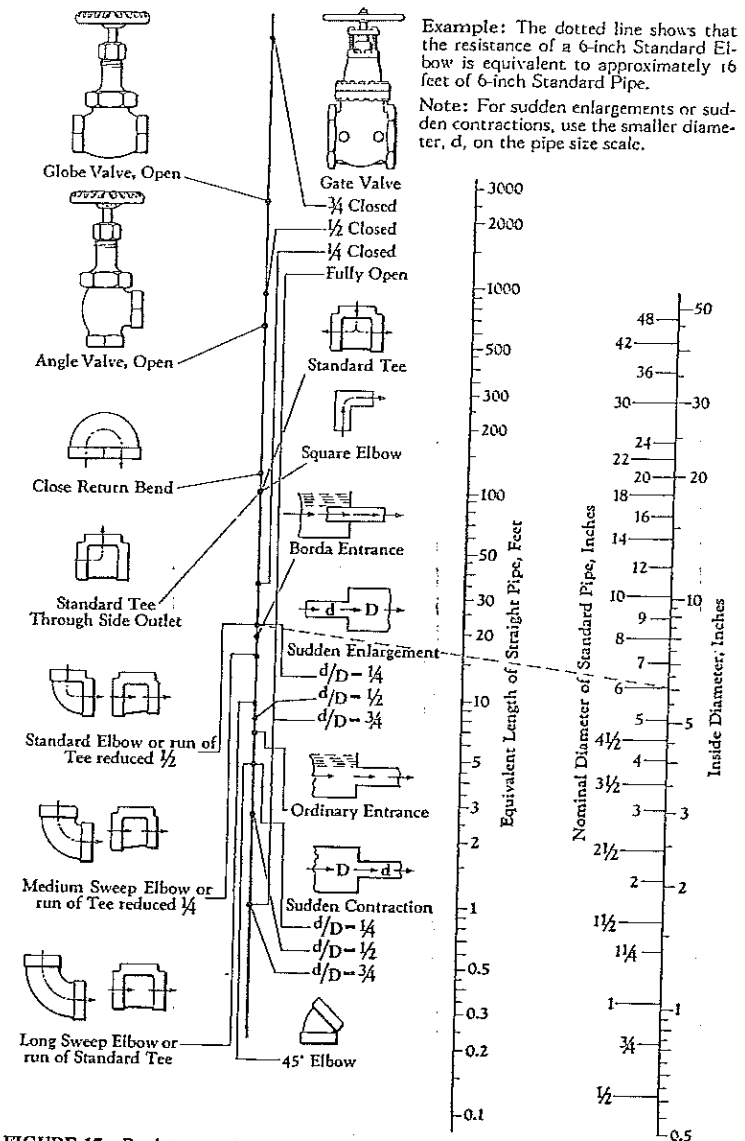



FIGURE 17 Resistance of valves and fittings to flow of fluid.

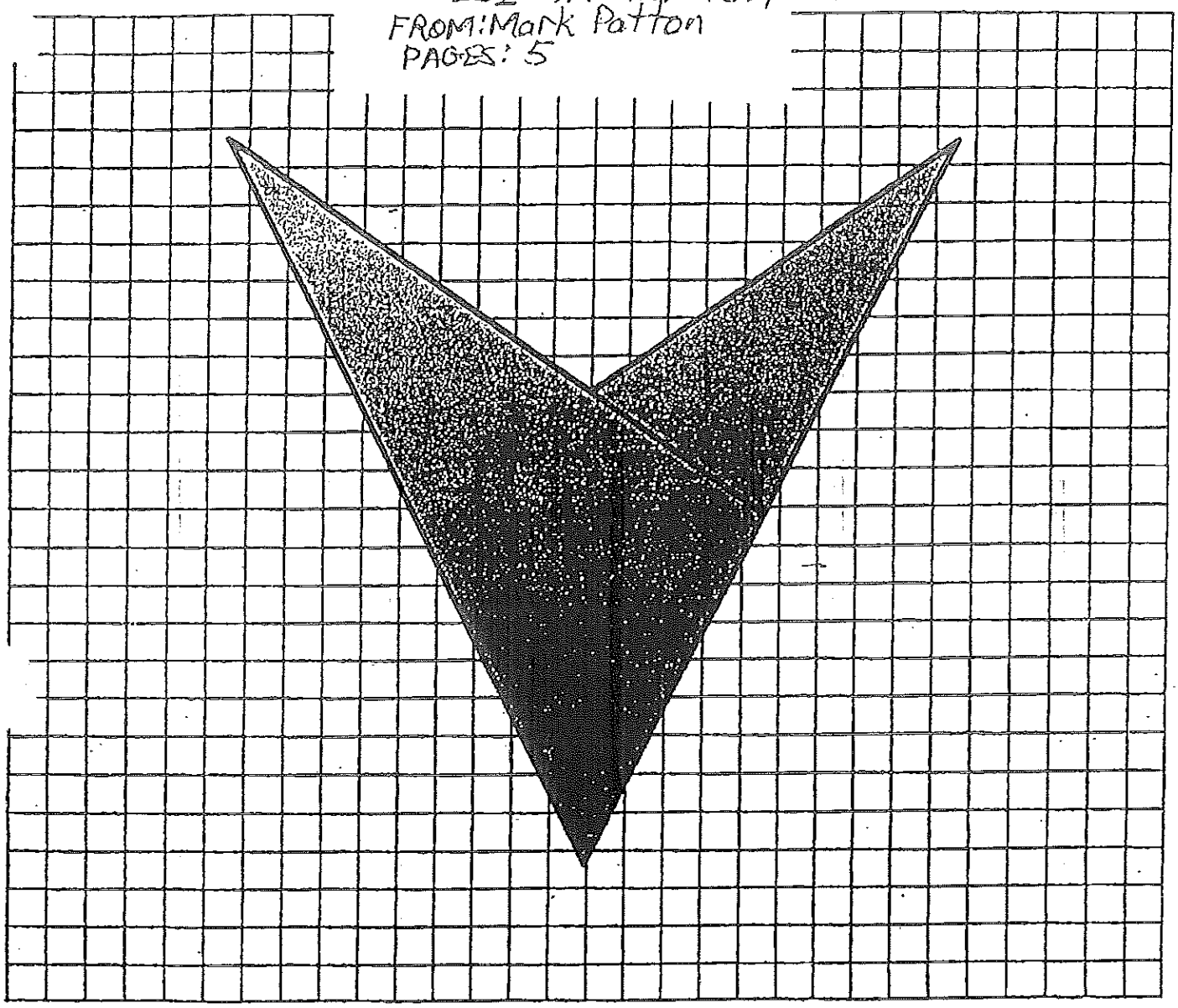
## ORIFICES

**25. High Head.** When the head is relatively large, as compared with the size of the orifice, the following equation will apply:

$$Q = CA\sqrt{2gH} \tag{37}$$

REF 7

TO: Stan Christie
ESI 714-727-7399
FROM: Mark Patton
PAGES: 5



# PROTEC®
# RECIP® PUMP

GROUNDWATER & LEACHATE RECOVERY PUMPS

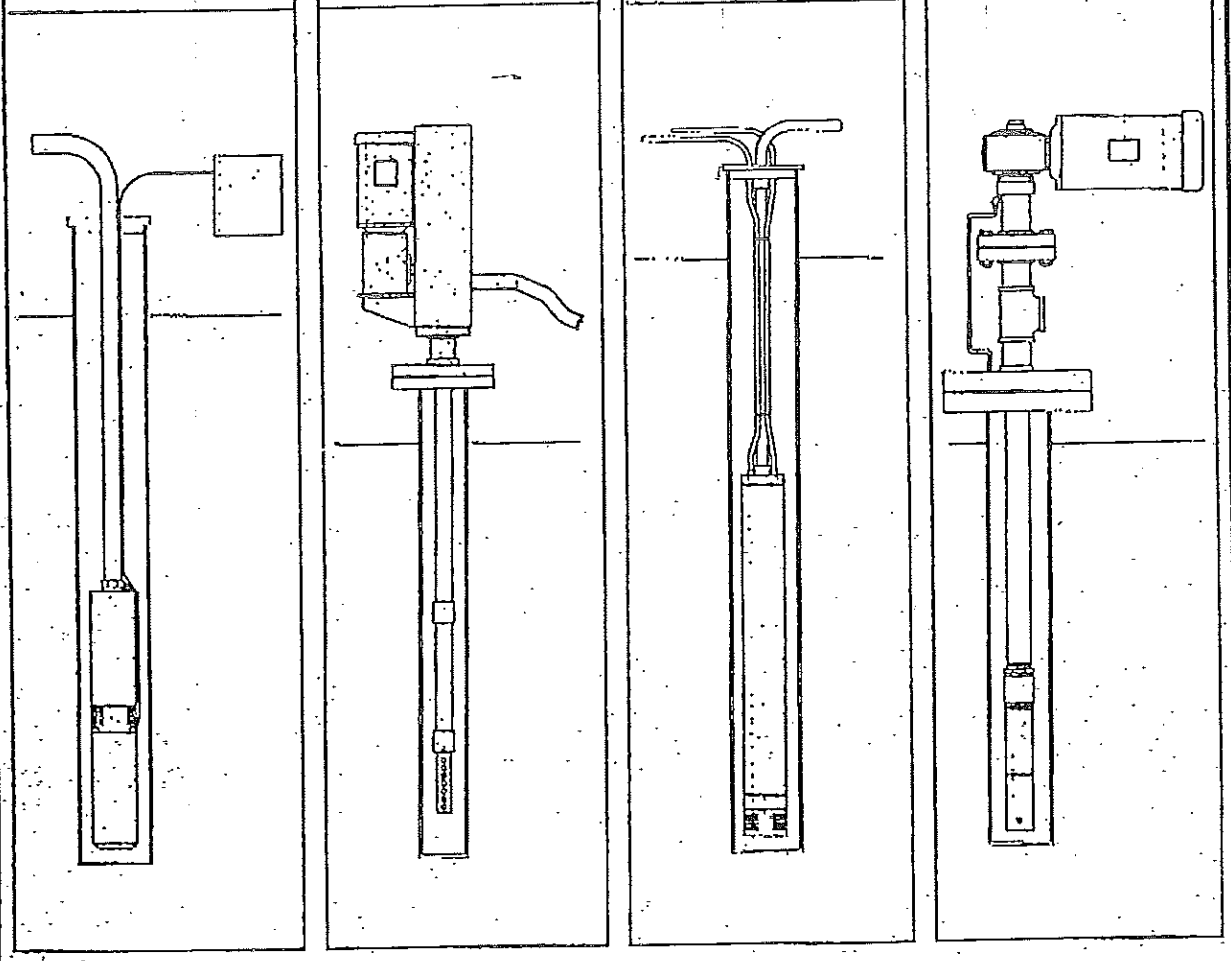
Stan Christie
714-727-7399
For your file
Mark Patton

# PROTEC

## ENVIRONMENTAL EQUIPMENT

## A COMPLETE LINE OF GROUNDWATER REMEDIATION LANDFILL LEACHATE & SAMPLING PUMPS

| GUARDIAN | RECIP | AUTOPILOT | ROTARY |
|---|---|---|---|
| Variable Speed Electric Submersible Pump | Electric or Air Driven Piston Pump | Automatic "Controllerless" Air Pump | Electric Drive Progressing Cavity Pump |

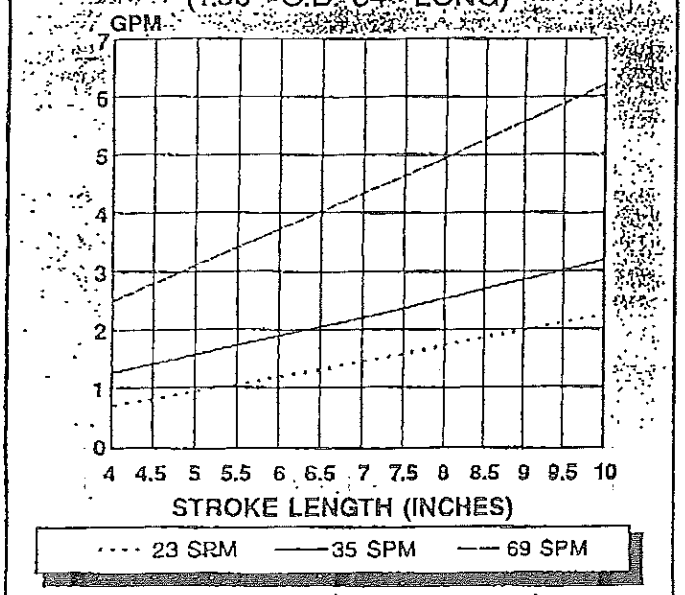


PROTEC

HOUSTON, TX SALES: 918-493-6101 TULSA, OK

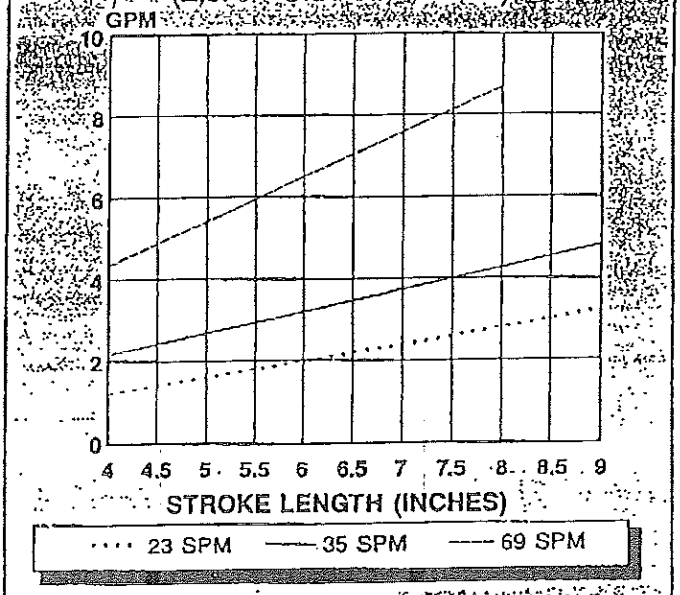
# PROTEC RECIP PUMP CURVES

## MODEL RP1
(1.90" O.D. 34" LONG)



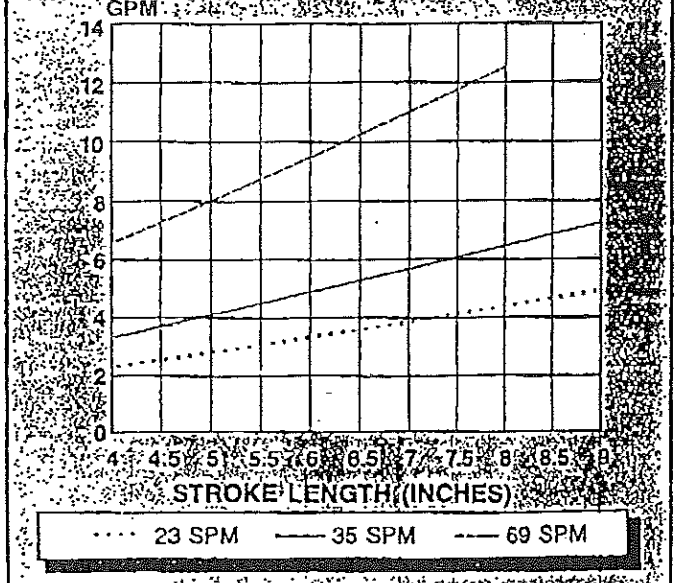

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1 HP

## MODEL RP2
(2.375" O.D. 34" LONG)



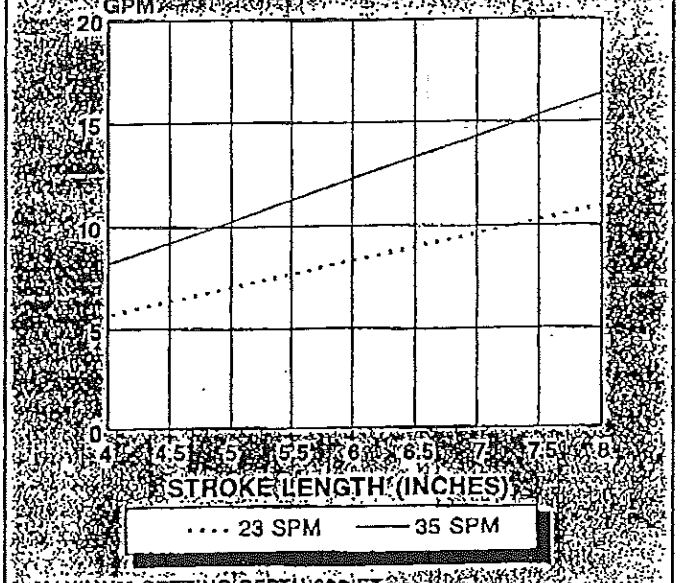

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1.5 HP

## MODEL RP3
(2.875" O.D. 34" LONG)




MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 2 HP

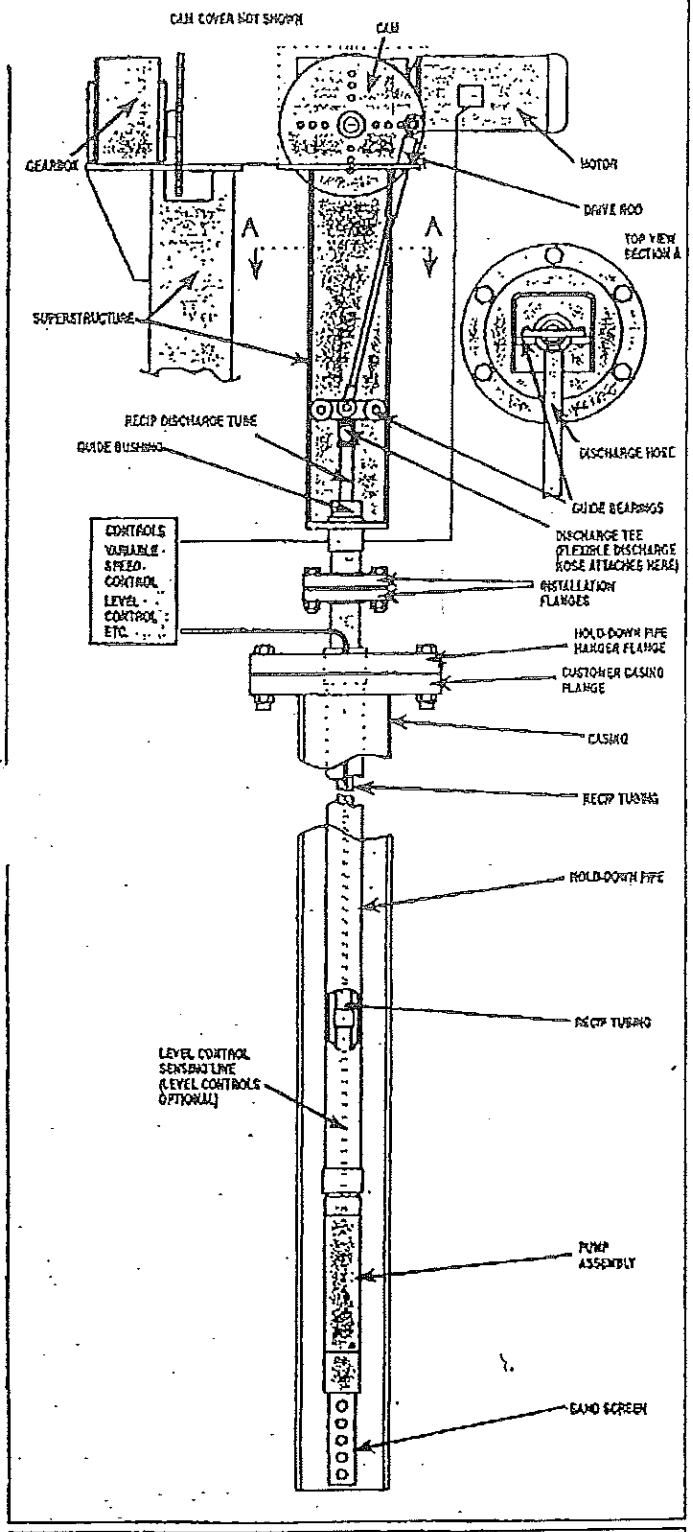
## MODEL RP5
(4.5" O.D. 34" LONG)




MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM
1750 RPM MTR = 35 SPM, APPROX. 3 HP

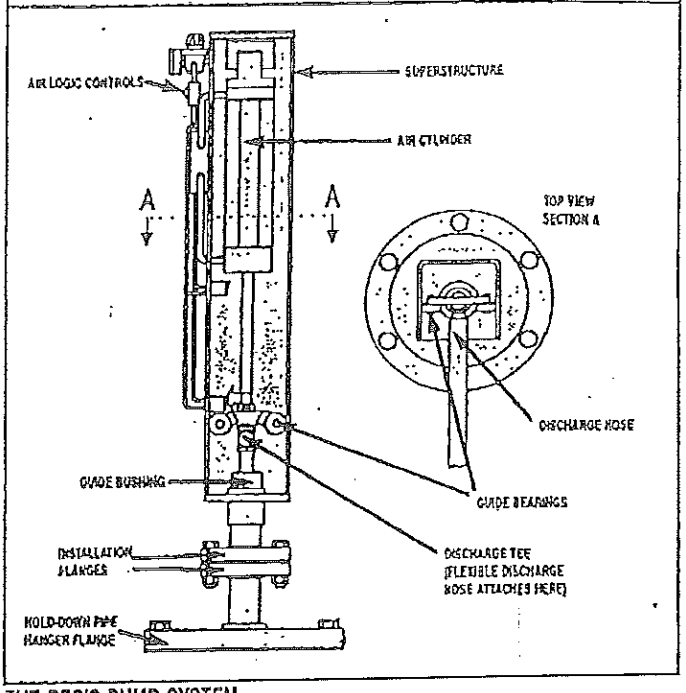

PROTEC
7136 S. Yale, Suite 200 • Tulsa, OK 74136 • 918-493-6101

## ELECTRIC DRIVE




**SURFACE DRIVE ASSY. APPROX. DIMENSIONS**
**ELECTRIC DRIVE: 55" H x 24" W x 12" D**
**AIR DRIVE: 51" H x 8" W x 8" D**
**LOW PROFILE DRIVES ALSO AVAILABLE WHEN THERE ARE HEIGHT LIMITATIONS**

## AIR DRIVE




### THE RECIP PUMP SYSTEM

The **RECIP PUMP** is a surface driven (air drive or electric drive) down-hole reciprocating pump. The down-hole pump assembly is anchored by a string of stationary pipe (Hold-Down Pipe). The pump piston is attached to the bottom of a string of reciprocating tubing (Recip Tubing) which is run inside the Hold-Down Pipe. The surface drive assembly alternately lifts and lowers the Recip Tubing which gives the down-hole pump its reciprocating motion. The surface drive assembly can be either Air Drive or Electric Drive. The Air Drive unit utilizes a dual acting air cylinder. The Electric Drive unit utilizes an electric motor (TEFC or X-Proof) coupled to a gearbox and cam assembly.

The **RECIP PUMP** is a positive displacement piston pump with pumping rate (GPM) directly proportional to strokes per minute (SPM) and stroke length (SL). On the Electric Drive unit SL is adjusted manually by changing the position of the drive rod connection to the cam and SPM depends on the motor RPM selected (1140, 1750 or 3450 RPM). An optional electronic VSD (Variable Speed Drive) is also available to give variable SPM capability to the Electric Drive unit. The Air Drive unit comes standard as a variable speed device since the pump speed (SPM) can be controlled by the pressure regulator on the drive unit. The Recip Pump is currently available in four sizes: RP1, RP2, RP3 and RP5. Pump rates range from fractional GPM to 16 GPM.

Down-hole pump materials of construction are stainless steel and Teflon for service in highly corrosive fluids. **RECIP PUMP** can run dry without causing damage to the pump. Pump operation is easily interfaced with down-hole level controls, tank level controls, safety shut-downs, timers, etc. to meet the operating requirements of any particular site.

### APPLICATIONS

The **RECIP PUMP** is an efficient low-maintenance system for installation in extraction wells and trench sumps associated with groundwater recovery and leachate collection projects. **RECIP PUMP** is also useful as a dedicated sampling pump for groundwater monitoring.

Notice that the Model RP1 can pump up to 6 GPM from wells with 2" casing. This means that often existing monitoring wells can be utilized for continuous recovery when a project advances from the sampling stage to the remedial pump and treat stage. And when new recovery wells must be drilled it is less expensive to drill and equip 2" wells than larger diameter wells.

### IN SUMMARY

High volumetric pump efficiency and low power requirements make the **RECIP PUMP** a highly efficient pumping system. Simple design, rugged construction and low operating speeds result in long operating life and low maintenance. Other features are: low noise, small size, quick installation and all moving parts fully enclosed.

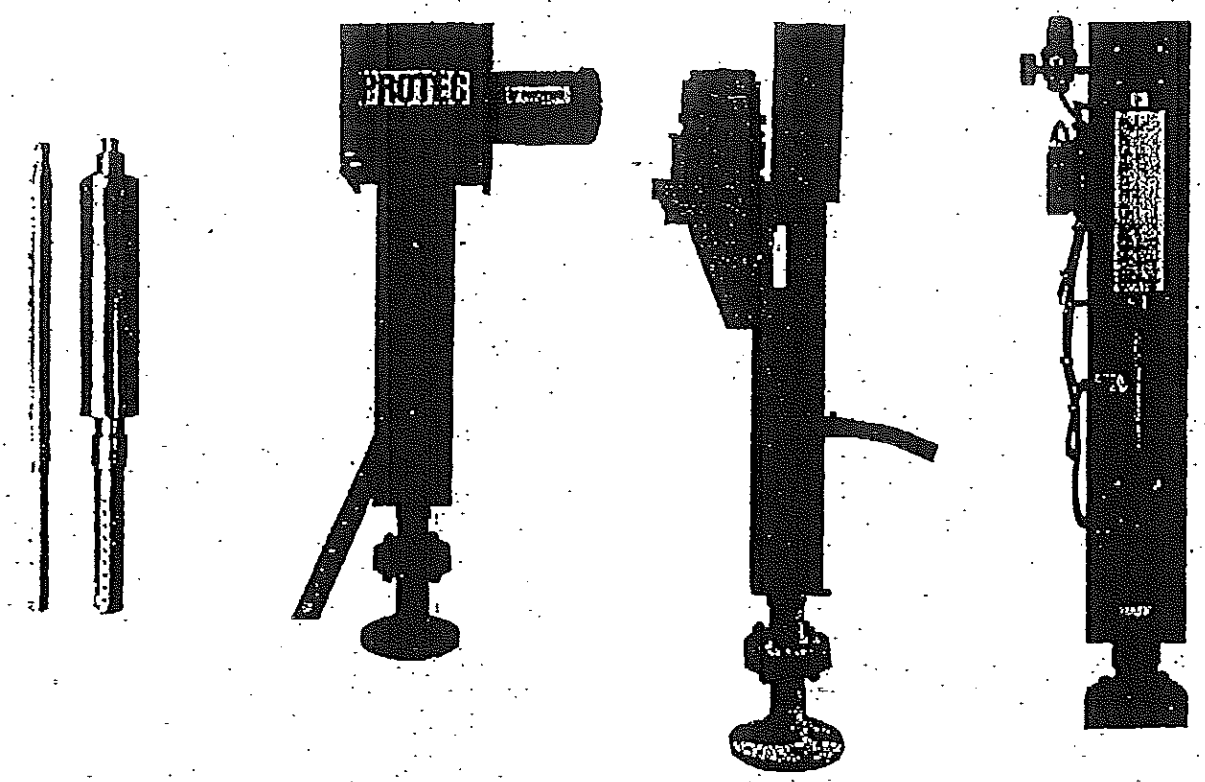
# PUMP SELECTION TABLE

| PUMP MODEL | RP1 | RP2 | RP3 | RP5 |
|---|---|---|---|---|
| PUMP OUTSIDE DIAMETER | 1.90 IN. | 2.375 IN. | 2.875 IN. | 4.50 IN. |
| STANDARD MOTOR HP[1] | 1.0 HP | 1.5 HP | 2.0 HP | 3.0 HP |
| PUMP SETTING DEPTH | 1 - 200 FT. | 1 - 200 FT. | 1 - 200 FT. | 1 - 200 FT. |
| GPM RANGE | | | | |
| 1. FIXED SPEED ELECTRIC ADJUSTABLE SL[2] | | | | |
| DEPENDS ON MOTOR RPM: | | | | |
| WITH 1140 RPM MOTOR[3] | 0.8-2.1 GPM | 1.4-3.2 GPM | 2.2-4.9 GPM | 5-10 GPM |
| WITH 1750 RPM MOTOR | 1.2-3.1 GPM | 2.1-4.8 GPM | 3.2-7.3 GPM | 8-16 GPM |
| WITH 3450 RPM MOTOR | 2.5-6.2 GPM | 4.2-8.5 GPM | 6.5-13.0 GPM | N/A |
| 2. VARIABLE SPEED ELECTRIC ADJUSTABLE SL & SPM[4] | | | | |
| USE ELECTRIC VSD[5] | 0.1-6.2 GPM | 1.4-8.5 GPM | 2.2-13.0 GPM | 5-16 GPM |
| 3. VARIABLE SPEED AIR ADJUSTABLE SPM | 0.1-6.2 GPM | 1.4-8.5 GPM | 2.2-13.0 GPM | 5-16 GPM |

[1] Motor HP can vary depending on operating conditions.
[2] SL: Strokes Length.
[3] 1140 RPM motors available in 3-Phase only.
[4] SPM: Strokes Per Minute.
[5] VSD: Variable Speed Drive.

NOTE: Above data is in accordance with the pump curves on the back cover.

PUMPS ELECTRIC DRIVE AIR DRIVE



# PROTEC RECIP PUMP
# PRICE LIST
(FOR ESTIMATING PURPOSES)
November 1994

The following are estimated prices for complete pumping units including down-hole pump, surface drive assembly and 4 feet of cross-linked polyethylene discharge hose. On Electric Drive units for variable SPM (Strokes Per Minute) add VSD (Variable Speed Drive). Air Drive price includes pneumatic controls and Air Drive units are inherently variable SPM.

| PUMP MODEL | AIR DRIVE 316 S.S | FIXED SPM TEFC MOTOR | FIXED SPM X-PROOF MOTOR | VSD ADD-ON NEMA 3R PANEL FOR USE WITH TEFC DC MOTOR | VSD ADD-ON NEMA 3R PANEL FOR USE WITH TEFC OR X-PROOF AC MOTOR |
|---|---|---|---|---|---|
| RP1 | 2,700.00 3100 | 2,975.00 | 3,175.00 | 875.00 | 1,075.00 |
| RP2 | 2,900.00 3100 | 3,175.00 | 3,425.00 | 1,025.00 | 1,175.00 |
| RP3 | 3,100.00 | 3,375.00 | 3,625.00 | N/A | 1,275.00 |
| RP5 | 3,700.00 | 3,975.00 | 4,225.00 | N/A | 1,325.00 |

## ACCESSORIES

**LEVEL CONTROL:**
- Dual Probe Level Control.....286.00
- Dual Float Level Control.....305.00
- Level Control Signal Wire.....0.50/FT (22 Gauge, Teflon Jacketed)
- Pneumatic Level Control.....275.00
- Pneumatic L/C Tube (3/8" Teflon).....2.50/FT
- Stroke Counter.....100.00
- Pneumatic Dual Timer.....275.00

## WELL TUBULARS

1. FOR USE IN 2" CASING ( RP1 ONLY ):
   - RECIP TUBING : 1/2" CS T&C.....1.23/FT
   - 1/2" 304SS T&C.....5.22/FT*
   - HOLD-DOWN PIPE: 1" CS T&C.....1.81/FT
   - 1" 304 SS T&C.....8.36/FT*

2. FOR USE IN 3" AND LARGER CASING ( RP5 6" AND LARGER CASING ):
   - RECIP TUBING ( RP1, 2, 3 ) : 3/4" CS T&C.....1.55/FT
   - 3/4" 304 SS T&C.....6.62/FT* ← Add 25 % for 316 S.S.
   - ( RP5 ONLY ): 1" CS T&C.....1.81/FT
   - 1" 304 SS T&C.....8.36/FT* ←
   - HOLD-DOWN PIPE ( RP1, 2, 3 ): 1 1/4" CS T&C.....2.43/FT
   - 1 1/4" 304 SS T&C.....10.53/FT* ←
   - ( RP5 ONLY ): 2" CS T&C.....2.96/FT
   - 2" 304 SS T&C.....13.86/FT* ←

*SS PRICES CAN FLUCTUATE SIGNIFICANTLY OVER TIME.

**WELL HEAD FITTINGS:** Standard Carbon Steel.....150.00
Stainless Steel.....price on request

**TOP LOADING INLET JACKET (PUMP CAN):** Carbon steel.....150.00

**CONTROL PANELS** - NEMA 3R Enclosure ( Contactor, Adjustable Thermal Overload, HOA. Does not include primary disconnect or short circuit protection.)

FIXED SPM: THRU 10 HP, 1-PHASE OR 3-PHASE.....250.00
FOR VARIABLE SPM: PANEL PRICE INCLUDED IN VSD PRICE ABOVE. CONTROL PANELS CAN ALSO BE CUSTOM BUILT PER CUSTOMER REQUIREMENTS.

HOUSTON, TX SALES: 918-493-6101 TULSA, OK

REF 8

CRC

# STANDARD MATHEMATICAL TABLES

28th EDITION

CRC PRESS

REF 8A



*Mensuration Formulas*

**Pyramid**

$S$ of regular pyramid $= \frac{1}{2}$(perimeter of base) $\times$ (slant height)

$V = \frac{1}{3}$(area of base) $\times$ (altitude)

**Frustum of Pyramid**

Let $B_1$ = area of lower base, $B_2$ = area of upper base, $h$ = altitude.

$S$ of regular figure $= \frac{1}{2}$(sum of perimeters of bases) $\times$ (slant height)

$V = \frac{1}{3}h(B_1 + B_2 + \sqrt{B_1B_2})$

**Prismatoid**

A *prismatoid* is a polyhedron having for bases two polygons in parallel planes, and for lateral faces triangles or trapezoids with one side lying in one base, and the opposite vertex or side lying in the other base, of the polyhedron. Let $B_1$ = area of lower base, $M$ = area of midsection, $B_2$ = area of upper base, $h$ = altitude.

$$V = \frac{1}{6}h(B_1 + 4M + B_2) \quad \text{(the } \textit{prismoidal formula}\text{)}$$

*Note:* Since cubes, rectangular parallelepipeds, prisms, pyramids, and frustums of pyramids are all examples of prismatoids, the formula for the volume of a prismatoid subsumes most of the above volume formulae.

**Regular Polyhedra**

Let $v$ = number of vertices, $e$ = number of edges, $f$ = number of faces, $\alpha$ = each dihedral angle, $a$ = length of each edge, $r$ = radius of the inscribed sphere, $R$ = radius of the circumscribed sphere, $A$ = area of each face, $T$ = total area, $V$ = volume.

$v - e + f = 2$ (the *Euler-Descartes formula*—actually holds for *any* convex polyhedron)

$$T = fA$$
$$V = \frac{1}{3}rfA = \frac{1}{3}rT$$

| Name | Nature of Surface | $T$ | $V$ |
|---|---|---|---|
| Tetrahedron | 4 equilateral triangles | $1.73205a^2$ | $0.11785a^3$ |
| Hexahedron (cube) | 6 squares | $6.00000a^2$ | $1.00000a^3$ |
| Octahedron | 8 equilateral triangles | $3.46410a^2$ | $0.47140a^3$ |
| Dodecahedron | 12 regular pentagons | $20.64573a^2$ | $7.66312a^3$ |
| Icosahedron | 20 equilateral triangles | $8.66025a^2$ | $2.18169a^3$ |

| Name | $v$ | $e$ | $f$ | $\alpha$ | $a$ | $r$ |
|---|---|---|---|---|---|---|
| Tetrahedron | 4 | 6 | 4 | 70° 32′ | $1.633R$ | $0.333R$ |
| Hexahedron | 8 | 12 | 6 | 90° | $1.155R$ | $0.577R$ |
| Octahedron | 6 | 12 | 8 | 109° 28′ | $1.414R$ | $0.577R$ |
| Dodecahedron | 20 | 30 | 12 | 116° 34′ | $0.714R$ | $0.795R$ |
| Icosahedron | 12 | 30 | 20 | 138° 11′ | $1.051R$ | $0.795R$ |

# LCRS FLOW CAPACITY AND PUMP SIZING

AquAeTer

*optimizing environmental resources - water; air; earth*

# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: August 16, 2007

CALCULATION NUMBER: C.8 Revision: Update per 2007 Design

**CALCULATION TITLE: LCRS Flow Capacity and Pump Sizing**

**DESCRIPTION OF CALCULATION:**

Calculation to determine if 1996 LCRS Flow Capacity and Pump Sizing are sufficient for 2007 proposed design

**REFERENCES USED:** Number of Reference Pages Attached:

1. August 6, 2007 Calculation of Infiltration Rates
2. GSE Geotextile Information
3. EPG Sump Pump Information
4. Previous calc: 1996 calculation titled "LCRS Flow Capacity and Pump Sizing"
5. Designing with Geosynthetics, Koerner, 1998.
6. USEPA. Solid Waste Disposal Facility Criteria – (EPA530-R-93-017), dated Noveber 1993

**REVIEW COMMENTS:**

CALCULATION MADE BY: CAB DATE: 8/22/2007

CALCULATION CHECKED BY: SLW DATE: 8/23/2007

CALCULATION REVISED BY: DATE:

CALCULATION REVIEWED BY: SLW DATE: 8/23/2007

**Purpose of Calculation**

Use the 1996 LCRS flow capacity and pump sizing calculation to determine if proposed changes in the 2007 trench design require changes to the LCRS or associated piping and pumps. The purpose of the LCRS is to ensure that the head on the primary liner does not exceed one foot.

**Method**

The flow to sumps will be calculated.

The sump flow elements will be sized to handle the flow.

A pump capable of evacuating the flow from the sumps will be specified.

**Analysis**

A 2-inch design storm occurring immediately following placement of the 30-inch operations layer and before placement of any additional waste, is the design criteria for the LCRS drainage system. As shown in the LCRS Infiltration Calcuation, the resulting infiltration into the LCRS drainage net is dependent on unsaturated flow conditions and result in the following flow.

| Cell | Infiltration (gal/min/cell) |
|---|---|
| 12A | 7.9 |
| 12B | 5.4 |
| 12C | 8.6 |

(Reference LCRS Infiltration Rate Calculation, August 6, 2007)

The geocomposite transmissivity is 4.35 gal/min/ft. See reference for GSE FabriNet Geocomposite (Double-Sided) – 8 oz/yd$^2$ at 300 mil. The relationship of transmissivity and flow is proven with d'Arcy's Law.

d'Aarcy Flow = $q_{ult}$ =kiA

Where k = hydraulic conductivity
i = gradient
A = area

Transmissivity = T = b*k where b is the thickness of the geocomposite.

Rearranging the transmissivity equation so k = $\frac{T}{b}$

For a unit width of geocomposite:

A = 1 x b, therefore A = b

then $q_{ult} = \frac{T}{b} * i * b = T*i$

Substituting the transmissivity (4.35 gal/min-ft) and the minimum bottom gradient of Trench 12 of 0.01:

$q_{ult}$ = 4.35 gal/min-ft * 0.01 = 0.0435 gal/min-ft.

Effective flow for the geosynthetic is calculated by applying several safety factors to the ultimate flow rate. The following from Koerner 1998 is used for that calculation. Definitions are provided in the attached reference.

$$q_{eff} = \frac{q_{ult}}{(RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC})}$$

The following table shows the unit flow capacity for the geosynthetic LCRS member based on the applicable transmissivity, hydraulic gradient, and safety factors:

| Flow Element | $q_{ult}$ | $RF_{IN}$ | $RF_{CR}$ | $RF_{CC}$ | $RF_{BC}$ | $q_{eff}$ | $q_{eff}$ |
|---|---|---|---|---|---|---|---|
| Units | gal/min-ft | NA | NA | NA | NA | gal/min/ft | gal/day/ft |
| GSE Fabrinet 8 ounce/yd$^2$ | 0.0435 | 1.5 | 1.4 | 1.5 | 1.5 | 0.00921 | 13.3 |

Using the effective flow through the geocomposite to determine permeability yields the following:

$$k = \frac{q_{eff}}{Ai}, \text{ for unit width (1 ft) where A = b, } k = \frac{q_{eff}}{bi}$$

Permeablility = $q_{eff}$ / geocomposite thickness / gradient

$$\text{Permeability} = 0.00921 \frac{gallons}{\text{min}-ft} \times \frac{0.134\,ft^3}{1 gallon} \times \frac{1}{0.3 inch} \times \frac{12 inch}{1 foot} \times \frac{1}{0.01} = 4.94\,ft/\text{min}$$

For cell 12C to accommodate $q_{eff}$ into the LCRS, the geonet must have a minimum perimeter of (8.6 gallons/minute)/(0.00921 gal/min/ft) = 930 feet. Providing this much flow capacity with geocomposites alone is not feasible; therefore, a pipe system will be provided to improve drainage characteristics into the LCRS sumps.

A single 3-inch diameter corrugated polyethylene pipe (Manning n = 0.015) at a slope of 1 percent has a flow capacity of approximately 34 gallons per minute (1996 Calculation C.8). This is more than sufficient to accommodate the maximum LCRS flow into the sump. As shown in Figure 1, the pipes will be located along the grade breaks of the bottom with lateral lines located every 100 feet along the grade break length. The basis for the layout is described below.

As shown in the 1996 LCRS flow calculation, from manufacturer's literature 3 inch diameter corrugated polyethylene pipe comes with slots providing 1.44 $in^2$ of flow area per foot of piple. The orifice equation is used to estimate flow into the pipe per foot of length. The orifice equation is as follows (Reference in 1996 Calculation):

$$Q = CA\sqrt{2gH}$$

The coefficient C = 0.6, g = 32.2 ft/$sec^2$, and H is assumed to be 1. The calculation is therefore:

$$Q = (0.6)(1.44in^2)\left(\frac{1ft^2}{144in^2}\right)\sqrt{2\left(\frac{32.2ft}{\sec^2}\right)(1in)\left(\frac{1ft}{12in}\right)}$$

$$Q = \frac{0.014ft^3}{\sec}\left(\frac{7.48gal}{ft^3}\right)\left(\frac{60\sec}{\min}\right) = 6.2gpm$$

Since this is substantially more than the maximum estimated flow rate, the spacing of laterals is controlled by the flow capacity of the geocomposite. The geocomposite flow capacity of 0.00921 gal/min/ft is used to verify the spacing of piping laterals. Water infiltration into the geocomposite was calculated in a separate calculation. The various rates for the three cells are shown in table below and in the attached reference. Lateral spacing is then calculated as:

L = Infiltration/Flow in Geotextile or for Cell 12C,

$$L = \left(0.00921\frac{gal}{\min - ft}\right)\left(\frac{\min - ft2}{9.2x10^{-5}gal}\right)$$

L = 100 ft

| Cell | Floor Area ($ft^2$) | Infiltration ($gal/min/ft^2$) | Flow in geocomposite gal/min-ft | Lateral Spacing (ft) |
|---|---|---|---|---|
| 12A | 149,149 | 5.31E-05 | 0.00921 | 173 |
| 12B | 122,425 | 4.43E-05 | 0.00921 | 208 |
| 12C | 93,409 | 9.23E-05 | 0.00921 | 100 |

The length between the laterals is not less than the 100 feet; therefore, the 1996 design criteria of 100 feet is sufficient and will be used.

The peak leachate head on the primary liner system will occur after the minimum initial thickness of waste (30 inches of select waste as protective cover) has been placed over the cell. According to the USEN permit regulation, head on the liner can not exceed 1 foot. The maximum depth of leachate above the primary liner system is described in the USEPA document

Solid Waste Disposal Facility Criteria – *Technical Manual* (EPA530-R-93-017), dated Noveber 1993 as:

$$h_{max} = \frac{L\sqrt{c}}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right]$$

Where c = amount of leachate (q/k)
k = permeability of geocomposite (from above)
q = vertical inflow rate (reference attached)
α = slope (1 percent or 0.57°)
L = distance between the piping laterals (100 feet)

Using the above equation, a maximum flow length of 100 feet (maximum distance between laterals), a rate of vertical inflow (infiltration rate from the Trench 12 Infiltration Rate Calculation (August 6, 2007)), the permeability (4.9 ft/min), and a bottom slope of 1 percent (or 0.57°) were applied.

The results for the three cells of Trench 12 are shown below.

| Cell | L<br>Farthest Length<br>ft | q<br>Rate of Vertical Inflow<br>ft/min | k<br>Permeability<br>ft/min | α<br>Slope<br>(°) | c<br>c=q/k<br>(unitless) | $\tan^2\alpha$ | $h_{max}$<br>Max Height<br>(ft) | $h_{max}$<br>Max Height<br>(in) |
|---|---|---|---|---|---|---|---|---|
| 12A | 100 | 7.10E-06 | 4.93 | 0.57 | 1.44E-06 | 9.89767E-05 | 0.030 | 0.36 |
| 12B | 100 | 5.93E-06 | 4.93 | 0.57 | 1.20E-06 | 9.89767E-05 | 0.027 | 0.33 |
| 12C | 100 | 1.23E-05 | 4.93 | 0.57 | 2.50E-06 | 9.89767E-05 | 0.040 | 0.48 |

The results of the calculation show that leachate head on the liner should not exceed the permit limit of 1.0 foot.

Pump Size

The LCRS pump must be capable of lifting the leachate vertically approximately 100 feet. As described in the 1996 calculation, head losses in the discharge line are expected to be minimal, allow for 5 feet of loss. Also minor losses are anticipated to be no more than 20 percent of the subtotaled loss, or approximately 21 feet. Total estimated dynamic head (TDH) is therefore:

TDH = 100 ft + 5 ft + 21 ft = 126 feet.

As done in the 1996 calculation, using a safety factor of 4 for the required pump capacity should be 4 x 8.6 gallons per minute or 34.4 gallons per minute. An EPG Vertical Sump Drainer Model 12-5 at 3.0 HP provides this capacity. Reference is attached.

**Results**

The effective flow of the LCRS geocomposite is 0.00921 gal/ft-min. Since infiltration could be as high as 8.6 gallons per minute, a sump with a perimeter of 930 feet would be needed to prevent backups from occurring. Since the sump has a perimeter of only 70 feet, backups could occur; therefore, 3" piping spaced at 100 feet will be used in the LCRS design. Maximum leachate head on the liner could be as much as 0.013 feet in cell 12C; however, this is less than the 1.0 foot maximum required in the permit therefore 100 feet lateral drainage piping and the selected geocomposite are acceptable.

Since flow through the LCRS system could be as high as 8.6 gallons per minute and assuming a safety factor or 4, an EPG Vertical Sump Drainer Model 12-5 at 3.0 HP was selected as the pump for the LCRS.

REFERENCE

INFILTRATION RATE - 2007 CALCULATION

SHEET OF RATES

$$Q = Ku * i * A$$

$$Q = (7.10 \times 10\text{-}6 \text{ ft / min})(1.0)(1.0 \text{ sq ft})$$

$$= 7.10 \times 10\text{-}6 \text{ cu ft / min per square foot area}$$

$$= 5.31 \times 10\text{-}5 \text{ gal/ min per square foot area}$$

Drainage over the entire 3.42 acre area of the Phase 1 floor is:

$$Q = (5.31 \text{ gal} \times 10\text{-}5 \text{ gal / sq ft – min}) \text{ X } 3.42 \text{ acre X } 43{,}560 \text{ sq ft / acre}$$

$$Q = 7.9 \text{ gallons per minute}$$

The calculation was repeated for cells 12B and 12C. The results of the analyses are provided in the attached table.

**Calculation result**

When the 2.5-feet thick select waste layer, before placement of any additional waste, is subject to the 2-inch design storm, the resulting infiltration into the LCRS drainage net is dependent on unsaturated flow conditions and result in the following flow.

| Cell | Infiltration (gal/min/cell) |
|---|---|
| 12A | 7.9 |
| 12B | 5.4 |
| 12C | 8.6 |

INFILTRATION RATE CALCULATION



**Infiltration Into the LCRS**

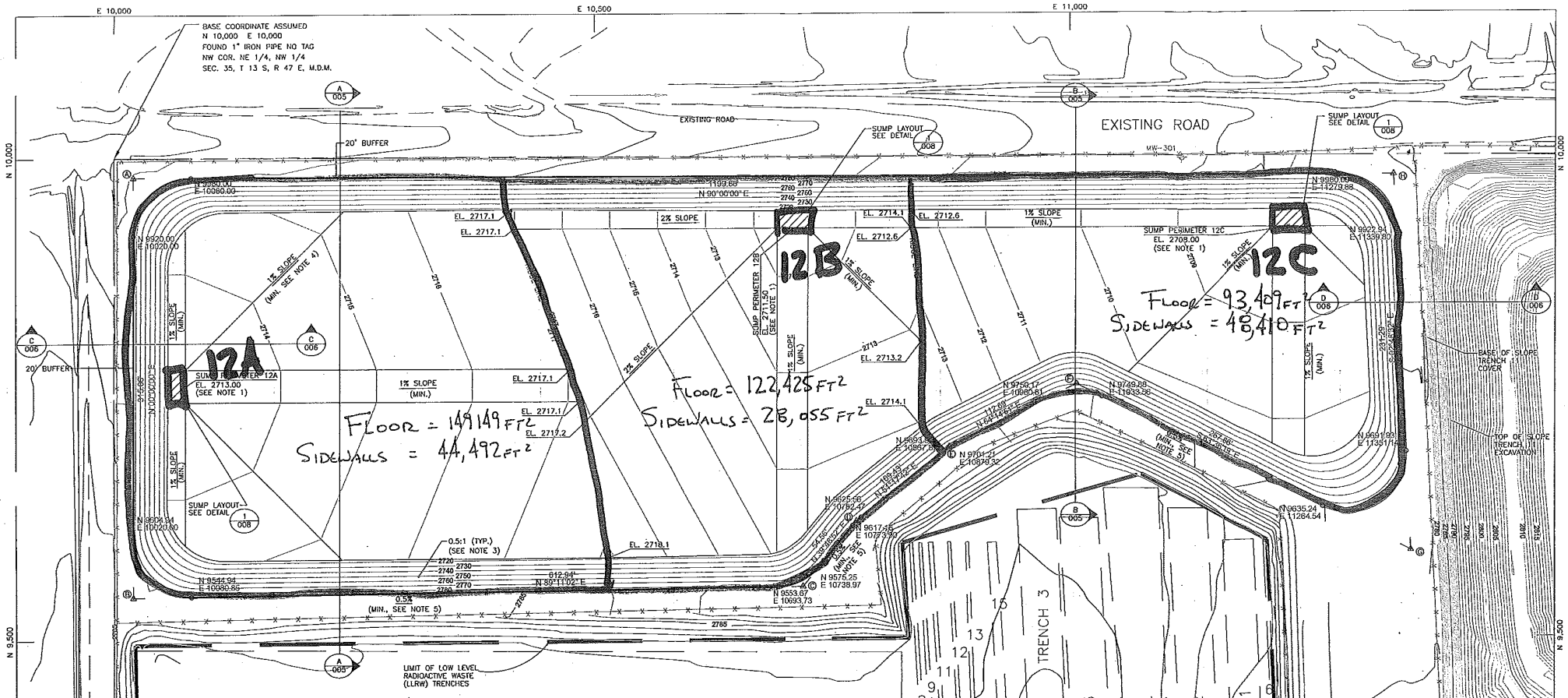
| Cell | Floor (ft2) | Sidewalls (ft2) | Design Storm (in) | Design Storm Precip to Floor (in) | Vol Water Content After Storm % | Ku (cm/sec) | Ku (ft/min) | $q$ ($ft^3/min/ft^2$) | $q$ ($gal/min/ft^2$) | $q$ (gal/min/cell) |
|---|---|---|---|---|---|---|---|---|---|---|
| 12A | 149,149 | 44,492 | 2 | 2.60 | 0.309 | 3.61E-06 | 7.10E-06 | 7.10E-06 | 5.31E-05 | 7.9 |
| 12B | 122,425 | 28,055 | 2 | 2.46 | 0.304 | 3.01E-06 | 5.93E-06 | 5.93E-06 | 4.43E-05 | 5.4 |
| 12C | 93,409 | 48,410 | 2 | 3.04 | 0.323 | 6.27E-06 | 1.23E-05 | 1.23E-05 | 9.23E-05 | 8.6 |

Variables

| | | k (cm/sec) | Porosity % | FC % | WP % | $\Psi b$ | $\lambda$ | $\theta r$ | $i$ | A ($ft^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil Type | SM | 5.20E-04 | 0.473 | 0.222 | 0.104 | 0.013 | 0.27 | 0.04 | 1 | 1 |

REFERENCE

2007 DESIGN AREAS




## NOTES:

1. CONTOURS SHOWN ARE TOP OF PREPARED SUBGRADE. SINCE GEOSYNTHETICS ARE USED EXCLUSIVELY FOR LINING, IT IS EFFECTIVELY ALSO THE TOP OF LINER. SEE DETAIL 2 ON SHEET 08 FOR LCRS PIPE DEPLOYMENT AND DETAIL 1 ON DRAWING 008 FOR LDS DRAINAGE LAYER DEPLOYMENT.
2. THE HORIZONTAL CONTROL LINE (HCL) IS ESTABLISHED BY THE OFFSET BUFFERS. THE HCL IS THE LIMIT OF EXCAVATION EXCLUDING EXCAVATION REQUIRED TO REPLACE LOOSE SURFACE SOIL AT TRENCH EDGES.
3. ALL SUBGRADE EXCAVATION SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e., THE HCL).
4. THE MINIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1% OR 2% AS INDICATED.
5. PROVIDE LOCAL GRADING AS NECESSARY TO PROVIDE DRAINAGE AWAY FROM THE HCL.
6. DURING FILLING OF TRENCH 12, PROVIDE A BERM ALONG THE TRENCH 12 TOP OF SLOPE TO PREVENT RUN-ON ONTO THE TRENCH.

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- PROPERTY LINE
- FENCE LINE
- HORIZONTAL CONTROL LINE (LIMIT OF EXCAVATION)
- PERMIT LINE (RADIOLOGICAL WASTE DISPOSAL AREA)
- UNIMPROVED ROAD
- 1' CONTOUR INTERVAL, FEET (MSL)
- 2785 — 5' CONTOUR INTERVAL, FEET (MSL)
- 2780 — 10' CONTOUR INTERVAL, FEET (MSL)
- SUMP AREA
- TRENCH 1 — LOW LEVEL RADIOLOGICAL WASTE TRENCH

SURVEY CONTROL TABLE

| PI/CURVE | PI COORDINATES | | CURVE DATA | | | |
|---|---|---|---|---|---|---|
| | | | RADIUS | LENGTH | TANGENT | DELTA |
| A | N 9,980.00 | E 10,020.00 | 60.00' | 94.25' | 60.00' | 90°00'00" |
| B | N 9,544.08 | E 10,020.00 | 60.00' | 95.10' | 60.86' | 90°48'58" |
| C | N 9,554.07 | E 10,721.31 | 60.00' | 51.70' | 27.58' | 49°22'10" |
| D | N 9,621.79 | E 10,777.76 | 60.00' | 12.02' | 6.03' | 11°28'50" |
| E | N 9,698.25 | E 10,873.18 | 60.00' | 13.56' | 6.81' | 12°57'10" |
| F | N 9,762.93 | E 11,007.26 | 60.00' | 54.61' | 29.36' | 52°08'50" |
| G | N 9,589.77 | E 11,356.15 | 60.00' | 124.83' | 102.28' | 119°12'14" |
| H | N 9,980.00 | E 11,337.00 | 60.00' | 91.31' | 57.13' | 87°11'28" |

GROUND CONTROL BY : GREAT WEST SURVEYORS LAS VEGAS, NEVADA

PHOTOGRAMMETRY BY: C & C AERIAL MAPPING CORP. SAN DIMAS, CALIFORNIA

BASED ON DRAWING NV-161-PMT-003 BY: ENVIRONMENTAL SOLUTIONS, INC. IRVINE, CALIFORNIA

50 25 0 50
SCALE FEET

FIGURE 1

| DESCRIPTION | DRWN BY | DSGN. BY | CHECK BY | APP'D BY | DATE |
|---|---|---|---|---|---|
| | | | | | |

**USEcology Nevada**
an American Ecology company

PROJECT NUMBER: 073113 DATE: 5/17/07

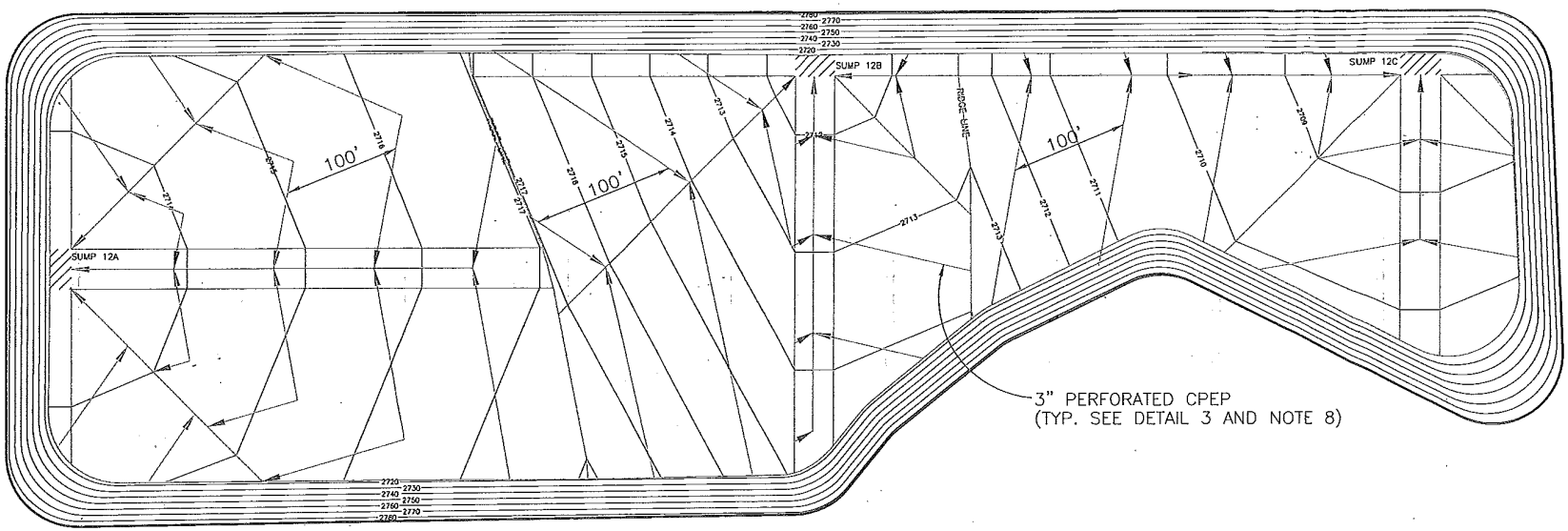
BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

EXCAVATION PLAN

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
|---|---|---|---|---|---|---|---|---|---|---|
| LAM | 5/17/07 | CAB | 5/17/07 | SLW | 5/17/07 | SLW | | 073113 | NV12-07-004 | -- |

CAD FILE NAME: F:\Data\073113\N12 Design Package\subgrade design\NV12-07-004.dwg PLOT DATE: 5/18/07

LATERAL SPACING

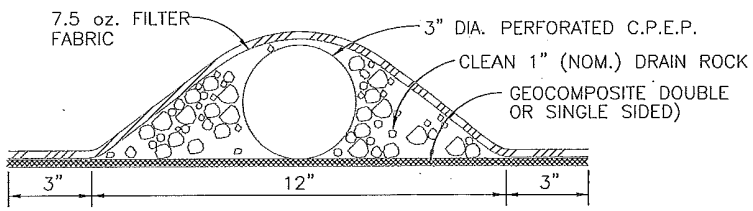



2 DEPLOYMENT LCRS PIPES

REF.: NV12-07-004

100 50 0 100

SCALE FEET




3 TYPICAL C.P.E.P SECTION

REF.: NV12-07-008

FIGURE 2

REFERENCE

GEONET PROPERTIES

GSE STANDARD PRODUCTS

# Product Data Sheet

## GSE PermaNet UL Geocomposite (Double-Sided)

GSE PermaNet UL (Ultra Load) Geocomposites are patent pending drainage products manufactured with a geonet heat-bonded to a nonwoven, needlepunched geotextile on both sides. The creep resistant structure ensures continuous flow performance over a broad range of conditions and long durations. These products work as an efficient drainage medium and are ideal for extremely high compressive stress applications.

Depending on filtration and interface strength requirements of a specific project, GSE can bond any type of nonwoven, needlepunched geotextiles to the geonet. GSE PermaNet UL Geocomposites are available in a 6, 8, and 10 oz/yd² geotextile as described in the product specification chart below. For more information on the performance transmissivity under site-specific conditions, please contact a GSE representative.

**GSE Advantage Products**

GSE GeoBond • GSE Conductive • GSE WEBs • GSE PermaNet • GSE Wetlands System

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | AVERAGE VALUE | | |
|---|---|---|---|---|---|
| **Geocomposite** | | | 6 oz/yd² | 8 oz/yd² | 10 oz/yd² |
| Product Code | | | FR82060060T | FR82080080T | FR82100100T |
| Transmissivity[a], gal/min/ft (m²/sec) | ASTM D 4716 | 1/540,000 ft² | 4.8 (1 x $10^{-3}$) | 4.8 (1 x $10^{-3}$) | 4.8 (1 x $10^{-3}$) |
| Ply Adhesion, lb/in (g/cm) | ASTM D 7005 | 1/50,000 ft² | 1.0 (178) | 1.0 (178) | 1.0 (178) |
| Roll Width[b], ft (m) | | | 15 (4.5) | 15 (4.5) | 15 (4.5) |
| Roll Length[b], ft (m) | | | 150 (45) | 140 (42) | 130 (39) |
| Roll Area, ft² (m²) | | | 2,250 (202) | 2,100 (189) | 1,950 (175) |
| **Geonet Properties** | | | AVERAGE VALUE | | |
| Transmissivity[c], gal/min/ft (m²/sec) | ASTM D 4716 | | 24 (5 x $10^{-3}$) | | |
| Compression Strength, lb/ft² (kPa) | ASTM D 1621 | 1/540,000 ft² | 50,000 (2,390) | | |
| Creep Reduction Factor | | once per formulation | 1.3 @ 25,000 psf | | |
| Mass, lb/ft² (g/m²) | ASTM D 5261 | 1/50,000 ft² | 0.43 (2,100) | | |
| Density, g/cm³ | ASTM D 1505 | 1/50,000 ft² | 0.94 | | |
| Tensile Strength (MD), lb/in (N/mm) | ASTM D 5035 | 1/50,000 ft² | 100 (17) | | |
| Carbon Black Content, % | ASTM D 1603, modified | 1/50,000 ft² | 2.0 | | |
| **Geotextile Properties[d]** | | | MINIMUM AVERAGE ROLL VALUE | | |
| Mass, oz/yd² (g/m²) | ASTM D 5261 | 1/90,000 ft² | 6 (200) | 8 (270) | 10 (335) |
| Grab Tensile, lb (N) | ASTM D 4632 | 1/90,000 ft² | 170 (755) | 220 (975) | 260 (1,155) |
| Puncture Strength, lb (N) | ASTM D 4833 | 1/90,000 ft² | 90 (395) | 120 (525) | 165 (725) |
| AOS, US sieve (mm) | ASTM D 4751 | 1/540,000 ft² | 70 (0.21) | 80 (0.180) | 100 (0.150) |
| Permittivity, (sec⁻¹) | ASTM D 4491 | 1/540,000 ft² | 1.5 | 1.5 | 1.2 |
| Flow Rate, gpm/ft² (lpm/m²) | ASTM D 4491 | 1/540,000 ft² | 110 (4,480) | 110 (4,480) | 85 (3,460) |
| UV Resistance, % retained | ASTM D 4355 (after 500 hours) | once per formulation | 70 | 70 | 70 |

**NOTES:**

- [a]This is an index transmissivity value measured at stress = 25,000 psf; gradient = 0.1; time = 15 minutes; boundary conditions = plate/geocomposite/plate. Contact GSE for performance transmissivity value for use in design.
- [b]Roll widths and lengths have a tolerance of ±1%.
- [c]This is an index transmissivity value measured at stress = 25,000 psf; gradient = 0.1; time = 15 minutes; boundary conditions = plate/geonet/plate
- [d]All geotextile properties are minimum average roll values except AOS ( in mm) which is a maximum average roll value (MaxARV); and UV resistance which is a typical value.

DS023 PermaNetUL R04/25/06

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www.gseworld.com

REFERENCE

KOERNER, DESIGNING w/ GEOSYNTHETICS

Fourth Edition

# Designing with Geosynthetics

Robert M. Koerner, Ph.D., P.E.

H. L. Bowman Professor of Civil Engineering,
Drexel University and Director, Geosynthetic
Research Institute

PRENTICE HALL
Upper Saddle River, New Jersey 07458

### 4.1.6 Allowable Flow Rate

As described previously, the very essence of the design-by-function concept is the establishment of an adequate factor of safety. For geonets, where flow rate is the primary function, this takes the following form.

$$\mathrm{FS} = \frac{q_{\mathrm{allow}}}{q_{\mathrm{reqd}}} \tag{4.3}$$

where

FS = factor of safety (to handle unknown loading conditions or uncertainties in the design method, etc.),
$q_{\mathrm{allow}}$ = allowable flow rate as obtained from laboratory testing, and
$q_{\mathrm{reqd}}$ = required flow rate as obtained from design of the actual system.

Alternatively, we could work from transmissivity to obtain the equivalent relationship.

$$\mathrm{FS} = \frac{\theta_{\mathrm{allow}}}{\theta_{\mathrm{reqd}}} \tag{4.4}$$

where $\theta$ is the transmissivity, under definitions as above. As discussed previously, however, it is preferable to design with flow rate rather than with transmissivity because of nonlaminar flow conditions in geonets.

Concerning the allowable flow rate or transmissivity value, which comes from hydraulic testing of the type described in Section 4.1.3, we must assess the realism of the test setup in contrast to the actual field system. If the test setup does not model site-specific conditions adequately, then adjustments to the laboratory value must be made. This is usually the case. Thus the laboratory-generated value is an ultimate value that must be reduced before use in design; that is,

$$q_{\mathrm{allow}} < q_{\mathrm{ult}}$$

One way of doing this is to ascribe reduction factors on each of the items not adequately assessed in the laboratory test. For example,

$$q_{\mathrm{allow}} = q_{\mathrm{ult}}\left[\frac{1}{\mathrm{RF}_{IN} \times \mathrm{RF}_{CR} \times \mathrm{RF}_{CC} \times \mathrm{RF}_{BC}}\right] \tag{4.5}$$

or if all of the reduction factors are considered together.

$$q_{\mathrm{allow}} = q_{\mathrm{ult}}\left[\frac{1}{\Pi\mathrm{RF}}\right] \tag{4.6}$$

where

$q_{\mathrm{ult}}$ = flow rate determined using ASTM D4716 or ISO/DIS 12958 for short-term tests between solid platens using water as the transported liquid under laboratory test temperatures,

$q_{allow}$ = allowable flow rate to be used in Eq. (4.3) for final design purposes,
$RF_{IN}$ = reduction factor for elastic deformation, or intrusion, of the adjacent geosynthetics into the geonet's core space,
$RF_{CR}$ = reduction factor for creep deformation of the geonet and/or adjacent geosynthetics into the geonet's core space,
$RF_{CC}$ = reduction factor for chemical clogging and/or precipitation of chemicals in the geonet's core space,
$RF_{BC}$ = reduction factor for biological clogging in the geonet's core space, and
$\Pi RF$ = product of all reduction factors for the site-specific conditions.

Some guidelines for the various reduction factors to be used in different situations are given in Table 4.2. Please note that some of these values are based on relatively sparse information. Other reduction factors, such as installation damage, temperature effects, and liquid turbidity, could also be included. If needed, they can be included on a site-specific basis. On the other hand, if the actual laboratory test procedure has included the particular item, it would appear in the above formulation as a value of unity. Examples 4.2 and 4.3 illustrate the use of geonets and serve to point out that high reduction factors are warranted in critical situations.

**Example 4.2**

What is the allowable geonet flow rate to be used in the design of a capillary break beneath a roadway to prevent frost heave? Assume that laboratory testing was done at the proper design load and hydraulic gradient and that this testing yielded a short-term between-rigid-plates value of $2.5 \times 10^{-4}$ m²/s.

**Solution:** Since better information is not known, average values from Table 4.2 are used in Eq. (4.5).

TABLE 4.2 RECOMMENDED PRELIMINARY REDUCTION FACTOR VALUES FOR EQ. (4.5) FOR DETERMINING ALLOWABLE FLOW RATE OR TRANSMISSIVITY OF GEONETS

| Application Area | $RF_{IN}$ | $RF_{CR}$* | $RF_{CC}$ | $RF_{BC}$ |
|---|---|---|---|---|
| Sport fields | 1.0 to 1.2 | 1.0 to 1.5 | 1.0 to 1.2 | 1.1 to 1.3 |
| Capillary breaks | 1.1 to 1.3 | 1.0 to 1.2 | 1.1 to 1.5 | 1.1 to 1.3 |
| Roof and plaza decks | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 | 1.1 to 1.3 |
| Retaining walls, seeping rock, and soil slopes | 1.3 to 1.5 | 1.2 to 1.4 | 1.1 to 1.5 | 1.0 to 1.5 |
| Drainage blankets | 1.3 to 1.5 | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 |
| Surface water drains for landfill covers | 1.3 to 1.5 | 1.1 to 1.4 | 1.0 to 1.2 | 1.2 to 1.5 |
| Secondary leachate collection (landfills) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 2.0 |
| Primary leachate collection (landfills) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 2.0 |

*These values are sensitive to the density of the resin used in the geonet's manufacture. The higher the density, the lower the reduction factor. Creep of the covering geotextile(s) is a product-specific issue.

REFERENCE

USEPA TECHNICAL MANUAL

HEAD ON LINER FORMULA REF.

United States Environmental Protection Agency
Solid Waste and Emergency Response (5305)
EPA530-R-93-017
November 1993
www.epa.gov/osw

EPA

# Solid Waste Disposal Facility Criteria

## Technical Manual

## Leachate Collection Pipes

All components of the leachate collection system must have sufficient strength to support the weight of the overlying waste, cover system, and post-closure loadings, as well as the stresses from operating equipment. The component that is most vulnerable to compressive strength failure is the drainage layer piping. Leachate collection system piping can fail by excessive deflection, which may lead to buckling or collapse (USEPA, 1988). Pipe strength calculations should include resistance to wall crushing, pipe deflection, and critical buckling pressure. Design equations and information for most pipe types can be obtained from the major pipe manufacturers. For more information regarding pipe structural strength, refer to U.S. EPA (1988).

Perforated drainage pipes can provide good long-term performance. These pipes have been shown to transmit fluids rapidly and to maintain good service lives. The depth of the drainage layer around the pipe should be deeper than the diameter of the pipe. The pipes can be placed in trenches to provide the extra depth. In addition, the trench serves as a sump (low point) for leachate collection. Pipes can be susceptible to particulate and biological clogging similar to the drainage layer material. Furthermore, pipes also can be susceptible to deflection. Proper maintenance and design of pipe systems can mitigate these effects and provide systems that function properly. Acceptable pipe deflections should be evaluated for the pipe material to be used (USEPA, 1989).

The design of perforated collection pipes should consider the following factors:

- The required flow using known percolation impingement rates and pipe spacing;
- Pipe size using required flow and maximum slope; and
- The structural strength of the pipe.

The pipe spacing may be determined by the Mound Model. In the Mound Model (see Figure 4-8), the maximum height of fluid between two parallel perforated drainage pipes is equal to (U.S. EPA, 1989):

$$h_{max} = \frac{L\sqrt{c}}{2}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right]$$

where c = q/k
k = permeability
q = inflow rate
$\alpha$ = slope.

The two unknowns in the equation are:

L = distance between the pipes; and
c = amount of leachate.

Using a maximum allowable head, $h_{max}$, of 30 cm (12 in), the equation is usually solved for "L" (U.S. EPA, 1989).

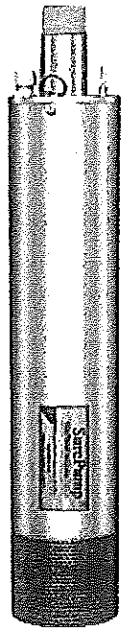
The amount of leachate, "c", can be estimated in a variety of ways including the Water Balance Method (U.S. EPA, 1989) and the computer model Hydrologic Evaluation of Landfill Performance (HELP). The HELP Model is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model uses climatologic, soil, and landfill design data and incorporates a solution technique that accounts for the effects of surface storage, run-off, infiltration, percolation, soil-moisture

REFERENCE

SURE PUMP DATA SHEET

SurePump™

# Vertical Sump Drainer



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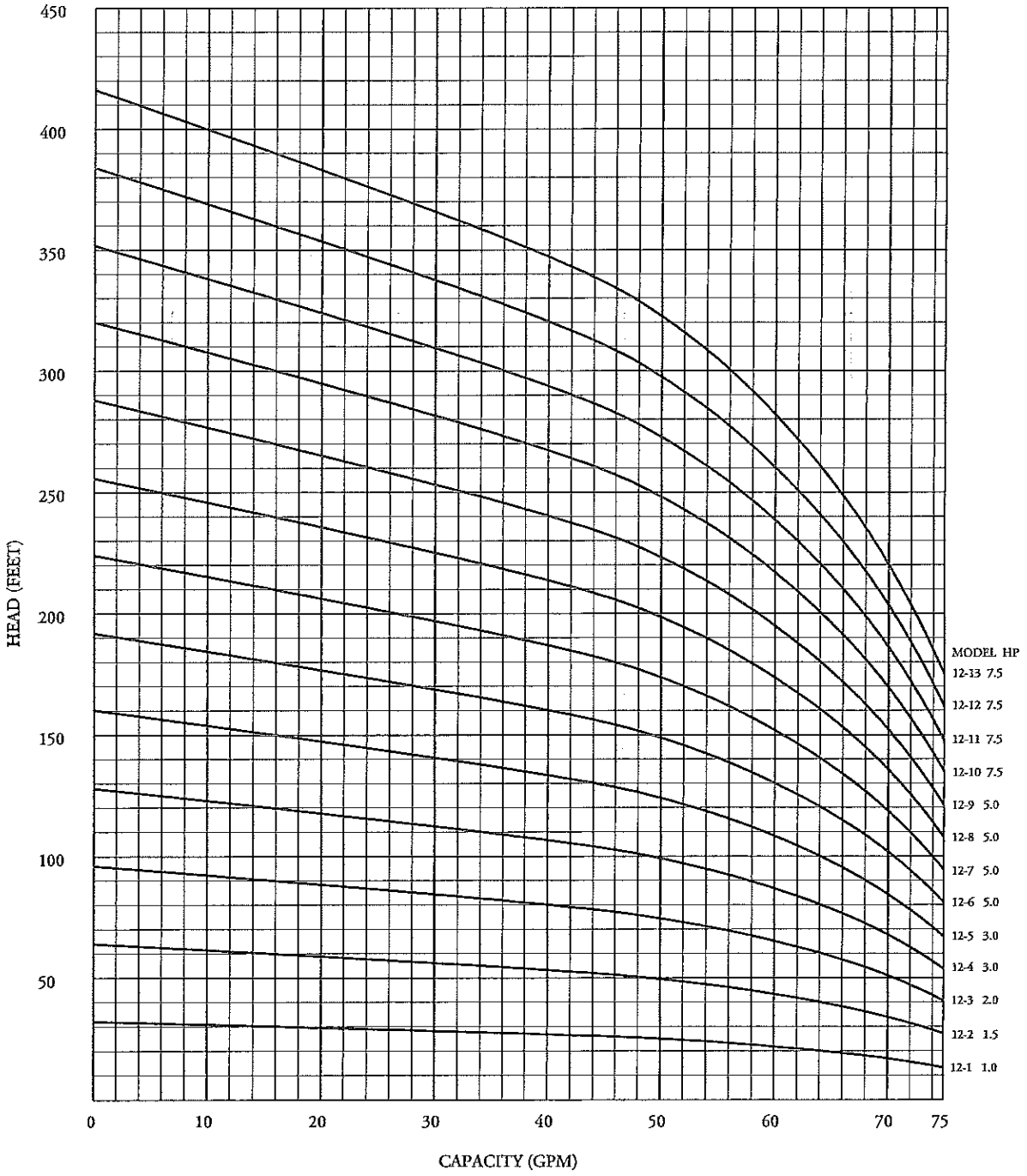


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REFERENCE

ESI 1996 CALCULATION

# C.8 LCRS FLOW CAPACITY AND PUMP SIZING

# Environmental Solutions, Inc.

By: RVH Date:2/22/96 Beatty Landfill-Cell 12 Page No. 1
Chk'd By: EC Date: 3/8/96 American Ecology Corporation Project No. 95-284

## LCRS Flow Capacity and Pump Sizing

**Purpose:**

1. Determine the potential flow rate into the leachate collection and removal sumps.

2. Size the flow elements (geonets, pipes, and gravel) and pumps to handle the projected flows.

3 Determine most effective method and pump requirements for run-off flows

**Method:**

1. Identify flow sources. The single largest source of liquid entering the sumps will be from infiltration when the cell has been completed but only the 2 foot thick select waste layer has been placed.

2. The design will assume the 25 year-24 hour storm event occurs just after placement of the select waste layer.

3. An infiltration factor will be selected.

4. The quantity of run-off will be calculated. Methods for handling run-off (which shall be considered hazardous waste) will be identified.

5. The quantity of infiltration, and the resultant flow to the sumps will be calculated. The sump flow elements will be sized to handle that flow. Pumps capable of evacuating that flow from the sumps will be identified.

**Summary**

1. 25 Year-24 Hour storm yields 2 inches of precipitation

2. Infiltration flow is controlled by unsaturated flow.

3. The maximum LCRS flow is 2 gallons per minute.

4. The geonet has insufficient capacity for the maximum infiltration flow and must be supplemented by 3 inch diameter slotted pipes (see layout in Figure 3).

5. In run-off systems must be able to store up to171,000 gallons of water, or be capable of pumping up to 100 gpm, if only a nominal impoundment is desired.

6. The maximum requirement for out of cell capacity is 300,000 gallons, assuming no measures to reduce contact between precipitation and waste are utilized.

**Analysis:**

Hydrology

1. The critical period for sizing the leachate collection system (i.e., when the greatest flow is likely to occur) is directly after placement of the 2 foot thick layer of select

## LCRS Flow Capacity and Pump Sizing

waste over the bottom. The quantity of infiltration reaching the LCRS through the waste will be the greatest at this point, although all water touching the waste will be considered leachate. During the construction period precipitation will be impounded within the cell, removed and discharged to the existing channels.

2. Figure 1 shows the configuration of Cell 12. Each phase of the cell is indicated along with slope, bottom, and total catchment areas. Cell 12C includes the top deck area where Cell 12 adjoins Cell 11.

3. The 25 year-24 hour storm yields 2 inches of precipitation (Reference 1A). The working deck is assumed to be well compacted by heavy equipment running over its surface, yielding a relatively high run-off curve number. Since the characteristics of the waste soil are unknown at this time assume soil group B (Reference 1A) and an SCS RCN of 85 (Ref 2A). Further assume run-off from the slopes (with the sacrificial liner) is intercepted and directed to run-off collection tanks/ponds. Table 1, below, shows the distribution for precipitation falling on the floor only:

**Table 1**

| Cell | Area (ac) | Precipitation (ac-ft) | Run-off (ac-ft) | Infiltration (ac-ft) |
|---|---|---|---|---|
| 12A | 2.36 | 0.39 | 0.16 | 0.24 |
| 12B | 1.81 | 0.30 | 0.12 | 0.18 |
| 12C | 1.46 | 0.24 | 0.10 | 0.15 |

LCRS Infiltration:

1. No allowance is made for evaporation, and all infiltration will be routed through the LCRS system. This provides a conservative total volume for the system design.

2. Sandy soils, assumed to comprise the 2 foot protective layer, have a wide range of porosities and moisture retention values. Typical values are taken from the HELP model literature (Reference 3A) as being conservative representations of this soil. The values are:

| | |
|---|---|
| Soil Type | SC |
| Hydraulic Conductivity | $1.2 \times 10^{-4}$ cm/s |
| Porosity | 0.398 |
| Field Capacity | 0.244 |
| Wilting Point | 0.136 |

3. For the largest infiltration case, Cell 12A, there is 0.24 ac-ft, or nearly 80,000 gallons, of infiltration. It is necessary to determine whether saturated or unsaturated flow conditions control drainage into the LCRS. It is assumed that the soil layer contains, at most, sufficient moisture to be at field capacity (i.e., no gravity drainage is initially occuring within the soil). A 2 foot thick layer of soil of unit area therefore has an available pore space of approximately:

$$2ft^3 \times 7.48\frac{gal}{ft^3} \times (0.398 - 0.244) = {}^{2.3gal}\!/_{ft^2}$$

## LCRS Flow Capacity and Pump Sizing

4. The rate at which the storm saturates the soil layer is given by:

$$0.24\text{ac}-\text{ft}\times\frac{1}{2.36\text{ac}}\times 7.48\frac{\text{gal}}{\text{ft}^3}\times\frac{1\text{day}}{1440\text{min}}\cong\frac{1\text{gal}}{1850\text{min}}$$

It would require nearly three days of steady rain at this rate to saturate the 2 foot soil layer assuming no simultaneous drainage occured. Conversely, only 34 percent of the available pore space is filled. Therefore unsaturated flow controls drainage from the 2 foot soil layer. Laminar flow through a porous media is estimated by:

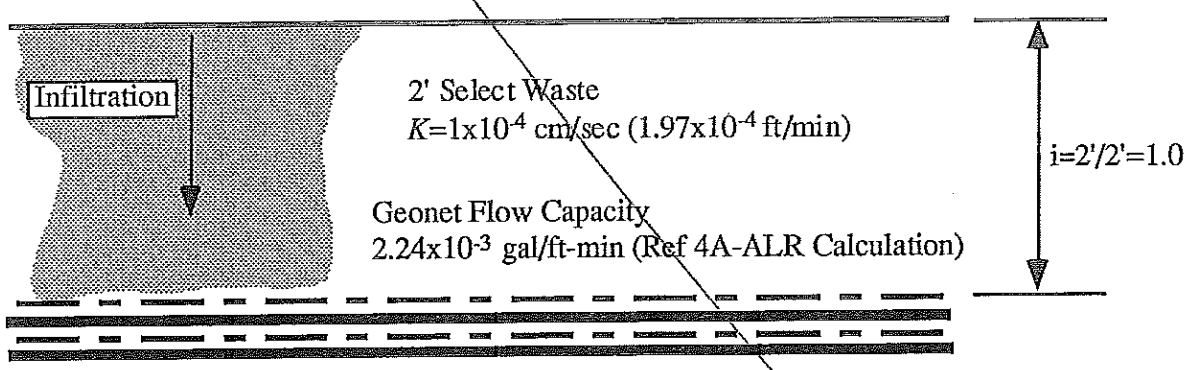
$$Q = Kia \qquad (1)$$

Where:

| | |
|---|---|
| $Q$ | Flow ($ft^3$/min) |
| $K$ | Hydraulic Conductivity (ft/min) |
| i | gradient |
| a | flow area ($ft^2$) |

for the unsaturated case unsaturated hydraulic conductivity, $K_u$, replaces $K$.

5. The unit flow parameters are shown in Figure 2 below:




6 Unsaturated hydraulic conductivity is estimated by Campbell's equation (Reference 3B), definitions for the terms are found in the reference:

$$K_u = K_s\left(\frac{\Theta-\Theta_r}{\phi-\Theta_r}\right)^{3+(\frac{2}{\lambda})}$$

7. The residual water content, $\Theta_r$, is the amount of water remaining in the soil pores under infinite capillary suction. Residual water content is calculated by Rawls (Reference 3C) as follows:

$$\Theta_r = 0.014+.25WP; WP \geq 0.04$$

## LCRS Flow Capacity and Pump Sizing

Where WP is wilting point, which for the designated soil is 0.136>0.04. Therefore the equation is applicable. The residual water content is then:

$$\Theta_r = 0.048$$

8. As discussed in the reference, residual water content and the pore-size distribution index, λ, are constants in the Brooks-Corey equation relating volumetric content to matrix potential (capillary pressure and adsorptive forces, Reference 3D):

$$\frac{\Theta - \Theta_r}{\phi - \Theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda}$$

9. This equation is solved assuming the volumetric water content is the field capacity, at 0.33 bars of capillary suction, $\psi$, and then the wilting point, at 15 bars capillary suction. Solving simutaneously yields both the pore size distribution index and bubbling pressure. Solving for the values assumed for the site soil yields the following:

**Constants:**

| | |
|---|---|
| Θr | 0.048 |
| ϕ | 0.398 |

| **Variables** | Θ | ψ | Θ−Θr/ϕ−Θr | (ψb/ψ)λ |
|---|---|---|---|---|
| Field Capacity | 0.244 | 0.33 | 0.56 | 0.56 |
| Wilting Point | 0.136 | 15 | 0.25 | 0.25 |

**Solved Values**

| | |
|---|---|
| ψb | 0.021 |
| λ | 0.210 |

10. Since only 34 percent of the available pore space was filled by infiltration the volumetric water content is:

$$\Theta = FC + 0.34(\phi - FC)$$
$$\Theta = 0.244 + 0.34(0.398 - 0.244)$$
$$\Theta = 0.296$$

11. Based on this calculation the unsaturated hydraulic conductivity is calculated from the following using Campbell's equation:

$$K_u = 1\times10^{-4}\,\frac{\text{cm}}{\text{sec}}\left(\frac{0.296-0.048}{0.398-.048}\right)^{\left(3+\left(\frac{2}{0.210}\right)\right)}$$

$$K_u = 1.361\times10^{-6}\,\frac{\text{cm}}{\text{sec}} = 2.68\times10^{-6}\,\frac{\text{ft}}{\text{min}}$$

## LCRS Flow Capacity and Pump Sizing

Previous Calc

12. Conservatively using a unit hydraulic gradient and assuming no evaporation, the rate at which the infiltration drains from the 2 foot layer into a unit area of the LCRS is:

$$q = \left(2.68\times10^{-6}\frac{\text{ft}}{\text{min}}\right)(1.0) = 2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}$$

$$q = 2.68\times10^{-6}\frac{\text{ft}^3}{\text{ft}^2-\text{min}}\left(7.48\frac{\text{gal}}{\text{ft}^3}\right) = 2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}$$

Drainage over the entire 2.36 acre cell is then:

$$Q = \left(2.00\times10^{-5}\frac{\text{gal}}{\text{ft}^2-\text{min}}\right)(2.36\text{ac})\left(\frac{43{,}560\text{ft}^2}{\text{ac}}\right)$$

$$Q = \frac{2.06\text{gal}}{\text{min}}$$

13. To accomodate this flow into the LCRS the geonet must have a minimum perimeter of $2.06/2.24\times10^{-3}=919$ feet. Since providing this much flow capacity with geocomposite alone is infeasible a pipe system will be provided to improve drainage characteristics into the LCRS sumps.

14. A single 3 inch diameter corrugated polyethylene pipe (manning n=0.015) at a slope of 1 percent has a flow capacity of approximately 34 gallons per minute (Reference 5A). This is more than sufficient to accomodate the maximum LCRS flow into the sump. As shown in Figure 3, the pipes will be located in along the grade breaks of the bottom with lateral lines located every 100 feet along the grade break length. The basis for the layout is described below.

15. From the manufacturer's literature 3" diameter pipe comes with slots providing 1.44 $\text{in}^2$ (Reference 5B) of flow area per foot. The orifice equation (Reference 6A) is used to estimate flow into the pipe per foot of length. The orifice equation is as follows:

$$Q = CA\sqrt{2gH}$$

The coefficient C=0.6, g=32.2ft/$\text{s}^2$, and H is assumed to be 1 inch. The calculation is therefore:

$$Q = (0.6)(1.44\text{in}^2)\left(\frac{1\text{ft}^2}{144\text{in}^2}\right)\sqrt{2\left(\frac{32.2\text{ft}}{\text{sec}^2}\right)(1\text{in})\left(\frac{1\text{ft}}{12\text{in}}\right)}$$

$$Q = \frac{0.014\text{ft}^3}{\text{sec}}\left(\frac{7.48\text{gal}}{\text{ft}^3}\right)\left(\frac{60\text{sec}}{\text{min}}\right) = 6.2\text{gpm}$$

## LCRS Flow Capacity and Pump Sizing

Since this is substantially more than the maximum estimated flow rate, the spacing of laterals is controlled by the flow capacity of the geocomposite. As stated above the geocomposite can accomodate $2.24 \times 10^{-3}$ gpm per foot of width. Since water percolates into the geocomposite at the rate of 2.00x10-5 gpm per square foot the lateral spacing is calculated as follows:

$$L = \left(2.24 \times 10^{-3} \frac{\text{gal}}{\text{min} - \text{ft}}\right)\left(\frac{\text{min} - \text{ft}^2}{2.00 \times 10^{-5} \text{gal}}\right)$$

$$L = 111 \text{ft}$$

Use 100 foot spacing for lateral pipes.

16. The LCRS sump is configured as shown in Figure 4. Beginning at the 10 percent slope the sump is filled with clean 1" diameter (nom.) drain rock. To assure unimpeded drainage into the riser the 3" diameter lines will be continued until adjacent to the riser.

17 The LCRS pump must be capable of lifting the leachate vertically approximately 100 feet, the maximum depth of fill above the sump. Head losses in the discharge line are expected to be minimal, allow 5 feet of loss. Minor losses are anticipated to be no more than 20 percent of the subtotaled loss, or approximately 21 feet. Total estimated dynamic head (TDH) is therefore:

$$TDH = 100ft + 5ft + 21ft = 126ft$$

18. Using a factor of safety of 4 for the pump capacity yields 8 gallons per minute. A Protec recipricating pump, Model No. RP-2, with variable speed electric control is recommended (See Reference 7).

Surface Run-Off:

1. During the critical period when waste filling has just started the greatest quantity of run-off is generated by Cell 12A. Approximately 0.16 acre-feet (53,000 gallons) of precipitation runs off the cell bottom. Since the slopes are covered by a sacrificial liner, no infiltration occurs at those surfaces and run-off is equal to the direct precipitation. Since Cell 12A has the largest slope area it is the conservative case. If a gutter system is not used another 0.19 acre-feet (61,000 gallons) runs off the slopes. Handling of run-off is an operational consideration. However, two methods are likely 1) directing the run-off to a temporary lined pond; 2) transferring the liquid to a holding tank.

2. If run-off is directed to a temporary holding pond it must have a capacity of:

(53,000 gal+61,000 gal)(1.5)=171,000 gal

## LCRS Flow Capacity and Pump Sizing

The value 1.5 is a factor of safety to assure adequate containment capacity. The volume of a regular type pond (frustrum of a pyramid) is found by the following formula (Reference 8A):

$$V = \frac{1}{3}h\left(A_{top} + A_{bot} + \sqrt{A_{top}A_{bot}}\right)$$

Assuming a depth of 5 feet, 80 foot sides, and 2:1 slopes yields a volume of

$$V = \frac{1}{3}(5)\left((80)^2 + (80-20)^2 + \sqrt{(80)^2(80-20)^2}\right)$$

$$V = 24{,}667\text{ft}^3\left(\frac{7.48\text{gal}}{\text{ft}^3}\right) = 185{,}000\text{gal} > 171{,}000\text{gal}$$

During the initial fill stages the bottom of the cell will slope towards the sump. The most likly location for a storage pond would be in the adjacent cell area. A pump system, as described below, would be necessary until the sufficient waste has been deposited to create the desired grade.

3. In the event alternative 2 is chosen a suitable pump must be specified. The peak flow into the sump, or other run-off collection area, can be estimated by the SCS unit hydrograph method (Reference 2B) where:

$$Q_p = \frac{484A}{T_R}$$

Total catchment area, A, is shown in Figure 1 to be 3.49 acres ($5.45\text{x}10^{-3}$ mi$^2$). A factor of 484 is used, which is likely conservative given the generally flat nature of the catchment slope. $T_R$ is the rising time and is calculated by the following relationship (Reference 2C):

$$T_R = \frac{D}{2} + t_p$$

The duration of the storm event, D, is 24 hours. The lag time, $t_p$, is found by the following equation (Reference 2D):

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}}$$

The catchment length, l, is found from Figure 1 to be approximately 450 feet (Cell 12A, east to west). The average catchment slope is 1 percent. The factor S is calculated from the SCS curve number, previously identified as 85. The relationship is
(Reference 2E):

**LCRS Flow Capacity and Pump Sizing**

$$S = \left(\frac{1000}{CN}\right) - 10 = \left(\frac{1000}{85}\right) - 10 = 1.76$$

This implies the lag time is:

$$t_p = \frac{(450)^{0.8}(1.76+1)^{0.7}}{1900(1)^{0.5}} = 0.14\text{hrs}$$

Given that result, the rising time is calculated to be:

$$T_R = \frac{24}{2} + 0.14 = 12.14\text{hrs}$$

and the peak flow is then:

$$Q_p = \frac{484(5.45\times10^{-3}\text{mi}^2)}{12.14} = 0.22\text{cfs}\left(\frac{449\text{gpm}}{\text{cfs}}\right) = 98\text{gpm}$$

4. To successfully transfer the accumulated water without undo ponding, and thus greater infiltration into the LCRS, a small impoundment ( e.g., 10,000-20,000 gallons) and a high capacity pump (e.g. 100 gpm) are required. The pump must be capable of generating sufficient head to lift the water out of the cell and into the desired holding facility. It is assumed the landfill operations staff will size the impoundment and select the necessary pump if this alternative is selected.

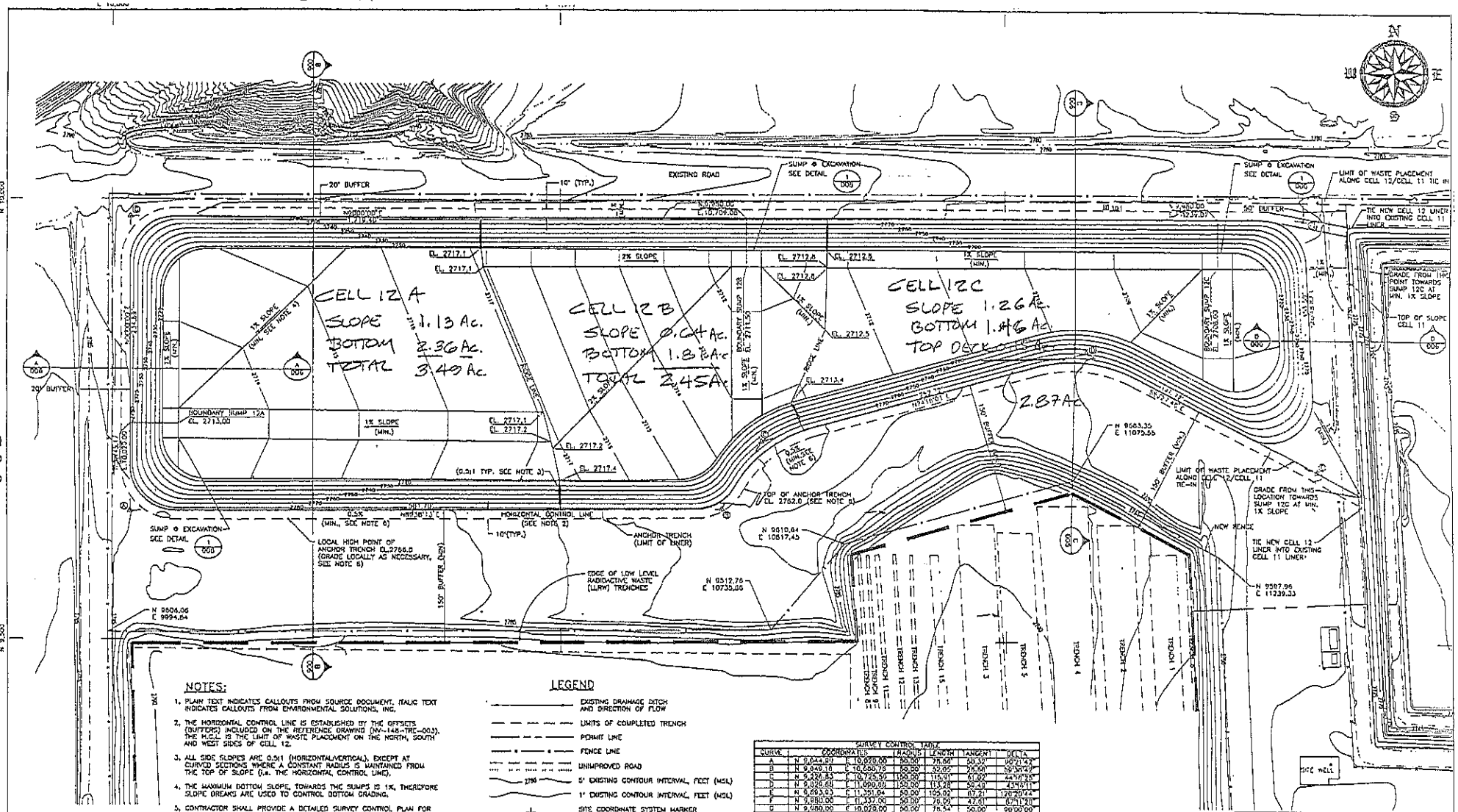
5. Construction of the starter berms, buttress fills and cover system will begin once waste filling is within 3 feet of the top of the excavation slope. The maximum waste area of (8.9 acres) within the horizontal control line (Figure 1) is potentially exposed to precipitation. As a conservative estimate it is assumed no exposure reduction measures are implemented, and the maximum run-off volume is contact water (i.e., has contacted waste).

6. The maximum volume of contact run-off is 198,282 gallons. The three foot freeboard around the facility is sufficient to contain this liquid on the surface of the fill. Should it be necessary to transfer the water out of the cell approximately 300,000 gallons of capacity is required (with a 50 percent factor of safety).

~85'
1' : 0.5 = MIDHEIGHT PERIMETER (MHP)

85' x MHP = SLOPE AREA

SHEET 9 OF 11




## NOTES:

1. PLAIN TEXT INDICATES CALLOUTS FROM SOURCE DOCUMENT. ITALIC TEXT INDICATES CALLOUTS FROM ENVIRONMENTAL SOLUTIONS, INC.
2. THE HORIZONTAL CONTROL LINE IS ESTABLISHED BY THE OFFSETS (BUFFERS) INCLUDED ON THE REFERENCE DRAWING (NW-148-TRE-003). THE H.C.L. IS THE LIMIT OF WASTE PLACEMENT ON THE NORTH, SOUTH AND WEST SIDES OF CELL 12.
3. ALL SIDE SLOPES ARE 0.5H (HORIZONTAL)/VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
4. THE MAXIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1%, THEREFORE SLOPE BREAKS ARE USED TO CONTROL BOTTOM GRADING.
5. CONTRACTOR SHALL PROVIDE A DETAILED SURVEY CONTROL PLAN FOR APPROVAL, BASED ON THE HORIZONTAL CONTROL PRIOR TO COMMENCING WORK.
6. PROVIDE LOCAL GRADING AS NECESSARY TO ESTABLISH MINIMUM ANCHOR TRENCH FLOWLINES, WHICH ARE REQUIRED FOR THE COVER SYSTEM DRAIN PIPE (SEE SHEET 4).

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 2780 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- + SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- • 302 MONITOR WELL LOCATION AND NUMBER

SCALE 50 25 0 50 FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

SURVEY CONTROL TABLE

| CURVE | COORDINATES | | RADIUS | LENGTH | TANGENT | DELTA |
|---|---|---|---|---|---|---|
| A | N 9,044.00 | E 10,070.00 | 50.00' | 78.54' | 50.00' | 90°00'00" |
| B | N 9,049.18 | E 10,060.76 | 50.00' | 32.00' | 25.58' | 36°39'42" |
| C | N 9,226.83 | E 10,725.50 | 150.00' | 115.91' | 61.00' | 44°16'25" |
| D | N 9,026.00 | E 11,080.00 | 150.00' | 113.48' | 59.49' | 43°16'11" |
| E | N 9,693.00 | E 11,351.04 | 50.00' | 105.02' | 67.71' | 120°39'14" |
| F | N 9,880.00 | E 11,337.00 | 50.00' | 76.00' | 42.61' | 87°11'28" |
| G | N 9,080.00 | E 10,070.00 | 50.00' | 78.54' | 50.00' | 90°00'00" |

| Rev | Drawn | Check | Appr | Date | Description |
|---|---|---|---|---|---|
| 3 | DKK | | | 5/95 | REDESIGN OF CELL 12 ABOVE GRADE |
| 2 | DKK | JGS | SDD | 10/94 | ADDED COORDINATES TO LLRW TRENCHES |
| 1 | DKK | JGS | SDD | 7/94 | SITE TOPO/LLRW CAP REVISED FOR SURVEY 6/94 |

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NW-148-TRE-003

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY

EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

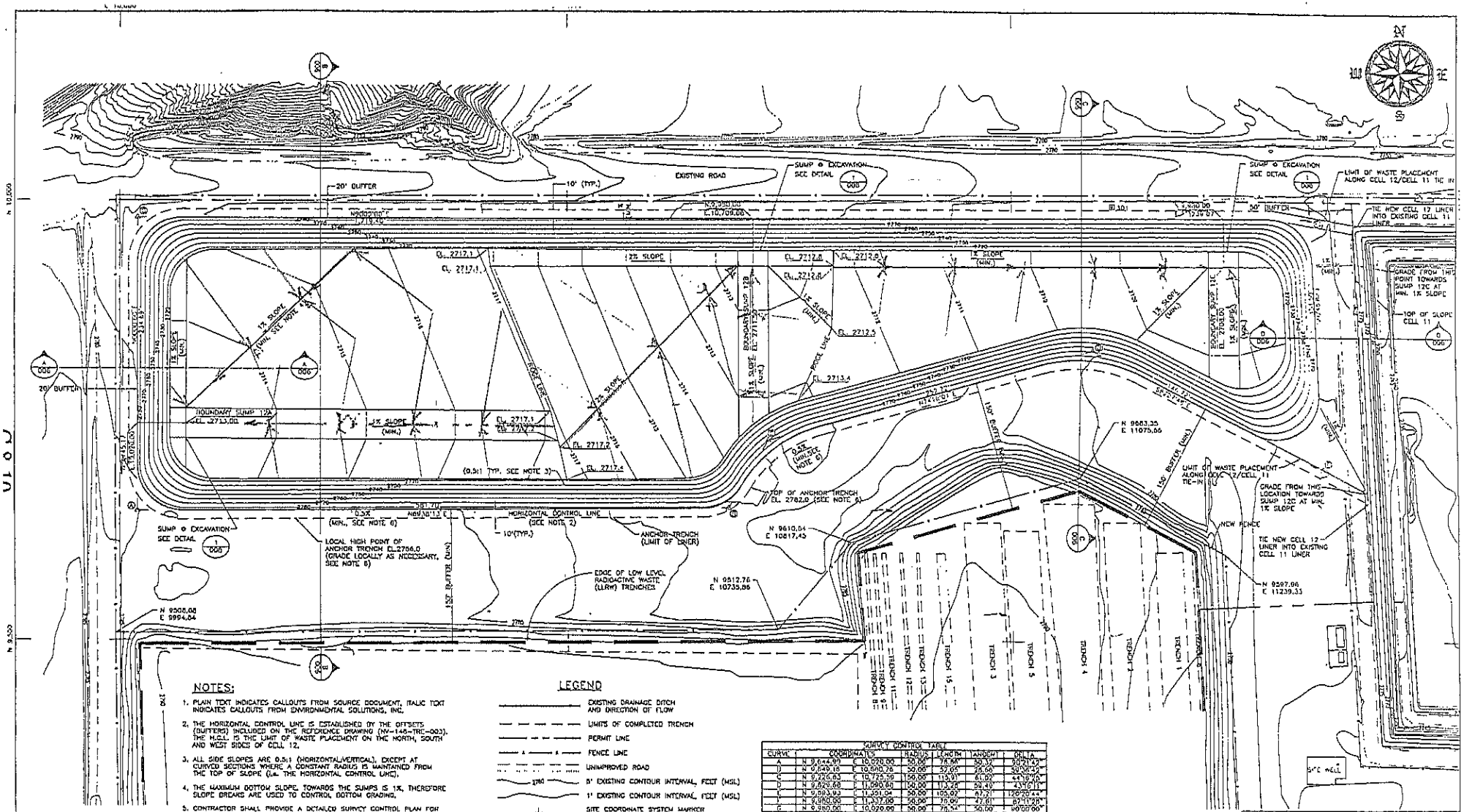
DRAWN BY ROD JONES

JOB NO. 95284
SCALE AS NOTED
D-95284-BL003
SHEET 3

C.8-9

Figure 1

SHEET 10 OF 11

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3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
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## LEGEND

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- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 2780 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- ● 302 MONITOR WELL LOCATION AND NUMBER

SURVEY CONTROL TABLE

| CURVE | COORDINATES | RADIUS | LENGTH | TANGENT | DELTA |
|---|---|---|---|---|---|
| A | N 9,644.88 E 10,020.00 | 50.00 | 78.54 | 50.00 | 90°00'00" |
| B | N 9,649.18 E 10,840.76 | 50.00 | 57.05 | 35.66 | 59°36'42" |
| C | N 9,226.83 E 10,726.50 | 150.00 | 115.91 | 61.02 | 44°16'16" |
| D | N 9,620.80 E 11,090.80 | 50.00 | 133.28 | 59.49 | 153°16'11" |
| E | N 9,993.90 E 11,291.04 | 50.00 | 105.02 | 67.21 | 120°20'44" |
| F | N 9,980.00 E 11,337.00 | 50.00 | 70.00 | 47.61 | 87°11'28" |
| G | N 9,980.00 E 10,020.00 | 50.00 | 78.54 | 50.00 | 90°00'00" |

SCALE 50 25 0 50 FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

| Rev | Drawn | Check | Appr | Date | Description |
|---|---|---|---|---|---|
| 3 | DGK | | | 5/95 | REDESIGN OF CELL 12 ABOVE GRADE |
| 2 | DGK | JCS | SDO | 10/94 | ADDED COORDINATES TO LLRW FENCELINE |
| 1 | DGK | JCS | SDO | 7/94 | SITE TOPO/LLRW CAP REVISED PER SURVEY 6/94 |

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NV-146-TRC-003

DRAWN BY BOB JONES

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY

EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

JOB NO. 95284
SCALE AS NOTED
D-95284-BL003
SHEET 3

FIGURE 3

# ENVIRONMENTAL SOLUTIONS, INC.

By RVH Date 1/20/96 Subject BEATTY LANDFILL CELL 12 Sheet No. 11 of 11

Chkd. By LMG Date 1/23/96 AMERICAN ECOLOGY CORP. Proj. No. 95-284

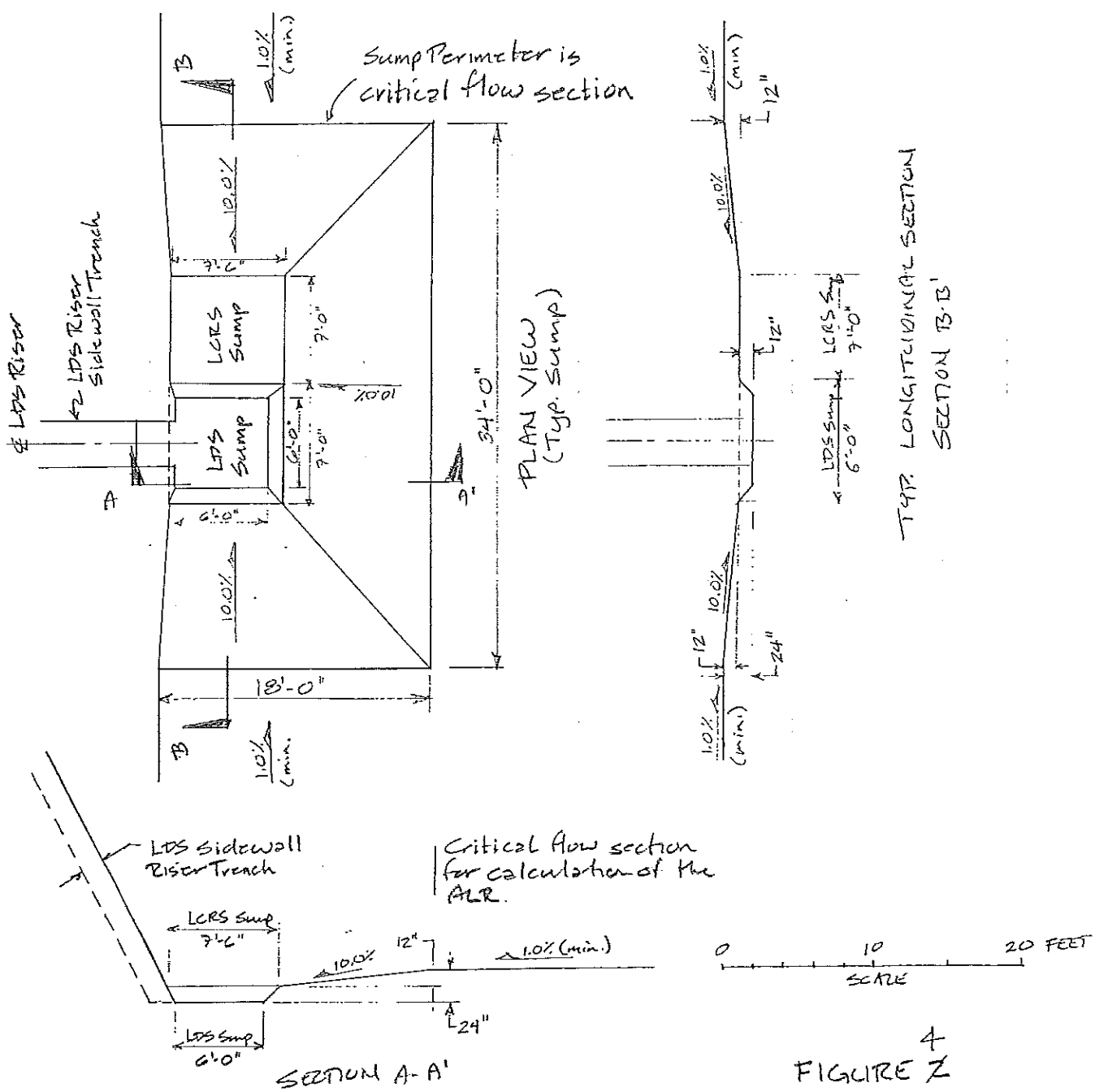


FIGURE 4

TYPICAL SUMP GEOMETRY

Notes:

1) Liner elements & riser pipes not shown for clarity.



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REF 1

# SECTION IV.D

# LANDFILL REPORT

US ECOLOGY, INC.

BEATTY, NEVADA

REF 1

# APPENDIX D

# DRAINAGE DIVERSION DITCHES

# DESIGN CALCULATIONS

BEATTY RUN-ON CONTROL SYSTEM DESIGN

Drainage Area Characteristics:

1. Drainage area = 1.7 sq. mi.

2. Max. flow length ($\ell$) = 21,650 ft.

3. Avg. land slope ($\gamma$) = $^{160}/(3.87)\ (5280) = 0.0078 = 0.78\%$

4. Sandy soil, barren land. SCS classifies soils as predominantly hydrological group B with some group A. Therefore, use soil group B and SCS Pasture/Range class with poor hydrologic condition.

5. Use AMC II for worst case.

6. SCS runoff curve No. (RCN) = 79 to account for steps 4 and 5

Compute Time of Concentration (Tc):

$$LAG\ (L) = \frac{(\ell)^{.8}\ (S+1)^{.7}}{1900\ (\gamma)^{.5}}$$

$$S = \frac{1000}{RCN} - 10 = \frac{1000}{79} - 10 = 2.66$$

$$L = \frac{(21{,}650)^{.8}\ (3.66)^{.7}}{1900\ (0.78)^{.5}} = 4.35 \text{ hrs.}$$

$$Tc = {}^{L}/0.6 = \frac{4.35}{0.6} = 7.25 \text{ hrs.}$$

Compute Excess Rainfall (Q):

25-yr, 24-hr storm = 2.0 in.

(From NOAA, Atlas 2, Precipitation-Frequency Atlas of the Western United States, Volume VII - Nevada)

Q = 0.52 in. for RCN = 79

Compute Peak Flow for 25-yr, 24-hr Rainfall:

Ref: SCS ENGR-20 (Rev. 2)

PK = (D.A.) (Q) (CSM)

CSM = 83 for Tc = 6 hrs, $T_t$ = 0 hrs.
CSM = 72 for Tc = 7.25 hrs by interpolation
CSM = 66 for Tc = 8 hrs, $T_t$ = 0 hrs.

Peak flow = (1.7) (0.52) (72) = 63.65 CFS

# Hydrology and Floodplain Analysis

Philip B. Bedient • Wayne C. Huber

REF 2

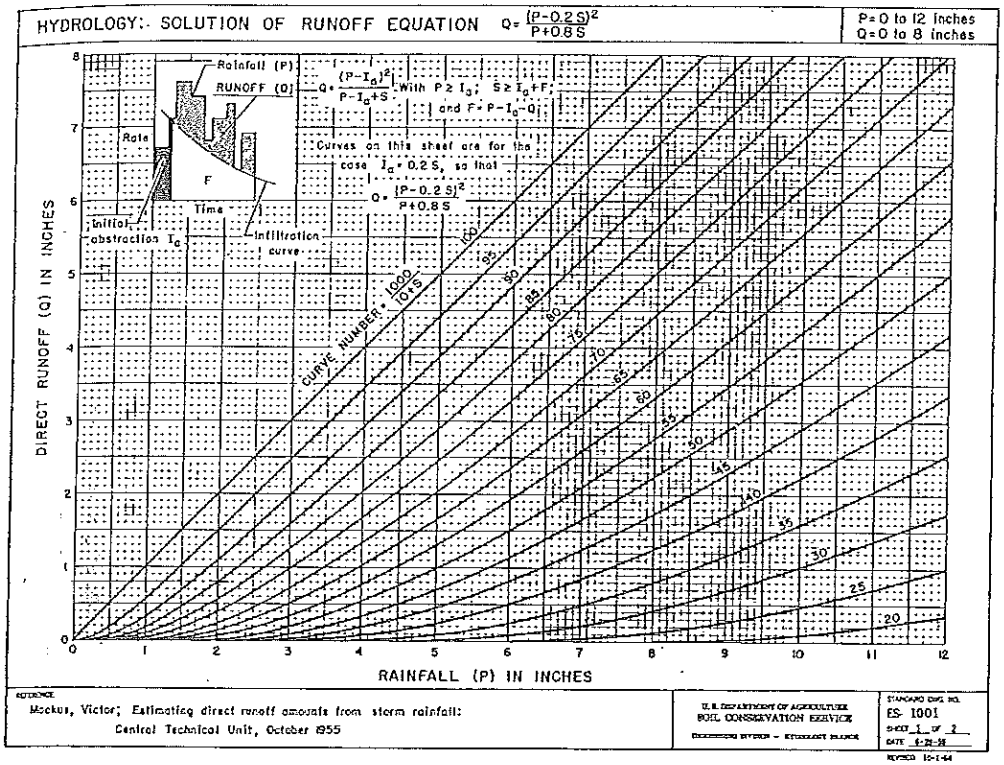



FIGURE 2.14

**Graphical solution of rainfall-runoff equation.**

EXAMPLE 2.8

## SCS UNIT HYDROGRAPH

For the watershed of Example 2.7, develop a unit hydrograph using the SCS method. The watershed consists of meadows in good condition with soil group D. The average slope in the watershed is 100 ft/mi. Assume the same duration of rainfall as found in Example 2.7. Sketch the resulting hydrograph.

SOLUTION

Equation (2.18) gives the following relationship for $t_p$:

$$t_p = \frac{\ell^{0.8}\,(S+1)^{0.7}}{1900y^{1/2}}.$$

From Table 2.1, the SCS curve number is found to be 78. Therefore,

Since this is a small watershed,

$$T_b \approx 4t_p = 4(8.6) \text{ hr}$$

$$\boxed{T_b = 34.4 \text{ hr.}}$$

And the duration of rainfall

$$D = t_p/5.5$$
$$= 8.6/5.5 \text{ hr}$$

$$\boxed{D = 1.6 \text{ hr.}}$$

## SCS Method

The method developed by the Soil Conservation Service (SCS, 1957) is based on a **dimensionless hydrograph,** developed from a large number of unit hydrographs ranging in size and geographic location. The hydrograph is represented as a simple triangle (Fig. 2.13), with rainfall duration $D$ (hr), time of rise $T_R$ (hr), time of fall $B$(hr), and peak flow $Q_p$ (cfs). The volume of direct runoff is

$$\text{Vol} = \frac{Q_p T_R}{2} + \frac{Q_p B}{2}, \qquad \text{or}$$

$$Q_p = \frac{2 \text{ Vol}}{T_R + B} \tag{2.14}$$

From a review of a large number of hydrographs, it was found that

$$B = 1.67\, T_R. \tag{2.15}$$

Therefore, Eq. (2.14) becomes, for 1.0 in. of rainfall excess,

$$Q_p = \frac{0.75 \text{ Vol}}{T_R}$$
$$= \frac{(0.75)(640)A(1.008)}{T_R}$$
$$= \frac{484A}{T_R}, \qquad \text{REF 23} \tag{2.16}$$

where

$A$ = area of basin (sq mi),

$T_R$ = time of rise (hr).

Capece et al. (1984) found that a factor as low as 10–50 holds for flat, high-water-table watersheds rather than the value 484 presented here. Thus, care must be used when applying this method.

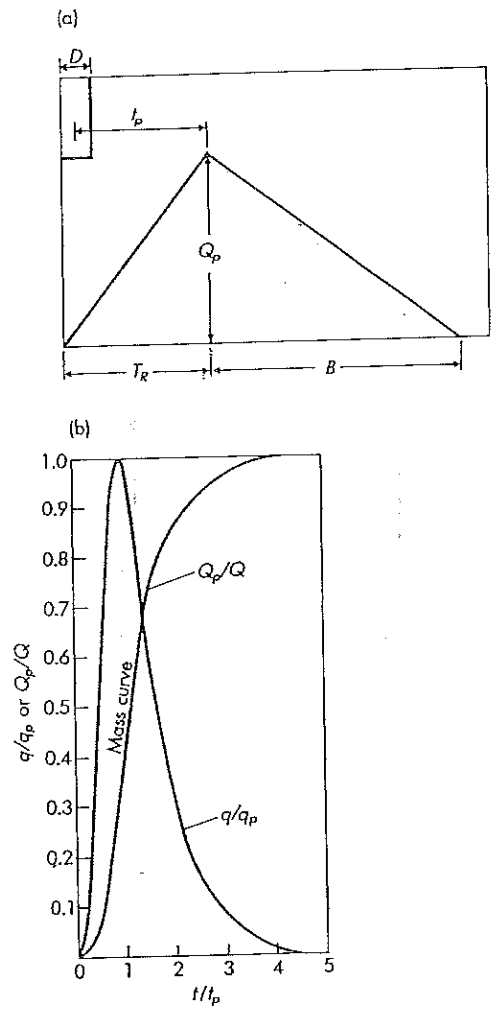



FIGURE 2.13
**(a) SCS triangular unit hydrograph. (b) SCS dimensionless unit hydrograph (SCS, 1964).**

From Fig. 2.13 it can be shown that

$$T_R = D/2 + t_p, \tag{2.17}$$

REF 2C

where

$D$ = rainfall duration (hr),
$t_p$ = lag time from centroid of rainfall to $Q_p$ (hr).

Lag time $t_p$ is estimated from any one of several empirical equations used by the SCS, such as

$$t_p = \frac{\ell^{0.8}(S+1)^{0.7}}{1900y^{0.5}}, \quad \text{REF 20} \tag{2.18}$$

where

$t_p$ = lag time (hr),
$\ell$ = length to divide (ft),
$y$ = average watershed slope (%),
$S = 1000/\text{CN} - 10$,
CN = curve number for various soil/land use (see Table 2.1).

The SCS dimensionless unit hydrograph can be used to develop a curved hydrograph, using the same $t_p$ and $Q_p$ as the triangular hydrograph in Fig. 2.13.

Soil Conservation Service (1964) runoff estimates assume a relationship between accumulated total storm rainfall $P$, runoff $Q$, and infiltration plus initial abstraction $(F + I_a)$. It is assumed that

$$F/S = Q/P_e, \tag{2.19}$$

where $F$ is infiltration occurring after runoff begins, $S$ is **potential abstraction**, $Q$ is direct runoff in in., and $P_e$ is effective storm runoff $(P - I_a)$. With $F = (P_e - Q)$ and $P_e = (P - I_a) = (P - 0.2S)$ based on data from small watersheds,

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}. \tag{2.20}$$

The SCS method uses the **runoff curve number** CN, which is related to storage by

$$\text{CN} = 1000/(S + 10), \quad \text{REF 26} \tag{2.21}$$

where potential abstraction $S$ (in.) becomes

$$S = (1000/\text{CN}) - 10. \tag{2.22}$$

Figure 2.14 presents the SCS solution in graphical form for a range of CNs and rainfall amounts. Runoff curve numbers for selected land uses are presented in Table 2.1. The hydrologic soil group varies from A for sandy, well-drained soils to D for clayey, poorly drained soils. The SCS report *Urban Hydrology for Small Watersheds* (1986) provides a simple graphical and tabular procedure for determining peak flows for urban areas. Example 2.8 illustrates the SCS UH method.

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-94/168b
September 1994

3
REF X

EPA

# The Hydrologic Evaluation of Landfill Performance (HELP) Model

## Engineering Documentation for Version 3

REF 3A
3

TABLE 1. DEFAULT LOW DENSITY SOIL CHARACTERISTICS

| Soil Texture Class | | | Total Porosity vol/vol | Field Capacity vol/vol | Wilting Point vol/vol | Saturated Hydraulic Conductivity cm/sec |
|---|---|---|---|---|---|---|
| HELP | USDA | USCS | | | | |
| 1 | CoS | SP | 0.417 | 0.045 | 0.018 | $1.0 \times 10^{-2}$ |
| 2 | S | SW | 0.437 | 0.062 | 0.024 | $5.8 \times 10^{-3}$ |
| 3 | FS | SW | 0.457 | 0.083 | 0.033 | $3.1 \times 10^{-3}$ |
| 4 | LS | SM | 0.437 | 0.105 | 0.047 | $1.7 \times 10^{-3}$ |
| 5 | LFS | SM | 0.457 | 0.131 | 0.058 | $1.0 \times 10^{-3}$ |
| 6 | SL | SM | 0.453 | 0.190 | 0.085 | $7.2 \times 10^{-4}$ |
| 7 | FSL | SM | 0.473 | 0.222 | 0.104 | $5.2 \times 10^{-4}$ |
| 8 | L | ML | 0.463 | 0.232 | 0.116 | $3.7 \times 10^{-4}$ |
| 9 | SiL | ML | 0.501 | 0.284 | 0.135 | $1.9 \times 10^{-4}$ |
| 10 | SCL | SC | 0.398 | 0.244 | 0.136 | $1.2 \times 10^{-4}$ |
| 11 | CL | CL | 0.464 | 0.310 | 0.187 | $6.4 \times 10^{-5}$ |
| 12 | SiCL | CL | 0.471 | 0.342 | 0.210 | $4.2 \times 10^{-5}$ |
| 13 | SC | SC | 0.430 | 0.321 | 0.221 | $3.3 \times 10^{-5}$ |
| 14 | SiC | CH | 0.479 | 0.371 | 0.251 | $2.5 \times 10^{-5}$ |
| 15 | C | CH | 0.475 | 0.378 | 0.251 | $2.5 \times 10^{-5}$ |
| 21 | G | GP | 0.397 | 0.032 | 0.013 | $3.0 \times 10^{-1}$ |

$a$ = constant representing the effects of various fluid constants and gravity, 21 $cm^3/sec$

$\phi$ = total porosity, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\psi_b$ = bubbling pressure, cm

$\lambda$ = pore-size distribution index, dimensionless

A more detailed explanation of Equation 11 can be found in Appendix A of the HELP program Version 3 User's Guide and the cited references.

*Saturated Hydraulic Conductivity*

Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g., water). The saturated hydraulic conductivity of each layer is specified in the input. Equations for estimating the hydraulic conductivity for soils and other materials are presented in Appendix A of the HELP Program Version 3 User's Guide.

*Unsaturated Hydraulic Conductivity*

Unsaturated hydraulic conductivity is used to describe flow through a layer when the void spaces are filled with both wetting and non-wetting fluid (e.g., water and air). The HELP program computes the unsaturated hydraulic conductivity of each soil and waste layer using the following equation, reported by Campbell (1974):

RCF 2B 3

$$K_u = K_s \left[ \frac{\theta - \theta_r}{\phi - \theta_r} \right]^{3+\left(\frac{2}{\lambda}\right)} \tag{5}$$

where

$K_u$ = unsaturated hydraulic conductivity, cm/sec

$K_s$ = saturated hydraulic conductivity, cm/sec

$\theta$ = actual volumetric water content, vol/vol

$\theta_r$ = residual volumetric water content, vol/vol

$\phi$ = total porosity, vol/vol

$\lambda$ = pore-size distribution index, dimensionless

Residual volumetric water content is the amount of water remaining in a layer under infinite capillary suction. The HELP program uses the following regression equation, developed using mean soil texture values from Rawls et al. (1982), to calculate the residual volumetric water content:

RCF 2C 3

$$\theta_r = \begin{cases} 0.014 + 0.25\,WP & \text{for } WP \geq 0.04 \\ 0.6\,WP & \text{for } WP < 0.04 \end{cases} \tag{6}$$

where

$WP$ = volumetric wilting point, vol/vol

The residual volumetric water content and pore-size distribution index are constants in the Brooks-Corey equation relating volumetric water content to matrix potential (capillary pressure and adsorptive forces) (Brooks and Corey, 1964):

REF 2ND

$$\frac{\theta - \theta_r}{\phi - \theta_r} = \left(\frac{\psi_b}{\psi}\right)^{\lambda} \tag{7}$$

where

$\psi$ = capillary pressure, bars

$\psi_b$ = bubbling pressure, bars

Bubbling pressure is a function of the maximum pore size forming a continuous network of flow channels within the medium (Brooks and Corey, 1964). Brakensiek et al. (1981) reported that Equation 7 provided a reasonably accurate representation of water retention and matrix potential relationships for tensions greater than 50 cm or 0.05 bars (unsaturated conditions).

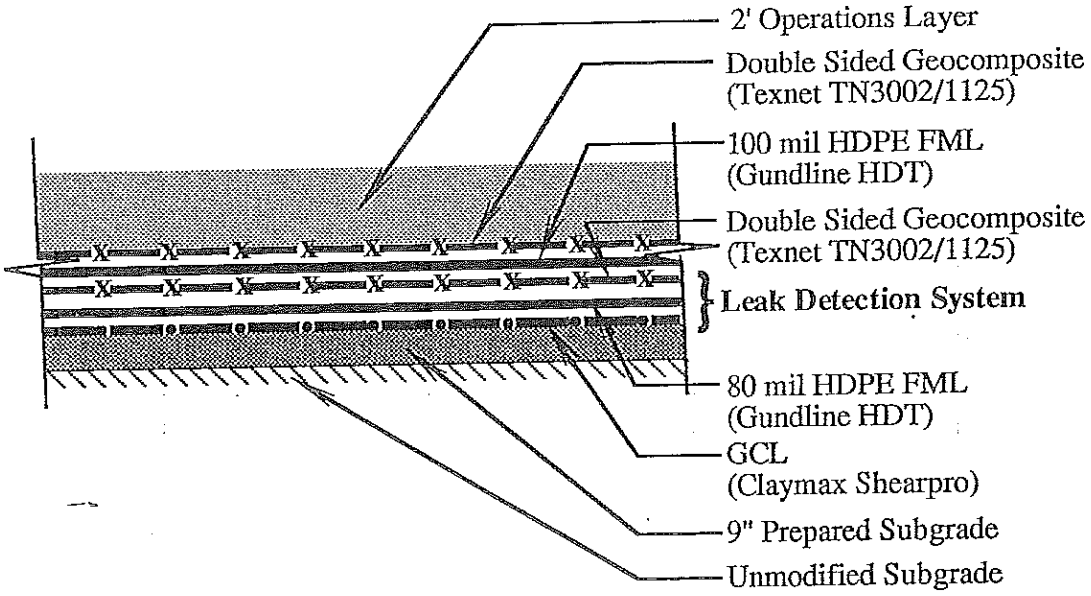
The HELP program solves Equation 7 for two different capillary pressures simultaneously to determine the bubbling pressure and pore-size distribution index of volumetric moisture content for use in Equation 7. The total porosity is known from the input data. The capillary pressure-volumetric moisture content relationship is known at two points from the input of field capacity and wilting point. Therefore, the field capacity is inserted in Equation 7 as the volumetric moisture content and 0.33 bar is inserted as the capillary pressure to yield one equation. Similarly, the wilting point and 15 bar are inserted in Equation 7 to yield a second equation. Having two equations and two unknowns (bubbling pressure and pore-size distribution index), the two equations are solved simultaneously to yield the unknowns. This process is repeated for each layer to obtain the parameters for computing moisture retention and unsaturated drainage.

### 3.3.3 Saturated Hydraulic Conductivity for Vegetated Materials

The HELP program adjusts the saturated hydraulic conductivities of soils and waste layers in the top half of the evaporative zone whenever those soil characteristics were selected from the default list of soil textures. This adjustment, developed for the model from changes in runoff characteristics and minimum infiltration rates as function of vegetation, is made to account for channeling due to root penetration. These adjustments for vegetation are not made for user-specified soil characteristics; they are made only for default soil textures, which assumed that the soil layer is unvegetated and free of continuous root channels that provide preferential drainage paths. The HELP program calculates the vegetated saturated hydraulic conductivity as follows:

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

Figure 1




2. The sump locations are shown on Figure 2 (Attached). There are three sumps proposed for Cell 12. The typical geometry is shown in Figure 3 (Attached).

Flow Capacities

1. The following flow elements will be used in the LDS

   - Double sided geocomposite (Texnet TN3002/1125)
   - Geonet (Polynet PN3000)-used in the sump areas if additional flow capacity is required.
   - Gravel (clean, poorly graded, nominal 3/4" diameter)-used in the sump proper only.

2. The double sided geocomposite is used in the slope liner LDS as well as in the bottom liner as shown in Figure 1. A continuous strip of geocomposite will be used for each system. Therefore flow within the LDS will be controlled by the minimum bottom slope.

3. Flow within the geosynthetics is calculated using Darcy's Equation (which assumes laminar flow within the net) as follows (Reference 2A):

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

$$q = \Theta_{eff} i \qquad (1)$$

Where:

$q$ = flow per unit width

$\Theta_{eff}$ = effective transmissivity

$i$ = hydraulic gradient

Flow within the gravel also uses Darcy's formula, however, transmissivity is replaced with hydraulic conductivity and the thickness of the flow area.

4. Effective transmissivity for the geosynthetics is calculated by applying several safety factors to the published transmissivity value. The following formula (Reference 2B) is used for that calculation, definitions are provided in the attached reference:

$$\Theta_{eff} = \frac{\Theta}{(FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC})} \qquad (2)$$

5. The following table shows the unit flow capacity for the geosynthetic elements and the gravel based on the applicable transmissivity, or hydraulic conductivities, hydraulic gradients, and safety factors:

**Table 1**

| Flow Element | Q | $FS_{CR}$ | $FSI_N$ | $FS_{CC}$ | $FS_{BC}$ | $Q_{eff}$[1] | $i$ | q | q |
|---|---|---|---|---|---|---|---|---|---|
| Units: | m2/s | NA | NA | NA | NA | m2/s | NA | m3/m-s | gal/ft-day |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.01 | 4.66E-07 | 3.24 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.01 | 4.23E-06 | 29.45 |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.1 | 4.66E-06 | 32.39 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.1 | 4.23E-05 | 294.47 |

Transmissivity values are provided by the manufacturer (Reference 3A and 3B). Safety factors are taken from the literature and are attached (Reference 2C). Flow capacities are shown at hydraulic gradients of 1 percent and 10 percent for the nominal cell bottom slope and the minimum sump slope, respectively. Since the gravel is used only within the minimum sump boundaries around the riser pipes, flow capacities are calculated for the geosynthethics only.

Controlling Section

1. As shown in Figure 3 there are two potentially controlling sections: 1) the 7'x7' LDS perimeter; and 2) the perimeter at the grade break between the 1 and 10 percent slopes. In the controlling sections multiple layers of geocomposite or geonet alone may be used to provide sufficient flow capacity.

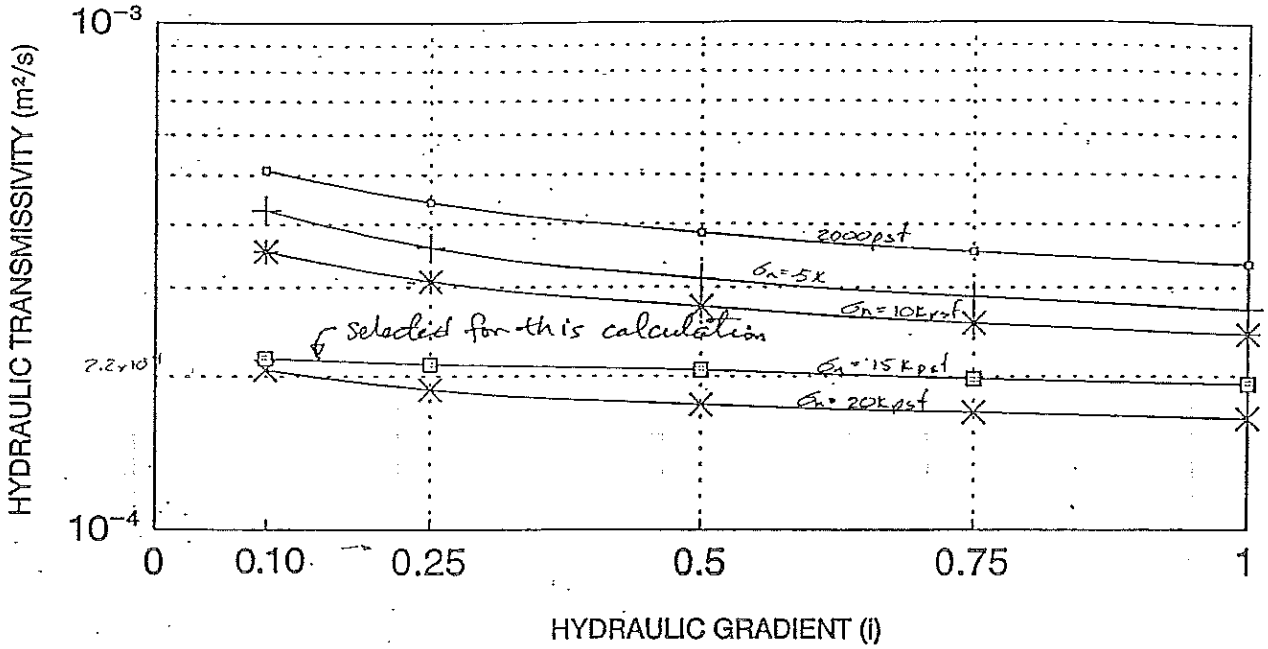
[1] The effective transmissivity of the geocomposite (using the factors of safety listed in Table 1) still exceeds the minimum transmissivity requirement ($3 \times 10^{-5}$ $m^2/s$) of 40 CFR § 264.301(c)(3)(ii).

Attachment B

REF 34
9

# TEX-NET TN3002/1125

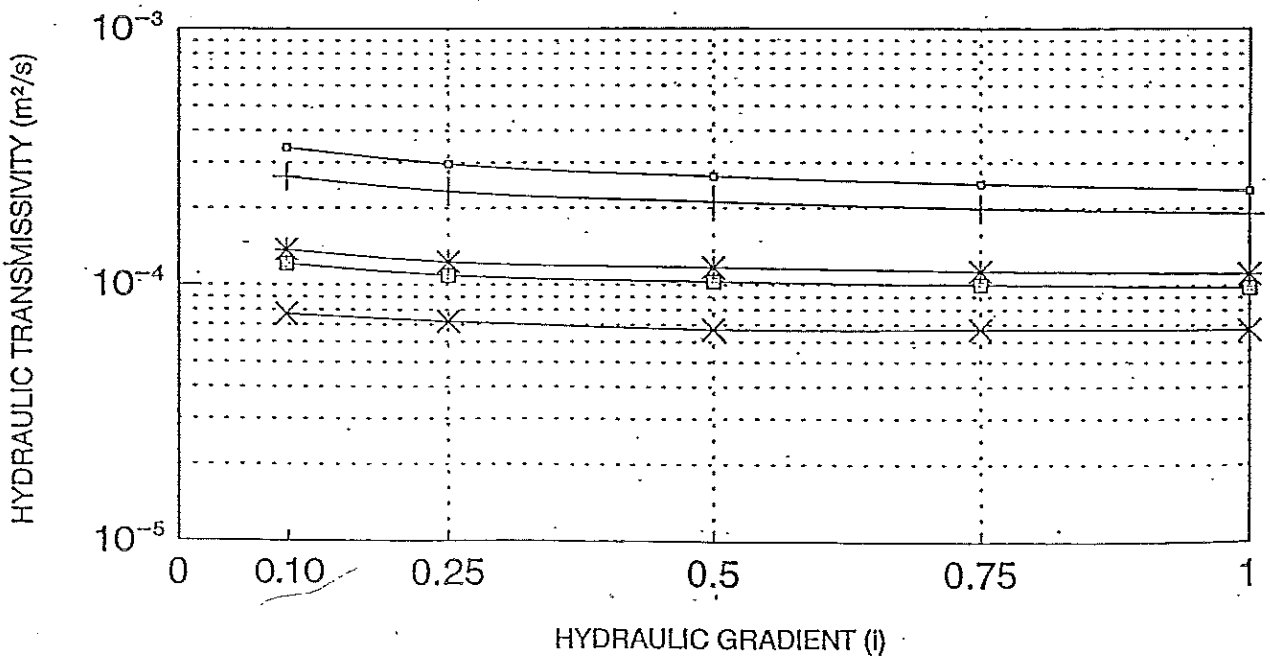
plate/FRICTION SEAL/TN3002/1125/FRICTION SEAL/plate




- 2000 psf
- 5000 psf
- 10000 psf
- 15000 psf
- 20000 psf

# TEX-NET TN3002CN/1125

plate/FRICTION SEAL/TN3002CN/1125/FRICTION SEAL/plate



REF # 5

# ADS SPECIFIER MANUAL

ADVANCED DRAINAGE SYSTEMS, INC.

ADVANCED DRAINAGE SYSTEMS, II

TABLE 7

CIRCULAR PIPE FLOW CAPACITY
Full Flow (cubic feet per second)

Mannings "n"= 0.015

| Dia. (in.) | *Conv. Factor | % Slope (feet per 100 feet) 0.02 | 0.05 | 0.10 | 0.20 | 0.35 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.0 | 2.5 | 5.0 | 10.0 | 20.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | (c.f.s.) | | | | | | | | |
| 3 | 0.766 | 0.011 | 0.017 | 0.024 | 0.034 | 0.045 | 0.054 | 0.066 | 0.077 | 0.086 | 0.09 | 0.10 | 0.11 | 0.12 | 0.17 | 0.24 | 0.34 |
| 4 | 1.649 | 0.023 | 0.037 | 0.052 | 0.074 | 0.098 | 0.117 | 0.143 | 0.165 | 0.184 | 0.20 | 0.22 | 0.23 | 0.26 | 0.37 | 0.52 | 0.74 |
| 5 | 2.991 | 0.042 | 0.067 | 0.095 | 0.134 | 0.177 | 0.211 | 0.259 | 0.299 | 0.334 | 0.37 | 0.40 | 0.42 | 0.47 | 0.67 | 0.95 | 1.34 |
| 6 | 4.863 | 0.069 | 0.109 | 0.154 | 0.217 | 0.288 | 0.344 | 0.421 | 0.486 | 0.544 | 0.60 | 0.64 | 0.69 | 0.77 | 1.09 | 1.54 | 2.17 |
| 8 | 10.473 | 0.148 | 0.234 | 0.331 | 0.468 | 0.620 | 0.741 | 0.907 | 1.047 | 1.171 | 1.28 | 1.39 | 1.48 | 1.66 | 2.34 | 3.31 | 4.68 |
| 10 | 18.99 | 0.27 | 0.42 | 0.60 | 0.85 | 1.12 | 1.34 | 1.64 | 1.90 | 2.12 | 2.33 | 2.51 | 2.69 | 3.00 | 4.25 | 6.00 | 8.49 |
| 12 | 30.88 | 0.44 | 0.69 | 0.98 | 1.38 | 1.83 | 2.18 | 2.67 | 3.09 | 3.45 | 3.78 | 4.08 | 4.37 | 4.88 | 6.90 | 9.76 | 13.81 |
| 15 | 55.98 | 0.79 | 1.25 | 1.77 | 2.50 | 3.31 | 3.96 | 4.85 | 5.60 | 6.26 | 6.86 | 7.41 | 7.92 | 8.85 | 12.52 | 17.70 | 25.04 |
| 18 | 91.04 | 1.29 | 2.04 | 2.88 | 4.07 | 5.39 | 6.44 | 7.88 | 9.10 | 10.18 | 11.15 | 12.04 | 12.87 | 14.39 | 20.36 | 28.79 | 40.71 |
| 21 | 137.32 | 1.94 | 3.07 | 4.34 | 6.14 | 8.12 | 9.71 | 11.89 | 13.73 | 15.35 | 16.82 | 18.17 | 19.42 | 21.71 | 30.71 | 43.43 | 61.41 |
| 24 | 196.06 | 2.77 | 4.38 | 6.20 | 8.77 | 11.60 | 13.86 | 16.98 | 19.61 | 21.92 | 24.01 | 25.94 | 27.73 | 31.00 | 43.84 | 62.00 | 87.68 |
| 27 | 268.41 | 3.80 | 6.00 | 8.49 | 12.00 | 15.88 | 18.98 | 23.24 | 26.84 | 30.01 | 32.87 | 35.51 | 37.96 | 42.44 | 60.0 | 84.9 | 120.0 |
| 30 | 355.48 | 5.03 | 7.95 | 11.24 | 15.90 | 21.03 | 25.14 | 30.79 | 35.55 | 39.74 | 43.54 | 47.03 | 50.27 | 56.21 | 79.5 | 112.4 | 159.0 |
| 36 | 578.05 | 8.17 | 12.93 | 18.28 | 25.85 | 34.20 | 40.87 | 50.06 | 57.81 | 64.63 | 70.80 | 76.47 | 81.75 | 91.40 | 129.3 | 182.8 | 258.5 |
| 42 | 872.0 | 12.33 | 19.50 | 27.57 | 38.99 | 51.6 | 61.7 | 75.5 | 87.2 | 97.5 | 106.8 | 115.3 | 123.3 | 137.9 | 195.0 | 275.7 | 389.9 |
| 48 | 1244.9 | 17.61 | 27.84 | 39.37 | 55.67 | 73.6 | 88.0 | 107.8 | 124.5 | 139.2 | 152.5 | 164.7 | 176.1 | 196.8 | 278.4 | 393.7 | 556.7 |

* Conveyance Factor = (1.486 x R2/3 x A) / n

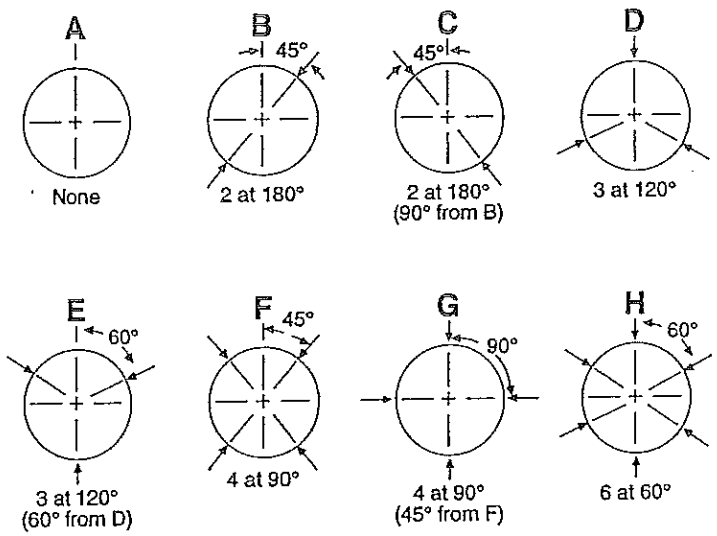
DET #4
5

REF 5B

# ADVANCED DRAINAGE SYSTEMS, INC.
## "FACT SHEET"
## STANDARD PIPE PERFORATIONS
## 3-24" I.D. SINGLE WALL PIPE

| Nominal I.D. | Perforation Type | Slot Length or Diameter (Max.) | Slot Width (Max.) | Nominal Water Inlet Area (Sq. In./Ft.) | Perforation Configuration |
|---|---|---|---|---|---|
| 3 | Slot | 1.25 | 0.125 | 1.44 | AF |
| 4 | Slot | 1.25 | 0.125 | 2.01 | AH |
| 5 | Slot | 1.57 | 0.125 | 2.01 | AH |
| 6 | Slot | 1.88 | 0.125 | 2.01 | AH |
| 8 | Slot | 2.50 | 0.125 | 1.57 | AD |
| 10 | Slot | 2.50 | 0.125 | 1.26 | AD |
| 12 | Slot | 2.50 | 0.125 | 3.38 | H |
| 15 | Slot | 2.50 | 0.125 | 1.58 | H |
| 18 | Circular | 0.375 | — | 1.58 | H |
| 24 | Circular | 0.375 | — | 1.58 | 11" Centers |

PERFORATION CONFIGURATIONS



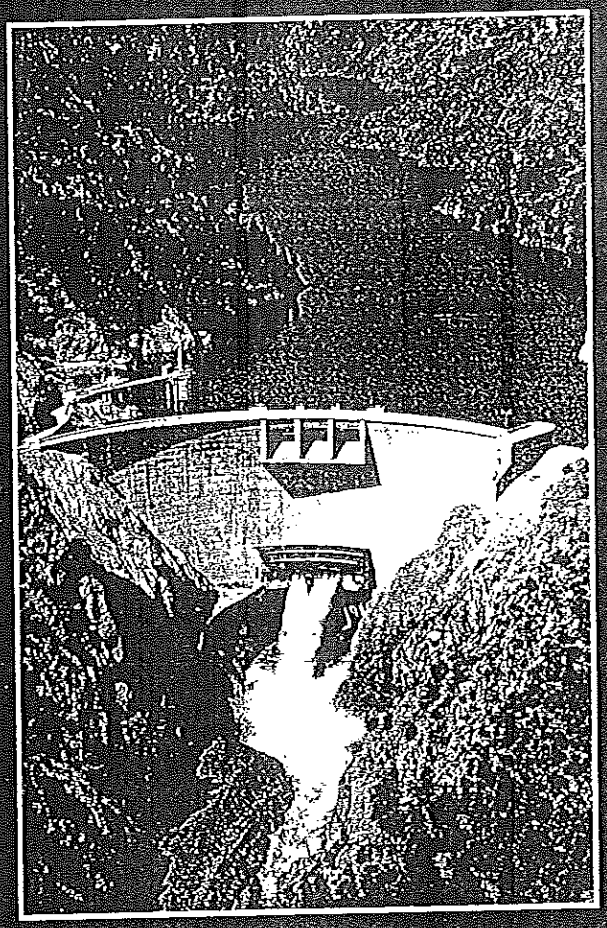

NOTE 1
ADS pipe is perforated for water entry with slots or circular perforations. The perforations are uniformly spaced along the length and circumference of the pipe.

NOTE 2
Unless otherwise specified, ADS pipe is manufactured to comply with the perforation requirements specified in the following industry standards: ASTM F405, ASTM F667, AASHTO M252, AASHTO M294, and SCS Code 606.

Issued: March 15, 1991

REF #
4

# DAVIS' HANDBOOK OF APPLIED HYDRAULICS



FOURTH EDITION

Vincent J. Zipparro
Hans Hasen

C 8-30

REF 8A

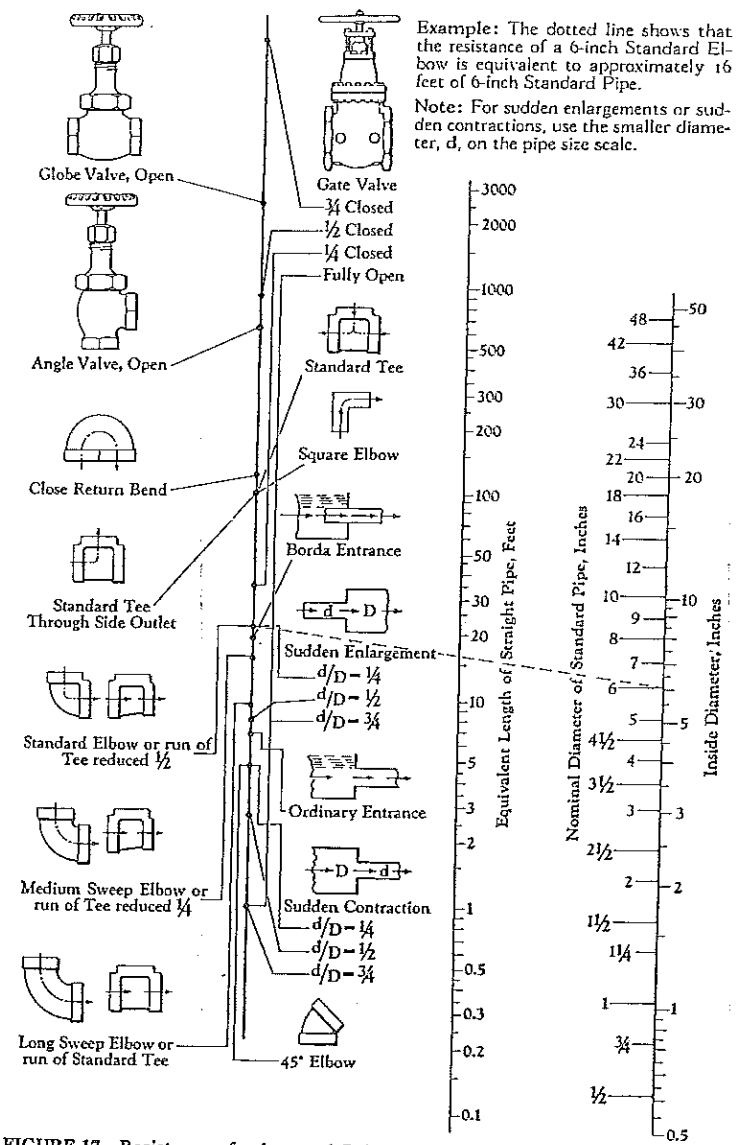



FIGURE 17 Resistance of valves and fittings to flow of fluid.

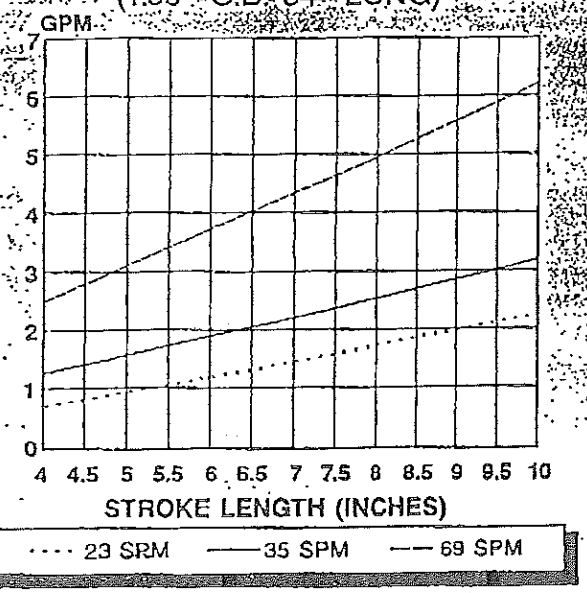
## ORIFICES

**25. High Head.** When the head is relatively large, as compared with the size of the orifice, the following equation will apply:

$$Q = CA\sqrt{2gH} \tag{37}$$

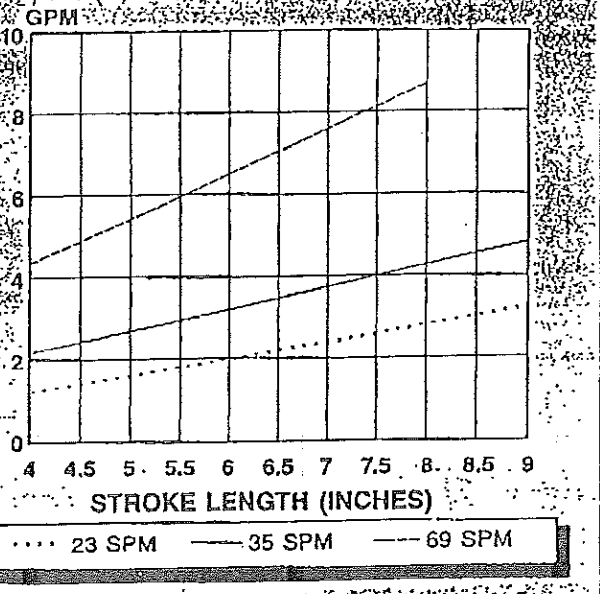
# PROTEC RECIP PUMP CURVES

## MODEL RP1
(1.90" O.D. 34" LONG)



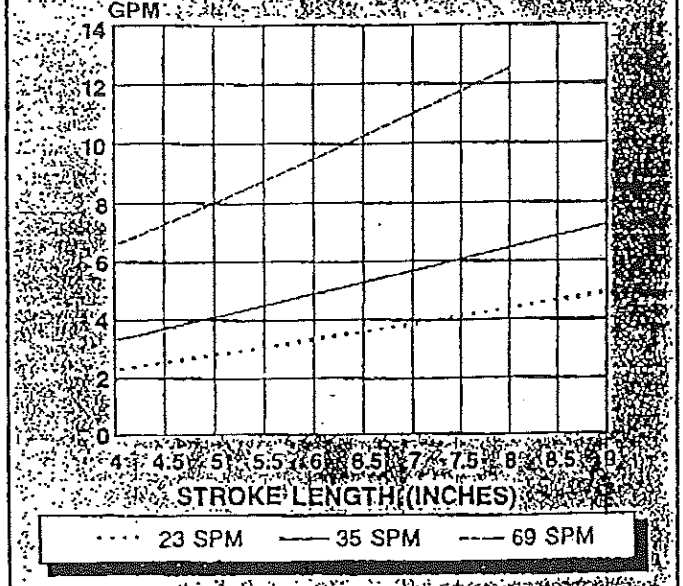

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1 HP

## MODEL RP2
(2.375" O.D. 34" LONG)



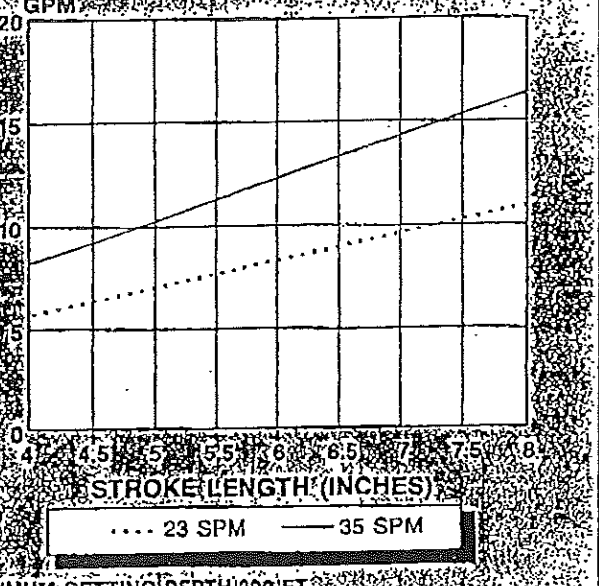

MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 1.5 HP

## MODEL RP3
(2.875" O.D. 34" LONG)




MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM, 1750 RPM MTR = 35 SPM
3450 RPM MTR = 69 SPM, APPROX. 2 HP

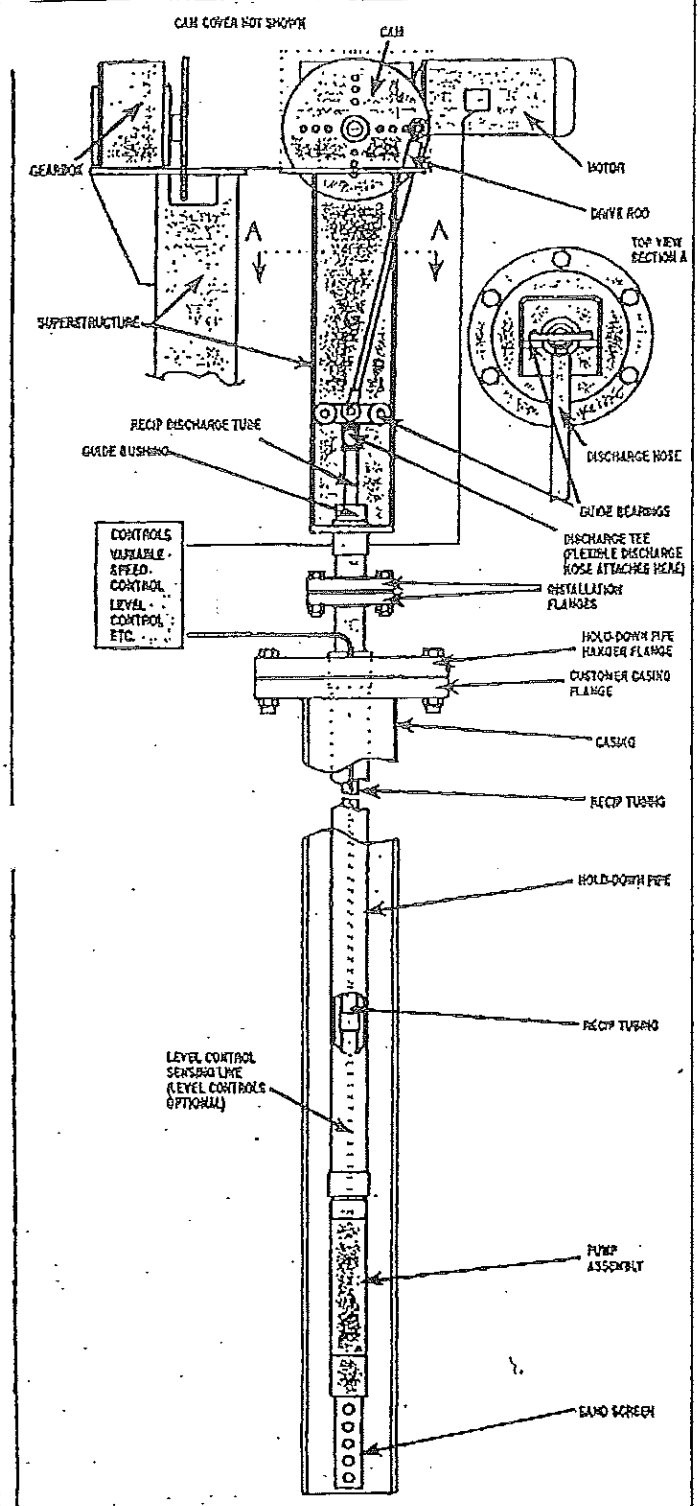
## MODEL RP5
(4.5" O.D. 34" LONG)




MAXIMUM SETTING DEPTH 200 FT.
1140 RPM MTR = 23 SPM
1750 RPM MTR = 35 SPM, APPROX. 3 HP

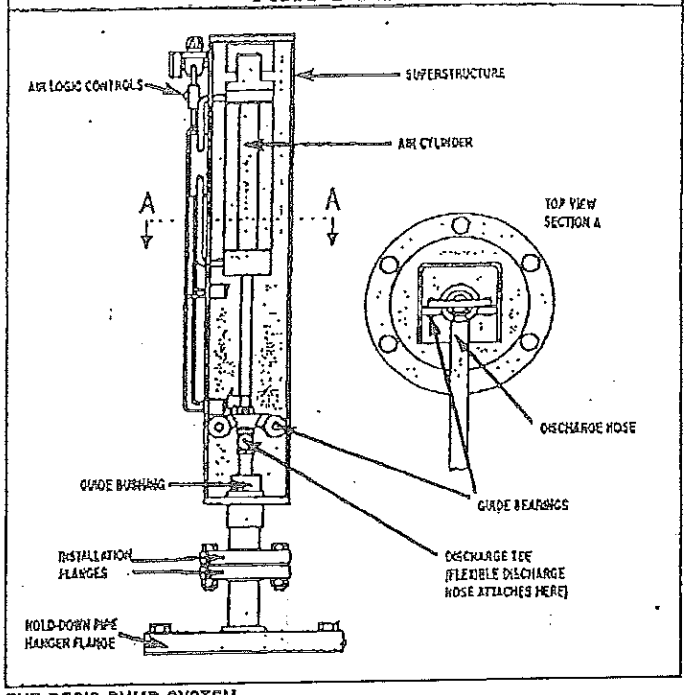

PROTEC
7136 S. Yale, Suite 200 • Tulsa, OK 74136 • 918-493-6101

## ELECTRIC DRIVE




**SURFACE DRIVE ASSY. APPROX. DIMENSIONS**
**ELECTRIC DRIVE: 55" H x 24" W x 12" D**
**AIR DRIVE: 51" H x 8" W x 8" D**
**LOW PROFILE DRIVES ALSO AVAILABLE WHEN THERE ARE HEIGHT LIMITATIONS**

## AIR DRIVE




### THE RECIP PUMP SYSTEM

The **RECIP PUMP** is a surface driven (air drive or electric drive) down-hole reciprocating pump. The down-hole pump assembly is anchored by a string of stationary pipe (Hold-Down Pipe). The pump piston is attached to the bottom of a string of reciprocating tubing (Recip Tubing) which is run inside the Hold-Down Pipe. The surface drive assembly alternately lifts and lowers the Recip Tubing which gives the down-hole pump its reciprocating motion. The surface drive assembly can be either Air Drive or Electric Drive. The Air Drive unit utilizes a dual acting air cylinder. The Electric Drive unit utilizes an electric motor (TEFC or X-Proof) coupled to a gearbox and cam assembly.

The **RECIP PUMP** is a positive displacement piston pump with pumping rate (GPM) directly proportional to strokes per minute (SPM) and stroke length (SL). On the Electric Drive unit SL is adjusted manually by changing the position of the drive rod connection to the cam and SPM depends on the motor RPM selected (1140, 1750 or 3450 RPM). An optional electronic VSD (Variable Speed Drive) is also available to give variable SPM capability to the Electric Drive unit. The Air Drive unit comes standard as a variable speed device since the pump speed (SPM) can be controlled by the pressure regulator on the drive unit. The Recip Pump is currently available in four sizes: RP1, RP2, RP3 and RP5. Pump rates range from fractional GPM to 18 GPM.

Down-hole pump materials of construction are stainless steel and Teflon for service in highly corrosive fluids. **RECIP PUMP** can run dry without causing damage to the pump. Pump operation is easily interfaced with down-hole level controls, tank level controls, safety shut-downs, timers, etc. to meet the operating requirements of any particular site.

### APPLICATIONS

The **RECIP PUMP** is an efficient low-maintenance system for installation in extraction wells and trench sumps associated with groundwater recovery and leachate collection projects. **RECIP PUMP** is also useful as a dedicated sampling pump for groundwater monitoring.

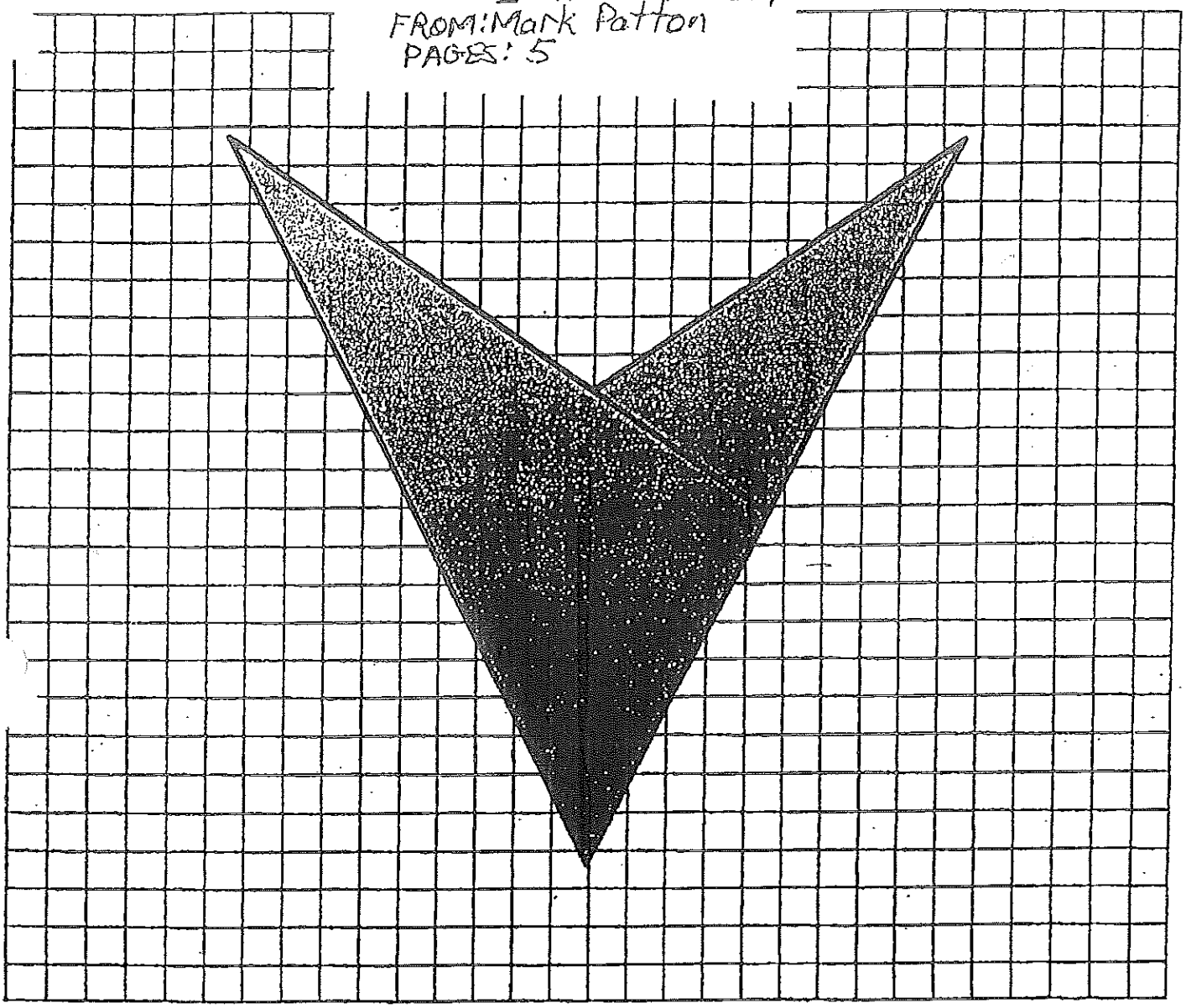
Notice that the Model RP1 can pump up to 6 GPM from wells with 2" casing. This means that often existing monitoring wells can be utilized for continuous recovery when a project advances from the sampling stage to the remedial pump and treat stage. And when new recovery wells must be drilled it is less expensive to drill and equip 2" wells than larger diameter wells.

### IN SUMMARY

High volumetric pump efficiency and low power requirements make the **RECIP PUMP** a highly efficient pumping system. Simple design, rugged construction and low operating speeds result in long operating life and low maintenance. Other features are: low noise, small size, quick installation and all moving parts fully enclosed.

REF 7

TO: Stan Christie
ESI 714-727-7399
FROM: Mark Patton
PAGES: 5



# PROTEC®
# RECIP® PUMP

GROUNDWATER & LEACHATE RECOVERY PUMPS

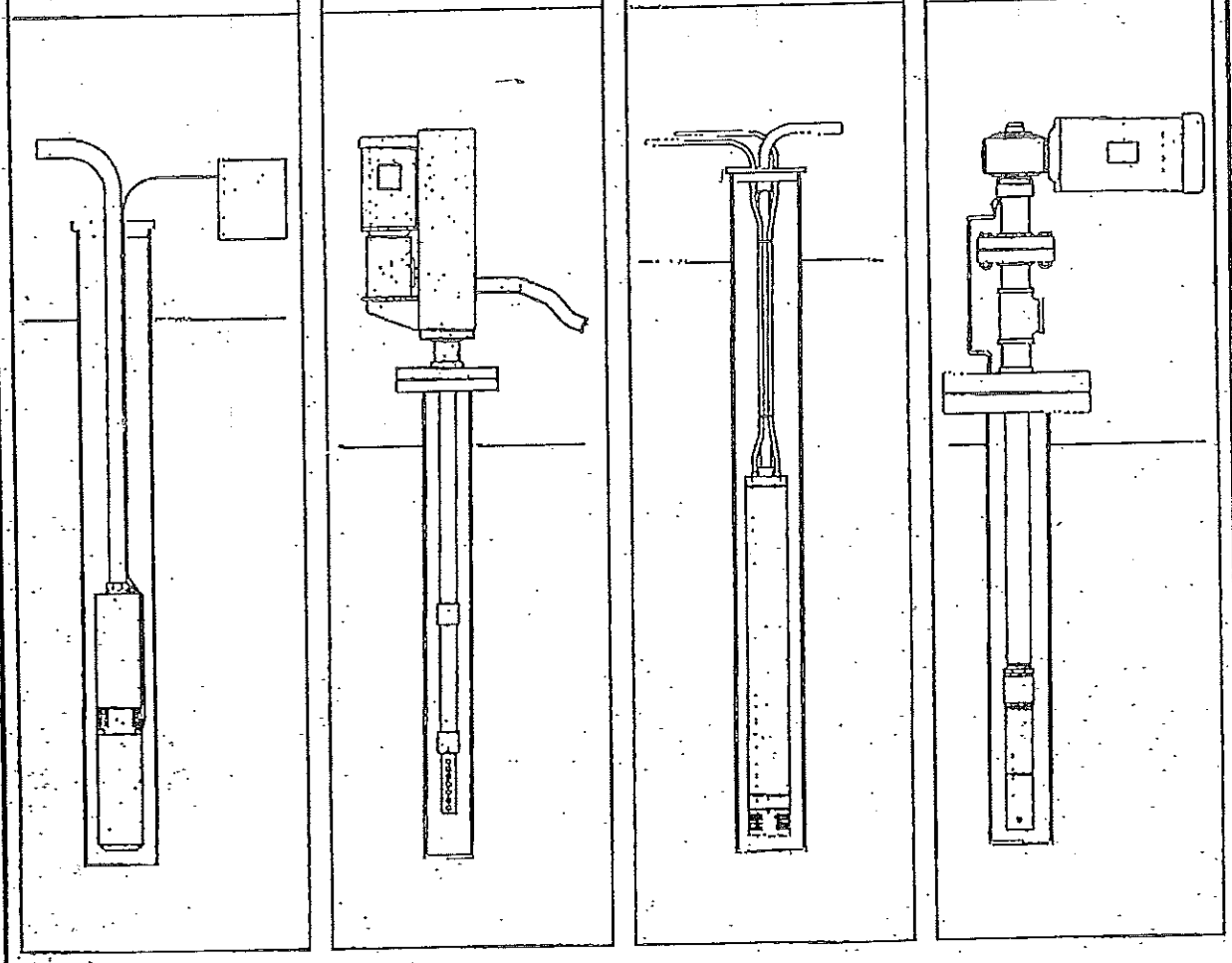
Stan Christie
714-727-7399
For your file
Mark Patton

# PROTEC

## ENVIRONMENTAL EQUIPMENT

### A COMPLETE LINE OF GROUNDWATER REMEDIATION LANDFILL LEACHATE & SAMPLING PUMPS

| GUARDIAN | RECIP | AUTOPILOT | ROTARY |
|---|---|---|---|
| Variable Speed Electric Submersible Pump | Electric or Air Driven Piston Pump | Automatic "Controllerless" Air Pump | Electric Drive Progressing Cavity Pump |



PROTEC

HOUSTON, TX SALES: 918-493-6101 TULSA, OK

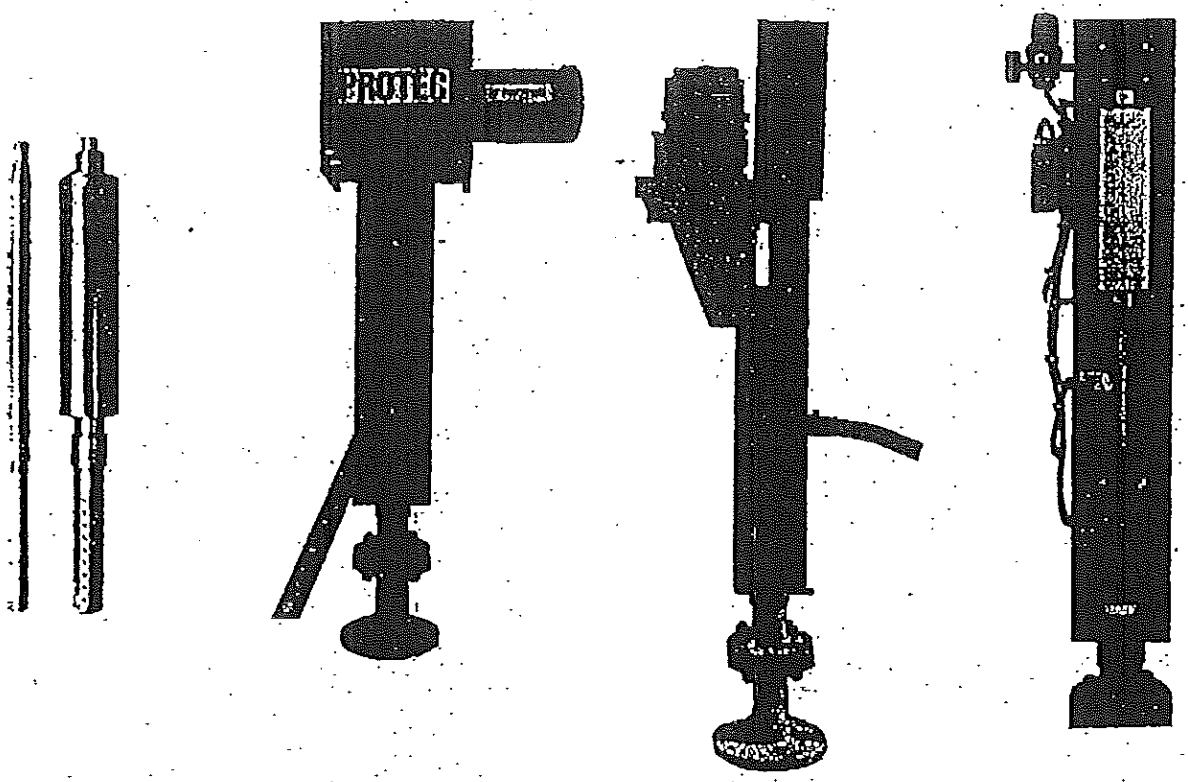
# PUMP SELECTION TABLE

| PUMP MODEL | RP1 | RP2 | RP3 | RP5 |
|---|---|---|---|---|
| PUMP OUTSIDE DIAMETER | 1.90 IN. | 2.375 IN. | 2.875 IN. | 4.50 IN. |
| STANDARD MOTOR HP[1] | 1.0 HP | 1.5 HP | 2.0 HP | 3.0 HP |
| PUMP SETTING DEPTH | 1 - 200 FT. | 1 - 200 FT. | 1 - 200 FT. | 1 - 200 FT. |
| GPM RANGE | | | | |
| 1. FIXED SPEED ELECTRIC ADJUSTABLE SL[2] | | | | |
| DEPENDS ON MOTOR RPM: | | | | |
| WITH 1140 RPM MOTOR[3] | 0.8-2.1 GPM | 1.4-3.2 GPM | 2.2-4.9 GPM | 5-10 GPM |
| WITH 1750 RPM MOTOR | 1.2-3.1 GPM | 2.1-4.8 GPM | 3.2-7.3 GPM | 8-16 GPM |
| WITH 3450 RPM MOTOR | 2.5-6.2 GPM | 4.2-8.5 GPM | 6.5-13.0 GPM | N/A |
| 2. VARIABLE SPEED ELECTRIC ADJUSTABLE SL & SPM[4] | | | | |
| USE ELECTRIC VSD[5] | 0.1-6.2 GPM | 1.4-8.5 GPM | 2.2-13.0 GPM | 5-16 GPM |
| 3. VARIABLE SPEED AIR ADJUSTABLE SPM | 0.1-6.2 GPM | 1.4-8.5 GPM | 2.2-13.0 GPM | 5-16 GPM |

[1] Motor HP can vary depending on operating conditions.
[2] SL: Strokes Length.
[3] 1140 RPM motors available in 3-Phase only.
[4] SPM: Strokes Per Minute.
[5] VSD: Variable Speed Drive.

NOTE: Above data is in accordance with the pump curves on the back cover.

**PUMPS** **ELECTRIC DRIVE** **AIR DRIVE**



# PROTEC RECIP PUMP
## PRICE LIST
(FOR ESTIMATING PURPOSES)
November 1994

The following are estimated prices for complete pumping units including down-hole pump, surface drive assembly and 4 feet of cross-linked polyethylene discharge hose. On Electric Drive units for variable SPM (Strokes Per Minute) add VSD (Variable Speed Drive). Air Drive price includes pneumatic controls and Air Drive units are inherently variable SPM.

| PUMP MODEL | AIR DRIVE 316 S.S | FIXED SPM TEFC MOTOR | FIXED SPM X-PROOF MOTOR | VSD ADD-ON NEMA 3R PANEL FOR USE WITH TEFC DC MOTOR | VSD ADD-ON NEMA 3R PANEL FOR USE WITH TEFC OR X-PROOF AC MOTOR |
|---|---|---|---|---|---|
| RP1 | 2,700.00 | 2,975.00 | 3,175.00 | 875.00 | 1,075.00 |
| RP2 | 2,900.00 3100 | 3,175.00 | 3,425.00 | 1,025.00 | 1,175.00 |
| RP3 | 3,100.00 | 3,375.00 | 3,625.00 | N/A | 1,275.00 |
| RP5 | 3,700.00 | 3,975.00 | 4,225.00 | N/A | 1,325.00 |

**ACCESSORIES**

**LEVEL CONTROL:**
Dual Probe Level Control.....286.00
Dual Float Level Control.....305.00
Level Control Signal Wire.....0.50/FT
(22 Gauge, Teflon Jacketed)
Pneumatic Level Control.....275.00
Pneumatic L/C Tube (3/8" Teflon).....2.50/FT
Stroke Counter.....100.00
Pneumatic Dual Timer.....275.00

**WELL TUBULARS**

1. FOR USE IN 2" CASING ( RP1 ONLY ):
   RECIP TUBING : 1/2" CS T&C.....1.23/FT
   1/2" 304SS T&C.....5.22/FT*
   HOLD-DOWN PIPE: 1" CS T&C.....1.81/FT
   1" 304 SS T&C.....8.36/FT*

2. FOR USE IN 3" AND LARGER CASING ( RP5 6" AND LARGER CASING ):
   RECIP TUBING ( RP1, 2, 3 ) : 3/4" CS T&C.....1.55/FT
   3/4" 304 SS T&C.....6.62/FT* ← Add 25 % for 316 S.S.
   ( RP5 ONLY ): 1" CS T&C.....1.81/FT
   1" 304 SS T&C.....8.36/FT* ←
   HOLD-DOWN PIPE ( RP1, 2, 3 ): 1 1/4" CS T&C.....2.43/FT
   1 1/4" 304 SS T&C.....10.53/FT* ←
   ( RP5 ONLY ): 2" CS T&C.....2.96/FT
   2" 304 SS T&C.....13.86/FT* ←

*SS PRICES CAN FLUCTUATE SIGNIFICANTLY OVER TIME.

**WELL HEAD FITTINGS:** Standard Carbon Steel.....150.00
Stainless Steel.....price on request

**TOP LOADING INLET JACKET (PUMP CAN):** Carbon steel .....150.00

**CONTROL PANELS** - NEMA 3R Enclosure ( Contactor, Adjustable Thermal Overload, HOA. Does not include primary disconnect or short circuit protection.)

FIXED SPM: THRU 10 HP, 1-PHASE OR 3-PHASE.....250.00
FOR VARIABLE SPM: PANEL PRICE INCLUDED IN VSD PRICE ABOVE. CONTROL PANELS CAN ALSO BE CUSTOM BUILT PER CUSTOMER REQUIREMENTS.

HOUSTON, TX SALES: 918-493-6101 TULSA, OK

REF 8

CRC

# STANDARD MATHEMATICAL TABLES

28th EDITION

CRC PRESS

C 8-38

REF 8A



*Mensuration Formulas*

**Pyramid**

$S$ of regular pyramid $= \frac{1}{2}$ (perimeter of base) $\times$ (slant height)

$V = \frac{1}{3}$ (area of base) $\times$ (altitude)

**Frustum of Pyramid**

Let $B_1$ = area of lower base, $B_2$ = area of upper base, $h$ = altitude.

$S$ of regular figure $= \frac{1}{2}$ (sum of perimeters of bases) $\times$ (slant height)

$V = \frac{1}{3}h(B_1 + B_2 + \sqrt{B_1 B_2})$

**Prismatoid**

A *prismatoid* is a polyhedron having for bases two polygons in parallel planes, and for lateral faces triangles or trapezoids with one side lying in one base, and the opposite vertex or side lying in the other base, of the polyhedron. Let $B_1$ = area of lower base, $M$ = area of midsection, $B_2$ = area of upper base, $h$ = altitude.

$$V = \tfrac{1}{6}h(B_1 + 4M + B_2) \quad \text{(the } \textit{prismoidal formula}\text{)}$$

*Note:* Since cubes, rectangular parallelepipeds, prisms, pyramids, and frustums of pyramids are all examples of prismatoids, the formula for the volume of a prismatoid subsumes most of the above volume formulae.

**Regular Polyhedra**

Let $v$ = number of vertices, $e$ = number of edges, $f$ = number of faces, $\alpha$ = each dihedral angle, $a$ = length of each edge, $r$ = radius of the inscribed sphere, $R$ = radius of the circumscribed sphere, $A$ = area of each face, $T$ = total area, $V$ = volume.

$v - e + f = 2$ (the *Euler-Descartes formula*—actually holds for *any* convex polyhedron)

$$T = fA$$
$$V = \tfrac{1}{3}rfA = \tfrac{1}{3}rT$$

| Name | Nature of Surface | $T$ | $V$ |
|---|---|---|---|
| Tetrahedron | 4 equilateral triangles | $1.73205a^2$ | $0.11785a^3$ |
| Hexahedron (cube) | 6 squares | $6.00000a^2$ | $1.00000a^3$ |
| Octahedron | 8 equilateral triangles | $3.46410a^2$ | $0.47140a^3$ |
| Dodecahedron | 12 regular pentagons | $20.64573a^2$ | $7.66312a^3$ |
| Icosahedron | 20 equilateral triangles | $8.66025a^2$ | $2.18169a^3$ |

| Name | $v$ | $e$ | $f$ | $\alpha$ | $a$ | $r$ |
|---|---|---|---|---|---|---|
| Tetrahedron | 4 | 6 | 4 | 70° 32′ | $1.633R$ | $0.333R$ |
| Hexahedron | 8 | 12 | 6 | 90° | $1.155R$ | $0.577R$ |
| Octahedron | 6 | 12 | 8 | 109° 28′ | $1.414R$ | $0.577R$ |
| Dodecahedron | 20 | 30 | 12 | 116° 34′ | $0.714R$ | $0.795R$ |
| Icosahedron | 12 | 30 | 20 | 138° 11′ | $1.051R$ | $0.795R$ |

# LDS FLOW CAPACITY AND PUMP SIZING

AquAeTer

*optimizing environmental resources - water; air; earth*

# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: August 21, 2007

CALCULATION NUMBER: _____ Revision: Update per 2007 Design

**CALCULATION TITLE: LDS Flow Capacity**

**DESCRIPTION OF CALCULATION:**

Calculation to determine LDS Flow Capacity and Pump Sizing

**REFERENCES USED:** Number of Reference Pages Attached: _____

1. GSE Geotextile Information
2. EPG Sump Pump Information
3. Previous calc: 1996 calculation titled "LDS Flow Capacity (ALR) and Pump Sizing"
4. Designing with Geosynthetics, Koerner, 1998.

**REVIEW COMMENTS:**

CALCULATION MADE BY: CAB DATE: 8/22/2007

CALCULATION CHECKED BY: SLW DATE: 8/22/2007

CALCULATION REVISED BY: _____ DATE: _____

CALCULATION REVIEWED BY: SLW DATE: 9/27/07

## Purpose of Calculation

Use the 1996 LDS flow capacity and pump sizing calculation to determine if proposed changes in the 2007 trench design require changes to the LDS or associated piping and pumps.

## Method

The flow to sumps will be calculated.

The sump flow elements will be sized to handle the flow.

Calculate action leakage rate (ALR) for cell 12 sumps

A pump capable of evacuating the flow from the sumps will be specified.

## Analysis

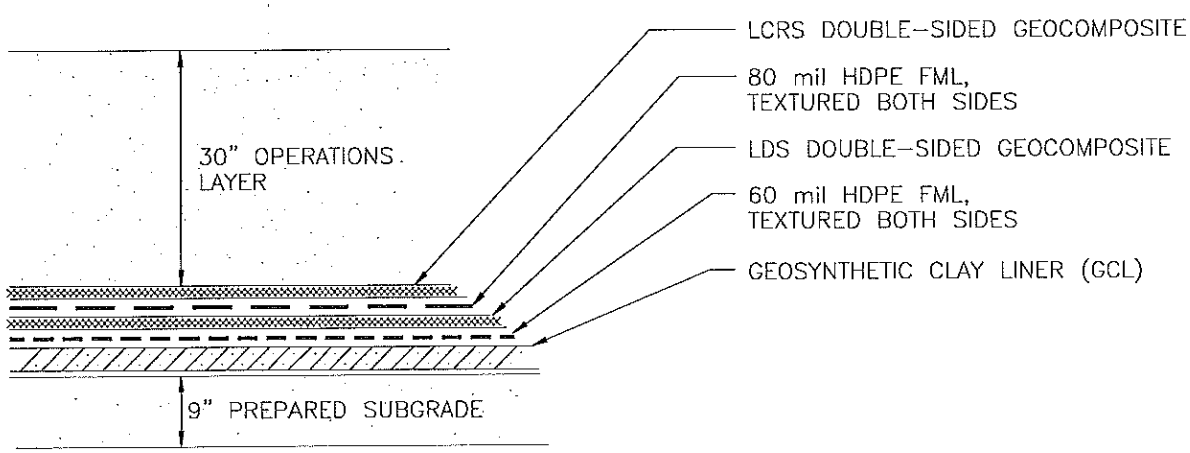
Applicable Regulations

As provided in the 1996 LDS Calculation, the regulatory definition of the ALR is the maximum design flow rate the LDS can convey without the fluid head on the secondary composite liner exceeding one foot.

Geometry

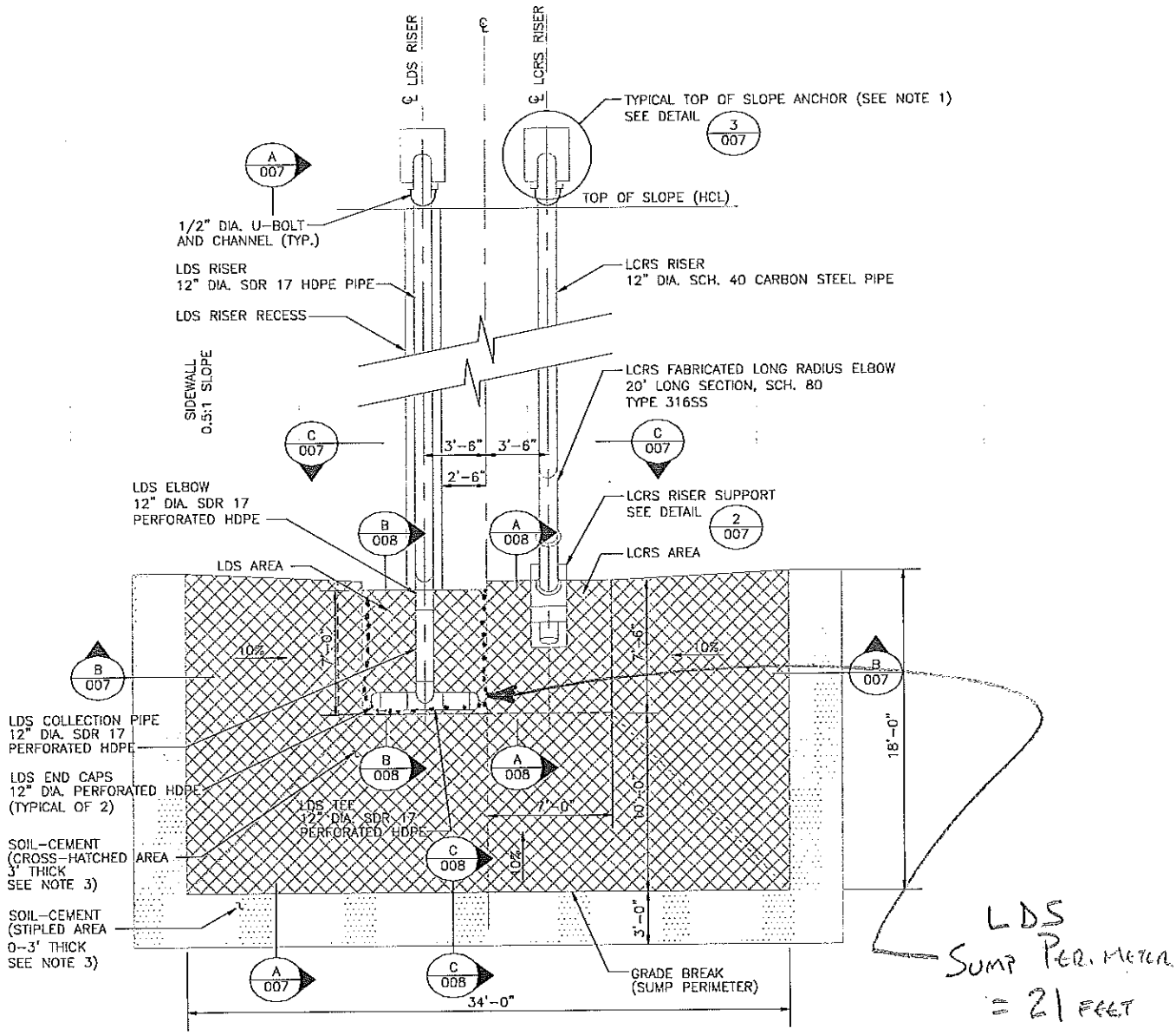
The typical bottom liner is shown below.

**Figure 1. Typical Trench Bottom Configuration**




There are three sumps in the Trench 12 design. The typical geometry is shown below.

**Figure 2. Typical Sump Layout**




## Flow Capacities

The following flow elements will be used in the LDS.

- Double sided geocomposite (GSE Fabrinet 8 ounce/yd$^2$).

- Gravel (clean, poorly graded, nominal ¾" diameter) used in the sump only.

The double sided geocomposite is used in the slope liner LDS as well as in the bottom liner as shown in Figure 1. A continuous strip of geocomposite will be used for each system. Therefore, flow within in the LDS will be controlled by the minimum bottom slope.

Flow within the Geocomposite is calculated using Darcy's Equation (which assumes laminar flow within the net). The reference for the formula below is included in the attached 1996 calculation references.

$$q = \Theta_{eff} * i$$

Where

$q$ = flow per unit width

$\Theta_{eff}$ = effective transmissivity

i = hydraulic gradient

Flow within the gravel also uses Darcy's formula, however, transmissivity is replaced with hydraulic conductivity and the thickness of the flow area.

Effective transmissivity for the geocomposite is calculated by applying several safety factors to the published transmissivity value. The following formula is used for that calculation. Definitions are provided in the references of the attached 1996 calculation.

$$\Theta_{eff} = \frac{\Theta}{(FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC})}$$

The following table shows the unit flow capacity for the geocomposite and the gravel based on the applicable transmissivity, or hydraulic conductivities, hydraulic gradients, and safety factors. Also, the flow through a drainage net was considered in the event that flow through the geocomposite was not sufficient.

| Flow Element | $\Theta$ | $FS_{CR}$ | $FS_{IN}$ | $FS_{CC}$ | $FS_{BC}$ | $\Theta_{eff}$ | i | $q$ | $q$ |
|---|---|---|---|---|---|---|---|---|---|
| Units | gal/min/ft | NA | NA | NA | NA | gal/min/ft | NA | gal/min/ft | gal/day/ft |
| GSE Fabrinet UF 8 ounce/yd$^2$ | 4.35 | 1.4 | 1.5 | 1.5 | 1.5 | 0.92 | **0.01** | 0.0092 | 13 |
| GSE HyperNet UF | 38.64 | 1.4 | 1.5 | 1.5 | 1.5 | 8.18 | **0.01** | 0.0818 | 118 |
| GSE Fabrinet UF 8 ounce/yd$^2$ | 4.35 | 1.4 | 1.5 | 1.5 | 1.5 | 0.92 | **0.1** | 0.0921 | 133 |
| GSE HyperNet UF | 38.64 | 1.4 | 1.5 | 1.5 | 1.5 | 8.18 | **0.1** | 0.8178 | 1178 |

Transmissivity values are provided by the manufacturer as included in the references. Safety factors are taken from the literature (Koerner 1998). Flow capacities are shown at hydraulic gradients of 1 percent and 10 percent for the nominal cell bottom slope and

the minimum sump slope, respectively. Since the gravel is used only within the sump boundaries around the riser pipes, flow capacities are calculated for the geocomposite only.

Controlling Section

As shown in the typical sump layout figure, there are two potentially controlling sections: 1) the 7'x 7' LDS perimeter at 15" thick; and 2) the perimeter at the grade break between the 1 and 10 percent slopes

Using EPA guidelines, the sumps will be designed for a maximum ALR of 200 gallons per acre per day (gpad). Total area contributing to each sump (including floor and sidewalls) and total flow for each cell are shown in the table below and are calculated as Total Area*ALR = Total Flow.

| Sump | Total Area (acres) | ALR (gpad) | Total Flow (ALR) (gpd) |
|---|---|---|---|
| 12A | 4.45 | 200 | 890 |
| 12B | 3.45 | 200 | 690 |
| 12C | 3.26 | 200 | 652 |

Since the maximum flow to the sump is only about 0.6 gpm (Sump 12A ALR), the EPG Vertical Sump Drainer, Model No. 12-5 (with a pumping capacity of 50 gpm at 125 feet) or equivalent provides more than adequate capacity. It is anticipated that liquid will be allowed to accumulate in the LDS until sufficient volume is present to remove efficiently with a pump. At no time however, would more than 12 inches of fluid be allowed to collect over the liner system.

Each sump has a perimeter of 70 feet at the grade break between 1 percent and 10 percent slope. The following table shows the minimum length (i.e., perimeter required to accommodate the total flow for each sump using the various flow elements. Since gravel is not used outside of the sumps, perimeters are calculated for only the geocomposite.

Total Flow (ALR) / Flow Capacity through Geocomposite (GSE Fabrinet UF at a slope of 0.01) as calculated in the table above = Length of Geocomposite required at its discharge point into the sump (i.e., the exterior perimeter of the sump). The calculated perimeter length must be less than 70 to prevent leachate backups.

| Sump | Total Flow (ALR) (gpd) | Flow Capacity Through GSE Fabrinet UF at i = 0.01 (gpd/ft) | Perimeter Length Flow at i = 0.01 (ft) |
|---|---|---|---|
| 12A | 890 | 13 | 68 |
| 12B | 690 | 13 | 53 |
| 12C | 652 | 13 | 50 |

At the 1 percent to 10 percent perimeter grade break, single geocomposite layers are adequate for the 70 feet long perimeter of all sumps without the need for additional drainage net thickness (or higher capacity) to increase flow.

Instead of calculating the needed sump perimeter, the following table calculates the design flow into each sump using the 1996 and 2007 sump design (of 70 feet) and compares it to the required ALR.

(Sump Perimeter (ft)) * (Flow Capacity through Geocomposite (gpd/ft)) / (Total Area (acre)) = (Design Flow (gal/acre/day))

Design Flow must exceed Required ALR to prevent backups on the liner.

| Sump | Total Flow - ALR (gpd) | Total Area (acres) | Sump Perimeter at i = 0.01 (ft) | Flow Capacity Through GSE Fabrinet UF at i = 0.01 (gpd/ft) | Design Flow (gal/acre/day) | Required ALR (gal/acre/day) |
|---|---|---|---|---|---|---|
| 12A | 890 | 4.45 | 70 | 13 | 204 | 200 |
| 12B | 690 | 3.45 | 70 | 13 | 264 | 200 |
| 12C | 652 | 3.26 | 70 | 13 | 279 | 200 |

Within the 7'x7' area immediately surrounding the LDS intake, the perimeter is 21 feet as shown in the typical sump layout figure. As shown in the table below, a single geocomposite layer has sufficient flow capacity to accommodate the design ALR without the need for additional drainage net to increase flow.

Total Flow (ALR) / Flow Capacity through Geocomposite (GSE Fabrinet UF at a slope of 0.1) as calculated in the table above = Length of Geocomposite required at its discharge point into the sump (i.e., the discharge point to gravel). The calculated perimeter length must be less than 21 to prevent leachate backups.

| Sump | Total Flow - ALR (gpd) | Flow Capacity Through GSE Fabrinet UF at i = 0.1 (gpd/ft) | Perimeter Length Flow at i = 0.1 (ft) |
|---|---|---|---|
| 12A | 890 | 133 | 6.7 |
| 12B | 690 | 133 | 5.2 |
| 12C | 652 | 133 | 4.9 |

Result

Flow through the GSE Fabrinet UF (or equivalent) at 1 percent up to the perimeter of the sump (at the grade break) provides sufficient flow to meet the ALR requirements for all three sumps. Flow through the GSE Fabrinet UF at 10 percent gradient up to the

perimeter of the 7' x 7' area around the LDS pipe and pump is sufficient and does not result in accumulation of water on the LDS liner. Therefore a single layer of double sided geocomposite (GSE Fabrinet UF 8 ounce/yd$^2$) is sufficient for the ALR requirements of the LDS and the second and third layers used in the 1996 design are not necessary.

REFERENCE

GSE SPECIFICATION

GSE STANDARD PRODUCTS

# Product Data Sheet

## GSE FabriNet UF Geocomposite (Double-Sided)

GSE FabriNet UF geocomposite consists of GSE HyperNet UF geonet heat-laminated on both sides with a GSE nonwoven needlepunched geotextile. GSE HyperNet UF is a 300 mil thick geonet manufactured from a premium grade high density polyethylene resin. For the purpose of lamination to geonets, GSE nonwoven needlepunched geotextiles are available in mass per unit area range of 6 oz/yd² (200 g/m²) to 16 oz/yd² (540 g/m²). GSE FabriNet UF geocomposites are designed and formulated to perform drainage function under a range of anticipated site loads, gradients and boundary conditions. Index properties for the product are provided in the table below. Please contact GSE for further information regarding performance under site-specific conditions.

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM AVERAGE ROLL VALUE[a] | | |
|---|---|---|---|---|---|
| **Geocomposite** | | | 6 oz/yd² | 8 oz/yd² | 10 oz/yd² |
| Product Code | | | F82060060T | F82080080T | F82100100T |
| Transmissivity[b], gal/min/ft (m²/sec) | ASTM D 4716 | 1/540,000 ft² | 4.35 (9.0 x $10^{-4}$) | 4.35 (9.0 x $10^{-4}$) | 4.35 (9.0 x $10^{-4}$) |
| Ply Adhesion, lb/in (g/cm) | ASTM D 7005 | 1/50,000 ft² | 1.0 (178) | 1.0 (178) | 1.0 (178) |
| Roll Width[c], ft (m) | | | 15.0 (4.5) | 15.0 (4.5) | 15.0 (4.5) |
| Roll Length[c], ft (m) | | | 160 (48) | 150 (45) | 140 (42) |
| Roll Area, ft² (m²) | | | 2,400 (223) | 2,250 (209) | 2,100 (195) |
| **Geonet core[d]** | | | | | |
| Transmissivity[b], gal/min/ft (m²/sec) | ASTM D 4716 | | 38.64 (8 x $10^{-3}$) | 38.64 (8 x $10^{-3}$) | 38.64 (8 x $10^{-3}$) |
| Thickness, mil (mm) | ASTM D 5199 | 1/50,000 ft² | 300 (7.6) | 300 (7.6) | 300 (7.6) |
| Density, g/cm³ | ASTM D 1505 | 1/50,000 ft² | 0.94 | 0.94 | 0.94 |
| Tensile Strength (MD), lb/in (N/mm) | ASTM D 5035 | 1/50,000 ft² | 75 (13.3) | 75 (13.3) | 75 (13.3) |
| Carbon Black Content, % | ASTM D 1603 | 1/50,000 ft² | 2.0 | 2.0 | 2.0 |
| **Geotextile (prior to lamination)[d,e]** | | | | | |
| Mass per Unit Area, oz/yd² (g/m²) | ASTM D 5261 | 1/90,000 ft² | 6 (200) | 8 (270) | 10 (335) |
| Grab Tensile, lb (N) | ASTM D 4632 | 1/90,000 ft² | 170 (755) | 220 (975) | 260 (1,155) |
| Puncture Strength, lb (N) | ASTM D 4833 | 1/90,000 ft² | 90 (395) | 120 (525) | 165 (725) |
| AOS, US Sieve (mm) | ASTM D 4751 | 1/540,000 ft² | 70 (0.212) | 80 (0.180) | 100 (0.150) |
| Permittivity, (sec⁻¹) | ASTM D 4491 | 1/540,000 ft² | 1.5 | 1.5 | 1.2 |
| Flow Rate, gpm/ft² (l/min/m²) | ASTM D 4491 | 1/540,000 ft² | 110 (4,480) | 110 (4,480) | 85 (3,460) |
| UV Resistance, % Retained | ASTM D 4355 (after 500 hours) | once per formulation | 70 | 70 | 70 |

**NOTES:**

- [a]These are MARV values and are based on the cumulative results of specimens tested by GSE. AOS in mm is a maximum average roll value.
- [b]Gradient of 0.1, normal load of 10,000 psf, water at 70° F (20° C), between stainless steel plates for 15 minutes.
- [c]Roll widths and lengths have a tolerance of ±1%.
- [d]Component properties prior to lamination.
- [e]Refer to geotextile product data sheet for additional specifications.

DS066 FabriNetUF R03/07/06

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| | | | | | |
|---|---|---|---|---|---|
| North America | GSE Lining Technology, Inc. | Houston, Texas | 800 435 2008 | 281 443 8564 | Fax: 281 230 8650 |
| South America | GSE Lining Technology Chile S.A. | Santiago, Chile | | 56 2 595 4200 | Fax: 56 2 595 4290 |
| Asia Pacific | GSE Lining Technology Company Limited | Bangkok, Thailand | | 66 2 937 0091 | Fax: 66 2 937 0097 |
| Europe & Africa | GSE Lining Technology GmbH | Hamburg, Germany | | 49 40 767420 | Fax: 49 40 7674234 |
| Middle East | GSE Lining Technology-Egypt | The 6th of October City, Egypt | | 202 2 828 8888 | Fax: 202 2 828 8889 |

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GSE STANDARD PRODUCTS

# Product Data Sheet

## GSE HyperNet, HF, HS and UF Geonet

GSE HyperNet geonets are synthetic drainage materials manufactured from a premium grade high density polyethylene (HDPE) resin. The structure of the HyperNet geonet is formed specifically to transmit fluids uniformly under a variety of field conditions. HDPE resins are inert to chemicals encountered in most of the civil and environmental applications where these materials are used. GSE geonets are formulated to be resistant to ultraviolet light for time periods necessary to complete installation. GSE HyperNet geonets are available in standard, HF, HS, and UF varieties.

The table below provides index physical, mechanical and hydraulic characteristics of GSE geonets. Contact GSE for information regarding performance of these products under site-specific load, gradient, and boundary conditions.

### *Product Specifications*

| TESTED PROPERTY | TEST METHOD | FREQUENCY | MINIMUM AVERAGE ROLL VALUE[b] | | | |
|---|---|---|---|---|---|---|
| | | | HyperNet | HyperNet HF | HyperNet HS | HyperNet UF |
| Product Code | | | XL4000N004 | XL5000N004 | XL7000N004 | XL8000N004 |
| Transmissivity[a], gal/min/ft ($m^2$/sec) | ASTM D 4716 | 1/540,000 $ft^2$ | 9.66 (2 x $10^{-3}$) | 14.49 (3 x $10^{-3}$) | 28.98 (6 x $10^{-3}$) | 38.64 (8 x $10^{-3}$) |
| Thickness, mil (mm) | ASTM D 5199 | 1/50,000 $ft^2$ | 200 (5) | 250 (6.3) | 275 (7) | 300 (7.6) |
| Density, g/$cm^3$ | ASTM D 1505 | 1/50,000 $ft^2$ | 0.94 | 0.94 | 0.94 | 0.94 |
| Tensile Strength (MD), lb/in (N/mm) | ASTM D 5035 | 1/50,000 $ft^2$ | 45 (7.9) | 55 (9.6) | 65 (11.5) | 75 (13.3) |
| Carbon Black Content, % | ASTM D 1603, modified | 1/50,000 $ft^2$ | 2.0 | 2.0 | 2.0 | 2.0 |
| Roll Width[c], ft (m) | | | 15 (4.6) | 15 (4.6) | 15 (4.6) | 15 (4.6) |
| Roll Length[c], ft (m) | | | 300 (91) | 250 (76) | 220 (67) | 200 (60) |
| Roll Area, $ft^2$ ($m^2$) | | | 4,500 (418) | 3,750 (348) | 3,300 (305) | 3,000 (278) |

**NOTES:**

- [a]Gradient of 0.1, normal load of 10,000 psf, water at 70° F (20° C), between steel plates for 15 minutes.
- [b]These are MARV values that are based on the cumulative results of specimens tested by GSE.
- [c]Roll widths and lengths have a tolerance of ±1%.

DS017 HyperNet R01/13/06

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| Europe & Africa | GSE Lining Technology GmbH | Hamburg, Germany | | 49 40 767420 | Fax: 49 40 7674234 |
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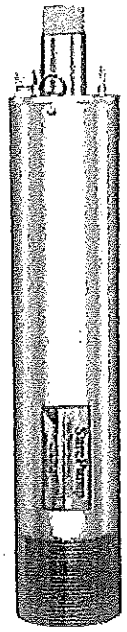
Reference

EPG Sump Pump Info

SurePump™

# Vertical Sump Drainer



EPG's SurePump™ Vertical Sump Drainer (VSD) pumps contaminated liquids for recovery, leachate collection, gas condensate removal, and sampling applications. It can be used in aggressive environments. Other designs may fail while EPG Vertical Sump Drainers are still going strong. EPG backs the vertical sump drainers with a one year warranty effective the date of installation. For more information please call the experts at EPG companies Inc.

- Stainless steel construction
- Corrosion resistant
- E-Glide™ bearings for extra durability
- Teflon seal rings
- Franklin Electric motor
- Sealed unit with liquid flow drawn past motor for cooling
- Facilitates drawdown to the very bottom of the vessel
- Chemical resistant jacketed CP motor lead
- Vent valve system purges air from the sump drainer preventing pump air lock
- Flow rates available from 2 - 1,200 gpm
- UL listed control panels are available for precise control

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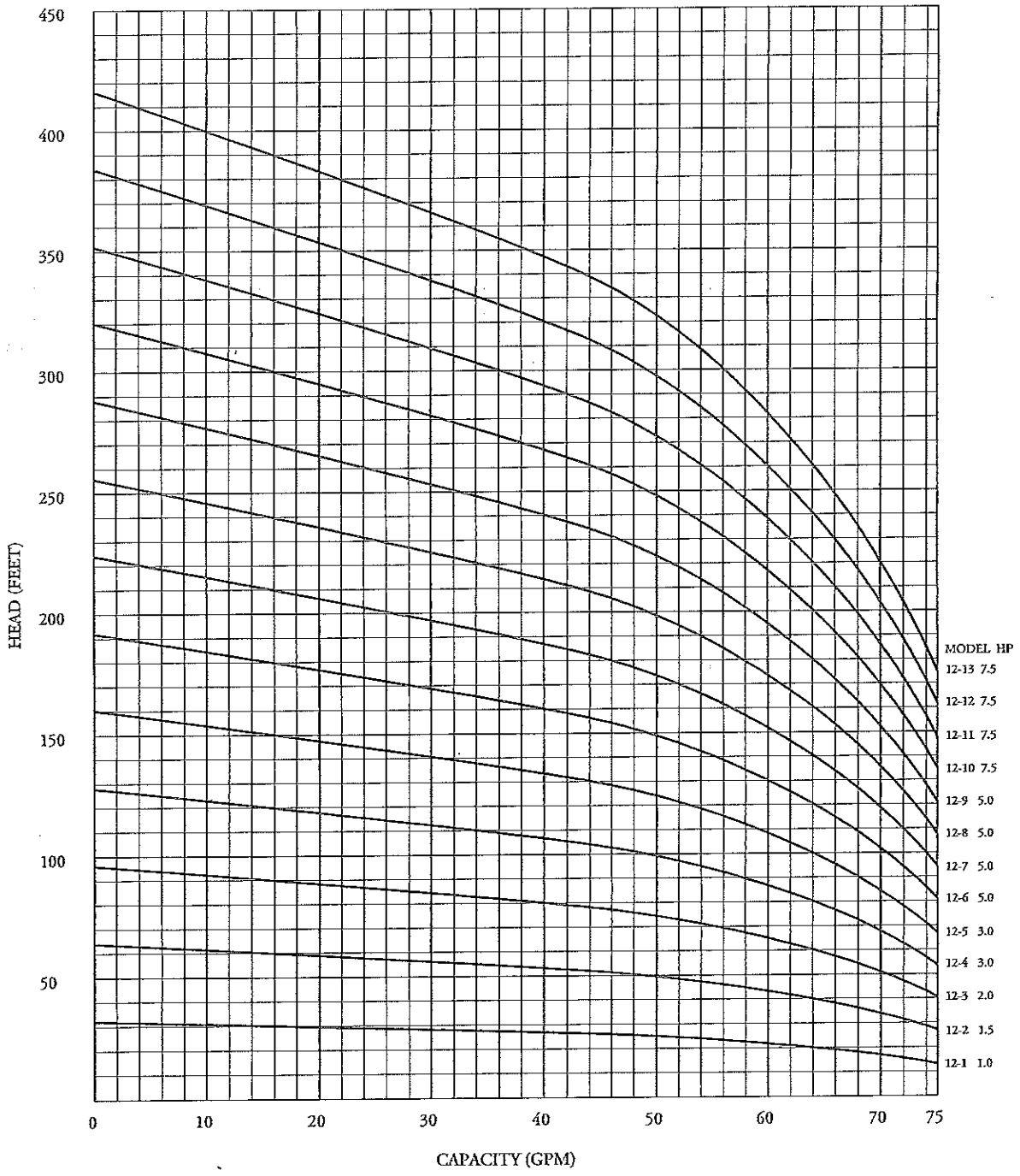
Bulletin 0330c

# SERIES 12 SurePump™

Flow Range 35-75 GPM

60 Hz

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REFERENCE

1996 CALCULATION

# C.9 LDS FLOW CAPACITY AND PUMP SIZING

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

### Purpose:

1. Determination of the action leakage rate (ALR) for each of the three sumps proposed for Cell 12 in the Beatty Landfill.

### Method:

1. Identify applicable regulations and standards.
2. Generate conceptual sump geometry.
3. Determine flow capacities of the selected drainage elements
4. Refine sump geometry as necessary, and identify controlling flow section.
5. Calculate ALR for Cell 12 sumps.

### Summary

1. Double layers of geocomposite are required for each sump at the grade break to provide sufficient flow capacity.
2. Sumps in cell corners require geonet rather than geocomposite to provide adequate flow capacity due to reduction of effective perimeter.
3. ALR's for sumps are as follows:

| Sump | Total Area | ALR |
|---|---|---|
| 12A | 3.49 ac | 200 gpad |
| 12B | 2.45 ac | 185 gpad |
| 12C | 2.87 ac | 212 gpad |

4. Variable speed recipricating pumps, identical to those used in the LCRS are recommended for use.

### Analysis:

#### Applicable Regulations

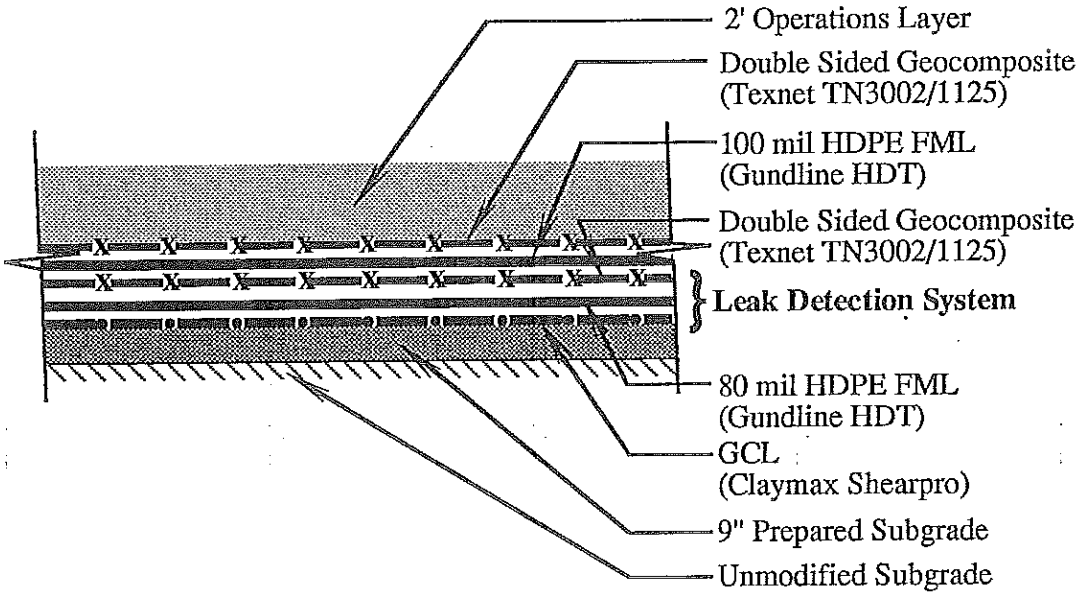
1. By regulatory definition (Reference 1A) the ALR is the maximum design flow rate the leak detection system (LDS) can convey without the fluid head on the secondary, composite, liner exceeding one foot.

#### Typical Geometry

1. The typical bottom liner is shown below in Figure 1:

LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

**Figure 1**




2. The sump locations are shown on Figure 2 (Attached). There are three sumps proposed for Cell 12. The typical geometry is shown in Figure 3 (Attached).

Flow Capacities

1. The following flow elements will be used in the LDS

   - Double sided geocomposite (Texnet TN3002/1125)
   - Geonet (Polynet PN3000)-used in the sump areas if additional flow capacity is required.
   - Gravel (clean, poorly graded, nominal 3/4" diameter)-used in the sump proper only.

2. The double sided geocomposite is used in the slope liner LDS as well as in the bottom liner as shown in Figure 1. A continuous strip of geocomposite will be used for each system. Therefore flow within the LDS will be controlled by the minimum bottom slope.

3. Flow within the geosynthetics is calculated using Darcy's Equation (which assumes laminar flow within the net) as follows (Reference 2A):

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

$$q = \Theta_{eff} i \qquad (1)$$

Where:

$q$ = flow per unit width

$\Theta_{eff}$ = effective transmissivity

$i$ = hydraulic gradient

Flow within the gravel also uses Darcy's formula, however, transmissivity is replaced with hydraulic conductivity and the thickness of the flow area.

4. Effective transmissivity for the geosynthetics is calculated by applying several safety factors to the published transmissivity value. The following formula (Reference 2B) is used for that calculation, definitions are provided in the attached reference:

$$\Theta_{eff} = \frac{\Theta}{(FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC})} \qquad (2)$$

5. The following table shows the unit flow capacity for the geosynthetic elements and the gravel based on the applicable transmissivity, or hydraulic conductivities, hydraulic gradients, and safety factors:

**Table 1**

| Flow Element | $\Theta$ | $FS_{CR}$ | $FS_{IN}$ | $FS_{CC}$ | $FS_{BC}$ | $\Theta_{eff}$[1] | $i$ | q | q |
|---|---|---|---|---|---|---|---|---|---|
| Units: | m2/s | NA | NA | NA | NA | m2/s | NA | m3/m-s | gal/ft-day |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.01 | 4.66E-07 | 3.24 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.01 | 4.23E-06 | 29.45 |
| TN3002/1125 | 2.20E-04 | 1.4 | 1.5 | 1.5 | 1.5 | 4.66E-05 | 0.1 | 4.66E-06 | 32.39 |
| PN3000 | 2.00E-03 | 1.4 | 1.5 | 1.5 | 1.5 | 4.23E-04 | 0.1 | 4.23E-05 | 294.47 |

Transmissivity values are provided by the manufacturer (Reference 3A and 3B). Safety factors are taken from the literature and are attached (Reference 2C). Flow capacities are shown at hydraulic gradients of 1 percent and 10 percent for the nominal cell bottom slope and the minimum sump slope, respectively. Since the gravel is used only within the minimum sump boundaries around the riser pipes, flow capacities are calculated for the geosynthethics only.

Controlling Section

1. As shown in Figure 3 there are two potentially controlling sections: 1) the 7'x7' LDS perimeter; and 2) the perimeter at the grade break between the 1 and 10 percent slopes. In the controlling sections multiple layers of geocomposite or geonet alone may be used to provide sufficient flow capacity.

[1] The effective transmissivity of the geocomposite (using the factors of safety listed in Table 1) still exceeds the minimum transmissivity requirement ($3 \times 10^{-5}$ $m^2/s$) of 40 CFR § 264.301(c)(3)(ii).

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

2. Using EPA guidelines (Reference 4A) the sumps will be designed for a nominal ALR of 200 gallons per acre per day (gpad). Total flow for each cell is shown in Table 2, below:

**Table 2**

| Sump | Tributary Area (ac) | Total Flow (gpd) |
|---|---|---|
| 12A | 3.49 | 698 |
| 12B | 2.45 | 490 |
| 12C | 2.87 | 574 |

Since the maximum flow to the sump is only about 0.5 gpm (Sump 12A ALR), the Protec recipricating pumps recommended in the LCRS calculation are acceptable units. It is anticipated that liquid will be allowed to accumulate in the LDS until sufficient volume is present to remove efficiently with a pump. At no time however, would more than 12 inches of fluid be allowed to collect over the liner system.

2. Each sump has a nominal perimeter of 70 feet (Figure 3), however sumps 1 and 3 have one short edge near the slope. Therefore, as a conservatism, the effective perimeter for each cell will be reduced by 25 percent to 53 feet. Table 3 shows the minimum length (i.e., perimeter) required to accomdate the total flow for each sump using the various flow elements. Since gravel is not used outside of the sumps, perimeters are calculated for only the geosynthetics.

**Table 3**

| | | Min. Perimeter Length (ft) Required for Flow at i=.01 | | | |
|---|---|---|---|---|---|
| | | No. of Geocomposites | | | |
| Sump | Design Flow (gpd) | 1 | 2 | 3 | Geonet |
| 12A | 698 | 215 | 108 | 72 | 24 |
| 12B | 490 | 151 | 76 | 50 | 17 |
| 12C | 574 | 177 | 89 | 59 | 19 |

3. Given the minimum grade break perimeter of 53 feet triple geocomposite layers are adequate for only sump 12B. Also note that geonet is adequate in all cases. Hence, geonet will be used between the grade break and the perimeter. Double geocomposite provides adequate flow capacity beyond the grade break perimeter.

4. Within the 7'x7' area, the minimum perimeter is 21 feet (Figure 3). As shown in Table 4, below, a single geocomposite layer has sufficient flow capacity to accomodate the design ALR. However geonet will also be used in the 10 percent slope areas, to facilitate construction and prevent capacity losses in the transition between the higher capacity geonet and the double geocomposite.

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 3/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

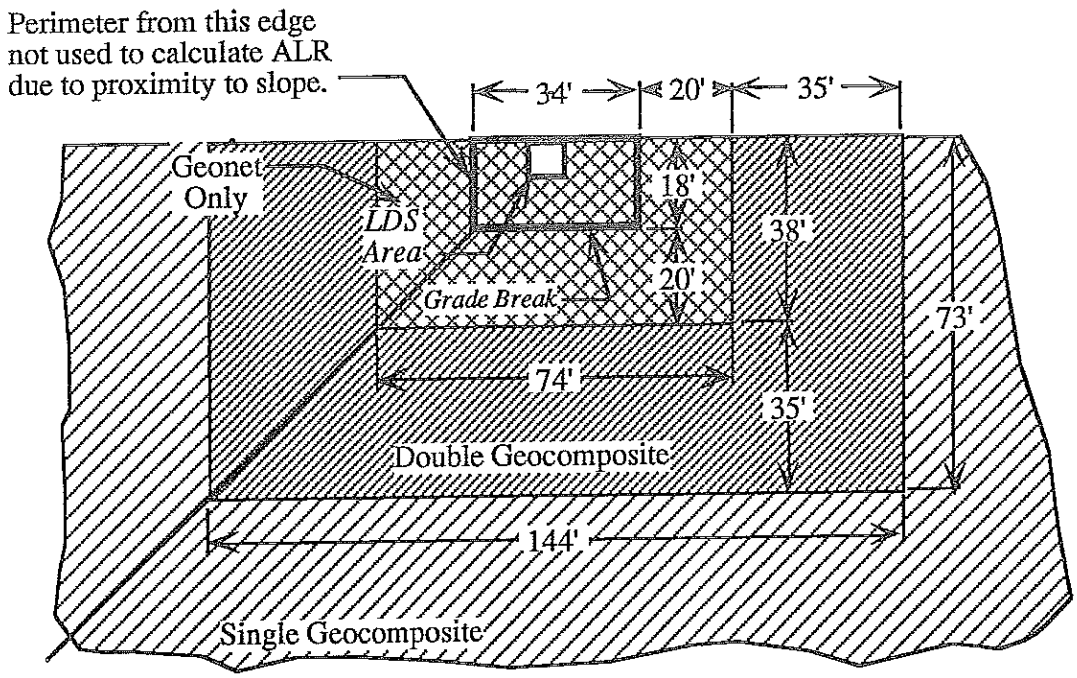
**Table 4**

| Sump | Design Flow (gpd) | Min. Perimeter Length (ft) Required for Flow at i=.10 — No. of Geocomposites: 1 | 2 | 3 | Geonet |
|---|---|---|---|---|---|
| 12A | 698 | 22 | 11 | 7 | 2 |
| 12B | 490 | 15 | 8 | 5 | 2 |
| 12C | 574 | 18 | 9 | 6 | 2 |

ALR

1. Using the perimeters identified above, flow elements are arranged for each sump. Figure 4 is the arrangement for Sump 12A.

**Figure 4**




**Sump 12A**

The ALR for Sump 12A is controlled by the minimum perimeter of the single geocomposite layer. The perimeter and resulting ALR are:

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

Checked By: EC
Checked On: 2/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

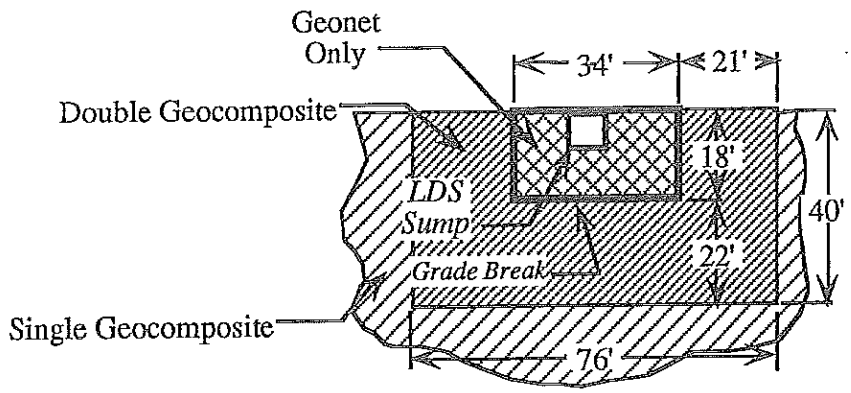
$$Perim = 144\,ft + 73\,ft$$
$$= 217\,ft$$

$$Capacity = 217\,ft\left(3.24\frac{\text{gal}}{\text{ft - day}}\right)$$
$$= 703\text{gpd}$$

$$\text{ALR} = \frac{703\text{gpd}}{3.49\text{ac}} = 201\text{gpad} \approx 200\text{gpad}$$

2. None of theSump 12B flow edges are located next to a slope. Therefore the entire perimeter is available to collect leakage. As shown in Table 3 the double geocomposite provides nearly enough capacity for the design ALR of 200 gpad at thegrade break. On the 1 percent side of the grade break double and single geocomposite will be used as shown in Figure 5. On the 10 percent side of thegrade break geonet will be used as for the other sumps.

**Figure 5**




**Sump 12B**

The ALR for Sump 12B is controlled by the minimum perimeter of the double geocomposite layer. The perimeter and resulting ALR are:

$$Perim = 34\,ft + 18\,ft + 18\,ft$$
$$= 70\,ft$$

$$Capacity = 70\,ft \times 2\left(3.24\frac{\text{gal}}{\text{ft - day}}\right)$$
$$= 453\text{gpd}$$

$$\text{ALR} = \frac{453\text{gpd}}{2.45\text{ac}} = 185\text{gpad}$$

# Environmental Solutions, Inc.

By: RVH
Date: 1/19/96

Subject: Beatty Landfill-Cell 12
American Ecology Corporation

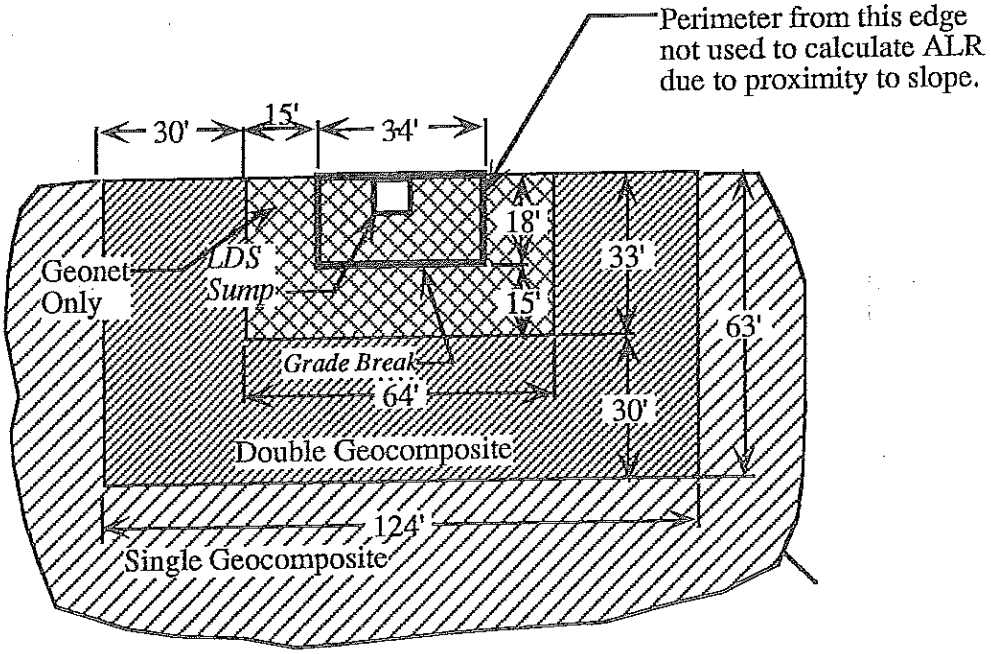
Checked By: EC
Checked On: 3/8/96

## LDS Flow Capacity (Action Leakage Rate) and Pump Sizing

Although slightly less than the design ALR, it is within 5 percent and therefore adequate.

3. Sump 12C is situated similar to Sump 12A. Flow elements are arranged as shown in Figure 6.

**Figure 6**




**Sump 12C**

The ALR for Sump 12C is controlled by the minimum perimeter of the single geocomposite layer. The perimeter and resulting ALR are:

$$Perim = 124ft + 64ft$$
$$= 188ft$$

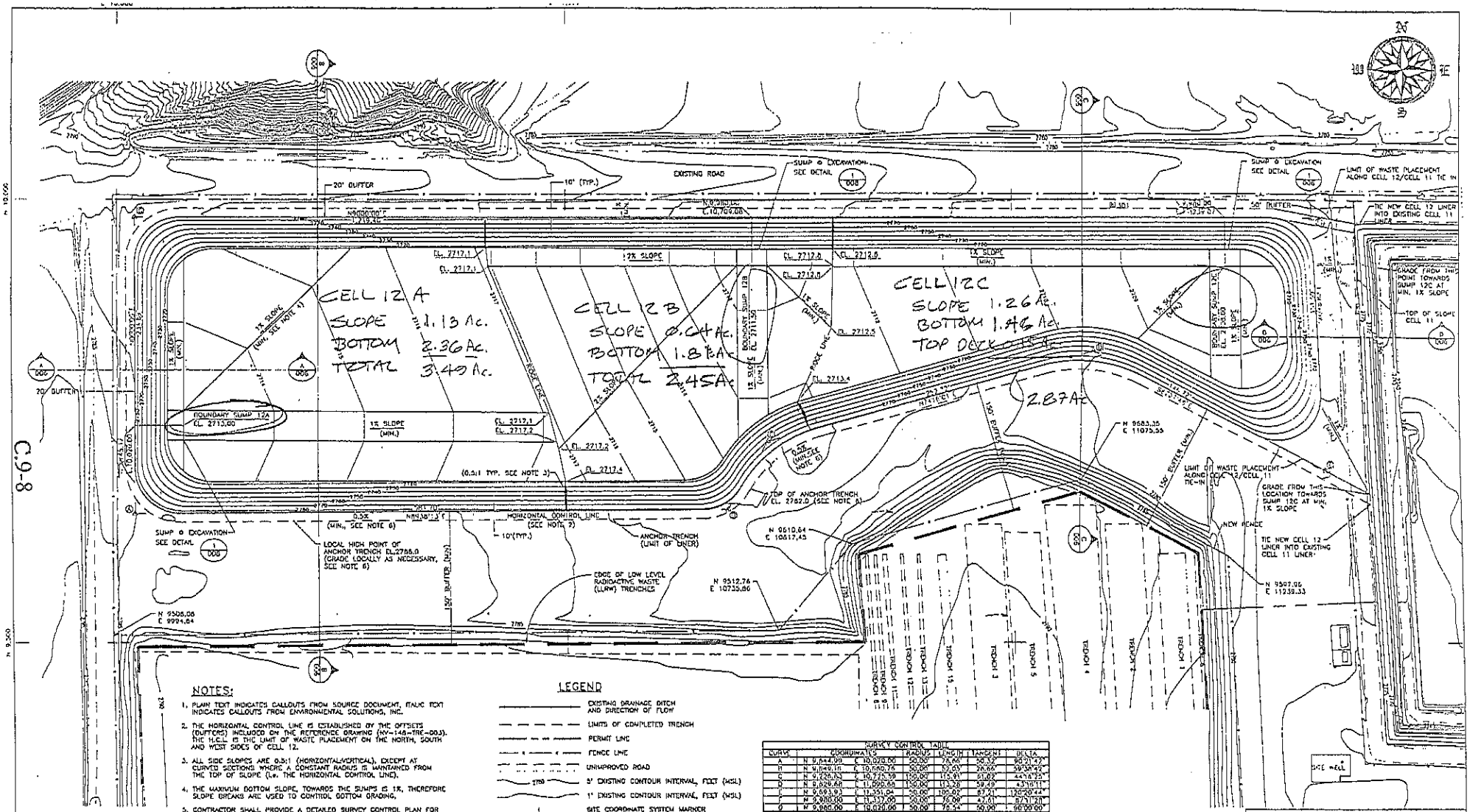
$$Capacity = 188ft\left(3.24\frac{\text{gal}}{\text{ft - day}}\right)$$
$$= 609\text{gpd}$$

$$\text{ALR} = \frac{609\text{gpd}}{2.87\text{ac}} = 212\text{gpad}$$

4. Double layers of geocomposite will consist of a double-sided geocomposite overlain by a single-sided geocomposite with the geotextile up. At the transition between the single layer to the double layer, a one foot width of the upper geotextile of the double-sided geocomposite will be removed so that the geonet elements of each are in contact.

35'
1:1 ~ MIDHEIGHT
3:1 PERIMETER (MHP)

35' x MHP = SLOPE AREA




## NOTES:

1. PLAIN TEXT INDICATES CALLOUTS FROM SOURCE DOCUMENT, ITALIC TEXT INDICATES CALLOUTS FROM ENVIRONMENTAL SOLUTIONS, INC.
2. THE HORIZONTAL CONTROL LINE IS ESTABLISHED BY THE OFFSETS (BUFFERS) INCLUDED ON THE REFERENCE DRAWING (NV-148-TRE-003). THE H.C.L. IS THE LIMIT OF WASTE PLACEMENT ON THE NORTH, SOUTH AND WEST SIDES OF CELL 12.
3. ALL SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED FROM THE TOP OF SLOPE (i.e. THE HORIZONTAL CONTROL LINE).
4. THE MAXIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1%, THEREFORE SLOPE BREAKS ARE USED TO CONTROL BOTTOM GRADING.
5. CONTRACTOR SHALL PROVIDE A DETAILED SURVEY CONTROL PLAN FOR APPROVAL, BASED ON THE HORIZONTAL CONTROL PRIOR TO COMMENCING WORK.
6. PROVIDE LOCAL GRADING AS NECESSARY TO ESTABLISH MINIMUM ANCHOR TRENCH FLOWLINES, WHICH ARE REQUIRED FOR THE COVER SYSTEM DRAIN PIPE (SEE SHEET 4).

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- LIMITS OF COMPLETED TRENCH
- PERMIT LINE
- FENCE LINE
- UNIMPROVED ROAD
- 2760 5' EXISTING CONTOUR INTERVAL, FEET (MSL)
- 1' EXISTING CONTOUR INTERVAL, FEET (MSL)
- SITE COORDINATE SYSTEM MARKER LOCATION IN NORTHING AND EASTING
- ● 302 MONITOR WELL LOCATION AND NUMBER

SURVEY CONTROL TABLE

| CURVE | COORDINATES | RADIUS | LENGTH | TANGENT | DELTA |
|---|---|---|---|---|---|
| A | N 9,044.09 E 10,020.00 | 50.00' | 78.54 | 50.12 | 90°01'47" |
| B | N 9,096.16 E 10,550.75 | 50.00' | 52.07 | 28.66' | 59°38'42" |
| C | N 9,228.53 E 10,775.59 | 100.00' | 115.91 | 61.02 | 44°16'25" |
| D | N 9,329.68 E 11,090.64 | 150.00' | 113.28 | 59.43 | 43°16'11" |
| E | N 9,693.90 E 11,351.04 | 50.00' | 105.02 | 87.21 | 120°29'44" |
| F | N 9,980.00 E 11,337.00 | 50.00' | 76.09 | 42.61 | 87°11'28" |
| G | N 9,980.00 E 10,020.00 | 50.00' | 78.54 | 50.00 | 90°00'00" |

SCALE 50 25 0 50 FEET

DATE OF AERIAL TOPOGRAPHY: JUNE 1994

| Rev | Drawn | Check | Appr | Date | Description |
|---|---|---|---|---|---|
| 3 | DKK | | | 5/95 | REDESIGN OF CELL 12 ABOVE GRADE |
| 2 | DKK | JGS | SDO | 10/94 | ADDED COORDINATES TO LLRW FENCELINE |
| 1 | DKK | JGS | SDO | 7/94 | SITE TOPO/LLRW CAP REVISED PER SURVEY 6/94 |

REVISIONS

American Ecology
5333 WESTHEIMER
Suite 1000
Houston, Texas 77056

Reference Drawings
NV-148-TRE-003

HAZARDOUS WASTE MANAGEMENT FACILITY
U.S. ECOLOGY
BEATTY NEVADA

EXCAVATION PLAN AND LIMITS OF GRADING CELL 12

ENVIRONMENTAL SOLUTIONS, INC.

ZOC NO. 95264
SCALE AS NOTED
D-95284-BL003

C.9-8

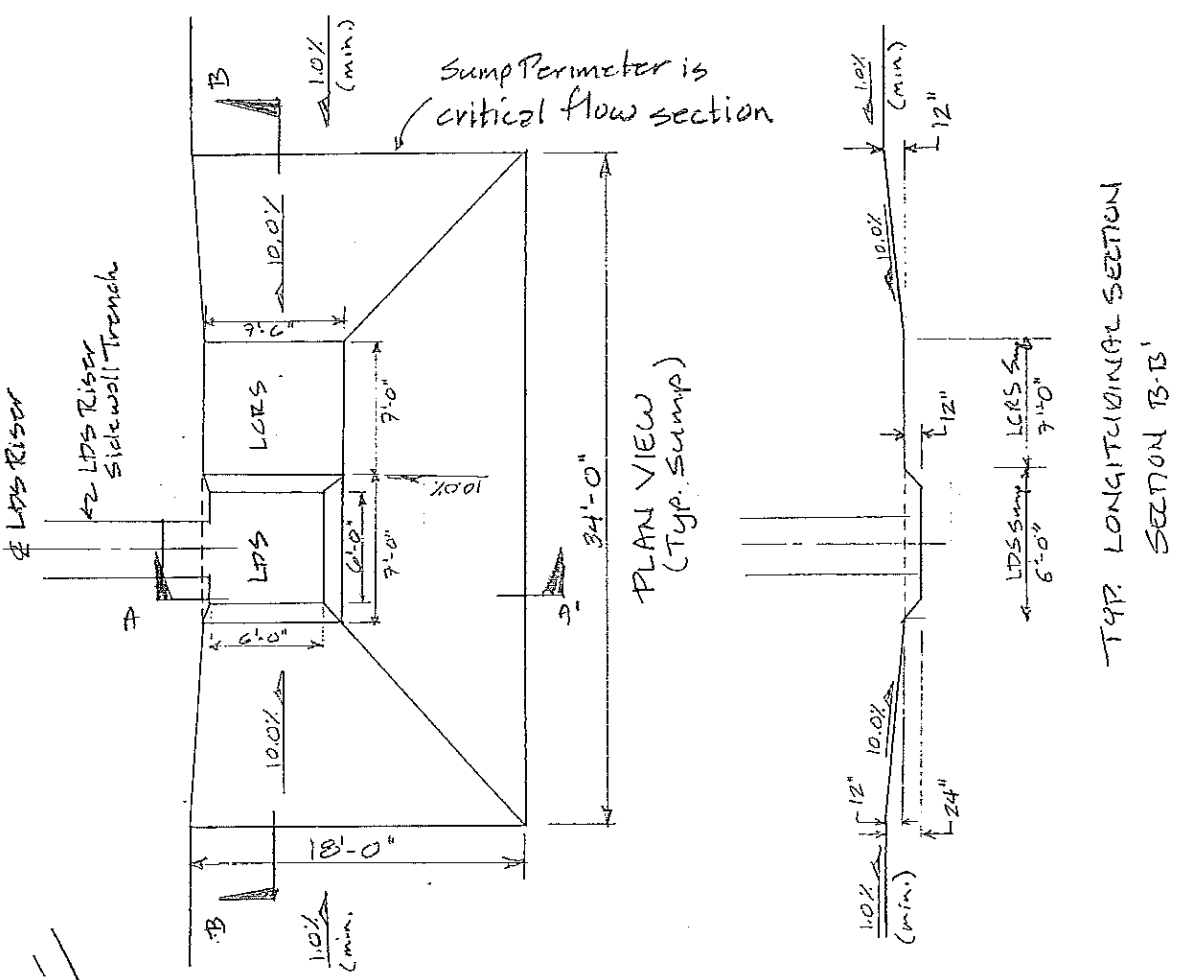
Figure 2
Proposed Sump Location

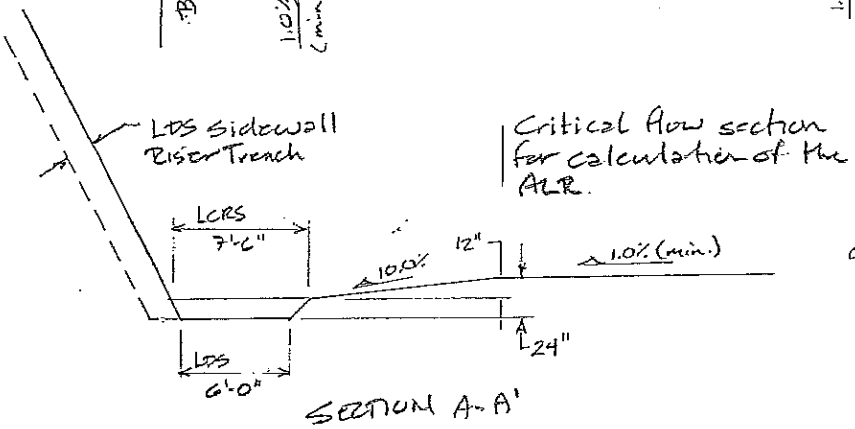
95.254
8 of 20

# ENVIRONMENTAL SOLUTIONS, INC.

By RVH Date 1/20/96 Subject BEATTY LANDFILL-CELL 12 Sheet No. 9 of 20

Chkd. By CMG Date 1/23/96 AMERICAN ECOLOGY CORP. Proj. No. 95-284



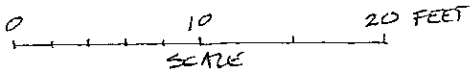




FIGURE 3

TYPICAL SUMP GEOMETRY

Notes:

1) Liner elements & riser pipes not shown for clarity.



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SHEET 10 OF 20

 REF 1A

(j), and (k) as paragraphs (g), (h), (i), (j), (k), and (l), respectively, by revising paragraphs (c) and (d), and by adding new paragraph (f) to read as follows:

**§ 264.301 Design and operating requirements.** LANDFILLS

* * * * *

(c) The owner or operator of each new landfill unit on which construction commences after January 29, 1992, each lateral expansion of a landfill unit on which construction commences after July 29, 1992, and each replacement of an existing landfill unit that is to commence reuse after July 29, 1992 must install two or more liners and a leachate collection and removal system above and between such liners. "Construction commences" is as defined in § 260.10 of this chapter under "existing facility".

(1)(i) The *liner system* must include:

(A) A top liner designed and constructed of materials (e.g., a geomembrane) to prevent the migration of hazardous constituents into such liner during the active life and post-closure care period; and

(B) A composite bottom liner, consisting of at least two components. The upper component must be designed and constructed of materials (e.g., a geomembrane) to prevent the migration of hazardous constituents into this component during the active life and post-closure care period. The lower component must be designed and constructed of materials to minimize the migration of hazardous constituents if a breach in the upper component were to occur. The lower component must be constructed of at least 3 feet (91 cm) of compacted soil material with a hydraulic conductivity of no more than $1\times10^{-7}$ cm/sec.

(ii) The liners must comply with paragraphs (a)(1) (i), (ii), and (iii) of this section.

(2) The *leachate collection and removal system* immediately above the top liner must be designed, constructed, operated, and maintained to collect and remove leachate from the landfill during the active life and post-closure care period. The Regional Administrator will specify design and operating conditions in the permit to ensure that the leachate depth over the liner does not exceed 30 cm (one foot). The leachate collection and removal system must comply with paragraphs (3)(c) (iii) and (iv) of this section.

(3) The *leachate collection and removal system* between the liners, and immediately above the bottom composite liner in the case of multiple leachate collection and removal systems, is also a *leak detection system*. This leak detection system must be capable of detecting, collecting, and removing leaks of hazardous constituents at the earliest practicable time through all areas of the top liner likely to be exposed to waste or leachate during the active life and post-closure care period. The requirements for a leak detection system in this paragraph are satisfied by installation of a system that is, at a minimum:

(i) Constructed with a bottom slope of one percent or more;

(ii) Constructed of granular drainage materials with a hydraulic conductivity of $1\times10^{-2}$ cm/sec or more and a thickness of 12 inches (30.5 cm) or more; or constructed of synthetic or geonet drainage materials with a transmissivity of $3\times10^{-5}$ $m^2$/sec or more;

(iii) Constructed of materials that are chemically resistant to the waste managed in the landfill and the leachate expected to be generated, and of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and equipment used at the landfill;

(iv) Designed and operated to minimize clogging during the active life and post-closure care period; and

(v) Constructed with sumps and liquid removal methods (e.g., pumps) of sufficient size to collect and remove liquids from the sump and prevent liquids from backing up into the drainage layer. Each unit must have its own sump(s). The design of each sump and removal system must provide a method for measuring and recording the volume of liquids present in the sump and of liquids removed.

(4) The owner or operator shall collect and remove pumpable liquids in the leak detection system sumps to minimize the head on the bottom liner.

(5) The owner or operator of a leak detection system that is not located completely above the seasonal high water table must demonstrate that the operation of the leak detection system will not be adversely affected by the presence of ground water.

(d) The Regional Administrator may approve alternative design or operating practices to those specified in paragraph (c) of this section if the owner or operator demonstrates to the Regional Administrator that such design and operating practices, together with location characteristics:

(1) Will prevent the migration of any hazardous constituent into the ground water or surface water at least as effectively as the liners and leachate collection and removal systems specified in paragraph (c) of this section; and

(2) Will allow detection of leaks of hazardous constituents through the top liner at least as effectively.

* * * * *

(f) The owner or operator of any replacement landfill unit is exempt from paragraph (c) of this section if:

(1) The existing unit was constructed in compliance with the design standards of section 3004(o)(1)(A)(i) and (o)(5) of the Resource Conservation and Recovery Act; and

(2) There is no reason to believe that the liner is not functioning as designed.

* * * * *

13. New § 264.302 is added to read as follows:

**§ 264.302 Action leakage rate.**

(a) The Regional Administrator shall approve an action leakage rate for surface impoundment units subject to § 264.301(c) or (d). The action leakage rate is the maximum design flow rate that the leak detection system (LDS) can remove without the fluid head on the bottom liner exceeding 1 foot. The action leakage rate must include an adequate safety margin to allow for uncertainties in the design (e.g., slope, hydraulic conductivity, thickness of drainage material), construction, operation, and location of the LDS, waste and leachate characteristics, likelihood and amounts of other sources of liquids in the LDS, and proposed response actions (e.g., the action leakage rate must consider decreases in the flow capacity of the system over time resulting from siltation and clogging, rib layover and creep of synthetic components of the system, overburden pressures, etc.).

(b) To determine if the action leakage rate has been exceeded, the owner or operator must convert the weekly or monthly flow rate from the monitoring data obtained under § 264.303(c), to an average daily flow rate (gallons per acre per day) for each sump. Unless the Regional Administrator approves a different calculation, the average daily flow rate for each sump must be calculated weekly during the active life and closure period, and monthly during the post-closure care period when monthly monitoring is required under § 264.303(c).

14. Section 264.303 is amended by adding new paragraph (c) to read as follows:

**§ 264.303 Monitoring and inspection.**

* * * * *

(c)(1) An owner or operator required to have a leak detection system under § 264.301(c) or (d) must record the amount of liquids removed from each leak detection system sump at least

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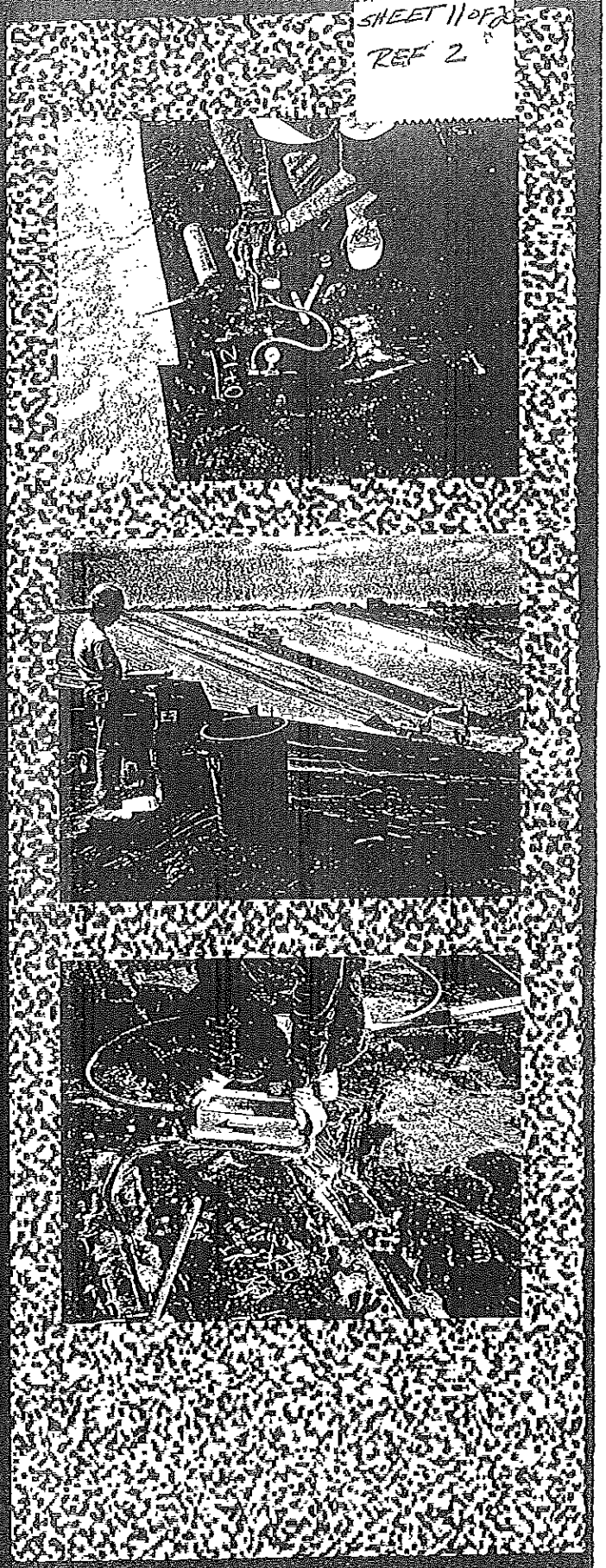
# DESIGNING WITH GEOSYNTHETICS

ROBERT M. KOERNER



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REF 2

C.9-11

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REF 2A



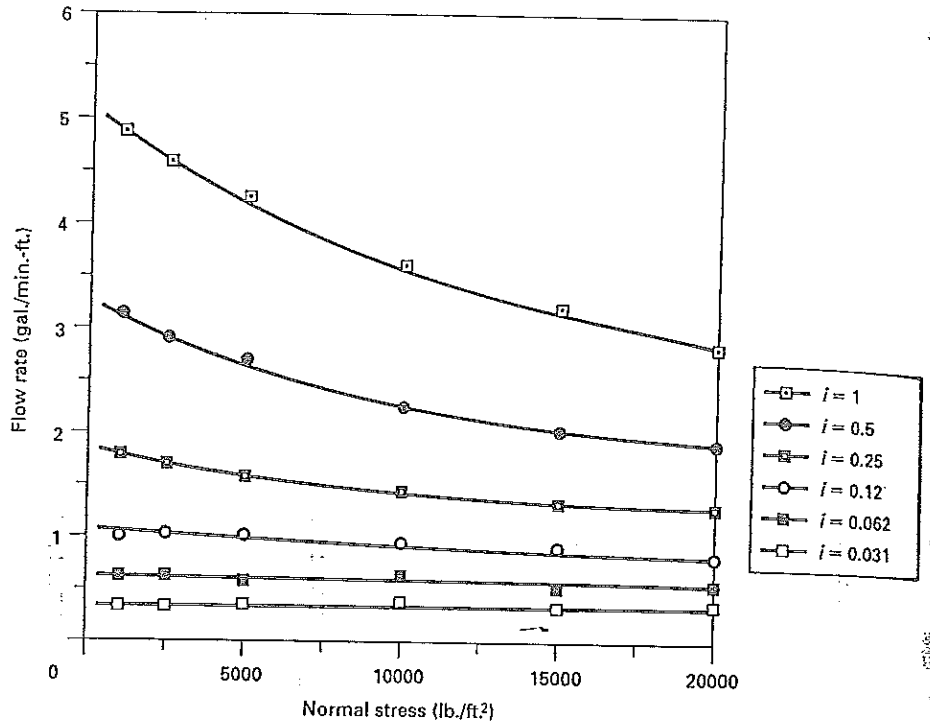


**Figure 4.8** Flow rate behavior of a 0.25-in. (6.3-mm) geonet sandwiched between a 16-oz./yd.² (540-g/m²) nonwoven needle-punched geotextile with clay above and a 60-mil (1.5-mm) HDPE geomembrane below.

met with the typical flow regime in a geonet. Yet current EPA Leak Detection regulations [2] state the following:

- For landfills and waste piles, the geonet's transmissivity must be

$$\theta \geq 3 \times 10^{-5}\ \text{m}^2/\text{sec}.$$

- For surface impoundments, the geonet's transmissivity must be

$$\theta \geq 3 \times 10^{-4}\ \text{m}^2/\text{sec}.$$

One converts from flow rate per unit width to transmissivity as follows:

$$q = kiA \tag{4.1}$$

$$q = ki(t \times W)$$

$$q/W = i(k \times t)$$

$$q/W = i\theta \tag{4.2}$$

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generated value is an ultimate value which, using ASTM D4716 for flow rate determination, must be reduced before use in design; that is,

$$q_{\text{allow}} < q_{\text{ult}}$$

One way of doing this is to ascribe partial factors of safety on each of the items not adequately assessed in the laboratory test. For example,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{FS_{IN} \times FS_{CR} \times FS_{CC} \times FS_{BC}}\right] \tag{4.5}$$

or if all of the partial factors of safety are lumped together,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\Sigma\, FS_p}\right] \tag{4.6}$$

where $q_{\text{ult}}$ = the flow rate determined from ASTM D4716 for short-term tests between solid plates using water as the transported liquid under laboratory test temperatures,

$q_{\text{allow}}$ = the allowable flow rate to be used in Equation 4.3 for final design purposes,

$FS_{IN}$ = the factor of safety for elastic deformation, or intrusion, of the adjacent geosynthetics into the geonet's core space,

$FS_{CR}$ = the factor of safety for creep deformation of the geonet and/or adjacent geosynthetics into the geonet's core space,

$FS_{CC}$ = the factor of safety for chemical clogging and/or precipitation of chemicals in the geonet's core space,

$FS_{BC}$ = the factor of safety for biological clogging in the geonet's core space, and

$\Sigma\, FS_p$ = the *product* of all partial factors of safety for the site-specific conditions.

Some guidelines for various factors of safety to be used in different situations are given in Table 4.2. Example problems follow, which illustrate the use of geonets and point out that high factors of safety are warranted in critical situations. Please note that these values are based on preliminary and relatively sparse information. Other factors of safety, such as installation damage, temperature effects, and liquid turbidity, could also have been included. If needed they can be included on a site-specific basis. On the other hand, if the test method has included the particular item, it would appear in the foregoing formulation as a value of unity.

**Example:**

What is the allowable geonet flow rate to be used in the design of a capillary break beneath a roadway to prevent frost heave? Assume that laboratory testing was

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REF 2C



**Table 4.2** Recommended preliminary factor of safety values for determining allowable flow rate or transmissivity of geonets

| | *Partial Factor of Safety Value in Equation 4.5* | | | |
|---|---|---|---|---|
| *Application Area* | $FS_{IN}$ | $FS_{CR}$* | $FS_{CC}$ | $FS_{BC}$ |
| Sport fields | 1.0 to 1.2 | 1.0 to 1.5 | 1.0 to 1.2 | 1.1 to 1.3 |
| Capillary breaks | 1.1 to 1.3 | 1.0 to 1.2 | 1.1 to 1.5 | 1.1 to 1.3 |
| Roof and plaza decks | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 | 1.1 to 1.3 |
| Retaining walls, seeping rock and soil slopes | 1.3 to 1.5 | 1.2 to 1.4 | 1.1 to 1.5 | 1.0 to 1.5 |
| Drainage blankets | 1.3 to 1.5 | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 |
| Surface water drains for landfill caps | 1.3 to 1.5 | 1.2 to 1.4 | 1.0 to 1.2 | 1.2 to 1.5 |
| Secondary leachate collection (landfills) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 2.0 |
| Primary leachate collection (landfills) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 2.0 |

*These values assume that the $q_{ult}$ value was obtained using an applied normal pressure of 1.5 to 2 times the field-anticipated maximum value. If not, values must be increased.

done at the proper design load and hydraulic gradient and that this testing yielded a short-term between-rigid-plates value of 1.2 gal./min.-ft.

**Solution:** Since better information is not known, average values from Table 4.2 are used.

$$q_{allow} = q_{ult}\left[\frac{1}{FS_{IN} \times FS_{CR} \times FS_{CC} \times FS_{BC}}\right] \tag{4.5}$$

$$= 1.2\left[\frac{1}{1.1 \times 1.1 \times 1.1 \times 1.2}\right]$$

$$= 1.2\left[\frac{1}{1.60}\right]$$

$$= 0.75 \text{ gal./min.-ft.}$$

**Example:**

What is the allowable geonet flow rate to be used in the design of a secondary leachate collection system? Assume that laboratory testing at proper design load and proper hydraulic gradient gave a short-term between-rigid-plates value of 1.2 gal./min.-ft.

**Solution:** Average values from Table 4.2 are used; however, note the large reduction.

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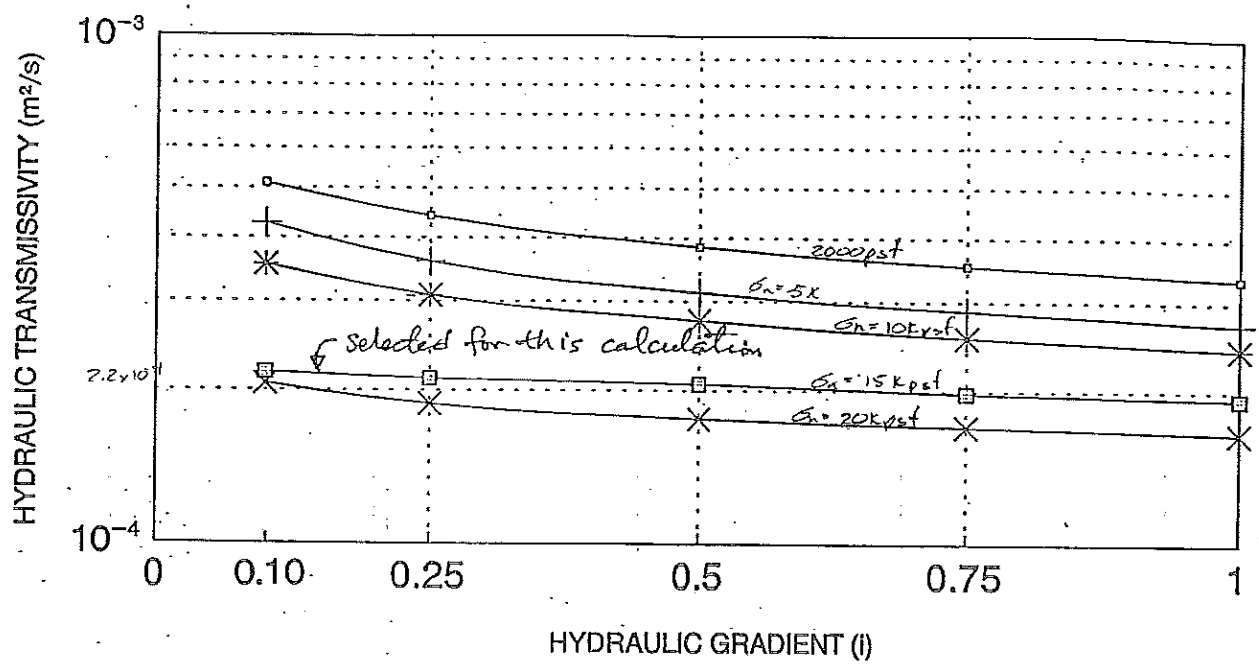
REF 3A

# TEX-NET TN3002/1125

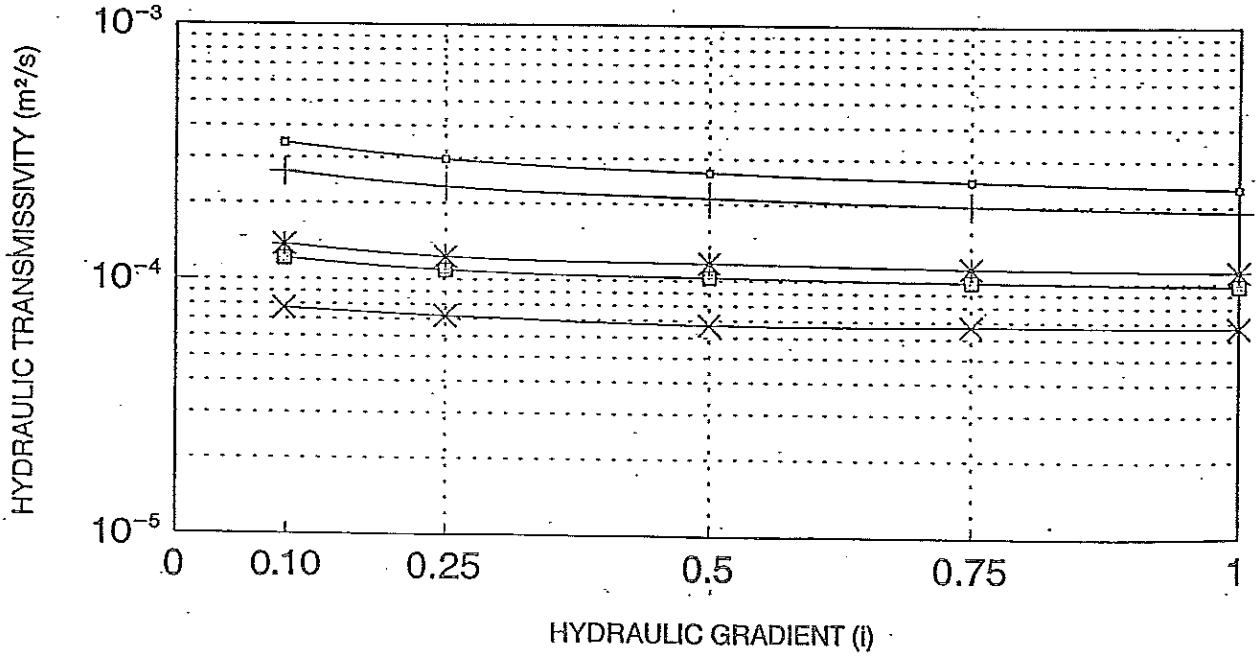
plate/FRICTION SEAL/TN3002/1125/FRICTION SEAL/plate




- 2000 psf
- 5000 psf
- 10000 psf
- 15000 psf
- 20000 psf

# TEX-NET TN3002CN/1125

plate/FRICTION SEAL/TN3002CN/1125/FRICTION SEAL/plate



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| POLY-NET® TRANSMISSIVITY | INSTALLATION METHOD<br>LEAK DETECTION<br>HDPE LINER/POLY-NET/HDPE LINER | HYDRAULIC PRESSURE |
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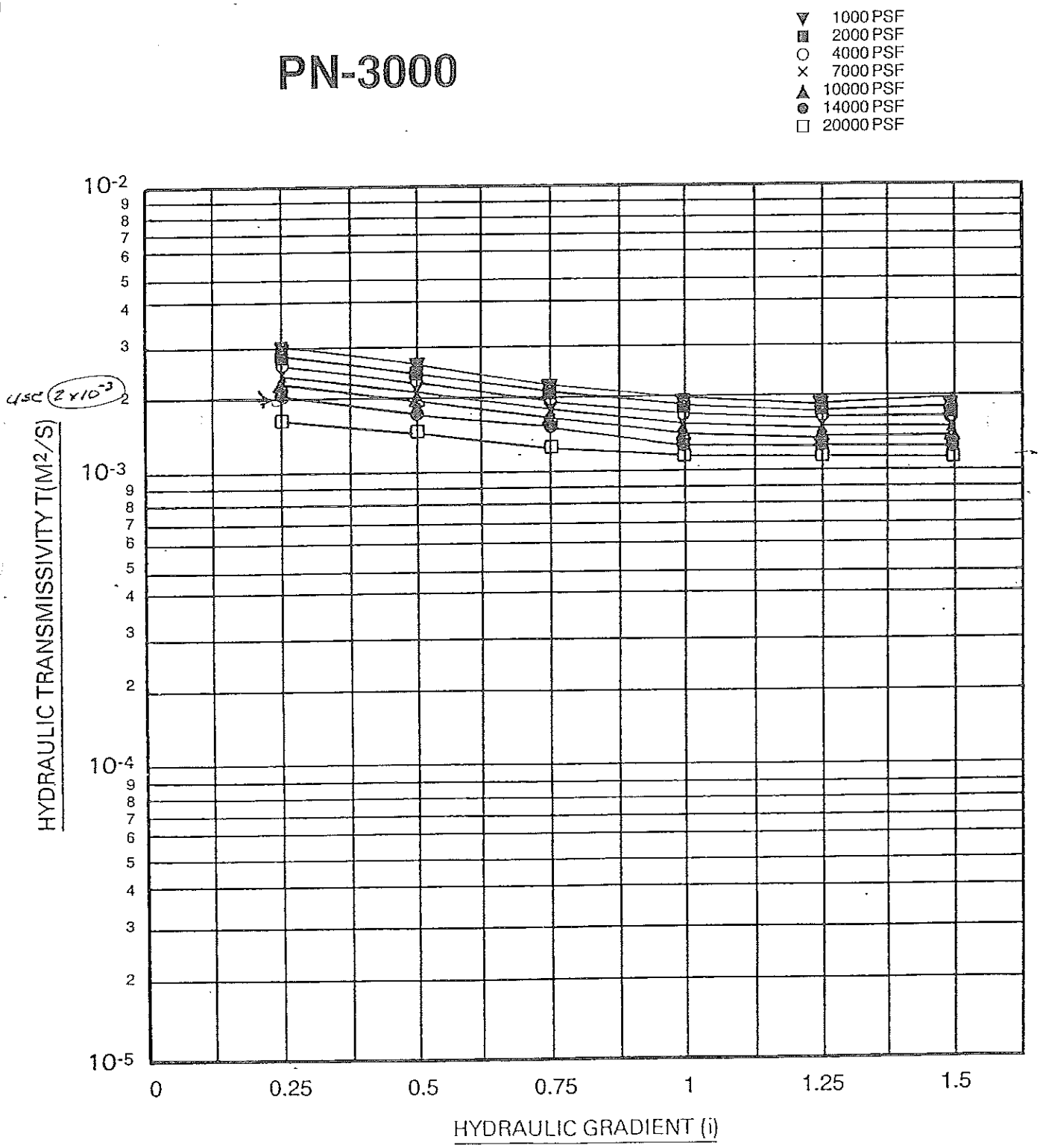



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CINCINNATI, OH 45246
513/771-5656
800/346-9107
FAX - 513/771-4844




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REPORTS
US EPA
530/R-92-004
1992

REF 4
EPA 530-R-92-004
PB92-128214
SHEET 18 OF 20

# ACTION LEAKAGE RATES FOR LEAK DETECTION SYSTEMS

[Supplemental Background Document for
the Final Double Liners and Leak Detection Systems Rule for
Hazardous Waste Landfills, Waste Piles, and Surface Impoundments]

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste
January 1992



REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
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SPRINGFIELD, VA 22161

$B_{avg}$ = average width of the flow in the leak detection system, perpendicular to the flow.

Assumming that the gradient of flow through the hole, at the hole, is sin $\alpha$ and depth of flow at the hole for concentrated flow = the thickness of the drainage layer:

$$B_{avg} = D/\sin \alpha$$

where D = leak detection system thickness.

Then, with D = 1 ft and sin $\alpha$ = 0.01, $B_{avg}$ = 100 ft
0.02, $B_{avg}$ = 50 ft
0.03, $B_{avg}$ = 33 ft.

Using these values for $B_{avg}$ and Equation 1 with $h \approx D = 1$ ft ($h \approx D$ for small values of $\alpha$), Q in gpad =

| k (cm/sec) | sin $\alpha$ | $B_{avg}$ (ft) | | |
|---|---|---|---|---|
| | | 33 | 50 | 100 |
| 1 | .01 | ---- | ---- | 21,000 |
| | .02 | ---- | 21,000 | ---- |
| | .03 | 21,000 | ---- | ---- |
| .1 | .01 | ---- | ---- | 2,100 |
| | .02 | ---- | 2,100 | ---- |
| | .03 | 2,100 | ---- | ---- |
| .01 | .01 | ---- | ---- | 210 |
| | .02 | ---- | 210 | ---- |
| | .03 | 210 | ---- | ---- |

Thus, using the minimum specifications in today's rule: 1% slope, 12 in thick drainage layer, and 1 X $10^{-1}$ cm/sec hydraulic conductivity for surface impoundments and 1 X $10^{-2}$ cm/sec hydraulic conductivity for landfills and waste piles, and assuming that the head is 1 ft and the average width of flow ($B_{avg}$) is as given above, the results show maximum flow rates of 2,100 gpad for surface impoundments and 210 gpad for landfills and waste piles. Using a safety factor of two, as suggested in the example given in the proposed rule preamble, yields about 1,000 gpad for surface impoundments and 100 gpad for landfills and waste piles as the Agency recommended action leakage rates, for units that are designed to the minimum specifications in today's rule. As listed in the rule and above, the safety factor helps account for uncertainties in the design, construction, operation, and location of the drainage layer and potential decreases in flow over time as a result of overburden compressive forces and clogging caused by fines and biological and chemical actions in any leachate that seeps through. Of course, all of the above mechanisms that could result in potential decreases in flow over time should also be considered when selecting the design, especially the hydraulic conductivity of the drainage layer, and in construction. Because this calculation used the

increasing length of run from 20 ft to 80 ft [Table 1; Figure 4 shows that length of run has negligible effect for slopes at or greater than the 1% minimum]; 43% increase when hole size is increased from .25 $ft^2$ to 1.0 $ft^2$ but a much less significant increase for holes > 3 $ft^2$ [Table 2; Figure 5 graphically shows the effect of leak size on flow rates]). However, the effect of these three variables is relatively insignificant compared to hydraulic conductivity, head, and drainage layer thickness (e.g., ten times increase (900%) when increased from .01 cm/sec to .1 cm/sec hydraulic conductivity [Tables 1, 3-5]; 382% increase when increased from no head to 2 ft head above the top liner, e.g., in a 2 ft deep surface impoundment [Table 3]; and 210% increase when geonet thickness is doubled from 5 mm to 10 mm [Table 5]).

Figures 2a-2d (side view) and 3a-b (top view) show the shape of the saturated zone for various designs, assuming no head above the top liner. These show only small portions of the bottom liner are actually exposed to the 1 ft head (as assumed in the simpler models discussed above). Figures 6-8b, however, show that as the head increases, so does the area of the bottom liner exposed to the greater heads. The graph for 8 ft head for surface impoundments is almost rectangular and therefore is not shown. Table 5 and Figure 10 show the results for geonets, which because of their high hydraulic conductivities have high flow rates.

Table 4 shows flow rates of 204 gpad and 2,040 gpad respectively for the landfill and surface impoundment specifications (i.e., 1% slope and hydraulic conductivity of $10^{-1}$ cm/sec for surface impoundments and $10^{-1}$ cm/sec for landfills, but with 1 ft of head above the top liner, 180 ft length of run, and a .1 $ft^2$ hole size). Comparing the results of the 3-D model to those of Equations 1 and 3, using the 1% slope and $10^{-1}$ cm/sec hydraulic conductivity for surface impoundments, shows that if the hole size is somewhat less than .25 $ft^2$, the flow rate with a 2 ft head would be about 2100 gpad [Table 3]. For 0 ft head above the top liner, the hole would be somewhat larger than 30 $ft^2$, or close to uniform flow [Figure 5].

### 3.2 Alternative Action Leakage Rates

While EPA recommends the above action leakage rates (100 and 1,000 gpad) for units that are built to the minimum design specifications, the Agency recognizes that a number of site-specific factors affect the maximum flow capacity of a leak detection system, and owners and operators may want to propose alternative action leakage rates. For example, the leak detection system design may be different than the minimums specified in the final rule. As indicated above, the hydraulic conductivity is a factor that significantly affects the flow capacity of the system. Since they are directly proportional, a ten times increase in hydraulic conductivity (i.e., from $10^{-2}$ to $10^{-1}$ cm/sec) increases the flow capacity ten times. Therefore, EPA believes that leak detection systems with greater hydraulic conductivities would have higher action leakage rates. In addition, owners or operators may have information to justify a

REFERENCE

KOERNER 1998

Fourth Edition

# Designing with Geosynthetics

Robert M. Koerner, Ph.D., P.E.

H. L. Bowman Professor of Civil Engineering,
Drexel University and Director, Geosynthetic
Research Institute

PRENTICE HALL
Upper Saddle River, New Jersey 07458

**TABLE 8.4** ESTIMATES OF REQUIRED FLOW RATES (DISCHARGE) FOR WICK DRAINS

| Source | Required Flow Rate* (l/min) | Normal Stress (kPa) | Hydraulic Gradient |
|---|---|---|---|
| den Hoedt [31] | 0.17 | — | — |
| Kremer et al. [32] | 0.30 | 100 | 0.62 |
| Kremer et al. [32] | 0.09† | — | — |
| Kremer et al. [33] | 1.51 | 15 | 1.00 |
| Holtz et al. [34] | 0.23 | 400 | — |
| Koerner et al. [35] | 0.10 | in situ | 1.00 |
| Rixner et al. [28] | 0.19 | in situ | 1.00 |
| Holtz and Christopher [36] | 0.95 | in situ | 1.00 |
| Bergado et al. [37] | 0.76 | in situ | 1.00 |
| | 0.47† | in situ | 1.00 |

*Note, in the literature many authors use the unit of $m^3$/yr for the required rate. 1.0 l/min = 526 $m^3$/yr

†In flattened S-configuration, i.e., in deformed state.

$RF_{BC}$ = reduction factor for biological clogging of the geotextile or within the drainage core space.

A guide for typical values in Eq. (8.10) is presented as Table 8.5 (compare this with Table 4.2 for geonets). Note, however, that wick drains are temporary construction expedients, thus the chemical and biological clogging potential is probably quite low. Creep is dependent on the time the strip drains are required and the normal stress arising from the depth within the soil to be consolidated. For intrusion $RF_{IN}$, ASTM D4716 can be evaluated with soil above and below the wick drains. In this case, the intrusion reduction factor would be included as a value of unity. Now, having an in situ modified value of $q_{allow}$, a traditional design-by-function can be performed. See Example 8.4.

**TABLE 8.5** RECOMMENDED REDUCTION FACTORS FOR EQ. (8.10) TO DETERMINE ALLOWABLE FLOW RATE OF DRAINAGE GEOCOMPOSITES (WICK DRAINS, SHEET DRAINS AND EDGE DRAINS)

| Application Area | $RF_{IN}$ | $RF_{CR}^{*}$ | $RF_{CC}$ | $RF_{BC}$ |
|---|---|---|---|---|
| Sport fields | 1.0 to 1.2 | 1.0 to 1.2 | 1.0 to 1.2 | 1.1 to 1.3 |
| Capillary breaks | 1.1 to 1.3 | 1.0 to 1.2 | 1.1 to 1.5 | 1.1 to 1.3 |
| Roof and plaza decks | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 | 1.1 to 1.3 |
| Retaining walls, seeping rock and soil slopes | 1.3 to 1.5 | 1.2 to 1.4 | 1.1 to 1.5 | 1.0 to 1.5 |
| Drainage blankets | 1.3 to 1.5 | 1.2 to 1.4 | 1.0 to 1.2 | 1.0 to 1.2 |
| Surface water drains for landfill caps | 1.3 to 1.5 | 1.2 to 1.4 | 1.0 to 1.2 | 1.2 to 1.5 |
| Secondary leachate collection (landfill) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 2.0 |
| Primary leachate collection (landfill) | 1.5 to 2.0 | 1.4 to 2.0 | 1.5 to 2.0 | 1.5 to 10 |
| Wick drains† | 1.5 to 2.5 | 1.0 to 2.5 | 1.0 to 1.2 | 1.0 to 1.2 |
| Highway edge drains | 1.2 to 1.8 | 1.5 to 3.0 | 1.1 to 5.0 | 1.0 to 1.2 |

*These values assume that the ultimate value was obtained using an applied normal pressure of approximately 1.5 times the field anticipated maximum value. If not, the values must be increased.

†An additional term for kinking should be included, where $RF_{KG}$ = 1.0 to 4.0.

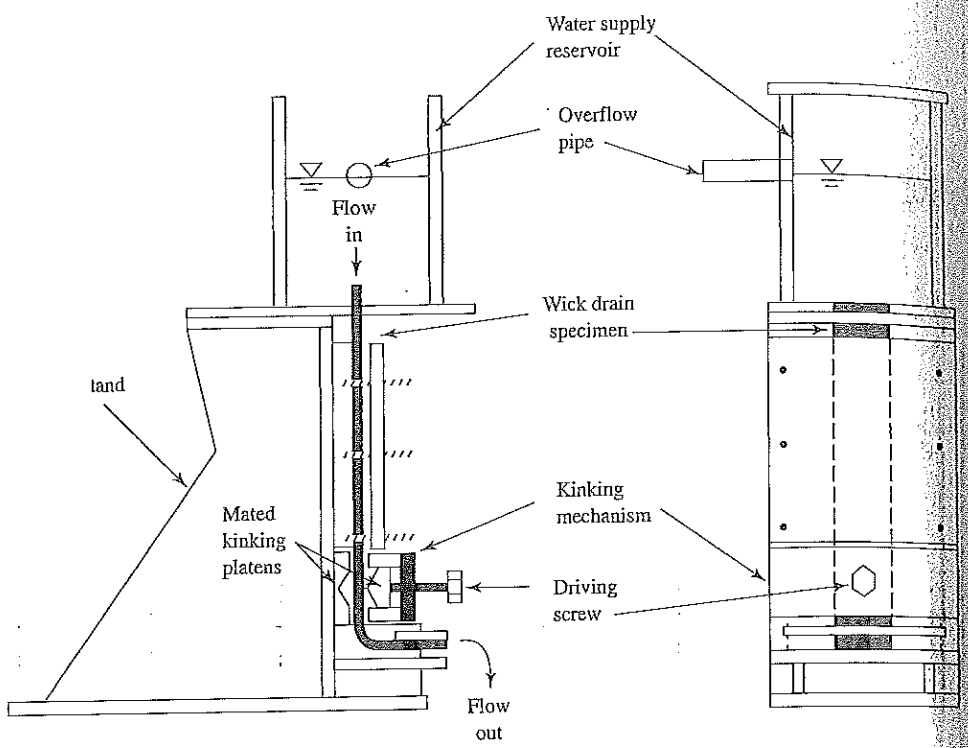


**Figure 8.12** Side and front views of laboratory kinking test device.

For the allowable flow rate $q_{\text{allow}}$ the ultimate flow rate from a ASTM D4716 test method should be obtained (recall Section 4.1.3). Typical values of ultimate flow rate at a hydraulic gradient of 1.0 under 200 kPa normal stress vary from 2.5 to 5.0 l/min for a 100 mm wide wick drain. This value must then be reduced on the basis of site specific reduction factors,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\text{RF}_{IN} \times \text{RF}_{CR} \times \text{RF}_{CC} \times \text{RF}_{BC}}\right] \tag{8.10}$$

where

$q_{\text{allow}}$ = allowable flow rate to be used in design,
$q_{\text{ult}}$ = ultimate flow rate (as determined from ASTM D4716) for short-term tests,
$\text{RF}_{IN}$ = reduction factor for elastic deformation of the adjacent geotextile intruding into the drainage core space,
$\text{RF}_{CR}$ = reduction factor for creep deformation of the drainage core itself and/or intrusion of the adjacent geotextile into the drainage core space,
$\text{RF}_{CC}$ = reduction factor for chemical clogging and/or precipitation of chemicals onto the geotextile or within the drainage core space, and

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# CALCULATION SUMMARY SHEET



PROJECT NUMBER: 073113

PROJECT NAME: USEN – Trench 12 Design, Supplemental Calculations

DATE: September 18, 2007

CALCULATION NUMBER: _____ Revision: Permit Requirement

**CALCULATION TITLE: Hydraulic Conductivity of Sump Gravel**

**DESCRIPTION OF CALCULATION:**

Calculation to re-evaluate the hydraulic conductivity of proposed sump gravel in the LCRS and LDS.

**REFERENCES USED:** Number of Reference Pages Attached: _____

1. Foundations Analysis and Design by Bowles
2. Groundwater by Freeze and Cherry

**REVIEW COMMENTS:**

CALCULATION MADE BY: SLW DATE: 9/18/2007

CALCULATION CHECKED BY: CAB DATE: 9/18/2007

CALCULATION REVISED BY: _____ DATE: _____

CALCULATION REVIEWED BY: SLW DATE: 9/18/2007

**Purpose of Calculation**

Compliance Schedule item 7.12.8 asks that USEN specify the gravel to be used in leachate sumps to obtain a "transmissivity" of 10 cm/sec. A calculation identifying the gravel "permeability" as 10 cm/sec was previously accepted by NDEP. That gravel permeability is a conservative, mid-range textbook value considered typical for coarse-grained gravel and was used as a typical value in the prior calculation.

Recent materials tests have determined that a permeability between 1.7 and 2.1 cm/sec can be achieved using screened gravel from the Trench 12 excavation. This also is a conservative value and is adequate to handle leachate flow in the LCRS and LDS systems. This calculation is done in the same manner as the 1996 calculation that supported the previous gravel permeability specification. The revised calculation shows that a minimum gravel permeability specification of 1 cm/sec or higher is sufficient in the design application (LCRS collectors and sump).

**Method**

Use Darcy's equation to determine flow the flow capacity of the gravel.

**Analysis**

Darcy's equation = Q = k*i*A*n
Where:
Q = Flow capacity
k = hydraulic conductivity of the gravel = 2.1 cm/sec = 4.1 ft/min
i = slope = 10%
A = cross sectional area of the sump surrounding the LCRS((14'+7'+7.5')*1' = 28.5 $ft^2$ (see attached Figure 1)
n = porosity = 30%

Q = (4.1 ft/min)*(0.10)*(28.5 $ft^2$)*(0.30) = 3.5 $ft^3$/min = 26 gallons/min

As calculated in the LCRS Flow Capacity and Pump Sizing calculation revision, the flow through the LCRS could be as high as 8.6 gallons per minute. Running the calculation in reverse and using Q set at 8.6 gallons per minute (or 1.2 $ft^3$/min), and solving for k yields the following:

1.2 $ft^3$/min = (k)*(0.10)*(28.5 $ft^2$)*(0.30)

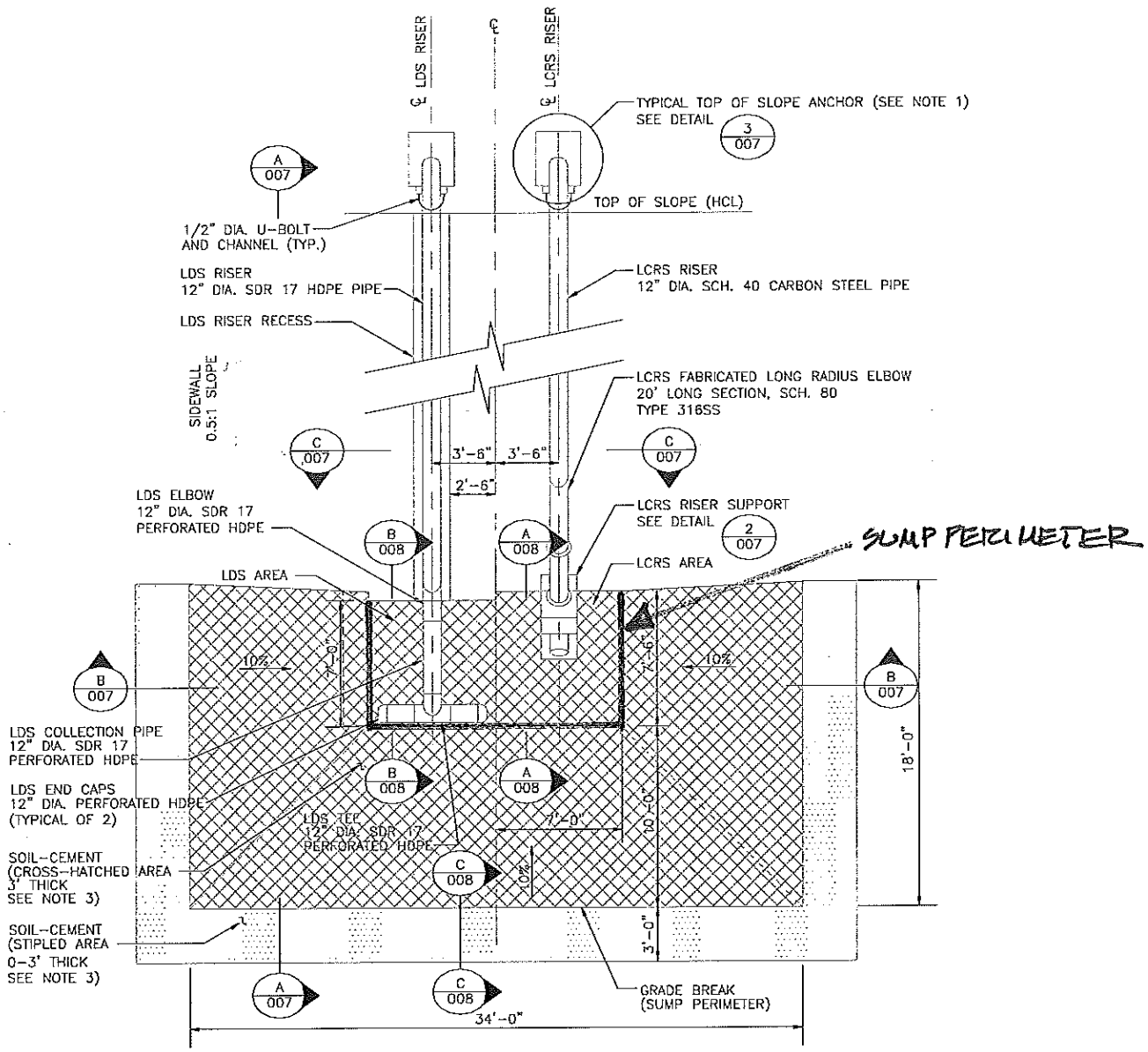
Solving for k;

k = 1.4 ft/min or 0.71 cm/sec

**Results**

As calculated in the LCRS Flow Capacity and Pump Sizing calculation revision, the flow through the LCRS could be as high as 8.6 gallons per minute. Based on the assessment above, gravel with a hydraulic conductivity of 0.71 cm/sec or higher is sufficient and will not produce backups of leachate on the liner. The hydraulic conductivity of screened gravel from the US Ecology site had a hydraulic conductivity of 1.7 to 2.1 cm/sec and is sufficient for use in the sumps.

## Figure 1. Typical Sump Layout



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Project Number: 073113 Sheet No. 5 of 5

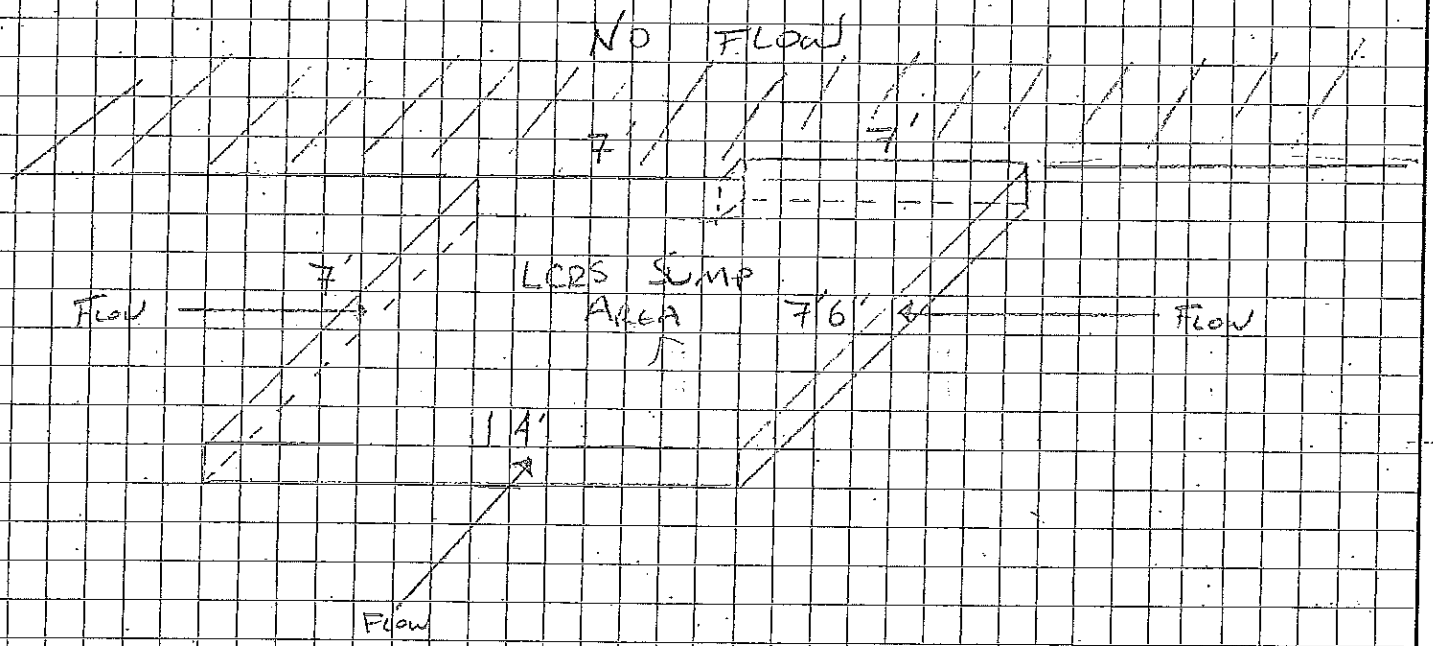
Project Name: BEATTY SUMP GRAVEL

Prepared by: SLW Date: 9/18/07

Checked by: CAB Date: 9/18/07

Title:

TYPICAL SUMP GRAVEL AT LCRS COLLECTION POINT



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# FOUNDATION ANALYSIS AND DESIGN

Second Edition

Joseph E. Bowles

*Professor of Civil Engineering*
*Bradley University*

McGRAW-HILL BOOK COMPANY
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Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

Table 2-6. Order of magnitude values for permeability $k$, based on description of soil and by Unified Classification, cm/sec

| $10^2$ | $10^0$ | $10^{-3}$ | $10^{-7}$ | $10^{-9}$ |
|---|---|---|---|---|
| Clean gravel GW, GP | Clean gravel and sand mixtures GW, GP SW, SP GM | Sand-silt mixtures SM, SL, SC | Clays | |

## Permeability

Flow of soil water, for nonturbulent conditions, has been expressed by Darcy as

$$v = ki \tag{2-37}$$

where $i$ = hydraulic gradient $h/L$, as previously defined
$k$ = coefficient of permeability as proposed by Darcy, length/time. Table 2-6 lists typical order-of-magnitude values for various soils.

The quantity of flow $q$ is

$$q = kiA \qquad \text{volume/time}$$

Two tests commonly used in the laboratory to determine $k$ are the *constant-head* and *falling-head* methods. See Fig. 2-15 for a schematic diagram of each and the significance of the terms used.

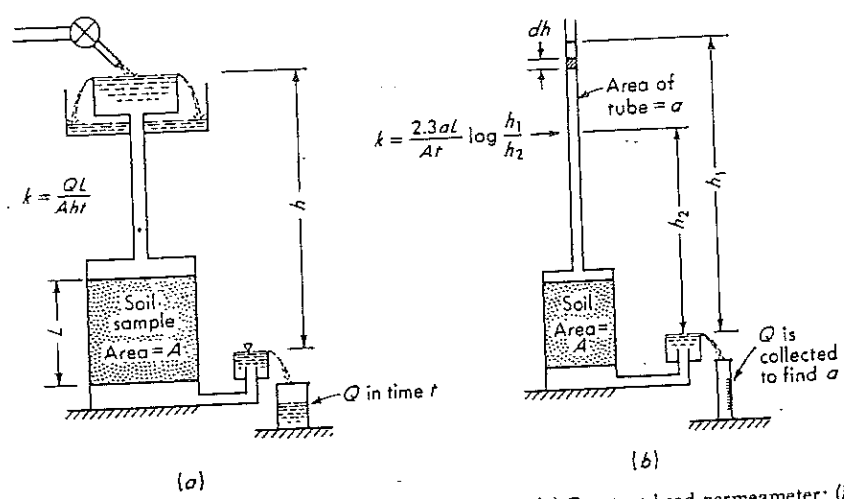
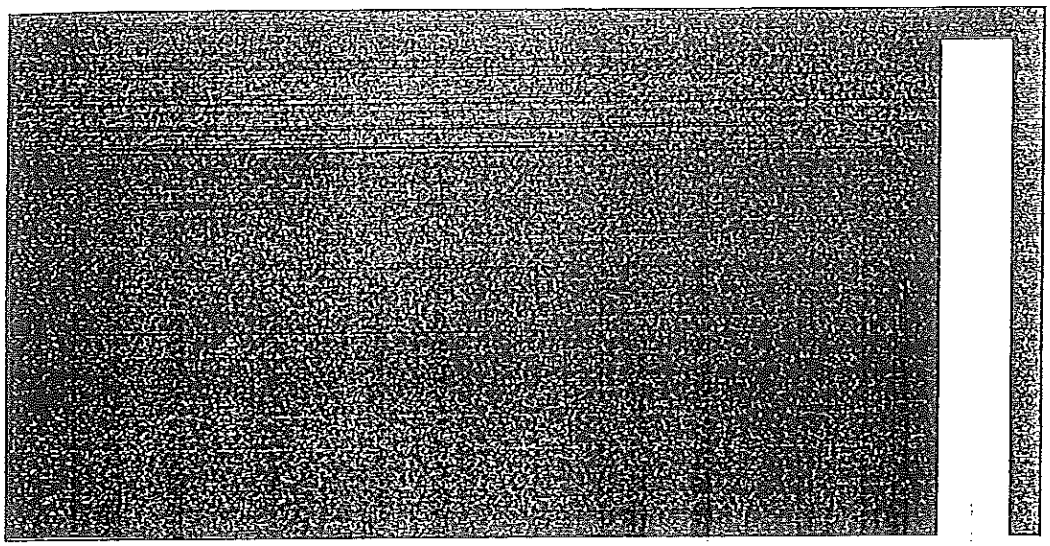



Figure 2-15. Schematic for permeability determination. (a) Constant-head permeameter; (b) falling-head permeameter.




R. Allan Freeze

Department of Geological Sciences
University of British Columbia
Vancouver, British Columbia

John A. Cherry

Department of Earth Sciences
University of Waterloo
Waterloo, Ontario


# GROUNDWATER


PRENTICE HALL, Englewood Cliffs, NJ 07632

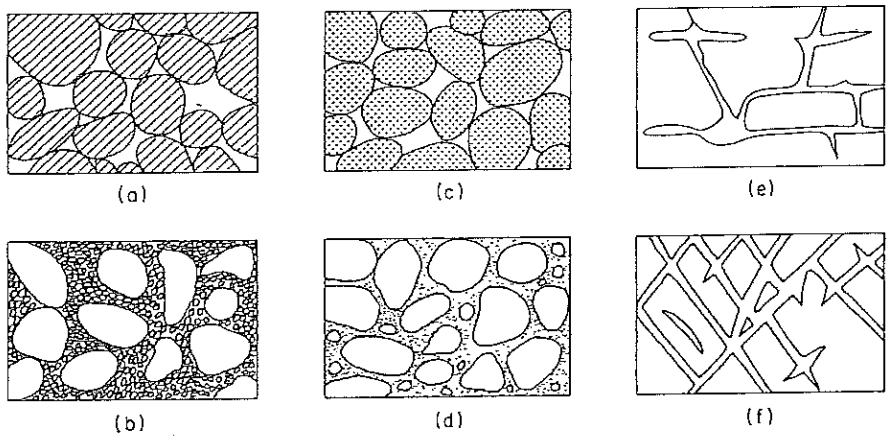



**Figure 2.11** Relation between texture and porosity. (a) Well-sorted sedimentary deposit having high porosity; (b) poorly sorted sedimentary deposit having low porosity; (c) well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; (d) well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; (e) rock rendered porous by solution; (f) rock rendered porous by fracturing (after Meinzer, 1923).

soil or rock matrix [Figure 2.11(a), (b), (c), and (d)], and *secondary porosity*, which may be due to such phenomena as secondary solution [Figure 2.11(e)] or structurally controlled regional fracturing [Figure 2.11(f)].

Table 2.4, based in part on data summarized by Davis (1969), lists representative porosity ranges for various geologic materials. In general, rocks have lower porosities than soils; gravels, sands, and silts, which are made up of angular and

**Table 2.4 Range of Values of Porosity**

| | $n$(%) |
|---|---|
| Unconsolidated deposits | |
| Gravel | 25–40 USE 30% |
| Sand | 25–50 |
| Silt | 35–50 |
| Clay | 40–70 |
| Rocks | |
| Fractured basalt | 5–50 |
| Karst limestone | 5–50 |
| Sandstone | 5–30 |
| Limestone, dolomite | 0–20 |
| Shale | 0–10 |
| Fractured crystalline rock | 0–10 |
| Dense crystalline rock | 0–5 |

# REFERENCE

# LCRS FLOW CALCULATION RESULTS

**Results**

The ~~effective flow of the LCRS~~ geocomposite is 0.00921 gal/ft-min. Since infiltration could be as high as 8.6 gallons per minute, a sump with a perimeter of 930 feet would be needed to prevent backups from occurring. Since the sump has a perimeter of only 70 feet, backups could occur; therefore, 3" piping spaced at 100 feet will be used in the LCRS design. Maximum leachate head on the liner could be as much as 0.013 feet in cell 12C; however, this is less than the 1.0 foot maximum required in the permit therefore 100 feet lateral drainage piping and the selected geocomposite are acceptable.

Since flow through the LCRS system could be as high as 8.6 gallons per minute and assuming a safety factor or 4, an EPG Vertical Sump Drainer Model 12-5 at 3.0 HP was selected as the pump for the LCRS.

# Reference

Soil Test Permeability

**Knight Piésold** CONSULTING

# Constant Head Permeability

*USBR 5605, Amended*

| | | | |
|---|---|---|---|
| Project | U.S. Ecology-NV Misc.Testing Proj.#07-3113 | Project No. | 07.1243 |
| Lab No. | | Date of Test | 08/20/07 |
| Sample No. | 07-0605E | Tested By | spb |
| Location | Native, USEN-B1 | Checked By | SPB |

## Specimen Data

| | | | |
|---|---|---|---|
| Target Dry Density, pcf | NA | Wet Sample Wt. + Tare, lbs. | 38.158 |
| Target Density, t/m$^3$ | NA | Tare, lbs. | 15.920 |
| Moisture Content, % | NA | Wet Sample Wt., lbs. | 22.238 |
| Mold Diameter, in. | 8.02 | Sample Length, in. | 8.701 |
| Mold Area, in.$^2$ | 50.52 | Sample Volume, in.$^3$ | 439.5 |
| Mold Area, ft$^2$ | 0.3508 | Sample Volume, ft$^3$ | 0.2544 |
| Depth to Mold Bottom, in. | 8.701 | Wet Density, pcf | 87.4 |
| | | Initial Depth to Plate, in. | 0.000 |
| Normal Stress Range, psf | 144 | | |

## Permeability Trial Data

| | | | | | |
|---|---|---|---|---|---|
| Normal Stress, psf | 144 | | | Head, cm | 1.2 |
| Avg. Depth to Plate, in. | 0.070 | Consolidated Length, in. | 8.631 | Wet Density, pcf | 88.1 |

| Trial No. | Q cc | Time sec | Flow cc/sec | Permeability k, cm/sec |
|---|---|---|---|---|
| 1 | 453 | 11.87 | 38.2 | 2.1E+00 |
| 2 | 453 | 12.13 | 37.3 | 2.1E+00 |
| 3 | 453 | 12.18 | 37.2 | 2.1E+00 |
| 4 | 453 | 11.88 | 38.1 | 2.1E+00 |
| 5 | 453 | 12.04 | 37.6 | 2.1E+00 |
| 6 | 453 | 12.08 | 37.5 | 2.1E+00 |
| 7 | 453 | 12.00 | 37.8 | 2.1E+00 |
| Averages | | | 37.672 | 2.1E+00 |

General Notes:

1) Tap water was used as permeant.
2) Flow conditions may vary depending on the particle distribution in the field.
3) The sample was allowed to saturate overnight prior to initializing flow trials.
4) The sample was prepared by placing the material in the mold loosely and then lightly tapping the sides of the mold.

# ATTACHMENT 4

# CONSTRUCTION QUALITY ASSURANCE PLAN FOR TRENCH 12

# CONSTRUCTION QUALITY ASSURANCE PLAN

# FOR TRENCH 12

## US Ecology Nevada, Inc.

## Hazardous Waste Management Facility

## Beatty, Nevada

**Nevada Hazardous Waste Treatment, Storage and Disposal Permit**

**NEV HW0019, USEPA ID #NVT330010000**

**October 8, 2007**

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## CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

**US Ecology Nevada Representative:** RL Marchand **Date:** 10/10/07

**Printed name:** Robert Marchand

**Title:** General Manager

**Nevada Professional Engineer** STEPHEN L. WAMPLER **Date:** 8 OCT 2007

PROFESSIONAL ENGINEER-STATE OF NEVADA
STEPHEN L. WAMPLER
CIVIL
No. 13641

10/8/07

EXPIRES: 6/30/08

# 1. INTRODUCTION

This Construction Quality Assurance (CQA) Plan is for Disposal Trench 12 at the US Ecology Nevada, Inc. (USEN) Hazardous Waste Management Facility (HWMF) located about 11 miles south of Beatty, Nevada, in Nye County. The CQA Plan has been prepared to comply with the requirements of HW Permit Number NEV HW0019 dated April 29, 2005 (RCRA Permit). The CQA Plan has been developed under the direction of a professional engineer registered in the state of Nevada. The Plan describes the design features and procedures to be employed in the construction of Trench 12.

USEN is proposing to construct a new hazardous waste disposal unit (Trench 12) at the Beatty facility to increase waste disposal capacity. This CQA Plan presents the design concept used to develop the below-grade and above-grade portions of the trench and details of its construction. Details of the Trench 12 final cover will be provided in an appendix to be added to to this CQA Plan.

The final design for disposal Trench 12 completes the design process that began in 1995 and has received conditional approval from the Nevada Division of Environmental Protection (NDEP) in the 2005 RCRA Permit. The 1996 design concept is modified in this 2007 final design based on minor changes in USEN's plan for the relationship between disposal Trench 12 and adjoining disposal Trench 11. Also, the lease agreement between USEN and the State of Nevada for the property occupied by the Beatty facility, that includes the location of new Trench 12, allows USEN to consider technically appropriate ways to more effectively utilize the portion of its leased property between the southern limit of waste disposal in new Trench 12 and the northern limit of the adjoining closed low-level radioactive waste (LLRW) disposal area.

The final design for Trench 12 incorporates much of the 1996 design concept, including many aspects previously approved by NDEP, and some design concept updates that take into consideration USEN experience at Beatty since the mid-1990s, updated concepts for final closure of waste disposal units in arid regions, and the provisions of the renewed property lease agreement.

Appendices to this CQA Plan include:

- Appendix A: Trench 12 design drawings;
- Appendix B, Construction materials specifications; and
- Appendix C, Construction methods and quality control requirements.

This CQA Plan and appended design drawings and specifications specifically address the at-grade and below-grade aspects of Trench 12 construction. That is, the CQA Plan addresses aspects of at-grade construction (surface soil improvement, liner anchor trench, and starter berm for above-grade waste disposal) and aspects of below-grade construction (trench excavation, leachate management systems, and liner systems). Aspects of Trench 12 closure, including final cover elevations, slopes, and cover materials are not addressed in the CQA Plan and Appendices A, B, and C. These Trench 12 aspects, including design justification, design drawings, and construction specifications, will be addressed by USEN in a supplement to this CQA Plan.

This CQA Plan discusses the development of Trench 12 in three phases, Phases 12A, 12B, and 12C. In the following plan and appendices, reference to the trench or disposal unit usually applies to the total below-grade or above-grade portion of Trench 12, and reference to cells usually applies to the individual phases of Trench 12 development. The phased cells could be constructed and begin operations either separately or concurrently depending upon final development scheduling by USEN. This CQA Plan is intended to be equally applicable to separate or concurrent development of Phases 12A, 12B and/or 12C.

# 2. DISPOSAL TRENCH DESIGN CONCEPT

## 2.1 DESIGN CONCEPT

The disposal structure of Trench 12 was designed considering the following design parameters.

1. The disposal structure must provide a disposal volume that is consistent with the high cost of its construction. The configuration presented in this Plan provides a total disposal capacity of over 1.65 million cubic yards.

2. Trench excavation and disposed waste position must be consistent with applicable regulatory requirements, including the lease agreement between USEN and the State of Nevada for the property on which Trench 12 is located. The configuration presented is consistent with these requirements, based upon frequent discussions between USEN and NDEP during design. Aspects of this consistency with requirements include the following.

   - The disposal structure, including the final cover, is designed (and will be constructed) to be entirely located within the legal metes and bounds of the leased facility property.

   - The structure will be designed with access to other facility components, including entrance facilities, such as offices, truck scale and laboratory; and operational facilities including shops, waste stabilization facilities, wash points, etc.

   - The structure will be capable of being constructed using conventional earthwork equipment.

   - The final (covered) trench configuration will have stable, maintenance-free outer slopes, considering normal static loading and seismic-induced loading associated with the prescribed design conditions. On the basis of stability evaluation, it was determined that the permanent outer slopes of the compacted fill berms and final cover can be approximately three horizontal to one vertical (3:1) for the upper slope and approximately two horizontal to one vertical (2:1) on the lowermost portions of the perimeter where the cover is a compacted soil berm. This slope provides the desired stability within the property boundaries and allows for surface water runoff and vehicle travel between the above-grade portion of Trench 12 and the closed LLRW disposal facility to the south.

### 2.1.1 Below-Grade

The design for below-grade waste disposal in Trench 12 presented in this CQA Plan is consistent with these parameters and with USEN's earlier Trench 12 design submittals. Important aspects of the below-grade design concept include the following.

- Trench 12 will be excavated to a depth below original ground surface of approximately 75 feet,
- Trench 12 excavated sidewalls will be approximately 0.5:1.0 (Horizontal:Vertical, H:V) or approximately 63.5 degrees below horizontal,
- Trench 12 will have a composite liner satisfying Federal and State requirements.

### 2.1.2 Above-Grade

To facilitate above-grade disposal, a low compacted soil berm (starter berm) will be constructed around the full perimeter of Trench 12. Above-grade waste disposal will proceed above the starter berm with final above-grade waste (and final cover) slopes of 3:1 (H:V) and a final maximum height (top of final cover) above original ground of approximately 75 feet. The Trench 12 final cover will be a monolithic profile designed specifically for the low precipitation, arid setting of the Beatty facility incorporating a surficial material on steeper slopes intended to resist erosion during the initial years following closure when vegetation coverage (and surface stabilization provided by vegetation) is minimal. Details of final cover design and construction are not included in Appendices A, B, or C, but will be included in a supplement to this CQA Plan.

## 2.2 SUBGRADE DESIGN

### 2.2.1 Trench Excavation

Trench 12 site preparation activities include removal and replacement of a small portion of an upper, low cohesion, soil layer. Improvement of this surface layer will be followed by trench excavation, trench subgrade and slope preparation (including LCRS riser recesses cut into the side walls). Liner placement on the trench floor and side walls (including excavation of a perimeter liner anchor trench) will follow excavation and preparation. The Trench 12 design was developed to facilitate landfill construction in three phases, with the westernmost portion of

the trench as the initial phase, and the middle and easternmost portions as the second and third phases (respectively).

The eastern portion of the Trench 12 footprint includes a portion of the existing site entrance, office, water storage tank and other facilities (see Appendix A, Drawing 002). Site development to utilize Trench 12 ultimately will include construction of a new site entrance and relocation of some existing facilities to another area.

### 2.2.2 Liner System Description

The below-grade portions of Trench 12 employ a liner system consistent with the liner system specified by the RCRA Hazardous and Solid Waste Amendments (HSWA) of 1984 as minimum technological requirements (MTR) to prevent the migration of hazardous wastes from land disposal units to groundwater and the surrounding environment. The liner system is identical, with changes (as necessary) to utilize materials that are currently manufactured and available, to the liner system that originally was designed and approved in 1996 and the current RCRA Permit as satisfying applicable Federal and State requirements.

The basic liner system is comprised of the following elements (in order from the deepest to the shallowest):

- Compacted native soil subgrade (nine inches of material meeting a $1.0 \times 10^{-5}$ cm/sec permeability specification),
- Geosynthetic-clay liner (GCL),
- 60 mil (0.060 inches thick) HDPE flexible membrane liner,
- double-sided geocomposite, consisting of a geonet heat-bonded between two geotextiles,
- 80 mil HDPE flexible membrane liner,
- double-sided geocomposite (on the bottom of the trench) or geonet with overlying non-woven geotextile (on the trench side walls), and
- 30-mil HDPE flexible membrane liner on trench side-walls. Note: this material provides UV protection to the underlying geotextile and prevents precipitation from entering the sidewall geonet, but serves no hydraulic purpose relative to compliance with RCRA requirements for liners.

The Trench 12 liner system base (subgrade) will be nine-inches (minimum) of compacted native soil subgrade beneath all trench floor areas except for leachate collection and recovery system (LCRS) sumps, and 36-inches of compacted soil subgrade beneath the sump areas.

The synthetic polyethylene liners used in the Trench 12 liner are manufactured specifically for liquid containment purposes. The quality of the geomembrane (also called flexible membrane liner or FML) material will be monitored by quality assurance/quality control (QA/QC) personnel so that the materials satisfy the required specifications (as presented in this CQA Plan). Manufacturer data on synthetic material resistance and strength, as well as USEN laboratory data for typical Beatty facility leachate, indicate that polyethylene liner materials are resistant to the wide range of chemicals likely to be disposed at the facility.

### 2.2.3 Leachate Collection and Recovery System

The Trench 12 double liner system incorporates a leachate collection and removal (LCRS) system and Leak Detection System (LDS). The LCRS is located above the primary liner, and is designed to collect and allow removal of liquids from within the disposal trench. The LDS system is located between the primary and secondary liner members, and its main function is to detect and remove any leakage through the primary liner.

The LCRS is associated with the primary liner system. The function of the LCRS is to intercept liquids infiltrating through the waste and to allow such liquid to flow toward and into the sumps for removal. The typical sump configuration is shown in the details on Drawing 007 in Appendix A. Liquid is removed from the sumps using pumps and riser piping as shown in Sections A, B, and C in Drawing 007. The components of the LCRS sump are sized to accommodate the maximum anticipated leachate flows while maintaining a fluid head above the primary liner that will not exceed one foot except during extreme (unusual) precipitation events when the one-foot head criterion might be exceeded briefly while being addressed by continuous, high-volume pumping. The basic design calculations for the LCRS sump and risers were presented in previous Trench 12 designs. Flow and pump sizing calculations are provided in the October 2007 Supplement to the Landfill Report (Landfill Report Supplement) and have been revised from the previous Trench 12 design (1996 Design) to acknowledge the slightly larger footprint and floor area.

## 2.3 ABOVE-GRADE DESIGN

A low compacted fill berm will serve as the perimeter and base of the above-grade waste disposal area. The final outer slopes of this starter or buttress berm will be 2:1. The starter berm will be constructed of native soil materials and placed with a minimum compaction requirement of 90 percent maximum dry density (MDD) and at a moisture content between the optimum moisture content (OMC) and OMC +2%, as determined by ASTM Method 1557. The starter berm will be constructed on the Trench 12 perimeter area after the native low cohesion surface soil has been recompacted to provide an acceptable foundation for the perimeter berm.

## 2.4 EXCAVATION SLOPE STABILITY EVALUATION

Excavation slope stability is of primary concern during waste disposal operations when the excavated slopes are not buttressed by disposed waste. After waste placement against the excavation sidewalls, the weight of disposed waste against the slopes will be sufficient to render the slopes stable under essentially any static or dynamic loading condition. USEN experience at this facility, including experience gained through extensive subsurface investigation, geotechnical engineering evaluations, and actual performance of excavated slopes, has clearly demonstrated that the excavation depths and slopes planned for Trench 12 will provide the required stability during construction and disposal operations. Extensive slope stability evaluations were included in the 1996 Design and supporting design documentation that are incorporated into the RCRA Permit. This design documentation included demonstration that excavation sidewalls were appropriately stable under static and pseudo-static (seismic) loading conditions. Since the present excavation slopes are the same as those considered in the 1996 design and design documentation, that demonstration of excavation slope stability also applies to the current design.

Important aspects of the 1996 slope stability evaluations are summarized below.

- The 75-feet deep, 0.5:1.0 (H:V) excavation slopes were determined to be acceptably stable under static loading and pseudo-static loading (simulating ground motion from seismic activity). That measure of stability is slopes with a safety factor (against failure) of at least 1.5 during static loading and at least 1.0 during pseudo-static loading.

- Of the possible deep-seated failure planes evaluated, the planes exhibiting the lowest safety factor (but still higher than minimum requirements) extended from near the base of the excavation slope to about 50 feet outside the excavation crest.

- Considering the modified excavation crest location (i.e., HCL location) on the south side of Trench 12 in the 2007 Design, this possible failure plane extends just a few feet (horizontally) into the area of the closed LLRW trenches.

- The period of time during which a deep-seated slope failure of this type is conceivable is very brief, likely only a few months in duration, since waste disposal in Trench 12 will begin to buttress the excavation slope, and increase safety factors, as soon as the first waste is placed against the base of the south trench side slope.

## 2.5 RUN-ON/RUN-OFF CONTROL

### 2.5.1 During Operations

The facility is located in a rise in the desert formed by an alluvial fan. This rise extends up-valley from the facility approximately 4.1 miles, forming an upstream drainage basin area of about 1.7 square miles. Drainage from the remainder of the desert and surrounding mountains is provided by the normally dry Amargosa River channel and natural drainage swales in the desert, and would not impact the facility during a 100-year storm event.

Run-on control is provided by a trapezoidal ditch north of the facility that diverts the major portion of the drainage area to natural swales west of the facility. Smaller triangular ditches along the northern and eastern boundaries of the facility divert the remainder of the drainage area around the facility. The 1996 Design references documentation that the run-on control ditches were designed to handle precipitation resulting from a 25-year, 24-hour storm. This referenced documentation also applies to the current design.

The 1996 and 2007 designs include measures to manage stormwater run-on and run-off during disposal operations and after final closure. During disposal operations, these measures will include temporary berms and drainage channels. These berms and channels prevent run-on from areas outside the Trench 12 foot print and direct runoff from the perimeter of an active Trench 12 to natural or enhanced drainage channels outside of the facility boundaries. The trench design (1996 and 2007) does not include features that are intended to cause stormwater retention (ponding) inside or outside the facility boundaries.

Stormwater falling inside the trench during disposal operations will be managed appropriately inside the trench as leachate or will be managed outside the trench as a waste. There are no situations where leachate would be allowed to enter surface water outside the trench.

### 2.5.2 Post-Closure

With regard to surface-water management, the 1996 and 2007 designs include final covers that essentially are identical. The final covers will prevent run-on from areas outside the final cover footprint from affecting the final cover or covered waste. Both final cover designs incorporate measures intended to manage stormwater run-off from the cover and control cover material erosion. Stormwater runoff conveyances constructed on both covers lead to stormwater channels along the base of the cover that lead to natural or enhanced drainage channels outside of the facility boundaries.

The 2007 Design includes a corridor about 15-feet wide between the toe of the final Trench 12 cover and the toe of the LLRW site cover that will provide for permanent routing of surface-water runoff originating on the adjoining portions of Trench 12 and the closed LLRW disposal site.

## 2.6 SURFACE FACILITIES MODIFICATIONS

Some of the surface facilities at the Beatty facility will be relocated as part of Trench 12 construction.

### 2.6.1 Support Facilities Relocation

Facility entrance and support facilities will be relocated. When the entrance and support facilities are relocated, and before excavation for Trench 12 Phase 12C, all surface and subsurface features (e.g., structures, concrete slabs, foundations, wiring, piping, etc.) inside the trench footprint, including the area between Trenches 12 and 11, will be removed.

### 2.6.2 Temporary Fence Relocation

Trench 12 construction, including surface soil improvement, anchor trench excavation, and liner construction, will require earthmoving equipment traffic to pass close to the north, west, and south boundaries of the Trench 12 area. In each of these areas, it probably will be necessary that

construction equipment temporarily cross the area boundaries that are marked by fencing. Beginning with Phase 12A excavation and continuing through Phase 12C excavation, USEN expects the necessity to temporarily relocate the boundary fences and fence signage in these areas. Temporary boundary fence relocation will be done in a manner that does not reduce facility security or permanently impact the adjoining buffer zone (north and west boundaries) or LLRW disposal area cover. The boundary fence, along with appropriate signage, will be relocated to the correct HWMF boundary following completion of Trench 12 excavation and liner construction.

Similar fence relocation might be necessary during final cover construction. If so, the boundary fence, along with appropriate signage, will be relocated to the correct HWMF boundary following completion of the final cover.

# 3. RESPONSIBILITY AND AUTHORITY

The following paragraphs generally outline the areas of responsibility and lines of authority for each organization involved in Trench 12 construction. This section is intended to establish the necessary lines of communication and the decision-making process for the execution of construction within the guidelines of this CQA Plan.

## 3.1 PERMITTING AGENCY

The Nevada Department of Conservation and Natural Resources, Division of Environmental Protection (NDEP) is authorized by law to issue a permit for the construction of a hazardous waste management facility. The Permitting Agency (or State) has the responsibility and authority to review and accept or reject any design revisions or requests for variance that are submitted by USEN after the permit is issued. The agency also has the responsibility and authority to review all CQA documentation during or after facility construction to confirm that the facility was constructed in accordance with the facility operating permit.

## 3.2 OPERATOR

USEN is responsible for the operation of the HWMF. The Operator has the authority to select and dismiss organizations charged with construction and quality assurance activities. The Operator also has the authority to accept or reject reports and recommendations of the CQA Officer and the materials and workmanship of the contractor. The Operator will also provide a Project Manager who will be responsible for coordinating and scheduling construction activities. The construction supervisor will keep the Project Manager and Project Engineer informed of the construction progress.

## 3.3 PROJECT MANAGER

The Project Manager is responsible for the design and construction of the Trench 12 disposal area at the Beatty facility. This responsibility includes assuring the Permitting Agency, by arranging for submission of CQA documentation, that the disposal area is constructed as specified in an approved design. The Operator and Project Manager have the authority to select

and dismiss organizations charged with CQA and construction activities. The Project Manager also has the authority to accept or reject design plans and specifications, CQA Plans, reports and recommendations of the CQA Officer, and the materials and workmanship of any contractors.

## 3.4 PROJECT ENGINEER

USEN may retain the services of one or more Project Engineer for the design and construction of Trench 12. Each Project Engineer will be a registered professional engineer in the State of Nevada. The Project Engineer is responsible for designing a hazardous waste land disposal facility that fulfills the operational requirements of the facility and the performance requirements of the Permitting Agency. Design activities might not end until the facility is completed. The Project Engineer might be requested to change some component designs if unexpected site conditions are encountered or changes in construction methodology occur that could adversely affect facility performance.

Additional responsibility and authority can be delegated to the Project Engineer by the expressed consent of the Project Manager. Additional responsibility and authority may include formulating and implementing a site-specific CQA Plan, periodic review of CQA documentation, modifying construction site activity, and specifying specific corrective measures in cases where deviation from the specified design or failure to meet design criteria, plans, and specifications is detected by CQA personnel.

## 3.5 CONSTRUCTION QUALITY ASSURANCE CONTRACTOR

The CQA Officer is the firm or individual responsible for observation, testing, and documentation of the activities related to construction quality assurance during the installation of the various materials, soil, and geosynthetics associated with the project. The CQA Officer is also responsible for issuing a final report to the Operator summarizing the observations and testing performed during the construction process, and certifying that the facility was constructed in accordance with the project specifications.

### 3.5.1 CQA Personnel

The overall responsibility of the CQA personnel is to perform those activities specified in the CQA Plan (e.g., inspection, sampling, and documentation). At a minimum, CQA personnel will include a CQA Officer and the necessary supporting CQA personnel. The CQA Officer will report to the Project Manager. The specific responsibilities and authority of each of these individuals are defined in the CQA Plan and in the associated contractual agreements with USEN. Specific responsibilities of the CQA Officer include:

- Reviewing design criteria, plans, and specifications for clarity and completeness so that the CQA Plan can be implemented, and documenting their review;
- Educating CQA personnel on CQA requirements and procedures;
- Scheduling and coordinating CQA inspection activities, including surveying and quality control checks;
- Reviewing survey data to assure that construction is proceeding in accordance with the design plans;
- Directing and supporting CQA personnel in performing observations and tests by:
    - Confirming that the equipment is uniquely identified and the calibration of measuring and testing equipment is conducted, recorded properly, and the calibration status is indicated;
    - Confirming that the testing equipment, personnel, and procedures do not change over time or making sure that any changes do not adversely impact the inspection process;
    - Confirming that the test data are accurately recorded and maintained (this may involve selecting reported results and backtracking them to the original observation and test data sheets);
    - Verifying that the raw data are properly recorded, validated, reduced, summarized, and interpreted.
- Providing to Project Manager and Project Engineer daily reports on the inspection results including:
    - Identification of work that the CQA Officer believes should be accepted, rejected, or uncovered for observation, or that may require special testing, inspection, or approval;

- Rejection of defective work and written verification that corrective measures are implemented;
- Verifying that a contractor's performance is in accordance with the project specifications;
- Reporting to the Project Managers immediately, any work that is not in compliance with the plans and specifications if corrective measures are not being taken; and
- Reporting to the contractor results of all observations and tests as the work progresses and verifying that they are in conformance with the specified acceptance criteria;

- For the supporting CQA personnel, specific responsibilities may include:
  - Performing independent on-site inspection of the work-in-progress to assess compliance with the facility design criteria, plans, and specifications;
  - Verifying that the equipment used in testing meets the test requirements and that the tests are conducted according to the standardized procedures defined by the CQA Plan; and
  - Reporting to the CQA Officer results of all inspections including work that is not of acceptable quality or that fails to meet the specified designs.

### 3.5.2 Quality Assurance Laboratory

The Quality Assurance Laboratory (or laboratories) is a party, independent from the Operator, Manufacturer, fabricator, transporter and Installer, responsible for conducting tests on samples of the various geosynthetic materials and/or soil obtained from the site. The Quality Assurance Laboratory may be from the same firm as the CQA Officer.

## 3.6 CHIEF SURVEYOR

The Chief Surveyor will be responsible for project layout, survey control, cross-sections and as-built drawings. The Chief Surveyor will provide certification that the facility was constructed to the lines and grades indicated on the as-built drawings. The CQA Officer in concurrence with the Project Manager will ensure that the required surveying is performed for verification of compliance with the plans and specifications.

## 3.7 EARTHWORK CONTRACTOR

The Earthwork Contractor is the firm responsible for disposal area construction, placement of excavated soil as directed, and placement and compaction of soil fill. The Earthwork Contractor will store equipment and materials in a manner that does not interfere with access to the facility or permanently impact areas not included in the USEN leased property.

## 3.8 GEOSYNTHETIC MATERIAL MANUFACTURERS

### 3.8.1 Geomembrane Manufacturer

The Manufacturer is responsible for the production of geomembrane. If required by contract, the Manufacturer also may be responsible for the fabrication and/or the transportation of the geomembrane rolls between the manufacturing facility and the fabricator and/or the site.

### 3.8.2 Geotextile Manufacturer

The Manufacturer is responsible for the production of geotextile rolls. If required by contract, the Manufacturer also may be responsible for the transportation of the geotextile rolls between the manufacturing facility and the site.

### 3.8.3 Geocomposite/Geonet Manufacturer

The Manufacturer is responsible for the production of geocomposite and geonet. If required by contract, the Manufacturer also may be responsible for the fabrication and/or the transportation of the geocomposite/geonet rolls between the manufacturing facility and the fabricator and/or the site.

### 3.8.4 Geosynthetic Clay Liner (GCL) Manufacturer

The Manufacturer is responsible for the production of the GCL from granulated bentonite and geotextile rolls. If required by contract, the Manufacturer also may be responsible for the transportation of the GCL between the manufacturing facility and the site.

Throughout the remainder of this document the word "Manufacturer" will be used generically in reference to the respective geomembrane, geotextile, or GCL Manufacturer.

## 3.9 GEOMEMBRANE FABRICATOR

The Fabricator is responsible for the fabrication of geomembrane panels from geomembrane rolls. If required by contract, the Fabricator also may be responsible for transportation of the geomembrane panels to the site. The Fabricator and Manufacturer could be the same entity.

## 3.10 GEOSYNTHETIC MATERIALS INSTALLER

The geosynthetic materials Installer is responsible for the handling, storing, placing, seaming, temporary loading and other aspects of the geosynthetic material installation as required herein. The geosynthetic materials Installer is also responsible for submitting all quality control certificates to the Operator including, but not limited to, those from the geomembrane, geotextile, geocomposite, and GCL Manufacturer. The Installer will store equipment and materials in a manner that does not interfere with access to the facility or permanently impact the buffer zone.

# 4. CQA PERSONNEL QUALIFICATIONS

## 4.1 CQA OFFICER

The CQA Officer is the individual assigned singular responsibility for all aspects of the CQA Plan implementation. On a day-to-day basis, the CQA Officer reports to the Project Manager. The CQA Officer will possess adequate formal academic training in engineering, engineering geology, or closely associated disciplines and will possess sufficient practical, technical, and managerial experience to oversee successfully and implement construction quality assurance activities for hazardous waste management facilities. The CQA Officer will be expected to ensure that communication of all CQA-related matters is conveyed to and acted upon by the affected organizations. The CQA Officer will be a professional engineer registered in the State of Nevada.

## 4.2 CQA INSPECTION PERSONNEL

The CQA personnel will report to the CQA Officer. The CQA personnel will possess adequate formal training and sufficient practical, technical, and administrative experience to execute and record inspection activities successfully. This will include demonstrated knowledge of specific field practices relating to construction techniques used for hazardous waste management facilities, observation and testing procedures, equipment, documentation procedures and site safety.

## 4.3 CHIEF SURVEYOR

The Chief Surveyor will be land surveyor registered in the State of Nevada.

# 5. MEETINGS

## 5.1 PRE-BID MEETING

A pre-bid meeting will be held at the project site to allow all geosynthetic materials, earthwork, and other services/materials bidders the opportunity to preview the facility and the working conditions. The meeting will consist of a tour of the facility and the work area, followed by an overview of the work to be performed, the project schedule, and the project drawings and specifications.

## 5.2 PRE-CONSTRUCTION MEETING

A pre-construction meeting will be held on site prior to the start of the geosynthetic installation work. At a minimum, the Operator, the Project Engineer, the Installer, the Earthwork Contractor, and the CQA Officer will be in attendance.

The following topics will be addressed during this meeting.

- Construction methods and projected scheduling.
- Provide each party with all relevant documents and supporting information.
- Review the project plans and specifications, including addenda to this document, with each party.
- Familiarize each organization with this plan and its role relative to the design criteria, plans, and specifications.
- Determine any changes to this plan that are needed to ensure that the facility will be constructed to meet or exceed the specified design.
- Review methods for documenting and reporting inspection data.
- Review the responsibilities of each party.
- Review the lines of authority and communication with each party.
- Review work area security and safety protocol.

- Review the procedures for observation, testing, and documentation required of each party. This review will include a discussion of sampling and testing strategies.
- Review the methods for handling construction deficiencies, repairs, and re-testing.
- Review the methods for establishing pay quantities.
- Review the methods for distributing and storing material samples, documents and reports.
- Review the methods for the prevention of damage to the construction materials from inclement weather or other adverse events.
- Conduct a tour of the facility and the work area to review construction conditions and material and equipment storage locations.

The pre-construction meeting will be documented by the CQA Officer or other party designated at the beginning of the meeting. The minutes of the pre-construction meeting will become part of the official record of construction and will be transmitted to all appropriate parties.

## 5.3 WEEKLY PROGRESS MEETINGS

Progress meetings will be held at the work area on a regular basis unless otherwise specified by the Project Manager, at a minimum of once per week, with representatives of the Operator, Earthwork Contractor (during earth work construction), and CQA Officer and the Installer (during geosynthetic materials installation work only) in attendance. The purpose of the meetings will be to address the following:

- Review the progress of the work and the overall project schedule.
- Review the work activities and locations since the last meeting and subsequent to the next meeting.
- Discuss unresolved construction deficiencies,
- Discuss potential problem areas.
- Review recent observations and test data.

The progress meetings will be documented by the CQA Officer or the Project Manager. The meeting minutes will become part of the official construction record and will be transmitted to the Project Manager, Project Engineer and to all appropriate parties.

## 5.4 CONSTRUCTION PROBLEM OR WORK DEFICIENCY MEETING

A special meeting will be held when and if a problem or deficiency is present or is likely to occur. As a minimum, the problem or work deficiency meeting will be attended by the impacted parties, as appropriate, and the CQA Officer. If the problem requires a design clarification or modification, the Project Engineer will be consulted.

The problem or work deficiency meeting will address the following:

- Define and discuss the problem or deficiency or the potential for one to occur;
- Review the potential solutions and the pros and cons associated with each;
- Determine a course of action and notify the appropriate parties of such; and
- Implement a corrective action plan to resolve the problem or deficiency or prevent one from occurring.

The problem or work deficiency meeting will be documented by the CQA Officer. The meeting minutes will become part of the official construction record and will be transmitted to all appropriate parties. Documentation of the problem or deficiency is described in detail in Section 6.5.

# 6. DOCUMENTATION

## 6.1 PRE-CONSTRUCTION SUBMITTALS

After award and at least one week prior to commencement of the work, the appropriate party will submit the following information to the Project Manager.

### 6.1.1 Geomembrane Manufacturer

A detailed description of quality control procedures for the manufacturing and testing of the geomembrane including, but not limited to, the following:

- Geomembrane sampling and testing frequencies and procedures;
- Explanation of the geomembrane roll numbers, lot numbers, and/or batch numbers;
- A copy of each of the quality control certificates issued for the specific material to be utilized on this project;
- A copy of each of the geomembrane Manufacturers' quality assurance testing methods and results of tests conducted on the material manufactured for this project;
- A copy of the geomembrane Manufacturer's roll quality control certificates. These will be supplied at a minimum frequency of one per every 50,000 square feet of geomembrane material produced and supplied to this project and will indicate conformance with each of the properties listed in Appendix B. These certificates will be issued only for the actual geomembrane rolls sampled and tested by the geomembrane Manufacturer or his representative; and
- A list of actual property values for comparison to specifications for the geomembrane material being procured for this project.

The Operator reserves the right to visit the geomembrane manufacturing facility at any time, particularly during production of materials specifically produced for this project. The Operator reserves the right to refuse use of any geomembrane supplied without the proper quality control documentation.

### 6.1.2 Geomembrane Fabricator

A detailed description of quality control procedures for the fabrication and testing of the geomembrane panels including, but not limited to, the following.

- Fabricated geomembrane roll seam sampling and testing frequencies and procedures;
- Explanation of the geomembrane roll numbers and panel numbers; and
- A copy of the geomembrane fabricator's roll quality control certificates. These will be supplied at a minimum frequency of one per every 50,000 square feet of geomembrane material fabricated and supplied to this project and will indicate conformance with each of the properties listed in Appendix B. These certificates will be issued only for the actual geomembrane rolls sampled and tested by the geomembrane fabricator or his representative.

The Operator reserves the right to visit the fabricating facility at any time, particularly during fabrication of materials produced for this project. The Operator reserves the right to refuse use of any fabricated product without the proper quality control documentation.

### 6.1.3 Geotextile Manufacturer

The following is a detailed description of quality control procedures for the manufacturing and testing of the geotextile including.

- Geotextile sampling and testing frequencies and procedures;
- Explanation of the geotextile roll numbers, lot numbers, and/or batch numbers;
- A copy of each of the quality control certificates issued by the resin supplier for the specific material to be utilized on this project;
- A copy of each of the geotextile Manufacturer's quality assurance testing methods and results for the resin utilized in manufacturing the material for this project;
- A copy of the geotextile Manufacturer's roll quality control certificates. These will be supplied at a minimum frequency of one per every 50,000 square feet of geotextile material produced and supplied to this project and will indicate conformance with each of the properties listed in Appendix B. These certificates will be issued only for the actual geotextile, rolls sampled and tested by the geotextile Manufacturer or his representative; and

- A detailed list of minimum property values for the geotextile material being produced for this project.

The Operator reserves the right to visit the fabricating facility at any time, particularly during fabrication of materials produced for this project. The Operator reserves the right to refuse use of any fabricated product without the proper quality control documentation.

### 6.1.4 Geocomposite/Geonet Manufacturer

The manufacturer shall provide a detailed description of quality control procedures for the manufacturing and testing of the geocomposite including, but not limited to, the following.

- Geocomposite/geonet sampling and testing frequencies and procedures;
- Explanation of the geocomposite/geonet roll numbers, lot numbers, and/or batch numbers;
- A copy of each of the quality control certificates issued for the specific material to be utilized on this project;
- A copy of each of the geocomposite/geonet Manufacturers' quality assurance testing methods and results of tests conducted on the material manufactured for this project;
- A copy of the geocomposite/geonet Manufacturer's roll quality control certificates. These will be supplied at a minimum frequency of one per every 50,000 square feet of geocomposite/geonet material produced and supplied to this project and will indicate conformance with each of the properties listed in Appendix B. These certificates will be issued only for the actual geocomposite/geonet rolls sampled and tested by the geocomposite/geonet Manufacturer or his representative; and
- A detailed list of minimum property values for the geocomposite/geonet material being produced for this project.

The Operator reserves the right to visit the geocomposite/geonet manufacturing facility at any time, particularly during production of materials specifically produced for this project. The Operator reserves the right to refuse use of any geocomposite/geonet supplied without the proper quality control documentation.

### 6.1.5 Geosynthetic Clay-Liner Manufacturer

The manufacturer shall provide a detailed description of quality control procedures for the manufacturing and testing of the geosynthetic clay liner (GCL) including, but not limited to, the following.

- GCL sampling and testing frequencies and procedures;
- Explanation of the GCL roll numbers, lot numbers, and/or batch numbers;
- A copy of each of the quality control certificates issued by the supplier for the specific material (bentonite and geotextile) to be utilized on this project;
- A copy of each of the GCL Manufacturer's quality assurance testing methods and results for the materials utilized in manufacturing the liner for this project;
- A copy of the GCL Manufacturer's roll quality control certificate signed by a responsible party of the GCL Manufacturer and indicating conformance with the material properties specifications provided in Appendix B. These certificates will be issued only for the actual GCL rolls sampled and tested by the GCL Manufacturer or his representative. Each quality control certificate will include roll identification numbers and results of quality control tests; and
- A detailed list of minimum property values for the GCL material being produced for this project.

The Operator reserves the right to visit the fabricating facility at any time, particularly during fabrication of materials produced for this project. The Operator reserves the right to refuse use of any fabricated product without the proper quality control documentation.

### 6.1.6 Installer

The Installer will provide the following information.

- A quality control manual for the installation, seaming, repairing and testing of geomembrane;
- A detailed installation schedule for the project including, but not limited to, installation activities and dates and/or durations of the various activities;
- Chemical and ultra-violet resistance properties of the polymeric thread to be used in sewing geotextiles;

- Quality control certification for the extrudate material to be utilized on this project. The certification will include identification of the results of testing for, as a minimum, specific gravity and melt index; and

- A detailed geomembrane panel layout drawing or drawings. The drawing(s) submitted will be of sufficient size and detail to distinguish the geomembrane panels and various features of the cell. The Operator reserves the right to reject any drawings submitted and/or request additional information to be submitted to satisfy the intent of this specification.

The Installer will be responsible for obtaining and submitting the geosynthetic materials information outlined in Section 6.1.

## 6.2 DAILY RECORDKEEPING

A summary report with supporting inspection data sheets will be prepared daily by the CQA Officer. This report provides the chronological framework for identifying and recording all other reports. At a minimum, the summary reports will include the following information:

- Unique identifying sheet number for cross-referencing and document control;

- Date, project name, location, and other identification;

- Data on weather conditions;

- Reports on any meetings held and their results;

- Equipment and personnel being worked in each location, including subcontractors;

- Descriptions of areas being inspected and documented;

- Description of off-site materials received, including any quality verification (vendor certification) documentation;

- Descriptions of materials incorporated into cell construction;

- Calibrations, or re-calibrations, of test equipment, including actions taken as a result of re-calibration;

- Decisions made regarding approval of units of material and/or corrective actions to be taken in instances of substandard quality;

- Unique identifying sheet numbers of inspection data sheets and/or problem reporting and corrective measures reports used to substantiate the decisions described in the preceding item; and

- Signature of the CQA Officer.

## 6.3 INSPECTION DATA SHEETS

All observations, and field and/or laboratory tests, will be recorded on an inspection data sheet. Typical sheets are included as Figures CQA 1 and CQA 2.

At a minimum, the inspection data sheets will include the following information:

- Unique identifying sheet number for cross-referencing and document control;
- Description or title of the inspection activity;
- Location of the inspection activity or location from which the sample increment was obtained;
- Type of inspection activity; procedure used (reference to standard method when appropriate);
- Recorded observation or test data, with all necessary calculations;
- Results of the inspection activity; comparison with specification requirements;
- Personnel involved in the inspection activity; and
- Signature of the appropriate CQA personnel and concurrence by the CQA Officer.

## 6.4 LINER INSTALLATION SUBMITTALS

The Installer will submit the following information to the CQA Officer or Project Manager during the installation process.

- Daily reports detailing the names of personnel and their arrival and departure times, the progress of the work, the arrival of material on site, and any problems encountered.
- Signed subgrade acceptance certificates for each of the areas prior to that area being covered by the geomembrane.
- Quality control documentation for the various installation functions as required by this document.

## 6.5 CONSTRUCTION PROBLEM IDENTIFICATION AND CORRECTIVE MEASURES REPORTS

A problem is defined herein as an actual physical condition that is in some way significantly different or inconsistent with a project design feature, or an instance of material or workmanship that does not meet the specified design. As appropriate, Construction Problem Identification and Corrective Measures Reports will be cross-referenced to specific inspection data sheets where the problem was identified. A typical sheet is included as Figure CQA 3. At a minimum, they will include the following information:

- Unique identifying sheet number for cross-referencing and document control;
- Detailed description of the problem;
- Location of the problem;
- How and when the problem was located (reference to inspection data sheets);
- Estimation of how long problem has existed;
- Suggested corrective measure;
- Documentation of correction (reference to inspection data sheets);
- Final results;
- Suggested methods to prevent similar problems; and
- Signature of the appropriate CQA personnel and concurrence by the CQA Officer.

Upon receiving the CQA Officer's written concurrence, copies of the report will be sent to the Project Engineer for his comments and acceptance.

## 6.6 ACCEPTANCE OF COMPLETED COMPONENTS

All daily inspection summary reports, inspection data sheets, and problem identification and corrective measures reports, will be reviewed by the CQA Officer.

Upon completion of construction, the Project Manager or his designated representative and the CQA Officer will visit the facility for a final inspection of the completed disposal unit for compliance with the design. An inspection report will be prepared by the CQA Officer outlining

the results of the inspection and any corrective measures deemed necessary to correct deficiencies. Documentation of corrective measures will be attached to the inspection report once corrective measures are completed (see Figure CQA 3).

## 6.7 PROJECT COMPLETION SUBMITTALS

Within two weeks following completion of the project the Installer will supply the following:

- Geomembrane installation certification.
- A warranty obtained from the geomembrane Manufacturer and the geomembrane fabricator.
- A warranty for the installation of the geosynthetic materials.

The CQA Officer will submit a final certification report in accordance with Section 6.8 within 30 days of completion of cell construction.

## 6.8 FINAL DOCUMENTATION

Within 30 days following completion of each phase of construction, a final certification report must be submitted by the CQA Officer to the Project Manager. The final certification report will include descriptions of each phase of construction, construction materials, and quality assurance procedures. As a minimum, the following information will be included:

- Daily inspection summary reports;
- Laboratory and field test results summary sheets for all testing required by this plan;
- Problem identification and corrective measures reports;
- Acceptance reports;
- Design clarification forms;
- QA/QC submittals for geosynthetic materials;
- Minutes of pre-construction meetings and weekly meetings;
- Geomembrane repair summaries; and

- As-built drawings.

Inspection data sheets will be retained as backup. This document must include certification of each construction component by the CQA Officer responsible for that phase of construction. This certification must be signed by a professional engineer registered in the State of Nevada. This report will be reviewed by the Operator and submitted to the Permitting Agency.

# 7. CONSTRUCTION SEQUENCE AND CQA PROCEDURES

## 7.1 CONSTRUCTION SEQUENCE

Trench 12 below-grade construction will be performed in three phases. Construction and disposal operations will be closely coordinated to maintain continuous disposal operations and construction schedules. The basic construction sequence for each of the three phases of Trench 12 below-grade construction are expected to be as follows.

1. Relocate fences in the construction area.
2. Excavate surface soil around the perimeter of the construction area. Replace with compacted soil.
3. Excavate to final depth, incorporating LCRS riser trenches (also herein called 'recesses')into the sidewall above the sumps as excavation progresses. Construction access ramps will enter the trench from the east.
4. Construct subgrade with 9 inches (minimum) of compacted soil on bottom and 36 inches (minimum) of compacted soil beneath sump areas.
5. Construct sumps.
6. Excavate liner anchor trench around the trench perimeter
7. Install sidewall liner components
8. Install trench floor and sump liner and LDS/LCRS components.
9. Submit required construction completion documentation and obtain NDEP approval for disposal of waste.

Above-grade waste placement will commence when waste disposal in specific portions (e.g., Phase 12A area) reaches original ground level. The basic sequence for the Trench 12 above-grade waste placement and final cover placement are expected to be as follows.

1. Construct compacted soil starter berms around the Trench 12 perimeter. Final slopes of the starter berms will be approximately 2:1 on outside walls and inside walls.
2. Dispose waste in Trench 12 above-grade area with careful elevation control, placing one to two feet of interim cover soil on the exterior edges of the waste surface.
3. Continue waste and interim cover placement until the elevation of waste crest is within about four feet of final closed disposal trench elevation.

4. Confirm that waste elevations are appropriate for final cover placement, regrade waste as necessary.

5. Place soil cover component layers to complete the final cover.

## 7.2 CONSTRUCTION SPECIFICATIONS AND PROCEDURES

Material and construction specifications and installation procedures for all components of Trench 12 below-grade and above-grade construction are provided in Appendices B and C. A summary of the specifications and procedures is provided below. Drawings and specifications for final cover construction will be provided in a supplement to this document.

### 7.2.1 Excavation

The below-grade portion of Trench 12 will be constructed in three phases. No benches are planned in the excavation. The excavation requirement is that the total depth of the trench will be about 75 feet below grade. The slopes will be constructed at 0.5:1 (H:V). The walls will be smoothed to remove protruding rocks and reduce depressions. Specifications for excavation are provided in Appendix C, Section 3.1

### 7.2.2 Subgrade Preparation

The subgrade preparation for Trench 12 will include compaction of 9 inches of compacted soil across the trench bottom and 36 inches of compacted soil below the sump areas. Specifications for subgrade preparation are included in Appendix C, Section 3.2.

### 7.2.3 Trench Sidewalls

Trench sidewall preparation for Trench 12 will include smoothing and/or filling of irregularities in the sidewall surface. Specifications for sidewall preparation are included in Appendix C, Section 3.3.

### 7.2.4 Compacted Fill Placement

Procedures to be followed to construct the compacted fill perimeter berm is provided in Appendix C, Sections 3.4 and 3.5.

### 7.2.5 Liner Placement

7.2.5.1 GCL Installation Procedure

The procedures that are to be followed to install the GCL are provided in Appendix C, Section 5, as cited below.

- Section 5.2: Inspection of subgrade for material that could damage the GCL, and removal of such material.
- Section 5.3: GCL placement, and procedures for protection of the GCL material before and during placement of material on the GCL.
- Section 5.4: Techniques to bond GCL seams.

7.2.5.2 Geocomposite and Geonet Installation Procedure

Procedures to be followed to install geocomposite and geonet layers are provided in the various specifications in Appendix C, as identified below.

- Sections 6.1, 6.2 and 6.3: Geocomposite and geonet layers placement, and procedures for protection of the geocomposite and geonet layers material before and during placement of other material on top of these materials.
- Section 6.4: Techniques to bond geocomposite and geonet layers seams and to ensure continuity of flow.
- Sections 6.5 and 6.6: Techniques to repair damaged geocomposite and geonet layers, and to cover installed materials.

7.2.5.3 Geomembrane Installation Procedure

Procedures to be followed to install geomembranes are provided in the various specifications in Appendix C, as cited below.

- Section 7.2: Inspection of geomembrane bed for material that could puncture the geomembrane, and removal of such material.
- Section 7.3: Geomembrane placement, and procedures for protection of the geomembrane material before and during placement of material on the geomembrane.
- Section 7.4: Techniques to bond geomembrane seams.

- Section 7.5: Methods to be employed for repair of the liner system components.

7.2.5.4 Geotextile Installation Procedure

Procedures to be followed to install geotextile layers are provided in the various specifications in Appendix C, as identified below.

- Section 8: Procedures to be followed to install geotextiles.

### 7.2.6 Procedure for Confirming Line and Grade

The procedure to be followed to confirm, by surveying methods, the line and grade of soil construction and waste placement is provided in Appendix C, Section 1.

### 7.2.7 Quality Control Procedures

The QC procedures to be followed by USEN for all aspects of Trench 12 construction are incorporated into the specifications included in this section and Appendix C.

# 8. REFERENCES

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USEN, 1987, Design Report, Trench 10 Above-Grade Disposal Facility, USEN Hazardous Waste Management Facility, Beatty, Nevada.

USEN, 1993, Landfill Report, Appendix D, Drainage Diversion Ditches Design Calculations.

USEN, 1993, Landfill Report, Appendix E, Closure Cost Estimate.

USEN, 1993, Landfill Report, Appendix Q, Slope Stability Analysis for Cell Above-Grade Embankment.

USEN, 1994, Scheduled Closure Plan, Beatty, Nevada.

USEPA, 1985, Settlement and Cover Subsidence of Hazardous Waste Landfills, EPA/600/2-85/035.

## Figure CQA 1: Lift Control Requirements

**Inspection Sheet Number:** _____ **Location:** _____

**Date:** _____

| Item | Specifics | Inspector |
|---|---|---|
| **EQUIPMENT USED** | | |
| Type | | |
| Configuration | | |
| Weight | | |
| **PASSES PER LIFT** | | |
| Lift Number | | |
| **MOISTURE CONTENT** | | |
| Adjustment Method Used | | |
| Equilibration Time | | |
| Quantity of Water Used | | |
| **LIFT THICKNESS** | | |
| Loose (inches) | | |
| Compacted (inches) | | |
| **LIFT PLACEMENT** | | |
| Start Time | | |
| Finish Time | | |
| Observation Start/Complete | | |
| **GENERAL OBSERVATIONS** | | |

## Figure CQA 2: Sample / Test Locations Report

**Inspection Sheet Number:** _____ **Location:** _____

**Date:** _____

| Sample Type | Location | Time Collected | Collectors Initials | Pass / Fail | CQAO Approval | Comments |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| Field Analyses | Test Method | Requirement |
|---|---|---|
| DN = Density (nuclear) | ASTM D2922 | every 2,000 $yd^3$ |
| DS = Density (sand cone) | ASTM D1556 | every 10 DN samples |
| MN = Moisture (nuclear) | ASTM D3017 | every 2,000 $yd^3$ |
| Laboratory Analyses | | |
| MO = Moisture (oven dry) | ASTM D2216 | every 10 MN samples |

**Figure CQA 3: Construction Problem Identification and Corrective Measures Report**

**Corrective Measures Report Number:** _____ **Date:** _____

**Re: Inspection Sheet Number:** _____ **Date:** _____

| | | | |
|---|---|---|---|
| QA Inspection Location and Construction Activity | | | |
| Result of QA Inspection and Tests, Deficiencies Observed, Actions Taken, and Corrective Action of Contractor | | | |
| Verbal Instructions Given to Contractor | | | |
| Controversial Matters in Detail/Disagreements | | | |
| Resolution/Corrective Action (retest, rework) | | | |
| Remarks | | | |
| Inspector's Signature | Date | CQA Officer Signature | Date |

# APPENDIX A - ABOVE-GRADE FACILITY DESIGN DRAWINGS

## DRAWINGS LIST

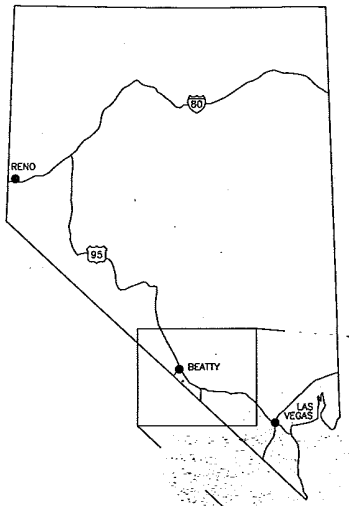
| | |
|---|---|
| NV12-07-001 | Title Sheet |
| NV12-07-002 | Site Plan |
| NV12-07-003 | Excavation Plan – Perimeter Soil Requiring Improvement |
| NV12-07-004 | Excavation Plan – Trench 12 |
| NV12-07-005 | Cross-Sections A-A' and B-B' |
| NV12-07-006 | Cross-Sections C-C', D-D' and Liner Details |
| NV12-07-007 | Sump Details |
| NV12-07-008 | Sump and Miscellaneous Details |

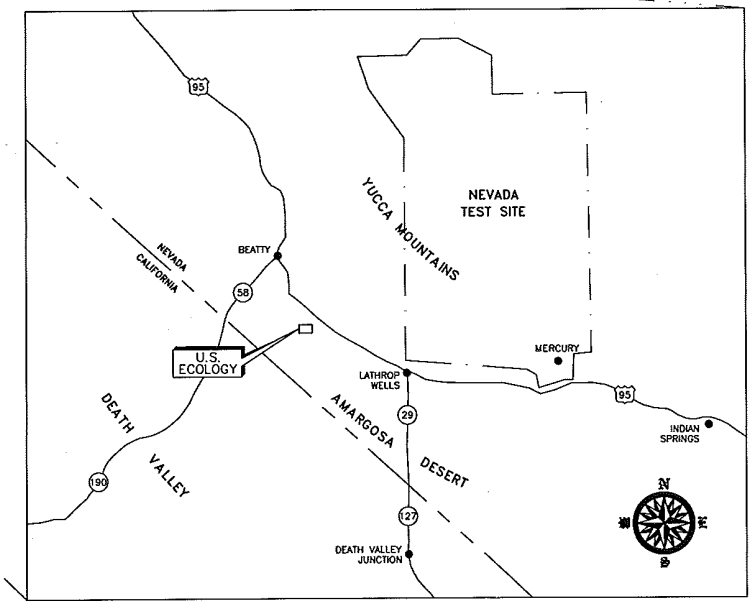
# USEcology Nevada

**an *American Ecology* company**

## LANDFILL TRENCH 12 DESIGN
## HAZARDOUS WASTE MANAGEMENT FACILITY
## BEATTY, NEVADA

## RCRA FACILITY ID NO. NVT330010000
## HAZARDOUS WASTE PERMIT NUMBER NV HW0019



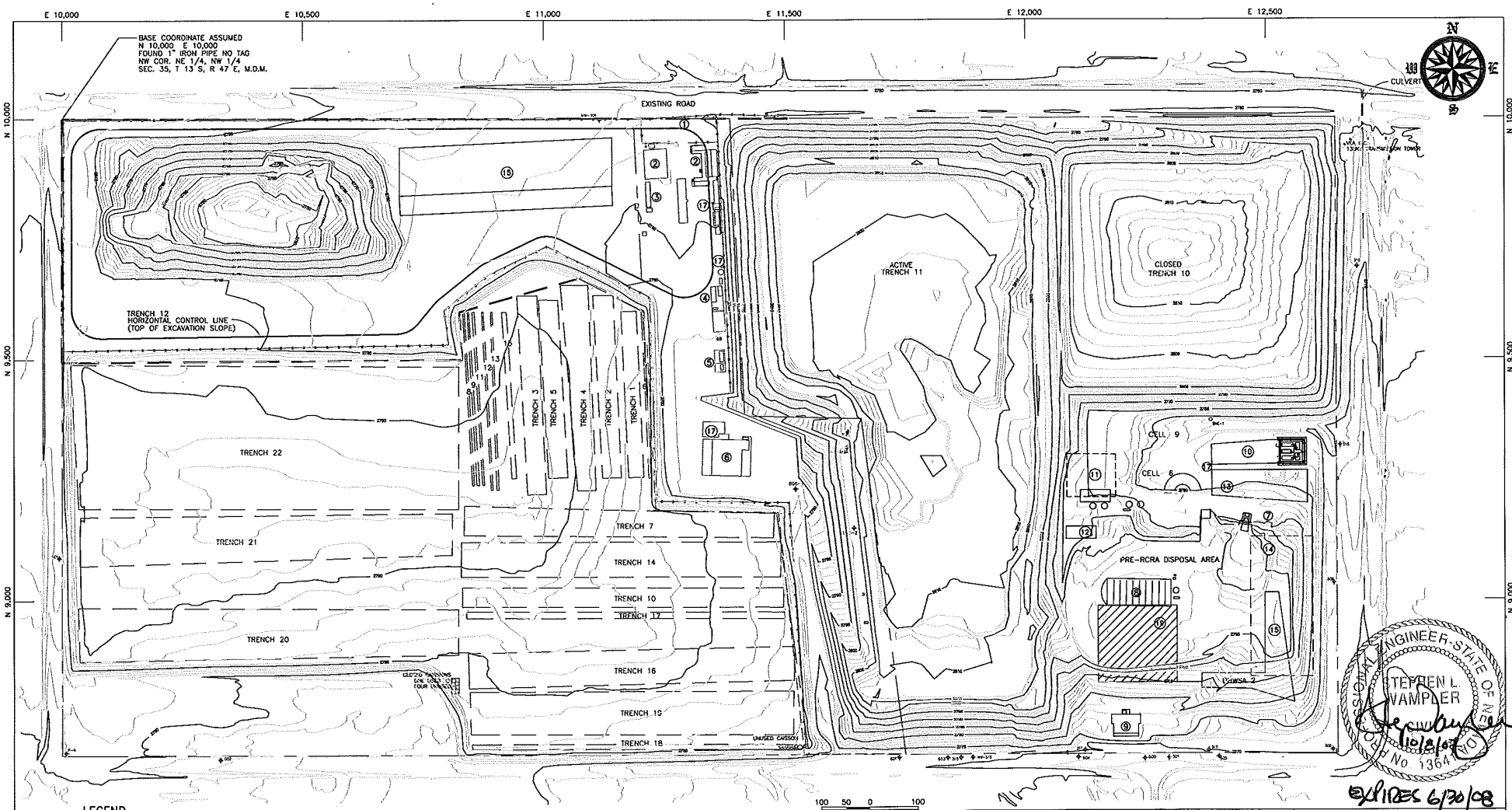

VICINITY MAP

20 10 0 20
SCALE MILES

## INDEX OF DRAWINGS

| SHEET NO. | DRAWING NO. | TITLE |
|---|---|---|
| 1 | NV12-07-001 | TITLE SHEET |
| 2 | NV12-07-002 | SITE PLAN |
| 3 | NV12-07-003 | EXCAVATION PLAN – PERIMETER SOILS REQUIRING RECOMPACTION |
| 4 | NV12-07-004 | EXCAVATION PLAN |
| 5 | NV12-07-005 | CROSS SECTIONS A–A AND B–B |
| 6 | NV12-07-006 | CROSS SECTIONS C–C, D–D AND LINER DETAILS |
| 7 | NV12-07-007 | SUMP DETAILS |
| 8 | NV12-07-008 | SUMP AND MISCELLANEOUS DETAILS |

NOTE: THESE TRENCH 12 PLANS ARE REVISED FROM 1996 TRENCH DESIGN DRAWINGS NV-161-001 THROUGH NV-161-010 WHICH WERE CONDITIONALLY APPROVED BY THE NEVADA DEPARTMENT OF ENVIRONMENTAL PROTECTION IN RCRA PERMIT NEV HW0019 DATED APRIL 29, 2005.




## LEGEND

- HORIZONTAL CONTROL LINE
- PERMIT LINE
- DRAINAGE DITCH AND DIRECTION OF FLOW
- PROPERTY LINE
- FENCE LINE
- MONITOR WELL LOCATION AND NUMBER
- SOIL VAPOR EXTRACTION WELL
- 1' CONTOUR INTERVAL, FEET (MSL)
- 5' CONTOUR INTERVAL, FEET (MSL)
- TRENCH 1 — LOW LEVEL RADIOLOGICAL WASTE TRENCH

1. MAIN SITE ENTRANCE
2. ADMINISTRATION OFFICE
3. DRIVERS LOUNGE
4. LABORATORY AND LAB STORAGE
5. FUEL STORAGE
6. MAINTENANCE SHOP
7. LOW TEMPERATURE THERMAL DESORPTION
8. TRUCK PARKING
9. EVAPORATION TANK
10. PCB PROCESSING AREA
11. BATCH STABILIZATION TANK AND SILOS
12. STABILIZATION TANKS
13. THERMAL TREATMENT AREA
14. LOW TEMPERATURE THERMAL DESORPTION FUTURE EXPANSION
15. DRY HAZARDOUS WASTE STORAGE AREA
17. FIRE CONTROL HYDRANT
18. CONTAINER MGMT./STAB. BUILDING

DATE OF TRENCH 11 TOPOGRAPHY: OCTOBER 2006
DATE OF TRENCH 12 TOPOGRAPHY: APRIL 2007
DATE OF AERIAL TOPOGRAPHY: JUNE 1994

| REV. | DESCRIPTION | DRWN BY | DSGN BY | CHECK BY | APP'D BY | DATE |
|---|---|---|---|---|---|---|
| 0 | ISSUED FOR REGULATORY REVIEW | LAM | CAB | | SLW | 10/1/07 |

**USEcology Nevada**

*an American Ecology company*

PROJECT NUMBER: 073113 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

SITE PLAN
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
|---|---|---|---|---|---|---|---|---|---|---|
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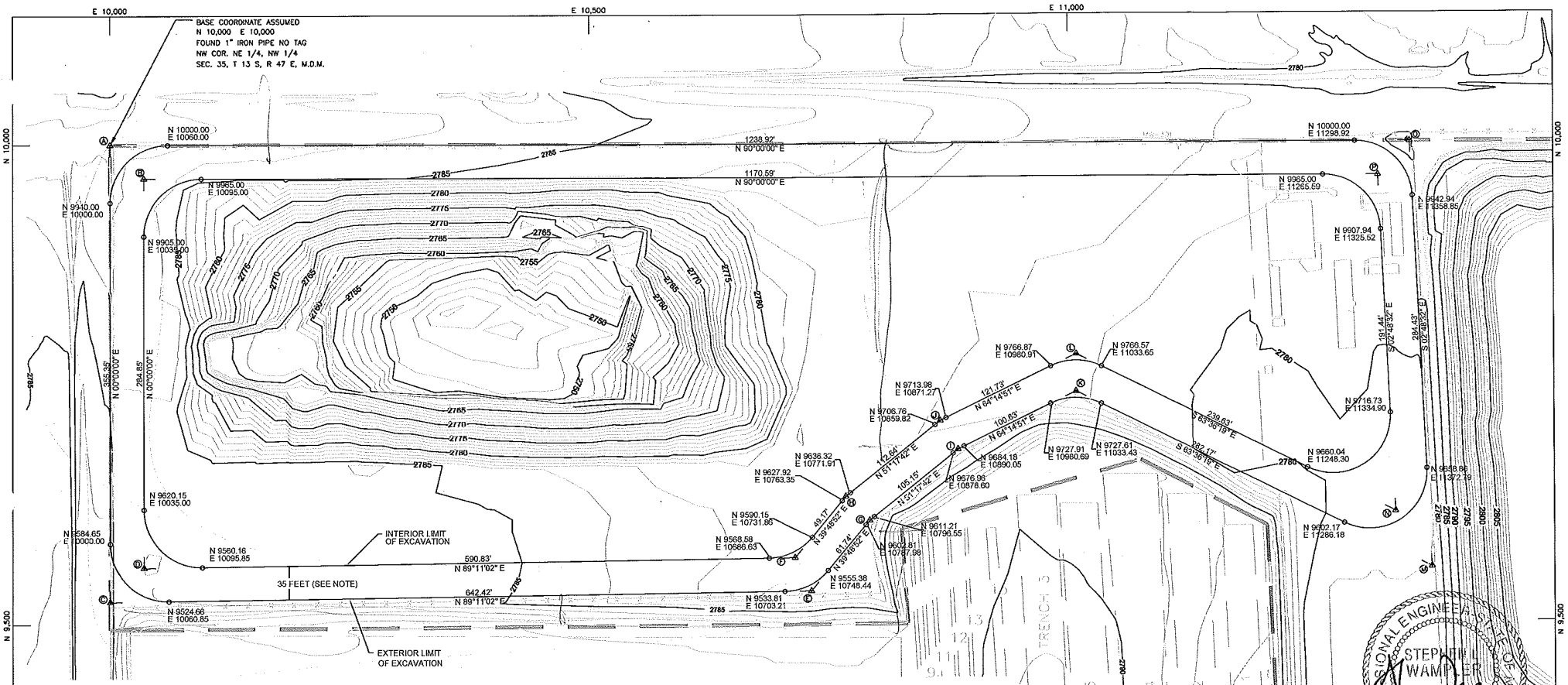
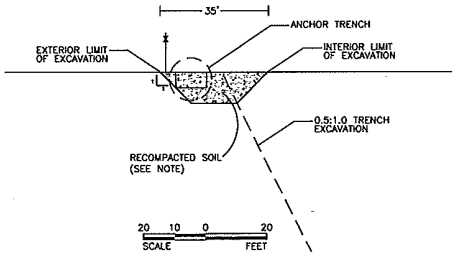
CAD FILE NAME: F:\Data\073113\T12 Design Package\subgrade design\NV12-07-002.dwg

PLOT DATE: 10/1/07

STEPHEN L. VAMPLER
NO. 13641
10/2/07

Exp 12/31/08 6/30/08




NOTE: LIMITS OF SURFACE SOIL REQUIRING RECOMPACTION ARE SHOWN NOMINALLY AS 10' BELOW THE TOP OF SLOPE, 35' WIDE TOWARD THE PERMIT LINE. ACTUAL DIMENSIONS WILL BE DETERMINED IN THE FIELD BASED ON ACTUAL DEPTH OF LOOSE SOILS.

| SURVEY CONTROL TABLE | | | | | | |
|---|---|---|---|---|---|---|
| PI/CURVE | PI COORDINATES | | CURVE DATA | | | |
| | | | RADIUS | LENGTH | TANGENT | DELTA |
| A | N 10,000.00 | E 10,000.00 | 60.00' | 94.25' | 60.00' | 90°00'00" |
| B | N 9,965.00 | E 10,035.00 | 60.00' | 94.25' | 60.00' | 90°00'00" |
| C | N 9,523.79 | E 10,000.00 | 60.00' | 95.10' | 60.86' | 90°48'58" |
| D | N 9,559.29 | E 10,035.00 | 60.00' | 95.10' | 60.86' | 90°48'58" |
| E | N 9,534.20 | E 10,730.79 | 60.00' | 51.70' | 27.58' | 49°22'10" |
| F | N 9,568.97 | E 10,714.20 | 60.00' | 51.70' | 27.58' | 49°22'10" |
| G | N 9,607.44 | E 10,791.84 | 60.00' | 12.02' | 6.03' | 11°28'50" |
| H | N 9,632.55 | E 10,787.21 | 60.00' | 12.02' | 6.03' | 11°28'50" |
| I | N 9,681.22 | E 10,883.92 | 60.00' | 13.56' | 6.81' | 12°57'10" |
| J | N 9,711.02 | E 10,865.13 | 60.00' | 13.56' | 6.81' | 12°57'10" |
| K | N 9,740.66 | E 11,007.13 | 60.00' | 54.61' | 29.36' | 52°08'50" |
| L | N 9,779.63 | E 11,007.35 | 60.00' | 54.61' | 29.36' | 52°08'50" |
| M | N 9,556.70 | E 11,337.80 | 60.00' | 124.83' | 102.28' | 119°12'14" |
| N | N 9,614.58 | E 11,339.92 | 60.00' | 124.83' | 102.28' | 119°12'14" |
| O | N 10,000.00 | E 11,356.05 | 60.00' | 91.31' | 57.13' | 87°11'28" |
| P | N 9,965.00 | E 11,322.72 | 60.00' | 91.31' | 57.13' | 87°11'28" |

GROUND CONTROL BY :
GREAT WEST SURVEYORS
LAS VEGAS, NEVADA

PHOTOGRAMMETRY BY:
C & C AERIAL MAPPING CORP.
SAN DIMAS, CALIFORNIA

50 25 0 50
SCALE FEET

STEPHEN L. WAMPLER
PROFESSIONAL ENGINEER
No. 13611
10/8/07
Expires 6/30/08

| | DESCRIPTION | DRWN BY | DSGN. BY | CHECK BY | APP'D BY | DATE |
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*an American Ecology company*

PROJECT NUMBER: 073113 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

EXCAVATION PLAN
PERIMETER SOILS REQUIRING RECOMPACTION
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
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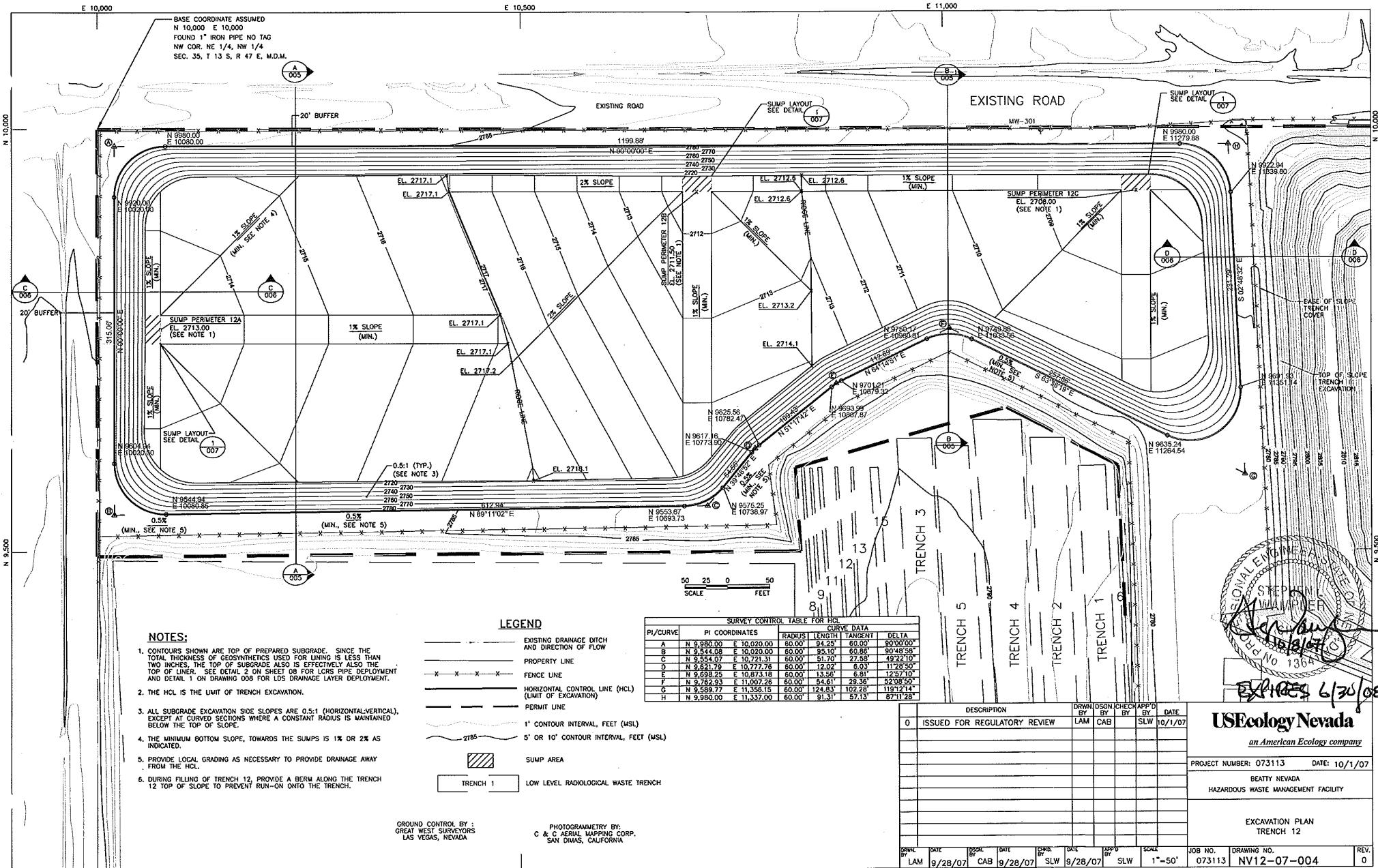


## NOTES:

1. CONTOURS SHOWN ARE TOP OF PREPARED SUBGRADE. SINCE THE TOTAL THICKNESS OF GEOSYNTHETICS USED FOR LINING IS LESS THAN TWO INCHES, THE TOP OF SUBGRADE ALSO IS EFFECTIVELY ALSO THE TOP OF LINER. SEE DETAIL 2 ON SHEET 08 FOR LCRS PIPE DEPLOYMENT AND DETAIL 1 ON DRAWING 008 FOR LDS DRAINAGE LAYER DEPLOYMENT.
2. THE HCL IS THE LIMIT OF TRENCH EXCAVATION.
3. ALL SUBGRADE EXCAVATION SIDE SLOPES ARE 0.5:1 (HORIZONTAL:VERTICAL), EXCEPT AT CURVED SECTIONS WHERE A CONSTANT RADIUS IS MAINTAINED BELOW THE TOP OF SLOPE.
4. THE MINIMUM BOTTOM SLOPE, TOWARDS THE SUMPS IS 1% OR 2% AS INDICATED.
5. PROVIDE LOCAL GRADING AS NECESSARY TO PROVIDE DRAINAGE AWAY FROM THE HCL.
6. DURING FILLING OF TRENCH 12, PROVIDE A BERM ALONG THE TRENCH 12 TOP OF SLOPE TO PREVENT RUN-ON ONTO THE TRENCH.

## LEGEND

- EXISTING DRAINAGE DITCH AND DIRECTION OF FLOW
- PROPERTY LINE
- FENCE LINE
- HORIZONTAL CONTROL LINE (HCL) (LIMIT OF EXCAVATION)
- PERMIT LINE
- 1' CONTOUR INTERVAL, FEET (MSL)
- 2785 5' OR 10' CONTOUR INTERVAL, FEET (MSL)
- SUMP AREA
- TRENCH 1 LOW LEVEL RADIOLOGICAL WASTE TRENCH

SURVEY CONTROL TABLE FOR HCL

| PI/CURVE | PI COORDINATES | | CURVE DATA | | | |
|---|---|---|---|---|---|---|
| | | | RADIUS | LENGTH | TANGENT | DELTA |
| A | N 9,980.00 | E 10,020.00 | 60.00' | 94.25' | 60.00' | 90°00'00" |
| B | N 9,544.08 | E 10,020.00 | 60.00' | 95.10' | 60.86' | 90°48'56" |
| C | N 9,554.07 | E 10,721.31 | 60.00' | 51.70' | 27.58' | 49°22'10" |
| D | N 9,621.79 | E 10,777.76 | 60.00' | 12.02' | 6.03' | 11°28'50" |
| E | N 9,698.25 | E 10,873.18 | 60.00' | 13.56' | 6.81' | 12°57'10" |
| F | N 9,762.93 | E 11,007.26 | 60.00' | 54.61' | 29.36' | 52°08'50" |
| G | N 9,589.77 | E 11,356.15 | 60.00' | 124.83' | 102.28' | 119°12'14" |
| H | N 9,980.00 | E 11,337.00 | 60.00' | 91.31' | 57.13' | 87°11'28" |

GROUND CONTROL BY : GREAT WEST SURVEYORS LAS VEGAS, NEVADA

PHOTOGRAMMETRY BY: C & C AERIAL MAPPING CORP. SAN DIMAS, CALIFORNIA

| | DESCRIPTION | DRWN BY | DSGN BY | CHECK BY | APP'D BY | DATE |
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| 0 | ISSUED FOR REGULATORY REVIEW | LAM | CAB | | SLW | 10/1/07 |

**USEcology Nevada**

*an American Ecology company*

PROJECT NUMBER: 073113 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

EXCAVATION PLAN
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
|---|---|---|---|---|---|---|---|---|---|---|
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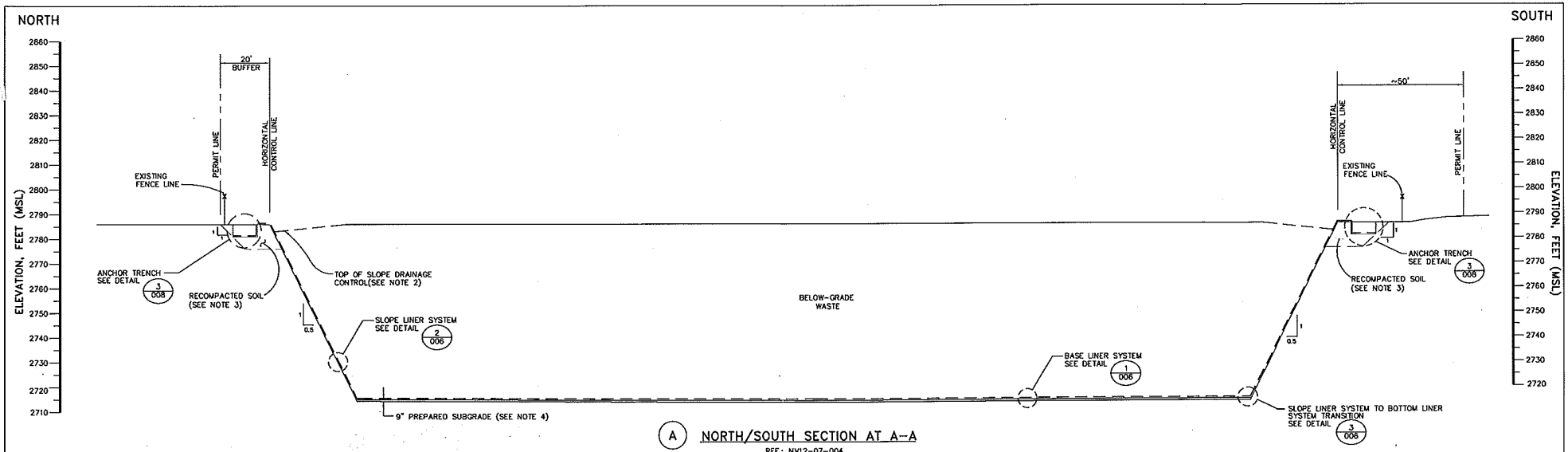
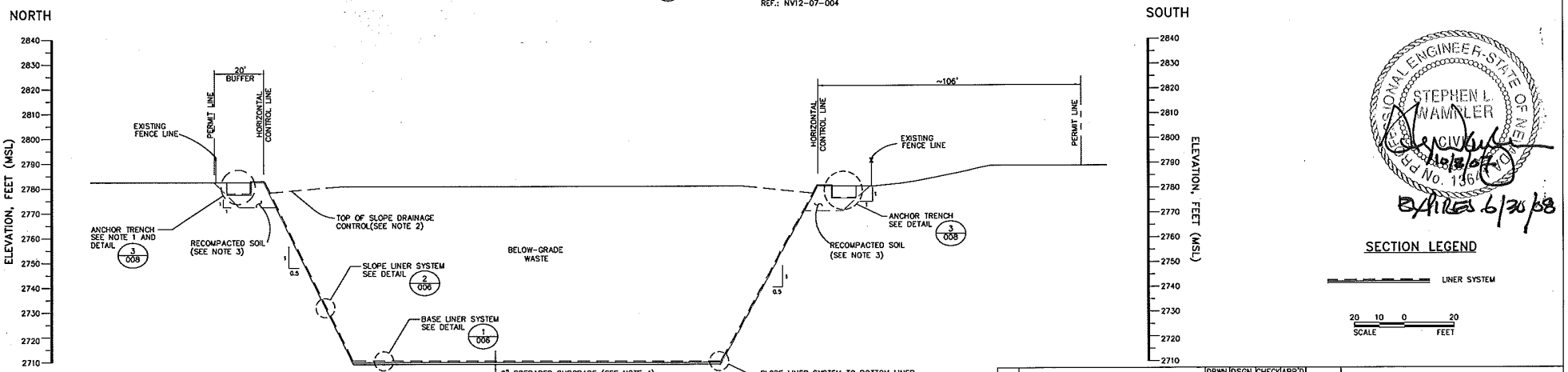



A NORTH/SOUTH SECTION AT A-A

REF.: NV12-07-004




B NORTH/SOUTH SECTION AT B-B

REF.: NV12-07-004

NOTES:

1. ANCHOR TRENCHES ARE USED TO SECURE LINER SYSTEMS WHILE EXCAVATIONS ARE BEING FILLED.
2. KEEP WASTE 3' BELOW TOP OF SLOPE UNTIL CONSTRUCTION OF STARTER BERM.
3. RECOMPACTED SURFACE SOIL LIMITS ARE SHOWN NOMINALLY AS 10' BELOW THE TOP OF SLOPE, 10' WIDE (OFFSET TOWARD THE PERMIT LINE). ACTUAL DIMENSIONS WILL BE DETERMINED IN THE FIELD BASED ON ACTUAL DEPTH OF LOOSE SOIL.
4. PREPARED SUBGRADE THICKNESS BENEATH SUMPS IS 36 INCHES.




SECTION LEGEND

LINER SYSTEM

20 10 0 20
SCALE FEET

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PROJECT NUMBER: 073113 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

CROSS SECTIONS A-A AND B-B
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
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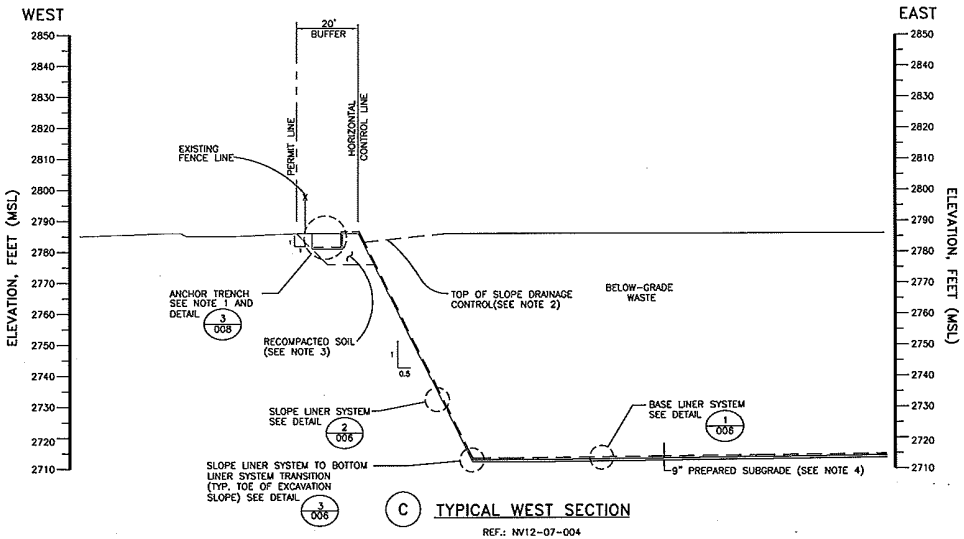
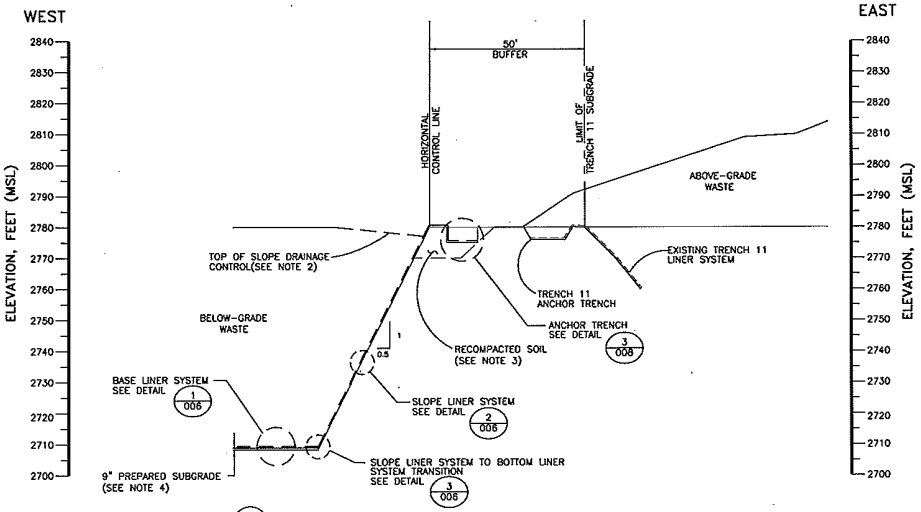



C TYPICAL WEST SECTION

REF.: NV12-07-004

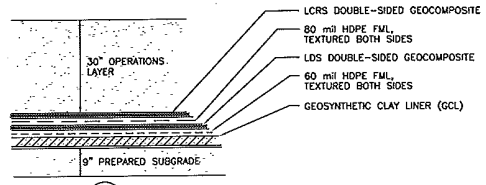
SCALE 20 10 0 20 FEET




D TYPICAL SECTION-TRENCH 12/TRENCH 11 TIE-IN

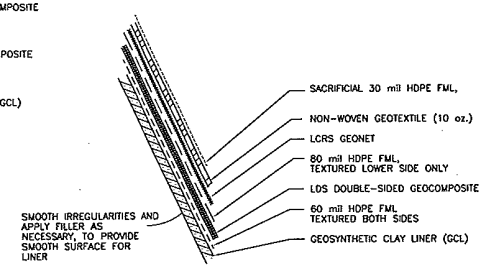
REF.: NV12-07-004

SCALE 20 10 0 20 FEET



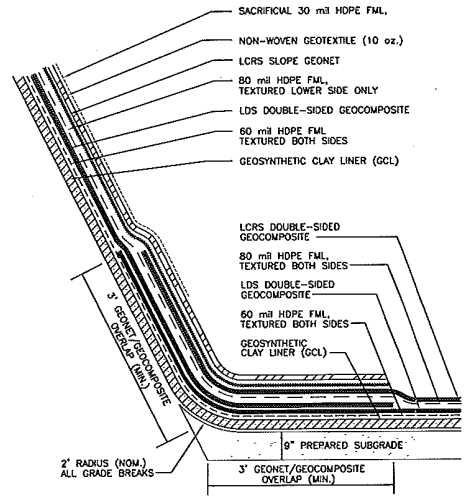

1 TYPICAL BASE LINER SYSTEM

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)




2 TYPICAL SLOPE LINER SYSTEM

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)




3 SLOPE LINER SYSTEM TO BASE LINER SYSTEM TRANSITION

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)

## SECTION LEGEND

BASE LINER SYSTEM (DETAILS C AND D)

## DETAIL LEGEND

- 10.0 oz. GEOTEXTILE
- GEONET
- DOUBLE-SIDED GEOCOMPOSITE
- 30 mil HDPE FML
- 60 mil HDPE FML
- 80 mil HDPE FML
- GEOSYNTHETIC CLAY LINER (GCL)

PROFESSIONAL ENGINEER STATE OF NEVADA STEPHEN L. WAMPLER No. 13641

10/2/07

EXPIRES 6/30/08

NOTES:

1. ANCHOR TRENCHES ARE USED TO SECURE LINER SYSTEMS WHILE EXCAVATIONS ARE BEING FILLED.

KEEP WASTE 3' BELOW TOP OF SLOPE UNTIL CONSTRUCTION OF STARTER BERM.

3. RECOMPACTED SURFACE SOIL LIMITS ARE SHOWN NOMINALLY AS 10' BELOW THE TOP OF SLOPE, 10' WIDE (OFFSET TOWARD THE PERMIT LINE). ACTUAL DIMENSIONS WILL BE DETERMINED IN THE FIELD BASED ON ACTUAL DEPTH OF LOOSE SOIL.

4. PREPARED SUBGRADE THICKNESS BENEATH SUMPS IS 36 INCHES.

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PROJECT NUMBER: 010917 DATE: 10/1/07

BEATTY NEVADA

HAZARDOUS WASTE MANAGEMENT FACILITY

CROSS SECTIONS C-C, D-D AND LINER DETAILS, TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
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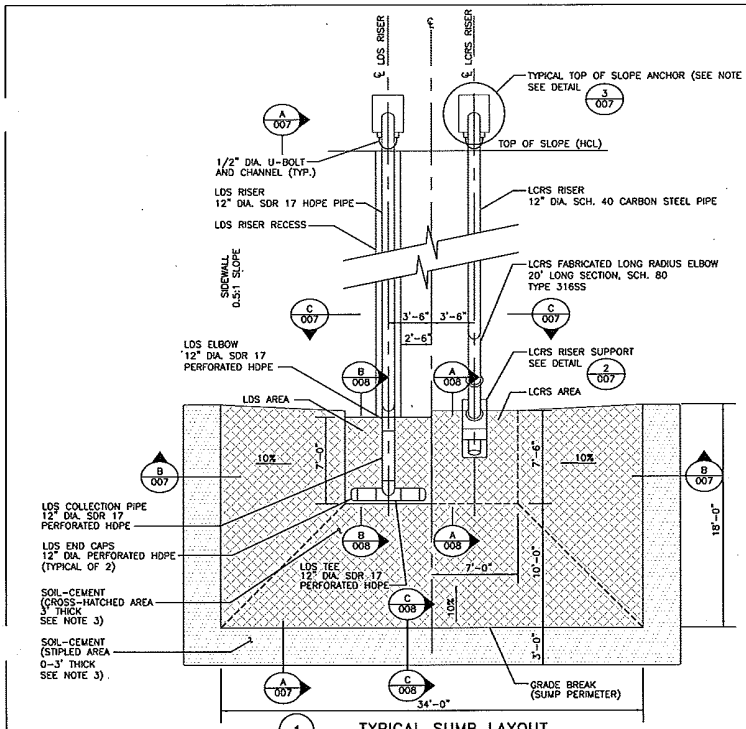
| LAM | 9/28/07 | CAB | 9/28/07 | SLW | 9/28/07 | SLW | | 010917 | NV12-07-006 | 0 |

CAD FILE NAME: F:\Data\073113\T12 Design Package\subgrade design\NV12-07-006.dwg

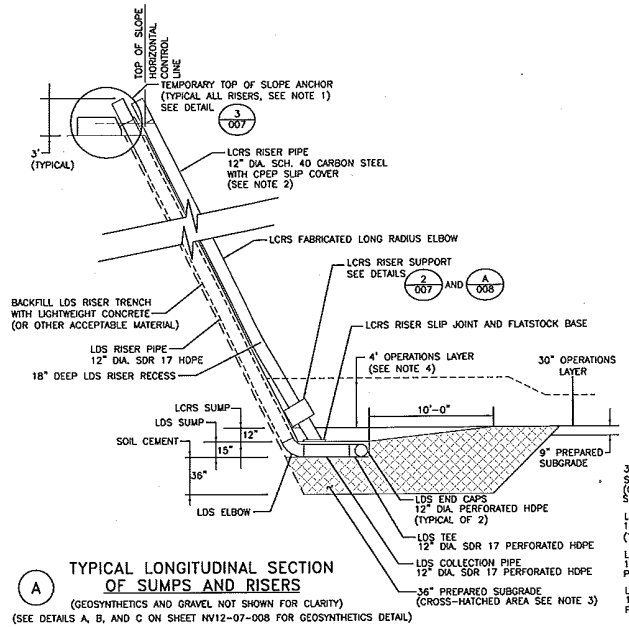
PLOT DATE: 10/1/07




1 TYPICAL SUMP LAYOUT

(GEOSYNTHETICS AND GRAVEL NOT SHOWN FOR CLARITY)
(SEE DETAILS A, B, AND C ON SHEET NV12-07-008 FOR GEOSYNTHETICS DETAIL)

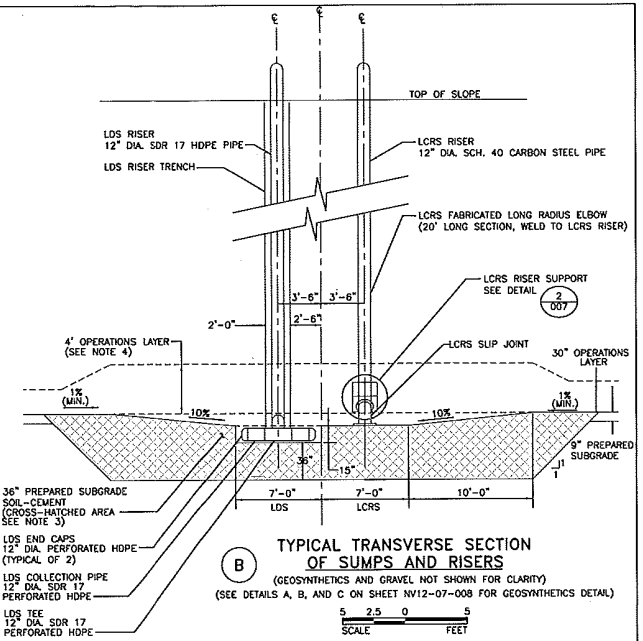
SCALE 5 2.5 0 5 FEET




A TYPICAL LONGITUDINAL SECTION OF SUMPS AND RISERS

(GEOSYNTHETICS AND GRAVEL NOT SHOWN FOR CLARITY)
(SEE DETAILS A, B, AND C ON SHEET NV12-07-008 FOR GEOSYNTHETICS DETAIL)

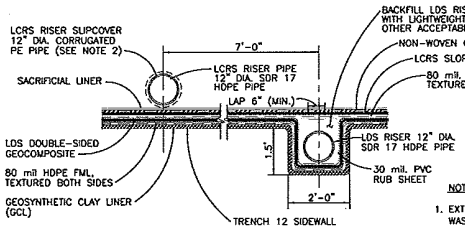
SCALE 5 2.5 0 5 FEET




B TYPICAL TRANSVERSE SECTION OF SUMPS AND RISERS

(GEOSYNTHETICS AND GRAVEL NOT SHOWN FOR CLARITY)
(SEE DETAILS A, B, AND C ON SHEET NV12-07-008 FOR GEOSYNTHETICS DETAIL)

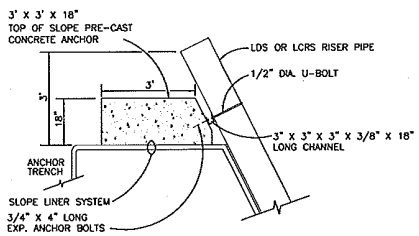
SCALE 5 2.5 0 5 FEET




C TYPICAL SIDEWALL SECTION SHOWING RISERS AND RECESS

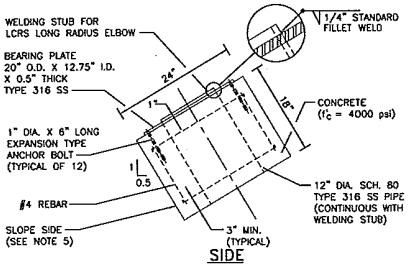
(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)
SEE DRAWING 008 FOR DETAIL LEGEND

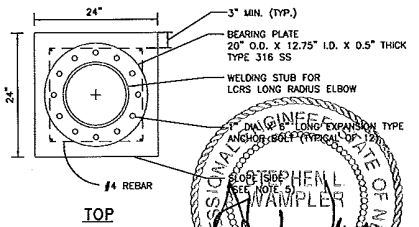
SCALE 2 1 0 2 FEET




3 TYPICAL TOP OF SLOPE RISER PIPE ANCHOR

SCALE 2 1 0 2 FEET




2 LCRS RISER SUPPORT

SCALE 1 0.5 0 1 FEET

NOTES:

1. EXTEND RISERS AND RELOCATE ANCHORS TO ACCOMMODATE ABOVE-GRADE WASTE DISPOSAL.
2. THE SLIP COVER IS SPLIT LONGITUDINALLY AND PLACED OVER THE LCRS RISER TO PREVENT WASTE SETTLEMENT FROM TRANSFERRING LOADS TO THE LCRS RISER OR LINER SYSTEM. USE 10' SECTIONS OF CORRUGATED POLYETHYLENE (CPEP) PIPE (OR ACCEPTABLE ALTERNATIVE), CUT TO FIT AS NECESSARY, AND DO NOT JOIN ADJACENT SECTIONS.
3. IN LDS SUMP AREA ADD 3-5% CEMENT (OR OTHER ACCEPTABLE MATERIAL) TO SUBGRADE TO PROVIDE SUFFICIENT COHESION TO ALLOW BOX CUT.
4. FOUR FEET OF OPERATIONS LAYER IS PROVIDED OVER THE SUMPS TO PROVIDE ADDITIONAL LATERAL SUPPORT FOR THE RISERS.
5. THE LCRS RISER SUPPORT SHOULD BE CAST-IN-PLACE. (SEE SECTION A ON DRAWING 008 AND DETAIL 002 ON DRAWING 007) THE SLOPE SIDE SHOULD BE FLUSH WITH THE EXCAVATION SIDEWALL. THE TOP AND BOTTOM SHOULD BE CAST SO AS TO BE SQUARE WITH THE LCRS LONG RADIUS ELBOW.

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PROJECT NUMBER: 010917 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

SUMP DETAILS
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
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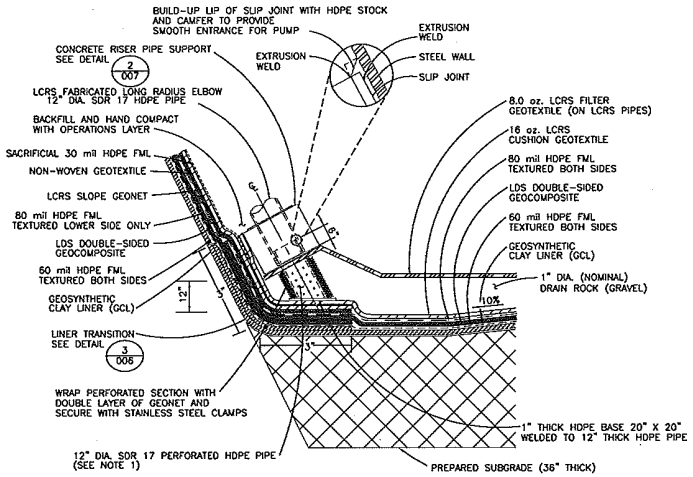
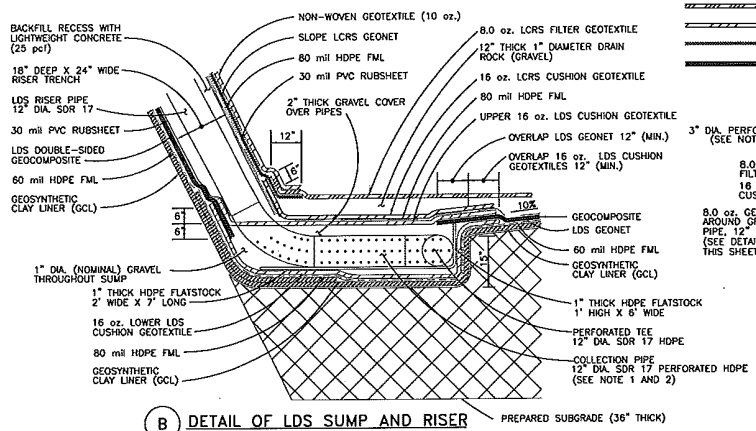
CAD FILE NAME: F:\Data\073113\T12 Design Package\subgrade design\NV12-07-007.dwg PLOT DATE: 10/1/07




A DETAIL OF LCRS SUMP AND RISER

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)
REF.: NV12-07-007

2 1 0 2
SCALE FEET



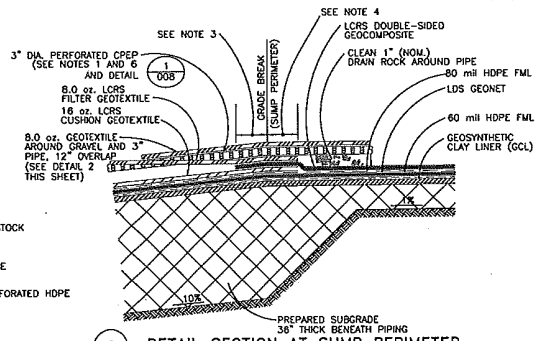

B DETAIL OF LDS SUMP AND RISER

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)
REF.: NV12-07-007

2 1 0 2
SCALE FEET

## DETAIL LEGEND

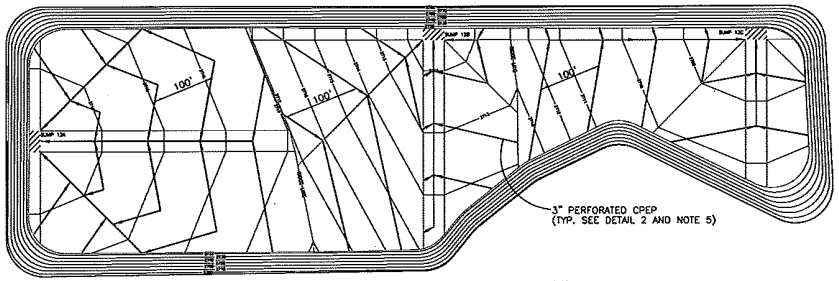
- 8.0 oz. GEOTEXTILE
- 16 oz. GEOTEXTILE
- GEONET
- DOUBLE-SIDED GEOCOMPOSITE
- 30 mil HDPE FML
- 60 mil HDPE FML
- 80 mil HDPE FML
- GEOSYNTHETIC CLAY LINER (GCL)




C DETAIL SECTION AT SUMP PERIMETER

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)
REF.: NV12-07-007

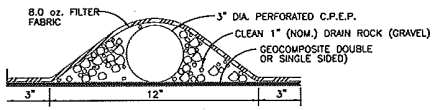
2 1 0 2
SCALE FEET



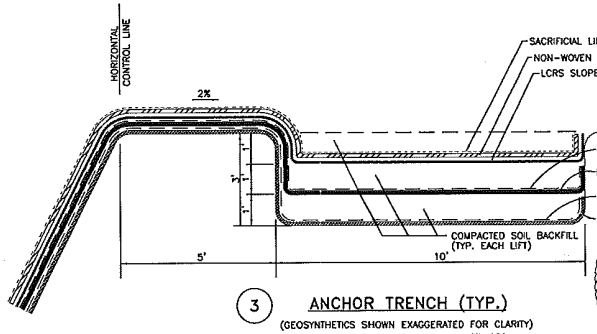

1 DEPLOYMENT LCRS PIPES

REF.: NV12-07-004

100 50 0 100
SCALE FEET




2 TYPICAL C.P.E.P SECTION




3 ANCHOR TRENCH (TYP.)

(GEOSYNTHETICS SHOWN EXAGGERATED FOR CLARITY)
REF: NV12-07-005 AND NV12-07-006

2 1 0 2
SCALE FEET

STEPHEN L. WAMPLER
PROFESSIONAL ENGINEER - STATE OF NEVADA
No. 13647
12/18/07

NOTES:

1. PERFORATIONS ARE 1/2" DIA. HOLES @ 60°; 24 HOLES PER FOOT.
2. DOUBLE LAYER OF GEONET AND SECURE WITH STAINLESS STEEL CLAMPS.
3. EXTEND LCRS GEOCOMPOSITE 12" (MIN.) INTO SUMP.
4. EXTEND 8.0 oz. FILTER AND 16 oz. LCRS CUSHION GEOTEXTILES 12" (MIN.) PAST GRADE BREAK.
5. CPEP = CORRUGATED POLYETHYLENE PIPE
6. CPEP PIPE PENETRATES UPPER GEOTEXTILE AT SUMP PERIMETER

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**USEcology Nevada**
*an American Ecology company*

PROJECT NUMBER: 010917 DATE: 10/1/07

BEATTY NEVADA
HAZARDOUS WASTE MANAGEMENT FACILITY

SUMP AND MISCELLANEOUS DETAILS
TRENCH 12

| DRWN. BY | DATE | DSGN. BY | DATE | CHKD. BY | DATE | APP'D BY | SCALE | JOB NO. | DRAWING NO. | REV. |
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CAD FILE NAME: F:\Data\073113\T12 Design Package\subgrade design\NV12-07-008.dwg PLOT DATE: 10/1/07

# APPENDIX B -CONSTRUCTION MATERIALS SPECIFICATIONS

# 1. CONSTRUCTION MATERIALS SPECIFICATIONS

This presentation of construction materials specifications is supplemental to such information provided in project drawings. In the event that information being included herein is in any way incomplete or conflicts with that provided in project drawings, the project drawings are to be considered primary.

# 2. SOIL MATERIALS

Soil materials will consist of the predominantly sand and gravel soils obtained from stockpiles and the Trench 12 excavation area, supplemented as needed with imported soil materials. Materials that cannot be satisfactorily placed and/or compacted to a stable condition will be designated as unsuitable. Unsuitable materials will include trash, organic substances, large rocks (more than six inches in diameter) or other materials determined to be unsuitable by the Project Manager. These materials will be removed from the fill material and segregated from suitable soil.

## 2.1 SPECIFICATION FOR SURFACE SOIL LAYER IMPROVEMENT

Soil materials for replacement of the loose surface soil layer will consist of site materials with no materials larger than six inches, 95% smaller than 3.0 inches, and not less than 10% and not more than 20% passing the #200 sieve. Suitable materials from direct excavation or stockpiles will be placed in lifts not exceeding 12 inches thick and compacted to 95 percent MDD by ASTM D 1557 at a moisture content between the OMC and OMC +2 percent. Mixture with fine-grained soil amendment(s) is not required if the natural material satisfies the grain size specification.

## 2.2 SPECIFICATION FOR LINER SUBGRADE ON TRENCH FLOOR AND IN SUMPS

Soil materials for the liner subgrade layer will consist of site materials, amended as necessary with imported fine-grained materials to achieve the grain size specification. The final subgrade soil will have not more than 10 percent (by weight) coarser than 1.0 inch and not less than 10 percent (by weight) smaller than the #200 sieve. Suitable materials from direct excavation or stockpiles will be placed in lifts not exceeding 12 inches thick (before compaction) and compacted to 90 percent MDD by ASTM D 1557 at a moisture content between the OMC and OMC +2 percent.

## 2.3 SPECIFICATION FOR PERIMETER STARTER BERM SOIL

Soil materials for the compacted soil starter berms will contain no materials larger than six inches, 95% smaller than 3.0 inches, and not less than 10% passing the #200 sieve. Suitable materials from direct excavation or stockpiles will be placed in lifts not exceeding 12 inches thick and compacted to 90 percent MDD by ASTM D 1557 at a moisture content between the OMC and OMC +2 percent.

## 2.4 GRAVEL MATERIALS FOR LDS/LCRS SUMPS

Gravel materials for use in LDS/LCRS sumps will consist of screened site materials with 95% falling within the size range between 1.0 and 3.0 inches and not more than 5% passing the #4 sieve. All gravel material will be stockpiled and placed in such a manner as to minimize the intrusion of fines and to minimize segregation of various gravel sizes. Gravel materials for LDS and LCRS sumps, and for placement along LCRS piping, will be loosely placed with no compaction or moisture content specification.

## 2.5 SELECT WASTE OPERATIONS LAYER

The operations layer is not a bottom liner component, but its presence and material type are significant in hydrologic calculations completed as part of LCRS design. It is the initial 30 inches of material placed above the liner across the bottom of each disposal cell (Phases 12A, 12B, and 12C). The operations layer is to be an SM (silty sand) material, by Universal Soil Classification System (ASTM D2487), can be comprised of clean soil, select waste, or a combination of clean soil and select waste. The first foot (12 inches) of operations layer above the liner will be primarily (i.e., greater than 50 percent) sand, with a total of less than 50 percent gravel and silt/clay size particles. It will contain no particles larger than one inch. The next 1.5 feet (18 inches) also should be SM material, but can contain particles up to 6.0 inches in diameter. The select waste operations layer should be placed in two lifts (as noted above), as dry as is practical, and with as little passage of heavy equipment as is practical (before the full layer is in placed). This layer has no compaction or moisture content specifications.

# 3. LINER MATERIAL

## 3.1 GEOTEXTILE

Minimum specifications geotextile for use in this project will consist of non-woven polypropylene or polyester materials designed and fabricated to meet the various thickness requirements of the project. All geotextile is to be stored and applied in such a way as to prevent degradation by direct sunlight, wind, or mechanical damage. Polyester or ultra-violet-resistant polypropylene geotextile should be used whenever the project requires exposure to direct sunlight for more than two weeks.

Unless otherwise indicated, specifications for geotextile materials are included in the tables below.

Minimum Specifications for 16 ounce geotextile.

| Property | Test Method | Value |
|---|---|---|
| Thickness | ASTM D5199 | 155 mil (0.155 inch) |
| Mass per Unit Area | ASTM D5261 | 16.0 oz/sq yard |
| Grab Tensile strength | ASTM D4632 | 390 lbs |
| Grab Elongation | ASTM D4632 | 50% |
| Puncture Strength | ASTM D4833 | 240 lbs |
| Trapezoidal Tear | ASTM D4533 | 150 lbs |
| UV Resistance | ASTM D4355 | 70% after 500 hours |

Minimum Specifications for 10 ounce geotextile.

| Property | Test Method | Value |
|---|---|---|
| Thickness | ASTM D5199 | 100 mil (0.100 inch) |
| Mass per Unit Area | ASTM D5261 | 10.0 oz/sq yard |
| Grab Tensile strength | ASTM D4632 | 260 lbs |
| Grab Elongation | ASTM D4632 | 50% |
| Puncture Strength | ASTM D4833 | 165 lbs |
| Trapezoidal Tear | ASTM D4533 | 100 lbs |
| UV Resistance | ASTM D4355 | 70% after 500 hours |

Minimum Specifications for 8 ounce geotextile.

| Property | Test Method | Value |
|---|---|---|
| Thickness | ASTM D5199 | 80 mil (0.080 inch) |
| Mass per Unit Area | ASTM D5261 | 8.0 oz/sq yard |
| Grab Tensile strength | ASTM D4632 | 220 lbs |
| Grab Elongation | ASTM D4632 | 50% |
| Puncture Strength | ASTM D4833 | 120 lbs |
| Trapezoidal Tear | ASTM D4533 | 95 lbs |
| UV Resistance | ASTM D4355 | 70% after 500 hours |

## 3.2 GEONET

The geonet materials will be made of new, high-density polyethylene (HDPE) or very flexible polyethylene (VFPE) materials, as required by the design drawings, manufactured specifically for the purpose of liquid conveyance. The geonet will have, unless otherwise indicated in these specifications or project drawings, the following minimum property values.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Thickness, mil | ASTM D 5199 | 200 (0.200 inch) |
| Density, min., g/cc | ASTM D 1505 | 0.940 |
| Carbon Black Content, % | ASTM D 1603 | 2.0 |
| Tensile Strength, (Peak, MD), lb/in | ASTM D 7179 | 45 |
| Transmissivity, (MD), gal/min·ft | ASTM D 4716 | 9.66 |

## 3.3 GEOMEMBRANE

The flexible membrane liner (FML) or geomembrane materials will be made of new, high-density polyethylene (HDPE) or very flexible polyethylene (VFPE or LLDPE) materials, as required by the design drawings, manufactured specifically for the purpose of liquid containment. All geomembrane liner materials will have sufficient strength and resistance to chemical or ultraviolet radiation attack for the intended use. Minimum specifications, unless otherwise indicated, for HDPE materials are included in the table below.

Minimum Specifications for 80 mil High Density Polyethylene Liner – Textured on both sides

| Property | Test Method | Value |
|---|---|---|
| Thickness, minimum average, mil | ASTM D5994 | 76 (0.076 inch) |
| Density | ASTM D1505 | 0.94 gm/cm$^3$ |
| Tensile strength @ yield | ASTM D6693 | 168 lb/in-width |
| Tensile strength @ break | ASTM D6693 | 120 lb/in-width |
| Elongation @ yield | ASTM D6693 | 12% |
| Elongation @ break | ASTM D6693 | 100% |
| Puncture Resistance, lb | ASTM D4833 | 120 |
| Tear Resistance, lb | ASTM D1004 | 56 |
| Percent carbon black | ASTM D1603 | 2.0% |

Minimum Specifications for 80 mil High Density Polyethylene Liner – Textured on one side

| Property | Test Method | Value |
|---|---|---|
| Thickness, minimum average, mil | ASTM D5994 | 76 (0.076 inch) |
| Density | ASTM D1505 | 0.94 gm/cm$^3$ |
| Tensile strength @ yield | ASTM D6693 | 168 lb/in-width |
| Tensile strength @ break | ASTM D6693 | 120 lb/in-width |
| Elongation @ yield | ASTM D6693 | 12% |
| Elongation @ break | ASTM D6693 | 100% |
| Puncture Resistance, lb | ASTM D4833 | 120 |
| Tear Resistance, lb | ASTM D1004 | 56 |
| Percent carbon black | ASTM D1603 | 2.0% |

Minimum Specifications for 60 mil High Density Polyethylene Liner – Textured on both sides

| Property | Test Method | Value |
|---|---|---|
| Thickness, minimum average, mil | ASTM D5994 | 57 (0.057 inch) |
| Density | ASTM D1505 | 0.94 gm/cm$^3$ |
| Tensile strength @ yield | ASTM D6693 | 126 lb/in-width |
| Tensile strength @ break | ASTM D6693 | 90 lb/in-width |
| Elongation @ yield | ASTM D6693 | 12% |
| Elongation @ break | ASTM D6693 | 100% |
| Puncture Resistance, lb | ASTM D4833 | 90 |
| Tear Resistance, lb | ASTM D1004 | 42 |
| Percent carbon black | ASTM D1603 | 2.0% |

The Manufacturer will certify that the geomembrane has been inspected and quality-control tested during the manufacturing process, and that the materials are free of holes, blisters, undispersed raw materials, and contamination by foreign materials.

In addition, the Manufacturer will certify that the geomembrane meets all strength and resistance requirements for the intended use.

Documentation must be provided verifying that all factory welds meet the requirements for field seaming, and that the destructive and non-destructive testing required for field seaming has been performed also for factory seams.

## 3.4 GEOCOMPOSITE

The geocomposite is a geonet sandwiched between two layers of geotextile to create a double-sided geocomposite. The geocomposite final product and its components will have the following property values.

Minimum specifications for the geocomposite material comprised on a 200 mil geonet bonded to two 6 ounce geotextile layers.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Transmissivity, (MD), gal/min·ft | ASTM D4716 | 0.48 |
| Ply Adhesion, lb/in | ASTM D7005 | 1 |

Minimum specifications for the geonet component.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Thickness, mil | ASTM D5199 | 200 |
| Density, min., g/cc | ASTM D1505 | 0.940 |
| Carbon Black Content, % | ASTM D1603 | 2.0 |
| Tensile Strength, (Peak, MD), lb/in | ASTM D5035 | 45 |
| Transmissivity, (MD), gal/min·ft | ASTM D4716 | 9.66 |

Minimum specifications for the geotextile component.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Unit Weight, oz/yd$^2$ | ASTM D5261 | 6 |
| Grab tensile strength, lb | ASTM D4632 | 170 |
| Puncture strength, lb | ASTM D4833 | 90 |
| Permittivity, sec$^{-1}$ | ASTM D4491 | 1.5 |
| Flow rate, gal/min/ft | ASTM D4491 | 110 |
| UV Resistance | ASTM D4355 | 70% after 500 hours |
| AOS, USC Sieve (mm) | ASTM D4751 | 70 |

Minimum specifications for the geocomposite material comprised on a 300 mil geonet bonded to two 8 ounce geotextile layers.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Transmissivity, (MD), gal/min·ft | ASTM D4716 | 4.35 |
| Ply Adhesion, lb/in | ASTM D7005 | 1 |

Minimum specifications for the geonet component.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Thickness, mil | ASTM D5199 | 300 |
| Density, min., g/cc | ASTM D1505 | 0.940 |
| Carbon Black Content, % | ASTM D1603 | 2.0 |
| Tensile Strength, (Peak, MD), lb/in | ASTM D5035 | 75 |
| Transmissivity, (MD), gal/min·ft | ASTM D4716 | 38.64 |

Minimum specifications for the geotextile component.

| Property | Test Method | Minimum Property Value |
|---|---|---|
| Unit Weight, oz/yd$^2$ | ASTM D5261 | 8 |
| Grab tensile strength, lb | ASTM D4632 | 220 |
| Puncture strength, lb | ASTM D4833 | 120 |
| Permittivity, sec$^{-1}$ | ASTM D4491 | 1.5 |
| Flow rate, gal/min/ft | ASTM D4491 | 110 |
| UV Resistance | ASTM D4355 | 70% after 500 hours |
| AOS, USC Sieve (mm) | ASTM D4751 | 80 |

## 3.5 GEOSYNTHETIC CLAY LINER (GCL)

This liner system component is a reinforced GCL consisting of a layer of sodium bentonite between two nonwoven geotextiles. The final product will have the following minimum values.

| Property | Test Method | Value |
|---|---|---|
| Bentonite Swell Index, mL/2g | ASTM D5890 | 24 (min) |
| Bentonite Fluid Loss, ml | ASTM D5891 | 18 (max) |
| Bentonite Mass/Area, lb/ft$^2$ | ASTM D5993 | 0.75 (min) |
| GCL Grab Strength, lbs/in MARV | ASTM D6768 | 50 |
| GCL Peel Strength, lbs/in | ASTM D6496 | 3.5 (min) |
| GCL Index Flux, m$^3$/m$^2$/sec | ASTM D5887 | 1x10$^{-8}$ (max) |
| GCL Hydraulic Conductivity, cm/sec | ASTM D5887 | 5 x 10$^{-9}$ (max) |
| GCL Hydrated Internal Shear Strength, psf | ASTM D5321 & D643 | 500 @ 200 psf |
| Textile Backing Weight, oz/sy | ASTM D3776 | 6 |

The bentonite will be bonded between the confining geotextiles in a manner to ensure that the bentonite will not be displaced during handling, transportation, storage and installation, including cutting, patching, and fitting around penetrations.

## 4. PIPING

Pipe used for LCRS collectors, LCRS risers, and LDS risers will consist of steel, HDPE, and polyethylene pipe materials of the type and diameters specified in project drawings. Collection piping will be of the diameter, wall thickness, and perforation detail indicated in project drawings. Non-perforated riser piping will be 12-inch diameter with a minimum standard dimensional ratio (SDR) of 17.0. All piping connections will be made in accordance with manufacturer recommendations.

# APPENDIX C

# CONSTRUCTION METHOD SPECIFICATIONS

# 1. INTRODUCTION

The Construction Specifications document provides detailed discussion and specifications for the construction of the at-grade and below-grade features of Trench 12. Within this Construction Specifications document, the following reference convention is used:

- References to material specifications are to Appendix B of the CQA Plan; and
- References to design drawings are to Appendix A of the CQA Plan. Drawings are referenced by the last three digits of their sequential number, e.g., Drawing NV12-07-007 is referred to as Drawing 007.

This presentation of Construction Specifications is supplemental to such information provided in project drawings. In the event that information being included herein is in any way incomplete or conflicts with that provided in project drawings, the project drawings are to be considered primary.

## 2. PHYSICAL LAYOUT

This work will consist of the layout of excavation area limits and other construction details. All components will be laid out in accordance with the location, lines and grades, and construction details shown on the project plans. Staking will be verified in accordance with the plans using standard surveying and inspection techniques.

Verification of the constructed dimensions (line, grade, and elevation) of the excavated trench will be accomplished in accordance with the following:

- As-constructed cross-sections of the excavated trench surveyed for each 100 linear feet of cover dimension in both the transverse and longitudinal directions or by other survey method providing equivalent dimensional accuracy; and
- The CQA Officer will be responsible for verifying construction by checking survey data for compliance with the design drawings. Any significant differences will be noted by the CQA Officer, and the Project Manager will be notified.

Changes to line and grade will have the approval of the Project Engineer prior to implementation.

# 3. EARTHWORK

Trench 12 site excavation activities include excavation and improvement of the surface soil layer, trench excavation, and excavation of LCRS riser recesses. Trench 12 will be excavated in three phases, with the westernmost portion planned to be the initial phase, and the middle and easternmost portions as the second and third phases (respectively). The eastern portion of the Trench 12 footprint overlies the existing site entrance, office, water storage tank, and other facilities. The facilities in this area must be completely relocated before Phase 12C excavation is done, but removal and relocation of some of these facilities might be required to provide access to the Trench 12 work area prior to Phase 12C.

## 3.1 EXCAVATION LIMITS

The excavation plan and horizontal limits of grading for Trench 12 are provided in Drawings 003 and 004.

### 3.1.1 Surface Soil Recompaction Excavation Limit

Drawing 003 shows the estimated horizontal limit of the excavation around the Trench 12 perimeter for surface soil removal and recompaction. The actual horizontal limits of the soil recompaction excavation will be based on field determination of the depth of the loose surface soil layer.

### 3.1.2 Anchor Trench Excavation Limit

The inside horizontal limit of the Trench 12 liner system anchor trench excavation is 5.0 feet outside of the HCL (away from the excavation crest) as shown on Drawing 004.

### 3.1.3 Trench 12 Excavation Limit

The excavation plan and horizontal limit of excavation for Trench 12 are provided in Drawing 004. Excavation slopes do not differ from those considered in the 1996 Trench 12 design (which was reviewed and approved by NDEP) and slope stability was fully addressed in the 1996 Design and supporting documents, as referenced by the current RCRA Permit. Trench bottom elevations and grades shown on Drawing 004 are those for the top of the subgrade, that

also corresponds approximately to the top of the liner system (excluding the 2.5-feet thick operations layer that will overlie the liner system).

Trench bottom grades are controlled by the elevation of the three LDS/LCRS sumps, with minimum floor slopes set at one percent in Phase 12A and most of Phase 12C, and at two percent in portions of Phase 12B and Phase 12C. Floor slopes facilitate leachate drainage into each of the three sumps. Bottom grading for Phase 12B and part of Phase 12C differs from one percent because of geometry constraints (see Drawing 004).

A horizontal control line (HCL) provides the lateral limit of excavation as shown on Drawings 002 and 004. The HCL is determined from constraints on the lateral extent of waste as described in Chapter 1.0 of the CQA Plan. The position of the HCL is consistent with the property lease agreement between USEN and the State of Nevada, and is about 20 feet inside the permitted facility boundaries (north and west sides), 50 feet inside the boundary with the closed LLRW disposal facility, and 50 feet from the western limit of disposed waste in Trench 11.

Trench depth (maximum) is about 75 feet. Sidewalls are designed with 0.5:1.0 (H:V) slopes, except at curved sections where constant-radius curves (which do not vary with elevation) are specified in order to facilitate efficient construction and a smooth transition for the lining system. These curved sections have slopes that are flatter than 0.5 1.0.

Excavated soil materials will be stockpiled off-site to the north of Trench 12. Some materials will be segregated by gradation, including materials that will be selectively screened on-site before reuse as Trench 12 construction materials.

## 3.2 SURFACE SOIL RECOMPACTION AREA – TRENCH PERIMETER

### 3.2.1 Surface Soil Recompaction Excavation Limit

Calculations provided with the 1996 Design documentation (as approved by NDEP in the previous and current RCRA Permits) conclude that this surface soil layer needs to achieve a cohesion value of approximately 1,000 pounds per square foot (PSF). Additional slope stability calculations done to complete the 2007 Final Design (Engineering Report Supplement, Attachment 3) indicate that this criterion is overly conservative, and that sufficient stability can be achieved by removing and recompacting the surface soil layer to achieve a cohesion value of

about 250 PSF. Laboratory testing conducted using Trench 12 area soil indicates that this cohesive strength can be achieved using the natural surface soil when recompacted to 90% MDD (by ASTM D 1557). These material amendment and compaction specifications are provided in Section 2.1 of Appendix B. Removal and recompaction of the surface soil around the Trench 12 perimeter must be completed prior to trench excavation.

Appendix A, Drawing 003 shows the expected limits of surface soil excavation. The Project Engineer or CQA personnel will determine the actual depth of the surface soil recompaction excavation as excavation proceeds. The horizontal and vertical limits of this excavation will be controlled to be as small an area (and volume) as is practical while assuring that the volume (and footprint) of surface soil recompaction is sufficiently large to include: 1) the horizontal control line (HCL) defines the lateral limit of the Trench 12 excavation, 2) the limits of the liner anchor trench, and 3) the limits of the compacted soil starter berm. The minimum horizontal limits of the surface soil recompaction excavation, as shown on Drawing 003, are designed to include these features.

Surface soil recompaction inspection activities that will be conducted during fill conditioning, placement, and compaction include:

- Testing of fill material characteristics;
- Measurement of loose lift thickness;
- Testing of the density and moisture content of the compacted fill;
- Ensuring that the fill contains no organic or other deleterious materials; and
- Observation of type of compaction equipment, number of passes, and uniformity of compaction coverage.

Sampling and testing of the fill materials will be accomplished periodically to verify type, gradation, and compaction curves to ensure the fill materials meet the applicable construction and materials specifications. The following minimum testing frequencies will be used.

- Moisture-density tests and grain-size determinations will be done to confirm that the material is acceptable and to determine fill compaction requirements. At least three sets of such tests will be done. The test results will be compared to the properties of materials tested during the development of the 2007 Design, as provided in Attachment 3 of the

Engineering Report Supplement, to confirm that an acceptable cohesive strength can be obtained using natural materials

- In-situ density tests will be performed at a minimum of one test per compacted lift or one test for every 2,000 cubic yards placed, whichever is less. (i.e. MORE TESTS)

A schedule of the soil placement inspection requirements is attached as Table C-1. If the grain size analysis test results do not satisfy project specifications, the Project Engineer will be contacted to determine the acceptability of the fill material.

In the event that density testing indicates that the target density is not achieved, the area within 100 feet of the failing testing will be recompacted and retested. Confirmation of satisfactory compaction in a re-compacted area will be by done by three satisfactory density tests, at locations selected to represent the entire 100 by 100 feet area, passing the density specification.

## 3.3 TRENCH SIDEWALLS

### 3.3.1 Sidewall Preparation

The possible irregularity of the excavated surface of Trench 12 sidewalls was addressed by USEN and NDEP in a series of questions and responses concerning the 1996 Design. At that time, it was agreed that some sidewall surface irregularities might require application of a filler material, such as a sprayed concrete surfacing e.g., gunite). A criterion for determining which such irregularities would require filler was developed during the exchange of information between USEN and NDEP. That criterion was that the yield strength of the weakest geosynthetic material should not be exceeded. This yield-based criterion is considered to be overly conservative for the following reasons.

1. On the basis of strain at yield, the HDPE geomembranes are the weakest liner system components. The 60-mil geomembrane yields at about 12 percent strain. However, material yield is not the same as material failure. An HDPE stretched past its yield strain still is an effective hydraulic barrier until it fails (tears), and the HDPE geomembrane will stretch to about 100 percent strain before failing.

2. Though deviations from a planar surface could be common in the excavated Trench 12 sidewalls, such irregularities are expected to be isolated. As such, zones within the geomembrane that might experience strains that exceed the yield criterion when waste is placed against the liner are not likely to be continuous over a long distance. Small yielded areas are not likely to significantly affect the overall strength of the liner system.

3. Loading against the liner system that could cause geomembrane components to stretch will be caused only by waste placement. If a small portion of the geomembrane is stretched to the point of exceeding its yield strength, there will be little load placed on the yield liner system member from materials lower on the sidewall since the placed wastes below the yielded area actually will be supporting the liner.

To reduce the possibility for surface irregularities to cause liner material strain, the Trench 12 sidewalls will be smoothed with a dragged chain or other method that can remove sharp or abrupt edges. As necessary, projecting objects, such as large or sharp-surfaced rocks, will be mechanically or manually removed. Deep sidewall depressions that cannot be satisfactorily smoothed will be filled with gunite or other suitable material. The determination that the sidewall surface has been satisfactorily smoothed or that further action, such as filling, will be made and documented by CQA personnel.

### 3.3.2 Slope Riser Trenched Recesses

As shown in Section C on Drawing 007, shallow recesses will be excavated into the trench sidewalls for placement of the LDS riser pipes that extend up the sidewalls from each of the three LDS sumps. The trenched recesses will allow the primary liner system (components above the primary HDPE geomembrane) to be installed above the secondary liner system and flush with trench sidewalls. The trenched recesses will be cut by backhoe or excavator as excavation proceeds. Light-weight concrete (or other satisfactory fill material) will be used as necessary to fill the trenched recesses after the secondary liner and LDS piping are placed and restore a suitable sidewall surface over which the primary liner system can be placed.

## 3.4 TRENCH BOTTOM SUBGRADE PREPARATION

The excavated trench bottom locations will be overlain by a compacted subgrade material that will be a minimum of 9.0 inches thick beneath all portions of the trench bottom except for sump areas, and will be a minimum of 36.0 inches thick beneath the sump areas (See Sections A and B of Drawing 007, and Sections A, B, and C of Drawing 008). The horizontal limits of the prepared subgrade layer will be the base of the trench sidewalls. The prepared subgrade layer will not be placed on trench sidewalls.

The purposes of this prepared subgrade layer are to provide:

- A smooth bearing surface for the geosynthetic components of the liner system;
- A low permeability stratum (1 x $10^{-5}$ cm/sec hydraulic conductivity) as required by the RCRA Permit, and
- Additional leachate adsorption capacity to supplement that of the GCL components.

Included in the Engineering Report Supplement is a summary of laboratory testing of Trench 12 soil materials conducted in accordance with RCRA Permit requirements. A portion of these required soil tests were conducted to confirm that the required hydraulic conductivity of subgrade materials could be achieved using either natural materials excavated from Trench 12 or natural materials mixed with another soil material. This testing confirmed that the specified hydraulic conductivity can be achieved using soil excavated from Trench 12 when not more than 10 percent (by weight) of these soil materials is more coarse than about 1.0-inch and at least 10 percent (by weight) is smaller than the #200 sieve (silt and clay size particles). USEN expects to segregate and stockpile excavated materials satisfying the necessary grain-size specification for subgrade construction. As necessary to achieve the grain-size specification, the natural materials will be screened (on site) and amended (as necessary) with fine grained soil.

The capacity of the proper gradation of subgrade material to achieve the hydraulic conductivity specification is documented in the Engineering Report Supplement. Quality control testing to confirm that the material stockpiled has the proper gradation will be determined by grain-size analyses of randomly located stockpile samples done at a frequency of one test per 2,000 cubic yards of material stockpiled. If the grain size analysis test results do not satisfy project specifications, the Project Engineer will be contacted to determine the acceptability of the fill material.

The layer will be placed and compacted to 90 percent of maximum dry density at a moisture content between the OMC and OMC +2%, as determined by ASTM D1557. The achievement of the proper subgrade compaction requirement will be determined by in-situ density tests performed at a minimum of one test per each one test for every 10,000 square feet of subgrade placed. A schedule of the subgrade placement inspection requirements is attached as Table C-1.

In the event that density testing indicates that the target density is not achieved, the area within 100 feet of the failing testing will be recompacted and retested. Confirmation of satisfactory

compaction in a re-compacted area will be by done by three satisfactory density tests, at locations selected to represent the entire 100 by 100 feet area, passing the density specification.

## 3.5 COMPACTED EARTH FILL PERIMETER BERM

The compacted earth fill perimeter berm (starter berm) will be constructed of soil materials meeting the requirements of Appendix B, compacted in nine-inch to 12-inch lifts to a density of at least 90 percent MDD and at a moisture contents between the OMC and OMC +2%, as determined by ASTM D-1557.

In-situ density tests will be performed at a minimum of one test per compacted lift or one test for every 2,000 cubic yards placed, whichever is less. In the event that density testing indicates that the target density is not achieved, the area within 100 feet of the failing testing will be recompacted and retested. Confirmation of satisfactory compaction in a re-compacted area will be by done by three satisfactory density tests, at locations selected to represent the entire 100 by 100 feet area, passing the density specification.

A schedule of the soil placement inspection requirements is attached as Table C-1. If the grain size analysis test results do not satisfy project specifications, the Project Engineer will be contacted to determine the acceptability of the fill material.

## 4. GEOSYNTHETIC MATERIALS (GENERAL)

The supplier of the geosynthetic materials will provide documentation confirming that the raw materials comply with the physical properties and performance requirements specified in Appendix B. The CQA Officer will review this information to ensure that the test results indicate that the materials meet these specifications. Documentation of the test results will be provided to the Project Engineer. Any non-conformance will be documented and reported to the Project Manager for corrective action recommendations.

# 5. GEOSYNTHETIC CLAY LINER (GCL)

The GCL materials will comply with the properties listed in Appendix B.

## 5.1 LABELING, PACKAGING, TRANSPORTATION AND STORAGE

CQA personnel will verify that the proper documentation accompanies each delivery of GCL to the job site and that the GCL is properly stored and protected from damage. The geomembrane material will be inspected by the CQA Officer to confirm that it is not damaged or to ensure that any damage observed is corrected. Damage could include:

- Puncture from nails or splinters;
- Tears from operation of equipment or inadequate packaging;
- Exposure to temperature extremes resulting in unusable material; or
- Crumpling or tearing from inadequate packaging support.

When damage to protective wrappers or outer material layers has occurred, careful examination of the underlying material by CQA personnel is required. If damage is found, CQA personnel will carefully examine the entire shipment for damage and document the defect. The Project Manager will be informed immediately of any damage to the geomembrane material.

Labeling - Each GCL roll delivered should be labeled with the following, as a minimum:

- Manufacturer's Name;
- Product Identification;
- Batch or lot number;
- Roll Number; and
- Roll length and width.

Any roll delivered to the site without the proper labeling will, at the Project Manager's discretion, be rejected and subsequently removed from the site at the expense of the Manufacturer or Installer.

Packaging - The GCL will be wound around a rigid core whose diameter is sufficient to facilitate handling. The core is not necessarily intended to support the roll for lifting but should be sufficiently strong to prevent collapse during transit.

All rolls will be labeled and bagged in packaging that is moisture-proof and resistant to photo-degradation by UV radiation.

Transportation - The Manufacturer assumes responsibility for initially loading the GCL. Shipping will be the responsibility of the party paying the freight. Unloading, on-site handling and storage of the GCL are the responsibility of the Installer.

A visual inspection of each roll should be made during unloading to identify if any packaging has been damaged. Rolls with damaged packaging should be marked and set aside for further inspection. The packaging should be repaired prior to being placed in storage.

The party responsible for unloading the GCL should contact the Manufacturer prior to shipment to ascertain the appropriateness of the proposed unloading methods and equipment.

Storage - Storage of the GCL rolls will be the responsibility of the Installer. A dedicated storage area will be selected at the job site that is away from high traffic areas and is level, dry and well-drained.

Rolls should be stored in a manner that prevents sliding or rolling from the stacks and may be accomplished by the use of chock blocks or the dunnage shipped between rolls. Rolls should be stacked at a height no higher than that at which the lifting apparatus can be safely handled (typically no higher than four).

All stored GCL materials and the accessory bentonite must be covered with a plastic sheet or tarpaulin until their installation.

The integrity and legibility of the labels will be preserved during storage.

## 5.2 SUBGRADE PREPARATION

The subgrade should be compacted (trench bottom) and graded or otherwise made smooth (trench bottom and sidewalls) prior to placement of the GCL. The subgrade will be free of debris and possible damaging material, such as

- Vegetation,
- Construction Debris,
- Sticks,
- Sharp rocks,
- Void spaces,
- Ice,
- Abrupt elevation changes,
- Standing water,
- Cracks larger than one-quarter inch in width,
- Any other foreign matter that could contact the GCL.

Immediately prior to GCL deployment, the subgrade will be final-graded to fill in voids or cracks to provide a relatively smooth surface for the GCL. At completion of this activity, no wheel ruts, footprints or other irregularities will exist in the subgrade. Furthermore, all protrusions extending more than one-inch (2.54 cm) from the surface will be removed, crushed or pushed into the surface manually or with a smooth-drum compactor. Areas that are judged to be too rough for GCL placement will be covered with at least one layer of geotextile material at least 0.100 inch thick.

On a continuing basis, the project CQA Officer will certify acceptance of the subgrade. It will be the GCL Installer's responsibility thereafter to indicate to the Project Manager any change in the condition of the subgrade that could cause the subgrade to be out of compliance with any of the requirements listed in this section.

## 5.3 GCL INSTALLATION

GCL rolls should be delivered to the working area of the site in their original packaging. Immediately prior to deployment, the packaging should be carefully removed without damaging the GCL. The orientation of the GCL (i.e., which side faces up) should be in accordance with the Project Manager's recommendations. However, unless otherwise specified, the GCL should be installed such that the product name printed on one side of the GCL faces up.

The CQA Officer will verify that GCL installation is performed in accordance with the specification. During installation, the following observations will be performed.

- Observations to ensure that workers are not engaging in any activity that could damage the liner.
- Observations to verity that the material is not damaged during the installation process.
- Observations of the anchor trench to ensure that it has been constructed as specified in the design drawings. Trench corners will be rounded to prevent stressing the geomembrane. Backfilling of the trench will be performed as soon as possible and compacted with care so as not to damage the GCL.
- The GCL will be installed to minimize instances of excessive tension or wrinkles.
- GCL panels should be placed so that edges are oriented parallel to steep slopes (trench sidewalls only). In corners and other tight areas, panel deployment will be performed such that field seams are minimized.
- Observations of the weather conditions (i.e., temperature, humidity, precipitation, and wind) to ensure that they are acceptable for GCL placement.
- Measurements to confirm that required overlaps of adjacent GCL panels were achieved, that proper temporary anchorage was used (e.g., sand bags or tires).

As each GCL panel is placed, it will be inspected visually for tears, punctures, or other damage. To accomplish this, the panels will be traversed by CQA personnel in such a way that the entire surface is inspected. Any defects will be marked for repair.

The GCL must be dry when installed and will not be installed in standing water or during rain. The GCL will be covered with the overlying geomembrane as soon as is practical to prevent exposure to weather. GCL that becomes hydrated must be replaced before placement of the overlying geomembrane.

Equipment that could damage the GCL will not be allowed to travel directly on top of the material. Acceptable installation, therefore, can be accomplished such that the GCL is unrolled in front of the backwards-moving equipment. If the installation equipment causes rutting of the subgrade, the subgrade must be restored to its originally accepted condition before placement continues. GCL rolls will not be released on the slope and allowed to unroll freely by gravity.

Care must be taken to minimize the extent to which the GCL is dragged across the subgrade in order to avoid damage to the bottom surface of the GCL. A temporary geosynthetic subgrade covering, commonly known as a slip sheet or rub sheet, may be used to reduce friction damage during placement.

All GCL panels should lie flat on the underlying surface, with no wrinkles or folds, especially at the exposed edges of the panels. The GCL will be installed in a relaxed condition and will be free of excessive tension or stress upon completion of the installation. Stretching of the GCL to fit will not be allowed. The GCL will be pulled tight to smooth out creases or irregularities in the runs.

Only as much GCL will be deployed as can be covered at the end of the working day with soil, a geomembrane, or a temporary waterproof tarpaulin. The GCL will not be left uncovered overnight. If the GCL is hydrated when no confining stress is present, it may be necessary to remove and replace the hydrated material. The Project Manager, CQA Officer, and GCL fabricator should be consulted for specific guidance if premature hydration occurs.

## 5.4 JOINING GCL PANELS

The GCL will be placed so that panel edges are parallel to the direction of the slope. Panel ends at the juncture between sidewalls and trench bottom should be overlapped by at least three feet. Joining of panel ends on steep sidewall slopes (i.e., trench 0.5:1.0 sidewalls) will not be allowed. Thus, full length seamless panels, overlapped by at least six inches on edges, are required for Trench 12 sidewalls. Seams at the ends of the panels should be constructed such that they are shingled in the direction of the grade to prevent the potential for runoff flow to enter the overlap zone.

For joining panels on the trench floor, bentonite-enhanced seams are to be emplaced between the overlapping adjacent panels. The underlying edge of the longitudinal overlap is exposed and then a continuous bead of granular sodium bentonite is applied along a zone defined by the edge of the underlying panel and the six-inch line. A similar bead of granular sodium bentonite is applied at the end-of-roll overlap. The bentonite will be applied at a minimum application rate of about one quarter pound per lineal foot of panel edges and ends.

The granular bentonite or bentonite sealing compound used for seaming, penetration sealing, and repairs will be made from the same natural sodium bentonite as used in the GCL and will be as recommended by the GCL fabricator.

## 5.5 DETAIL WORK AND PATCHING

The GCL will be sealed around penetrations and embedded structures embedded in accordance with the design drawings.

Cutting the GCL should be performed using a sharp utility knife. Frequent blade changes are recommended to avoid damage to the geotextile components of the GCL during the cutting process or damage to any underlying geosynthetic materials.

If the GCL is damaged (torn, punctured, perforated, etc.) during installation, it may be possible to repair it by cutting a patch to fit over the damaged area. The patch will be obtained from a new GCL roll and will be cut to size such that a minimum overlap of 12 inches is achieved around all of the damaged area. Dry bentonite or bentonite mastic should be applied around the damaged area prior to placement of the patch. It may be desirable to use an adhesive to affix the patch in place so that it is not displaced during cover placement. These repair pieces should not be stapled.

# 6. GEOCOMPOSITE/GEONET

The geocomposite and geonet materials will comply with the properties listed in Appendix B.

## 6.1 LABELING, PACKAGING, TRANSPORTATION AND STORAGE

The CQA Officer will check all delivery tickets and Manufacturer's quality control documentation to verify that all required shipping information is provided and to verify that the geocomposite/geonet rolls received meet the project specifications in Appendix B. The geocomposite/geonet material also will be inspected by the CQA Officer to confirm that it is not damaged and to ensure that any damage is corrected. Damage may include:

- Puncture from nails or splinters;
- Tears from operation of equipment or inadequate packaging;
- Exposure to temperature extremes resulting in unusable material; or
- Crumpling or tearing from inadequate packaging support.

When damage to a protective wrapping or outer material layer has occurred, careful examination of the underlying material by CQA personnel is required. If damage is found, CQA personnel will carefully examine the entire shipment for damage and document the defect. The Project Manager will be informed immediately of any damage to the geocomposite/geonet material.

Labeling - Each geocomposite/geonet roll delivered must be labeled with the following, as a minimum:

- Manufacturer's Name;
- Product Identification;
- Batch or lot number;
- Roll Number; and
- Roll length and width.

Any roll delivered to the site without the proper labeling will, at the Project Manager's discretion, be rejected and subsequently removed from the site at the expense of the Manufacturer or Installer.

Packaging - The geocomposite/geonet rolls will be wrapped in a plastic cover. The rolls will be shipped to the job site in a manner not to damage the rolls. The geocomposite/geonet will be wound around a rigid core whose diameter is sufficient to facilitate handling. The core is not necessarily intended to support the roll for lifting but should be sufficiently strong to prevent collapse during transit.

Transportation – The Manufacturer assumes responsibility for initially loading the geocomposite/geonet. Shipping will be the responsibility of the party paying the freight. Unloading, on-site handling and storage of the geocomposite/geonet are the responsibility of the Installer.

A visual inspection of each roll should be made during unloading to identify if any packaging has been damaged. Rolls with damaged packaging should be marked and set aside for further inspection. The packaging should be repaired prior to being placed in storage.

The party responsible for unloading the geocomposite/geonet should contact the Manufacturer prior to shipment to ascertain the appropriateness of the proposed unloading methods and equipment.

Storage - Storage of the geocomposite/geonet rolls will be the responsibility of the Installer. A dedicated storage area will be selected at the job site that is away from high traffic areas and is level, dry and well-drained. Rolls should be stored in a manner that prevents sliding or rolling from the stacks and may be accomplished by the use of chock blocks or by use of the dunnage shipped between rolls. Rolls should be stacked at a height no higher than that at which the lifting apparatus can be safely handled (typically no higher than four).

The integrity and legibility of the labels will be preserved during storage.

## 6.2 SUBGRADE PREPARATION

Geocomposite/geonet placement will be on top of other geosynthetic members of the liner system. Thus, only minimal surface preparation is expected to be necessary, such as sweeping or manual removal of soil, rock, or other solid material particles. Before installing geocomposite/geonet material, the Installer will provide written certification to the CQA Officer that the surface on which that geosynthetic material will be installed is acceptable. It will be the Installer's responsibility thereafter to indicate to the Project Manager any change in the condition of this surface that could cause the geocomposites/geonet to be out of compliance with any of the requirements listed in this section.

## 6.3 GEOCOMPOSITE/GEONET INSTALLATION

Rolls should be delivered to the working area of the site in their original packaging. Immediately prior to deployment, the packaging should be carefully removed without damaging the material. The subgrade should be free of foreign and organic material, sharp objects, or debris of any kind, which could potentially damage the geocomposite/geonet. The rolls should be deployed using a spreader bar assembly attached to a loader bucket or by other methods approved by the Project Engineer. The orientation of the geocomposite/geonet panels should be in accordance with the Project Manager's recommendations. On side slopes, the rolls must be deployed in the general direction of the maximum slope. The deployment equipment must not damage the underlying subgrade or geosynthetic materials. A smooth rub sheet may be needed for installation of the geocomposite/geonet over a textured geomembrane. The rub sheet is placed between the geocomposite/geonet and the textured geomembrane to prevent damage to geocomposite/geonet during positioning. The rub sheet must be removed after deployment. Drainage net and geocomposite/geonet should be placed and secured in an anchor trench as shown on the project drawings. Sandbags should be placed on leading edges of the panels to prevent wind uplift.

Observations of the anchor trench should be made to ensure that it has been constructed as specified in the design drawings. Trench corners will be rounded to prevent stressing the geocomposite/geonet. Backfilling of the trench will be performed as soon as possible and compacted with care so as not to damage the geocomposite/geonet.

## 6.4 JOINING GEOCOMPOSITE/GEONET PANELS

As each geocomposite/geonet panel is placed, it will be inspected visually for tears, punctures, or other damage or defect. To accomplish this, the panels will be traversed by CQA personnel in such a way that the entire surface is inspected. Any defects will be marked on the geocomposite/geonet for repair. Other general installation requirements include the following.

- Works should not engage in any activity that could damage the material.
- The geocomposite/geonet will be installed to minimize instances of excessive tension or wrinkles.
- The geocomposite/geonet panels will be placed such that seams will be oriented parallel to steep slopes (trench sidewalls only). In corners and other tight areas, panel deployment will be performed such that field seams are minimized.
- Weather conditions (i.e., temperature, humidity, precipitation, and wind) will be observed to ensure that they are acceptable for geocomposite/geonet placement and seaming.
- Measurements will be made to confirm that required overlaps of adjacent geocomposite/geonet e sheets were achieved, that proper temporary anchorage was used (e.g., sand bags or tires), and that specified temporary and final seaming materials/techniques were used.

Geocomposite/geonet panels must be overlapped by a minimum of 2 inches. Non-black (for visibility) plastic ties should be used at 5-feet intervals in the direction of the roll length to tie the drainage net panels. Metallic ties will not be allowed. Joining of panel ends on steep side slopes (i.e., 0.5:1.0 trench sidewalls) will not be allowed. Thus, full length seamless panels (or panels incorporating only factory seams with complete QC documentation) are required on sidewalls. The geotextile flaps of the adjacent panels should be continuously heat-bonded or sewn on all sides.

The CQA Officer will perform the following inspections and observations to verify that field seaming operations are in accordance with these construction specifications.

## 6.5 DETAIL WORK AND PATCHING

Cutting the geocomposite/geonet should be performed using a sharp utility knife. Care must be taken to avoid damage to any underlying geosynthetic materials.

If the geocomposite/geonet is damaged (torn, punctured, perforated, etc.) during installation, it may be possible to repair it by cutting a patch to fit over the damaged area. The patch will be obtained from a new material roll and will be cut to size such that a minimum overlap of 12 inches is achieved around all of the damaged area.

All repairs will be performed as soon as practicable and in accordance with the design specifications. Each repair will be non-destructively tested for continuity. All repairs will be documented including date, location, type, method used, operator, and apparatus.

## 6.6 LINER MATERIAL COVER

The trench floor geocomposite/geonet comprising the top of the liner system should be covered with a Select Waste Operations Layer (Section 2.5 of Appendix B) as soon as possible after placement. The covering operation must not damage the geocomposite/geonet. The cover material must be free of foreign and organic material, sharp objects, or debris of any kind that potentially could damage the geocomposite/geonet. No construction equipment or machinery will be allowed to operate directly on top of the geocomposite/geonet. The use of lightweight machinery (e.g., carts or wheeled generators) with low ground pressure is allowed.

# 7. GEOMEMBRANE

This item will consist of the installation of 60-mil (0.060 inch thick) and 80-mil (0.080 inch thick) high density polyethylene (HDPE) flexible membrane liners meeting the materials requirements of Appendix B at locations shown on the project drawings (Appendix A). The Manufacturer will provide certification that these materials meet the design requirements. The Installer will provide a geomembrane panel layout prior to material placement.

## 7.1 GEOMEMBRANE LABELING, DELIVERY, STORAGE, AND HANDLING

The CQA Officer will check all delivery tickets and Manufacturer's quality control documentation to verify that all required shipping information is provided and to verify that the geomembrane rolls received on site meet the project specifications.

The geomembrane material also will be inspected by the CQA Officer to confirm that it is not damaged and to ensure that any damage is corrected. Damage could include:

- Puncture from nails or splinters;
- Tears from operation of equipment or inadequate packaging;
- Exposure to temperature extremes resulting in unusable material;
- Blocking: the bonding together of adjacent membrane layers, that may be caused by excessive heat; or
- Crumpling or tearing from inadequate packaging support.

When damage to protective wrappers or outer material layers has occurred, careful examination of the underlying material by CQA personnel is required. If damage is found, CQA personnel will carefully examine the entire shipment for damage and document the defect. The Project Manager will be informed immediately of any damage to the geomembrane material.

Geomembrane material will be handled and stored on-site in accordance with this section. The CQA Officer will inform the Project Manager if secure storage is not being provided.

The checks and inspections required by this section will be recorded on an inventory control record that will be retained until the project is certified.

Labeling - Each roll of geomembrane delivered to the site will be labeled by the Manufacturer. The label will clearly state the Manufacturer's name, product identification, thickness, length, width and roll number. The label will be found on either of the end caps, an inside edge of the roll core, and outside the roll core.

Delivery - The rolls of liner will be packaged and shipped by appropriate means to prevent damage to the material and to facilitate off-loading.

Storage - The on-side storage location for geomembrane material should be level, smooth, elevated and dry. The storage place should be protected from damage by vehicles and equipment or vandalism. The Operator will provide a suitable storage site.

Handling - The materials are to be handled so as to prevent damage. Instructions for moving geomembrane rolls will be provided by the Manufacturer upon request.

## 7.2 SURFACE PREPARATION

Geomembrane placement will be on top of other geosynthetic members of the liner system. Thus, only minimal surface preparation is expected to be necessary, such as sweeping or manual removal of soil, rock, or other solid material particles. Before installing geomembrane material, the Installer will provide written certification to the CQA Officer that the surface on which that geosynthetic material will be installed is acceptable. It will be the Installer's responsibility thereafter to indicate to the Project Manager any change in the condition of this surface that could cause the geomembrane to be out of compliance with any of the requirements listed in this section.

## 7.3 GEOMEMBRANE INSTALLATION

### 7.3.1 Panel Layout

The Installer will submit a panel layout drawing for each geomembrane layer to be installed to the Project Manager for review a minimum of one week prior to the pre-construction meeting. The drawings submitted should be of sufficient size and detail to distinguish the geomembrane

panels. The Project Manager reserves the right to reject any drawing submitted and/or to request additional information to be submitted to satisfy the intent of this specification.

No geomembrane installation work will be allowed without the submission and review of the panel layout drawings as required by this specification.

The submitted panel layout will be considered a guideline for both the Installer and the Project Manager to follow. Minor deviations from the submitted layout will be allowed. However, marked deviations to the submitted and reviewed geomembrane panel layout will not be permitted without prior submission of a modification of such to the Project Manager. Any substantial modifications to the geomembrane configuration should be presented, in writing or drawing, by the Installer a minimum of three days in advance of the work to be performed.

### 7.3.2 Weather Conditions

Geomembrane placement will not proceed:

- At ambient temperatures below 34°F as measured at a pre-determined location acceptable to all parties.
- During precipitation events, in the presence of excessive moisture (humidity), or in areas of ponded water.
- In the presence of excessive wind as agreed upon by all parties or as determined by the performance of panels during the placement process.

Any damage incurred by the geomembrane material as a result of excessive wind will be repaired or removed by the Installer at the Installer's expense.

### 7.3.3 General Placement

Assign each panel a simple and logical identifying code. The coding system will be subject to approval and will be determined at the job site.

Visually inspect the geomembrane during placement for imperfections and mark faulty or suspect areas.

The geomembrane will be placed by the Installer in accordance with the following procedures.

- Motorized equipment used to move or place the geomembrane should not be in direct contact with the geomembrane or damage it by leaking fluids or other means. Areas that are damaged in this manner will be removed or repaired at the Installer's expense.
- Unroll geomembrane panels using methods that will not damage geomembrane and will protect underlying surface from damage.
- Personnel working on the geomembrane will not smoke, wear damaging shoes, throw equipment or engage in other activities that could damage the material.
- Do not allow heavy vehicular traffic directly on geomembrane. Rubber-tired ATVs and trucks are acceptable if wheel contact is less than six psi.
- Protect geomembrane in areas of heavy traffic by placing protective cover over the geomembrane.
- The geomembrane panels will be installed to allow for geomembrane expansion and contraction such that there will be neither excessive tension nor excessive wrinkling.

The panels will be placed in such a manner that the geomembrane is not scratched or crimped. Any such damage will be repaired or removed in accordance with the procedures described in this section.

As each geomembrane panel is placed, it will be inspected visually for tears, punctures, and thin spots. To accomplish this, the panels will be traversed by CQA personnel in such a way that the entire surface, including all factory seams, is inspected. Any defects will be marked on the geomembrane for repair. In addition, the thickness determinations for each panel will be performed by the CQA personnel using a micrometer. The panel thickness will be determined at five locations along each edge and each side of the panel. The average thickness along each side and each edge must be at least the nominal thickness, and the thickness for any single reading may not be less than 90 percent of the nominal thickness. If these criteria are not met, the panel must be rejected.

### 7.3.4 Geomembrane Anchoring

The Installer is responsible for both temporary and permanent geomembrane anchorage.

Temporary anchors: Geomembrane panels will be adequately, temporarily anchored by sand bags, rubber tires or a comparable means that does not damage the material, and does not degrade during the time it is in use.

Permanent anchors: The geomembrane panels covering the trench sidewalls will be permanently anchored by placement in anchor trench and being covered with soil as shown in Detail 3 in Drawing 008.

### 7.3.5 Panel Placement and Alignment

The geomembrane will be placed by the Installer in accordance with these procedures or alternate procedures approved in advance by the CQA Officer. As a minimum, the procedures outlined in the following paragraphs will be followed.

- The geomembrane panels will be placed and aligned in general accordance with the panel layout submitted by the Installer, or as modified and made part of this document. In general, the geomembrane panels will be configured to minimize the number of field seams, particularly in corners, odd-shaped geometric locations, and outside corners.

- Geomembrane panels will be placed in a controlled manner, such as pulling, hoisting, or rolling. Uncontrolled placement methods, such as "free-falling" will not be allowed.

- Adjacent geomembrane panels (horizontally adjacent on sidewalls or adjacent in any direction of trench bottom) will be overlapped by a minimum of three inches before seaming is completed. This minimum overlap or greater will be marked by the Installer (such as with chalk or high-visibility marker) at intervals of 25 feet or less on the exposed surface of the lower geomembrane. These markings will facilitate overlap inspection after the geomembrane panels are placed and aligned.

- Geomembrane seams with insufficient overlap will be repaired or replaced by, and at the expense of, the Installer in accordance with the procedures outlined in this section.

- Geomembrane panels placed on trench sidewalls will be continuous (unseamed) or factory seamed panels. Welding of horizontal seams (seams that are not parallel to slope) on the sideswalls will not be allowed.

- Geomembrane panels will be placed to minimize horizontal (cross-panel) seams on slopes steeper than 10 horizontal to 1 vertical. In addition, geomembrane panels placed on slopes that are flatter than 10:1 will be overlapped from top to bottom in the down-slope direction. In this configuration, the up-slope geomembrane panel will overlie the immediately adjacent down-slope panel. The geomembrane panels will be placed and aligned such that the resulting seam locations are, at a minimum, five feet from the toe of slopes and other abrupt changes in grade.

### 7.3.6 Panel Identification

As each geomembrane panel is placed, the Installer will label each in bold print visible from a distance of approximately 30 feet. In general, these markings will be placed in an area that will remain unobscured until overlying geosynthetic layers are placed. It is suggested that the labels be located near each end of the panels across the floor of the landfill area; and, on the crest, just below the crest, and just above the toe of the panels placed on the landfill sidewalls.

The labels will include, as a minimum, the following information.

- A sequential panel number based upon a pre-determined system agreed upon by Installer and CQA Officer.
- The roll number from which the panel was obtained. The Operator reserves the right to reject any geomembrane roll without the proper labeling. Additionally, any portion of a geomembrane roll that cannot be positively identified will be rejected.
- The date the panel was placed.
- The labeling will be made using marking materials that are compatible with the HDPE geomembrane or that is approved by the geomembrane Manufacturer. A sample of the materials used will be submitted to the Project Manager for archiving with the permanent record of construction.

### 7.3.7 Installation Schedule

The Installer will be responsible for seaming all geomembrane panels placed each day or providing adequate temporary anchoring in accordance with this section until such time as they can be seamed.

The Installer will be responsible for tracking and updating the installation schedule as submitted prior to the start of the work. This schedule will be updated, as a minimum, weekly and will be presented to the Project Manager in progress meetings.

## 7.4 FIELD SEAMING

These field-seaming requirements apply to any field seams made in HDPE geomembrane components of the liner system, including, in most aspects, the sacrificial liner materials. However, the sacrificial liner materials may be field seamed on sidewall slopes and quality control testing of seams in the sacrificial liner material is not required.

The CQA Officer will perform and document the required inspections and observations to verify that field seaming operations are in accordance with these construction specifications. Each seam will be observed for seam completeness. Documentation for each seam will include seam identification number, date, weather conditions, identification of seamer and apparatus, and approximate length of seam.

The CQA Officer will verify that the geomembrane has been installed in accordance with all plans and specifications and that all welds have passed both the laboratory strength tests and field tests prior to acceptance of the project by the Project Manager.

### 7.4.1 Geomembrane Panel Alignment

The geomembrane panels will be overlapped and aligned in accordance with this specification. In general, the panels should be installed such that the field seams are aligned parallel to slope (i.e., down and not across slope). Field-welded seams (i.e., seams made on the steep sidewalls) will not be allowed on trench sidewalls.

### 7.4.2 Personnel Requirements

All Installer personnel performing seaming operation will have a minimum of 1,000,000 square feet of experience using the same primary welding technique on HDPE or VFPE liner. In addition, the Installer will have at least one individual with, as a minimum, 2,000,000 square feet of similar experience, including experience at a hazardous waste management facility. No seaming operations will be performed without this individual present.

### 7.4.3 Weather Conditions

Seaming will not proceed when ambient air temperature or adverse weather conditions jeopardize the integrity of the liner installation. Installer will demonstrate that acceptable seaming can be performed by completing acceptable trial welds.

Field seaming of the geomembrane will not be performed at ambient temperatures below 50°F unless the geomembrane seam area is pre-heated, by sun or hot air device, to a temperature higher than 50°F. However, in any case, field seaming of the geomembrane will not be performed at ambient temperatures below 34°F.

The ambient temperature will be measured by a thermometer at a pre-determined location that will be mutually agreed upon by all parties in the pre-construction meeting. The temperature will be recorded at regular, periodic intervals by the CQA Officer.

### 7.4.4 Test Seams

All personnel responsible for seaming will perform test seams on geomembrane samples to verify welding equipment is operating properly. No welding equipment or welder will be allowed to perform production welds until equipment and welders have successfully completed a trial weld. Test seams should be made under the same surface and environmental conditions as the production welds (i.e., in contact with subgrade and similar ambient temperature).

A minimum of two test seams per day, per welding apparatus will be performed, one made prior to the start of work and one completed at mid- shift. A test seam also will be performed whenever seaming is discontinued for more than one hour.

Test seams will be performed on "fragment" pieces of geomembrane and will be a minimum of 12 inches in width by about three feet in length with a minimum of a three-inch overlap and the seam centered along the length.

The Installer will cut two adjacent specimens from near each end of the test seam (four samples total). The specimens will be cut in a controlled manner, by die or template, to a predetermined width. One of each pair of specimens will be tested in shear, the other in peel. In the case of dual-tracked fusion welding, both tracks of the weld will be tested in peel. (Note: Specimens cut in an uncontrolled fashion to a random width will not be acceptable as the strength of test seams is required to be determined).

All test seam specimens will be tested by the Installer in the field for shear and peel using an electrically operated tensiometer, with the capability of registering the force imparted on a geomembrane test specimen. The test seam specimens will be tested at a cross-head rate of two inches per minute. (Note: A hand-operated tensiometer is not acceptable.)

Recent calibration of the load registering device and the cross-head speed will be performed. Documentation of such calibration will be presented prior to the first use of the apparatus.

The Installer will record the following information for the testing performed on each test seam:

- Test seam sample number;
- Date and time of test;
- Welder performing test seam;
- Cross-head rate;
- Specimen number and the peak yield load and failure mode; and
- The force per unit width in pounds per inch. An accurate thickness measurement will be required to calculate stress in pounds per square inch.

### 7.4.5 Test Seam Evaluation Criteria

The criteria for evaluating test seams is as follows:

#### 7.4.5.1 Shear

Two test seam specimens will be tested in shear. Each must fail at a strength equal to or greater than 90 percent of the rated strength of the parent sheet material, or 1,500 psi, whichever is greater. The test seam will be designed as unacceptable if the failure occurs in the weld. If both of these criteria are not met, the entire test seam will be considered failing.

#### 7.4.5.2 Peel

Two test seam specimens will be tested in peel. The peel test will be designated unacceptable if the failure in either specimen occurs in the weld area. If this criterion is not met, the entire test seam will be considered failing.

If a test seam fails, the entire test seam procedure will be repeated after the appropriate adjustments to the welding apparatus have been made. This process will be repeated until a successful test seam has been achieved. Alternatively, if a successful test seam is not achieved the welding apparatus and/or the welder will be rejected by the CQA Officer and will not be used for seaming until such time as the deficiencies are resolved.

### 7.4.6 General Seaming Procedures

The following general seaming procedures must be met by the Installer:

- All geomembrane seams will extend to the end of each panel to be placed in the anchor trench.
- If geomembrane seaming operations are performed at night, adequate lighting will be provided for such as well as for inspection of the seaming conditions and the seams.
- All geomembrane seams will be clean and free of moisture, dust, dirt, debris of any kind, and foreign matter at the time of welding.
- "Fishmouths" and wrinkles at geomembrane seam overlaps will be cut along the ridge of such. Areas with sufficient overlap will be welded in accordance with this specification. Areas of insufficient overlap will be repaired in accordance with the procedures detailed in this section.

### 7.4.7 Extrusion Seaming Requirements

The extrusion welding apparatus will be equipped with temperature gauges that indicate the temperature of the extrudate in the machine.

The extruder will be purged to remove heat-degraded material prior to the beginning of seaming and whenever the extruder is stopped for an appreciable length of time.

### 7.4.8 Fusion Process

The fusion welding apparatus will be a vehicular mounted, automated device.

## 7.5 FACTORY SEAMS

If factory seamed materials are used, that seaming must satisfy the same requirements as field seams. Documentation must be provided that factory seams have been 100 percent non-destructively tested using recommended techniques before the geomembrane material is shipped from the fabrication plant. Rejected seams must be repaired and re-tested before being shipped, or must be re-tested on-site. The CQA Officer will review fabricator's quality control documentation to ensure that proper seaming procedures were followed and the resulting geomembrane material seams are of the specified quality. The CQA Officer will destructively test at least one factory seam sample for each 500 lineal feet of geomembrane factory seam. The CQA Officer will review the quality control documentation. Any necessary repairs to the

geomembrane will be in accordance with approved techniques, and the repaired areas will be non-destructively tested to verify their integrity.

## 7.6 DEFECTS AND REPAIRS

### 7.6.1 General

All seam and non-seam areas of the geomembrane will be visually inspected for signs of defective seams, blisters, punctures, undispersed raw materials, and any sign of contamination by foreign matter. Any problems discovered in both seam and non-seam areas will be marked, repaired and re-tested or reevaluated in accordance with this document. The geomembrane surface will be clean at the time of these inspections.

Any sheets that become seriously damaged (torn or twisted permanently) will be replaced at the Installer's expenses. Less serious damage (inadvertent punctures during installation) will be repaired by welding a piece of geomembrane over the damaged area. The repairs must pass non-destructive tests to be considered adequate.

### 7.6.2 Evaluation

Each suspect location in both seam and non-seam areas will be inspected and, where appropriate, non-destructively tested using the methods described in this document. Work will not proceed with any materials that will cover the locations that require repair or that have been repaired but require testing with passing results. Each patch repair will be numbered and logged.

### 7.6.3 Procedures for Repair

All repairs will be performed as soon as practicable and in accordance with the design specifications. Each repair will be non-destructively tested for continuity. All repairs will be documented including date, location, type, method used, operator, and apparatus.

The repair procedures will be in accordance with these specifications. The details of the specific repair procedures to be followed will be discussed in the pre-construction meeting. Procedures available include the following:

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

- Abrading and Re-welding - Used to repair small sections of deficient seams and small surface blemishes that do not penetrate the entire thickness of the geomembrane. The geomembrane surfaces requiring repair will be abraded no more than one hour prior to the repair being made. Grinding will be performed only within the area requiring repair and care will be taken not to significantly damage the liner.

- Spot Welding - Used to repair pinholes or other minor, localized flaws or where geomembrane thickness has been reduced.

- Capping - Used to repair large lengths of failed seams.

- Flap Welding - Used to extrusion weld the flap (excess outer portion) of a fusion weld in lieu of a full cap.

- Removing the unacceptable seam and replace with new material.

In addition, the following procedures will be observed.

- Surfaces of the HDPE that are to be repaired by extrusion welds will be lightly abraded to assure cleanliness.

- All geomembrane surfaces will be clean and dry at the time of repair. As a minimum, patches and caps (a cap is a patch with an extended length) will extend a minimum of six inches for extrusion weld and four inches for wedge weld beyond the limits of the defect, and all corners of patches and caps will be rounded with a radius of approximately one inch.

The seams associated with caps of long lengths may be destructively tested, if deemed necessary by the CQA Officer.

## 7.7 NON-DESTRUCTIVE SEAM CONTINUITY TESTING

Observations are necessary to verify that non-destructive tests are performed on 100 percent of the field seams. Failed seams will be recorded as to location and seaming crew. The data will be reviewed for possible patterns. Repairs will be made by the Installer in accordance with approved techniques and re-tested to verify their integrity.

### 7.7.1 General

All factory and field seams (except in sacrificial liner material) will be non-destructively tested over their entire length using the pressure test method or the vacuum test method, as appropriate, or other approved method. It is unacceptable for any portion of a seam to remain untested by

one of these methods. Non-destructive testing may be carried out as the seaming progresses or at completion of all field seaming.

Areas thought to be potentially inaccessible to non-destructive continuity testing equipment will be brought to the Project Manager's attention prior to the start of work with the submittal of the geomembrane panel layout drawings.

The non-destructive continuity testing of factory seams will be performed prior to the geomembrane rolls being delivered to the site. The non-destructive continuity testing of field seams will be performed by the Installer as the work progresses to provide the opportunity for immediate re-welding and re-testing as necessary. All defects discovered will be marked, repaired and re-tested by the Installer in accordance with these specifications.

### 7.7.2 Testing Procedures

The Installer will submit the proposed specific non-destructive testing procedures to be employed on this project to the Project Manager. The testing procedures will be consistent with the requirements of this specification. The testing procedures must be approved by the Project Manager and CQA Officer. The Operator reserves the right to reject and request modification of any and all non-destructive seam continuity testing procedures submitted.

7.7.2.1 Vacuum Testing:

The equipment will consist of the following: 1) a vacuum box assembly consisting of a rigid housing, a transparent viewing window, a soft gasket attached to the bottom, or valve assembly, and a vacuum gauge, 2) a vacuum pump assembly, and 3) a soapy solution.

Test Procedure is performed as follows: 1) apply soapy solution to the seam, 2) place vacuum box over the entire wetted seam area, 3) ensure that a leak-tight seal is created, 4) apply a vacuum of at least 5 psig, 5) examine the geomembrane through the viewing window for the presence of soap bubbles for not fewer than ten seconds, and 6) all areas where soap bubbles appear will be marked and repaired.

7.7.2.2 Air Pressure Testing (for double seam air channel):

The equipment will consist of the following: 1) an air pump or tank equipped with pressure gauge capable of generating and sustaining pressure over 30 psi, 2) a sharp, hollow needle, or other approved pressure feed device equipped with a pressure gauge, and 3) A hot air gun or other device to seal the ends of the air channel.

Test Procedure is performed as follows: **1)** seal both ends of seam to be tested, insert air needle into the air channel, and pressurize to at least 25 psi, **2)** the minimum pressure will be maintained for a two minute stabilization period, after which the air source will be disconnected from the air pressure gauge and the maximum pressure drop will be measured over a five-minute period, **3)** if pressure loss exceeds 4 psi or does not stabilize after five minutes, locate faulty area and repair. Puncture opposite end of seam to release air. If blockage is present, locate and test seam on both sides of blockage. A pressure gauge at both ends of the seam will also be acceptable. Remove needle or other approved pressure feed device and seal penetration holes by extrusion welding.

### 7.7.3 Installer Quality Control

The Installer will be responsible for providing quality control inspection staff and documentation for the equipment and testing performed. This will include, but will not be limited to, the following:

- Recent calibration of all gauges employed (vacuum and/or pressure). Proof of recent calibration, in the past six months will be submitted by the Installer for each gauge employed. This proof will be submitted no later than the first use of the apparatus. Negligence in producing this information will prohibit the Installer from using the apparatus.
- An individual who, as a permanent employee of the Installer, is experienced at and responsible for performing the non-destructive seam continuity test in accordance with the prescribed procedures and inspecting for areas of improperly welded geomembrane.
- Labeling directly on the geomembrane surface in the vicinity of the ends of each seam or tested section, the following:
    - Date and time of test;
    - Initials of the operator of the testing device;
    - Status or results of the outcome of non-destructive testing; and

- Start and finish time and pressure (pressure test method only).

## 7.8 DESTRUCTIVE SEAM TESTING

### 7.8.1 Testing Location and Frequency

Destructive seam samples will be obtained from factory and field seams at an average minimum frequency of one per 500 lineal feet of weld. The seam destructive test sampling frequency may be increased by the CQA Officer beyond the specified minimum based upon actual welding conditions and the results of other samples obtained. These additional locations may be based on suspicion of contamination by dirt or moisture, change in seaming materials, increase in failed non-destructive tests, and other causes that could result in unacceptable seams.

Test locations will be determined after welding. The sample locations will, in general, be randomly selected by the CQA Officer as welding progresses. However, selected sample locations may be prompted by suspicion of a poor quality weld.

The Installer will not be informed in advance of seam destructive test locations but will be required to physically obtain the samples from the geomembrane seam in the locations selected by the CQA Officer. The samples will be cut from the geomembrane by the Installer no later than three working days after the location has been selected.

The Installer will repair all holes in the geomembrane resulting from destructive testing. The repairs will be performed and tested in accordance with these Specifications.

### 7.8.2 Sample Size

The location for the destructive samples will be marked by the CQA Officer. The dimensions for the destructive samples will be, as a minimum, 12 inches wide by 34 inches long (minimum 40 inches long for dual tracked welds) with the seam centered lengthwise. The Installer will obtain a two-inch wide strip from each end of the marked seam destructive sample for preliminary field testing as described in the following section. If the preliminary field testing exceeds the pass/fail criteria, the sample will be cut and divided into two parts as described below:

- One portion of the sample, measuring 12 inches by 18 inches (24 inches for dual-tracked fusion welds), to the CQA Officer for laboratory testing.

- One portion of the sample, measuring 12 inches by 12 inches to the Operator for archiving.

The sample length will be increased to accommodate the additional length required by the Installer for laboratory testing or archiving.

Documentation of seam sampling will include sample location, date and time of sampling, operator and apparatus number used for the seam sampled, pass or fail description, and sample identification number. Each sample must be marked with its identification number.

### 7.8.3 Testing Procedure

7.8.3.1 Preliminary Field Testing

Two specimens, one from each end of the seam destructive sample, are to be removed from the geomembrane by the Installer while in the field. Each of these specimens is to be two inches in width. One specimen is to be tested in shear and the other in peel and neither is to fail in the seam.

If the laboratory destructive testing is to be performed on-site, the specification for preliminary field seam destructive testing may be waived.

7.8.3.2 Destructive Seam Testing

The destructive seam testing will be performed by the CQA Officer, or his duly appointed representative, in an on-site or off-site laboratory. This testing is to be completed within 72 hours of the time the samples are removed from the geomembrane installation.

The testing will be performed on a total of ten specimens (fifteen for dual-tracked fusion welds) obtained from the field sample. Five specimens will be tested in each of the shear and peel modes. For the dual-tracked fusion welds, five peel tests will be performed for each track of weld. These shear and peel specimens will be selected from the sample alternately so that no two immediately adjacent specimens are tested in the same mode.

The specimens will be of a size and shape in accordance with ASTM D638, Type I and will be tested at a cross-head rate of two inches per minute.

7.8.3.3 Seam Evaluation Criteria

Each seam sample must meet both the shear and peel criteria before being considered passing. The criteria for each is as follows.

*7.8.3.3.1 Shear*

Of the five specimens tested in the shear mode, each must have strength equal to or greater than 1,500 psi or 90 percent of the rated strength of the geomembrane sheet, whichever is greater. Additionally, as a minimum, four of the five specimens will not fail in the weld.

If, in the series of five specimens tested in shear, these criteria are not met, then the entire seam destructive sample is considered failing.

*7.8.3.3.2 Peel*

Of the five specimens tested in the peel mode, as a minimum, four will not fail in the weld. If more than one specimen fails to meet this criterion, then the entire seam destructive sample is considered failing.

In the instance of the dual-tracked fusion weld, both tracks of the weld will be tested in peel. If either peel test performed on specimens of this weld type fails, the entire specimen is considered failing.

7.8.3.4 Seam Destructive Test Failure Procedure

The Installer will submit a recommended procedure for the tracing and remediation of failed seam destructive tests. This procedure will be submitted as part of the Installer's Quality Control Manual and, as a minimum, will include the following:

- The Installer will reconstruct the failing seam bound by two passing seam destructive tests. The Installer will have the option of obtaining additional seam destructive tests at a minimum of ten-feet intervals in both directions along the failing seam from the failure location. The minimum interval may be increased by the CQA Officer and/or the Project Engineer if test failures become excessive.

- If both of these samples pass the laboratory seam destructive test, then the seam can be reconstructed between them. If one or both of these samples fail the laboratory seam

destructive test, then the procedure is repeated until passing laboratory results are obtained.

- If a seam is reconstructed to a length in excess of 125 feet, a seam destructive sample may be obtained from the reconstruction zone that must meet these specifications.

# 8. GEOTEXTILE

The geotextile materials will comply with the properties listed in Appendix B.

## 8.1 LABELING, PACKAGING, TRANSPORTATION AND STORAGE

Labeling - Upon initial delivery to the site, each geotextile roll will be labeled on the inside of the roll core and outside of the roll wrapping with the following, as a minimum:

- Manufacturer's Name;
- Product Identification;
- Batch or lot number;
- Roll Number;
- Roll length and width; and
- Material thickness.

Any roll delivered to the site without the proper labeling will, at the Project Manager's discretion, be rejected and subsequently removed from the site at the expense of the Manufacturer or Installer.

Packaging – New rolls of geotextile should be wrapped in a black wrap provided in UV radiation and abrasion protection.

Transportation - Deliver, store, and handle rolls in a manner to prevent damage.

Storage - Geotextile rolls should not be exposed to the elements for more than 30 days unless additional heavy-duty wrapping is provided.

Store rolls off the ground, protected from precipitation, UV radiation, strong chemicals, sparks and flames, temperatures in excess of 160 degrees F (71 degrees C), and other environmental conditions that could cause damage to the geotextile.

## 8.2 HANDLING AND PLACEMENT

The Installer will handle all geotextiles in such a manner as to ensure they are not damaged in any way, and will comply with the following. The surface to receive the geotextile will be of smooth condition. Fill deep or sharp-edged depressions, and remove large or sharp-edged rocks, debris and other obstructions that could damage the geotextile.

- In the presence of wind, all geotextiles will be weighted with sandbags or the equivalent. Such sandbags will be installed during placement and will remain until replaced with operations layer material. Sandbags will be made of material that will not degrade during the time they are in use. They will be filled with soil with a predominant grain size equivalent to sand or smaller.

- Geotextiles will be cut using a geotextile cutter approved by the CQA Officer. If in place, special care must be taken to protect other geosynthetic materials from damage that could be caused by the cutting ~~or~~ of the geotextiles.

- During placement, care will be taken not to entrap stones, excessive dust, or moisture in the geotextile that could damage an underlying or overlying geomembrane, generate clogging of drains or filters, or hamper subsequent seaming.

- An examination of the geotextile over the entire surface, after installation, will be conducted to ensure that no potentially harmful foreign objects, such as large or sharp-edged rocks or needles (e.g., broken geotextile sewing needles), are present. Any foreign objects so encountered will be removed by the Installer, or the geotextile will be replaced.

## 8.3 CONFORMANCE TESTING

The CQA Officer will collect samples of geotextile from the materials delivered to the site, for conformance testing.

## 8.4 SEAMS AND OVERLAPS

All geotextiles will be continuously sewn (i.e., discontinuous or tact sewing is not allowed). Geotextiles will be overlapped a minimum of three inches prior to seaming. Any sewing will be done using polymeric thread with chemical and ultraviolet resistance properties equal to or exceeding those of the geotextile.

## 8.5 REPAIR

Any holes or tears in the geotextile will be repaired.

Should any tear exceed ten percent of the width of the roll, that roll will be removed from the slope and replaced.

A patch made from the same geotextile will be sewn in place with a minimum of six-inches overlap in all directions.

Care will be taken to remove any soil or other material that may have penetrated the geotextile.

# 9. LINER SYSTEM COMPONENT DESCRIPTIONS

## 9.1 BASE LINER SYSTEM COMPONENTS

The cross section of the bottom liner system is shown in Details 1, 2, and 3 of Drawing 006, and includes the following components listed sequentially from top to bottom.

- Operations layer
- Double-sided geocomposite LCRS drainage layer (includes 3.0-inch diameter perforated pipes)
- 80-mil HDPE flexible membrane liner (FML), textured on both sides
- Double-sided geocomposite LDS drainage layer
- 60-mil HDPE FML, textured on both sides
- Geosynthetic clay liner (GCL)
- 9.0-inch prepared subgrade (fine-grained soil)

The 2.5-feet thick operations layer will be clean soil and/or select waste, with the purpose of protecting the underlying liner components from damage due to heavy equipment or other operations activities. The layer must not contain large or angular elements which could damage the underlying liner system. The first foot of material placed should be of relatively small particle size material (e.g., sand and gravel) not exceeding one inch in diameter. The second foot of material can have larger particles (e.g., up to 6.0 inches in diameter) provided they are encompassed in a soil matrix.

The upper double-sided geocomposite is the drainage layer of the LCRS. The thee-inch diameter leachate collection pipes augment flow capacity to accommodate infiltration from the 25-year, 24-hour design storm event. Detail 1 of Drawing 008 shows the layout of these pipes and a typical section. The geocomposite drainage layer and pipes discharge into the LCRS sumps.

The 80-mil HDPE FML is the low-permeability component of the primary liner system. The 80-mil HDPE FML will be textured on both sides to provide additional interface strength.

The lower double-sided geocomposite is the drainage layer for the LDS. Its function is to facilitate detection, collection and drainage of leachate into the LDS sump.

The 60-mil HDPE FML is the upper low-permeability component of the secondary composite liner system. It is a lesser thickness than the primary FML since the secondary FML is located further below operations activities and is underlain by a GCL. Textured HDPE on both sides is selected for the reasons stated above for the primary FML.

The GCL is the lower low-permeability component of the secondary composite liner system.

The nine-inch prepared subgrade layer provides a smooth surface for installation of the geosynthetics materials providing protection of the overlying geosynthetic layers from puncture by angular materials in the subgrade. The nine-inch thick prepared subgrade layer (36.0 inches thick beneath sumps) also provides an additional low permeability layer with added adsorptive capacity.

## 9.2 SLOPE LINER SYSTEM COMPONENTS

A cross section of the liner system on the slopes of the trench is shown in Detail 2 of Drawing 006, and includes the following components listed sequentially from top to bottom:

- 2-feet thick operations layer (measured normal to the sidewall, placed as waste is deposited)
- 30-mil HDPE FML(protective layer, not a hydraulic liner component)
- Nonwoven geotextile filter fabric
- Geonet LCRS drainage layer
- 80-mil HDPE FML, smooth on the top side and textured on the bottom side
- Double-sided geocomposite LDS drainage layer
- 60-mil HDPE FML, textured on both sides
- GCL (placed over smooth or specially prepared subgrade)

A 10-feet wide, four-feet deep anchor trench is provided at the top of each slope as shown in Detail 3 on Drawing 008.

The 2-feet thick operations layer is installed incrementally along the slopes as the waste fill is placed. Since the slopes are steep (0.5:1.0) the operations layer will be advanced incrementally at a maximum height of a few feet above the waste fill height.

The sacrificial 30-mil HDPE FML is specified to provide UV exposure protection for underlying geosynthetic materials, especially the uppermost geotextile member. The sacrificial 30-mil HDPE FML also directs rainfall, during cell filling, onto the cell floor for infiltration into the waste and management by the LCRS of infiltration that reaches the LCRS collectors.

## 9.3 TRENCH BOTTOM/SIDEWALL TRANSITION LINER SYSTEM COMPONENTS

The cross section of the liner system at trench bottom/sidewall transition locations is depicted in Detail 3 of Drawing 006. This detail shows how overlaps will be made for each drainage layer to assure continuity of the LCRS and LDS from the side slope to the base of the landfill. The overlap extends from three feet above the floor to three feet onto the trench bottom.

# 10. LEACHATE COLLECTION SYSTEM

## 10.1 LEACHATE COLLECTION AND RECOVERY SYSTEM

The primary LCRS is located above the primary liner, and is designed to collect and allow removal of liquids within each cell. The secondary system, the LDS, is located between the two liners, and its main function is to provide detection and removal of any leakage through the top liner.

The LCRS is associated with the primary liner system. The function of the LCRS is to intercept leachate draining through the waste and to discharge it into the sumps for removal from the landfill. The typical sump configuration is shown in Detail 1 on Drawing 007. The LCRS sump is 12 inches deep. Liquid is removed from the sump through a riser that is shown in Sections A and B on Drawing 007. The components of the LCRS sump are sized to accommodate the maximum anticipated leachate flows while maintaining fluid head above the primary liner at or below one foot.

Trench 12 LCRS sump components are shown on the typical sump layout details on Drawing 007. The components include:

- Geocomposite. This is the principal LCRS drainage component (at cell bottom locations) that discharges directly to the drain rock at the edge of the sump.
- 8.0-ounce LCRS geotextile: This geotextile is used to separate the operations layer from the 1-inch diameter drain rock (described below). It is used over the entire sump area within the sump perimeter.
- 3.0-inch diameter perforated corrugated polyethylene pipes: These pipes are secondary flow components that assist the LCRS in handling the maximum anticipated flow resulting from a 25-year, 24-hour design storm event. The pipes discharge directly to a slip joint in the primary riser pipe (described below).
- 1.0-inch diameter (nominal) drain rock: This is a clean gravel conforming to the gradation included in the specifications (Exhibit B). The LCRS gravel fills the entire sump to the grade break.
- 16-ounce LCRS cushion geotextile: This is a nonwoven geotextile used to provide additional puncture protection to the liner system within the sump perimeter (see Sections A, B, and C on Drawing 008).

- Components of the LCRS riser system include the following (starting at the sump):

  - Flatstock/Riser Base: The riser system is extrusion welded to a 1.0-inch thick, 20-inch square HDPE flatstock base. The pipe is perforated with 1/2-inch diameter holes, 60 degrees apart on 3.0-inch centers (24 holes per foot). A 16-ounce geotextile sheet is wrapped around the perforated section with a double layer of geonet and secure with stainless steel clamps.

  - LCRS Riser Pipe: This is a 12-inch diameter, SDR 17 HDPE pipe. A 24-inch wide section of the 30-mil HDPE sacrificial liner directly beneath the riser pipe functions as a rubsheet to protect the slope liner system.

  - Riser Pipe Slip Cover: The function of this component is to minimize the transfer of friction and down-drag loads on the riser pipe due to settlement of the waste. The riser pipe slip cover will be fabricated from a 12-inch diameter corrugated polyethylene pipe that has been split longitudinally and placed over the riser as shown in Section A of Drawing 007. It is not necessary to join the individual pieces of the slip cover.

  - Riser Pipe Support: The riser pipe support consists of a concrete foundation block shown in Detail 2 on Drawing 007. The riser pipe support is intended to be precast 4,000 psi concrete, using Type V sulfate resistant cement. A 12-inch diameter, Schedule 80, Type 316 stainless steel welding stub will be cast in the concrete and secured with one-inch diameter by six-inch long expansion type anchor bolts.

  - Top of Slope Anchor: This is a concrete block with an adjustable U-bolt (shown in Detail 2 on Drawing 007). This component provides lateral restraint for the riser pipe while allowing vertical movement to accommodate settlement. When the starter berms and buttresses are constructed, the riser pipe will be extended and the top of slope anchor repositioned accordingly.

## 10.2 LEAK DETECTION SYSTEM

The LDS is associated with the secondary liner system. The functions of the LDS are to detect and remove liquid that may migrate through the primary liner system. Components used in the Trench 12 LDS sumps are shown in the typical sump layout on Detail 1 and Section B of Drawing 007. The components include:

- Geocomposite. This is the principal LDS drainage component (at the cell bottom locations) that discharges to the geonet at or near the sump perimeter (see Section C on Drawing 008).

- Geonet: The geonet is a high capacity synthetic drainage layer. It is used within the grade break at each sump to convey liquid to the 15-inch deep sump area (see Section B on Drawing 008). Geonet is used around all three sumps, 12A, 12B, and 12C.

- 16-ounce LDS cushion geotextile: This is a nonwoven geotextile used to provide additional puncture protection to the liner system within the sump perimeter (see Sections B and C on Drawing 008).

- 1.0-inch diameter (nominal) drain rock: A clean gravel conforming to the gradation included in the specifications (Appendix B). As shown in Section B on Drawing 008, the LDS gravel fills only the 15-inch deep sump area.

- LDS End Caps, Tee, Collection Pipes and Elbow: These pieces are all 12-inch diameter SDR 17 HDPE that is perforated to collect flow into the LDS sump. The pieces rest on a 1-inch thick piece of HDPE flatstock. The pieces also transfer the lateral load of the riser pipe to the sidewall of the LDS sump. A 1.0-inch thick piece of HDPE flatstock is used to evenly distribute the load from the HDPE tee and collection pipes to the sidewall (see Section B on Drawing 008). Additional lateral resistance is provided by the 4-feet thick operations layer placed directly over the sump.

- 16-ounce lower LDS cushion geotextile: This is a nonwoven geotextile that provides puncture protection to the secondary liner system in the 15-inch deep portion of the sump as shown in Section B on Drawing 008.

Components of the LDS riser system include the following (starting at the sump):

- LDS Riser: A 12-inch diameter SDR 17 HDPE pipe used for pump access.

- LDS Riser Recess Trench and Backfill: The LDS Riser (described above) is placed in a 24-inch wide by 18-inch deep recess cut into the sidewall during excavation. A 30-mil PVC rubsheet is used to separate the backfill material from the geocomposite and to provide additional cushion to the liner system. Backfill will consist of a lightweight concrete.

- Top of slope anchor: See the LCRS top of slope anchor description above since the units are identical.

## 11. LINER SYSTEM EXPOSURE PROTECTION

Exposure protection is necessary for the liner and leachate collection system components, both during construction as well as during disposal operations. Exposure issues include the following:

- Ultraviolet (UV) Radiation: Some geosynthetic materials (without UV resistance additives) degrade when exposed to sunlight. For Trench 12, the HDPE materials (e.g., FML and geonet) are UV-resistant; hence protection from exposure to UV radiation is not necessary for these materials. Polyester geotextile materials, however are sensitive to UV radiation and must be protected during storage, construction and disposal operations.

- Precipitation/Water: The bentonite within GCLs may expand if exposed to moisture and allowed to hydrate in an unconfined condition (e.g., during material staging or placement). Thus, GCLs must be protected during storage and construction.

- Dust and soil: Geonet materials can become partially filled with dust and soil if not protected from wind and rain during storage and construction. This geonet must be protected during storage and construction.

- Wind: High winds can lift geosynthetics that have not been properly anchored (e.g., during construction). This can result in damage (e.g., tears) or the material blowing away. Therefore, temporary anchorage and repair/replacement procedures are needed during construction. Protection from wind during disposal operations is also needed.

- Geosynthetic materials requiring exposure protection and/or special handling during construction include the following.

    - GCLs: Store on pallets in delivered plastic packaging and cover with tarps. Protect from rain after installation.

    - HDPE FMLs: Store on pallets to avoid damage. Provide temporary anchorage to facilitate installation and prevent wind uplift. Follow inspection, repair, and replacement procedures if wind damage has potentially occurred.

    - Geonets: Store on pallets and cover with tarps. Keep free of dust, soil and precipitation during installation.

    - Geotextiles: Store on pallets and cover with tarps. Place subsequent layer of liner systems within a reasonable period of time (e.g., within four to six weeks).

    - Geocomposites: Same as geotextiles.

- Geosynthetics on the cell bottom are likely to be covered by the operations layer within a reasonable period of time (e.g., four to six weeks) after installation. No further protective measures are required for those elements.

The side slope liner system incorporates a sacrificial 30-mil HDPE FML. The sacrificial liner protects the slope liner during filling and specifically eliminates UV exposure of the primary nonwoven geotextile filter-fabric. The layer also prevents infiltration into the slope LCRS during precipitation. Sand tubes and wind vents will be installed to secure the slope lining system and prevent uplift from wind.

**Table C-1 - Soil Placement Inspection Schedule**

| Inspection Task | Inspection/Test Method Reference | Sample/Test Quantity/Frequency | Observation/Sample Locations | | |
|---|---|---|---|---|---|
| | | | Excavation | Soil Stockpile | Fill Area |
| FIELD INSPECTION OF SOIL EXCAVATION AND PLACEMENT OPERATIONS | | | | | |
| General project observations | Visual observations, plus basic measurements and recordkeeping | Continuous observation, during trench construction (excavation, soil screening and amendment and soil placement) | Yes | Yes | Yes |
| Trench feature layout | Observation of survey staking | Continuous observation, during excavation | Yes | NA | Yes |
| Soil material observation | Observation of excavated and imported soil material | Continuous observation, during construction | Yes | Yes | Yes |
| SOIL TESTS TO BE DONE DURING TRENCH 12 CONSTRUCTION | | | | | |
| Particle-size analysis | ASTM C 136 | 3 tests per material type, reconfirmed as needed | Yes | Yes | Yes |
| Moisture/density curve | ASTM D1557, Modified proctor moisture-density relation | 3 tests per material type, reconfirmed as needed | Yes | Yes | Yes |
| Lift thickness | Observation/measurement before and during compaction | Random locations | NA | No | Yes |
| In-place density and moisture content | ASTM D6938 (or approved alternative method) | As specified | No | No | Yes |

**Table C-1 - Soil Placement Inspection Schedule (continued)**

| Inspection Task | Inspection/Test Method Reference | Sample/Test Quantity/Frequency | Sample Location | | Acceptance Criteria |
|---|---|---|---|---|---|
| | | | Soil Stockpile | Fill Area | |
| SURFACE SOIL LAYER RECOMPACTION | | | | | |
| Direct shear strength of compacted fill | TBD | 3 tests per material type, reconfirmed as needed | Yes | No | cohesion ≥ 250 PSF |
| Particle-size analysis | ASTM C 136 | 3 tests per material type, reconfirmed as needed | Yes | No | 95% <3.0" sieve<br>>10% pass #200 sieve<br><20% pass #200 sieve |
| Moisture/density relation | ASTM D1557 | 3 tests per material type, reconfirmed as needed | Yes | No | NA |
| In-place density | ASTM D6938 (after compaction) | 1 per lift minimum, or 1 per 2,000 $yd^3$ (placed), or as specified | No | Yes | 95% MDD (min) by ASTM D 1557 |
| Moisture content | ASTM D6938 (after compaction) | 1 per lift minimum, or 1 per 2,000 $yd^3$ (placed), or as specified | No | Yes | OMC +2% |
| COMPACTED FILL STARTER BERM | | | | | |
| Moisture/density relation | ASTM D1557 | 3 tests per material type, reconfirmed as needed | Yes | No | NA |

**Table C-1 - Soil Placement Inspection Schedule (continued)**

| Inspection Task | Inspection/Test Method Reference | Sample/Test Quantity/Frequency | Sample Location | | Acceptance Criteria |
|---|---|---|---|---|---|
| | | | Soil Stockpile | Fill Area | |
| In-place density | ASTM D6938 (after compaction) | 1 per lift minimum, or 1 per 2,000 $yd^3$ (placed), or as specified | No | Yes | 90% MDD (min) by ASTM D 1557 |
| Moisture content | ASTM D6938 (after compaction) | 1 per lift minimum, or 1 per 2,000 $yd^3$ (placed), or as specified | No | Yes | OMC +2% |
| TRENCH 12 BOTTOM AND SUMP SUBGRADE | | | | | |
| Hydraulic conductivity of compacted subgrade | TBD | 3 tests per material type, reconfirmed as needed | Yes | No | $\leq 1 \times 10^{-5}$ cm/sec |
| Particle-size analysis | ASTM C136 | 3 tests per material type, reconfirmed as needed | Yes | No | ≤10% >1.0"<br>≥10% pass #200 sieve |
| Moisture/density relation | ASTM D1557, Modified proctor moisture-density relation | 3 tests per material type, reconfirmed as needed | Yes | No | NA |
| In-place density and moisture content, trench floor | ASTM D1557 (after compaction) | one test per each one test for every 10,000 square feet of subgrade placed (placed) | No | Yes | 90% MDD<br>OMC +2% |
| Thickness, after compaction, trench floor | Measurement after compaction | one test per each one test for every 10,000 square feet of subgrade placed (placed) | NA | No | Thickness ≥ 9.0" |

**Table C-1 - Soil Placement Inspection Schedule (continued)**

| Inspection Task | Inspection/Test Method Reference | Sample/Test Quantity/Frequency | Sample Location | | Acceptance Criteria |
|---|---|---|---|---|---|
| | | | Soil Stockpile | Fill Area | |
| In-place density and moisture content, sump bottom | ASTM D6938 (after compaction) | 1 test per lift, not less than 3 tests per sump | No | Yes | 90% MDD<br>OMC +2% |
| Lift thickness, sump bottom | Measurement after compaction | Not less than 3 measurements per lift in each sump | NA | No | Total compacted lift thickness at same location ≥36.0" |
| SUMP AND LCRS PIPING BEDDING GRAVEL | | | | | |
| Hydraulic conductivity of gravel | TBD | 3 tests per material type, reconfirmed as needed | Yes | No | Minimum hydraulic conductivity = 1 cm/sec |
| Particle-size analysis | ASTM C136 | 3 tests per material type, reconfirmed as needed | Yes | No | 100% <3.0" sieve<br>≥95% >1.0" sieve<br>≤5% passing #4 sieve |

MDD = Standard Proctor (ASTM D1557) maximum dry density.
OMC = Standard Proctor (ASTM D1557) optimum moisture content
TBD = to be determined by soil testing laboratory
PSF = pounds per square foot