APPENDIX K

CONSTRUCTION QUALITY ASSURANCE

1. SPECIFICATIONS
2. TWO-STAGE BOUTWELL PERMEAMETER TEST METHODOLOGY

APPENDIX K.1

SPECIFICATIONS

Shaw®

SECTION 02200

EARTHWORK

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered by this Section includes furnishing all supervision, labor, materials and equipment required to complete all earthwork at the site including, but not limited to, the following:

1. Excavations,

1. Unsuitable soil removal,

2. Landfill floor foundation fill earthwork,

3. Earth Liner construction,

4. Final Cover earthwork,

5. Random Fill placement and compaction,

6. Leachate collection system Sand Drainage Layer and Washed Gravel placement,

7. Pipe trench backfill placement and compaction, and

8. Riprap placement.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. D422 - Standard Test Method for Particle-Size Analysis of Soils.

2. D698 - Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)].

3. D2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

4. D2434 – Test Method for Permeability of Granular Soils (Constant Head).

5. D2488 – Standard Practice for Description and Identification of Soils (Visual – Manual Procedure).

6. D3042 – Standard Test Method for Insoluble Residue in Carbonate Aggregates

7. D4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

8. D5084 – Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

1.03 DEFINITIONS

A. Contractor: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, and services necessary to perform the work as detailed in this Section of the Specifications.

B. CQA Officer: Designated Construction Quality Assurance (CQA) Officer, including CQA Officer-in-Absentia.

C. Design Engineer: Engineer responsible for the landfill design.

D. Optimum Moisture Content: The moisture content corresponding to the SMDD.

A. Owner: Clinton Landfill Landfill, Inc.

E. Standard Maximum Dry Density (SMDD): The maximum dry unit weight determined in accordance with ASTM D698.

1.04 SUBMITTALS

A. The Contractor shall submit representative samples of imported earth materials to the CQA Officer for laboratory testing prior to importing the materials to the site. Alternatively, the Contractor shall submit laboratory test results from the aggregate products supplier(s) demonstrating that the supplied aggregates meet the specifications contained in this Section. Supplier-provided laboratory data shall be submitted to the CQA Officer prior to importing the material to the site.

1.05 SEQUENCING AND SCHEDULING

A. The Contractor shall not allow or cause any of the work performed or installed to be covered up or enclosed prior to required inspections, tests or approvals.

1.00 LINE, GRADE AND THICKNESS TOLERANCES

A. The thicknesses of Earth Liner, Sand Drainage Layer, Final Cover Barrier Soil, and Vegetative Cover shown on the Drawings are minimum thicknesses that shall be met at all locations.

B. The thicknesses of all other earthwork features shown on the Drawings are considered to be nominal thicknesses. The average of actual thickness measurements shall be no less than the nominal thickness shown on the drawings. No individual actual thickness measurement shall vary more than 15 percent below the nominal thickness shown on the Drawings, except as approved by the Design Engineer.

C. The landfill liner geomembrane subgrade shall be uniformly sloped to drain towards the leachate collection pipe trench as shown on the Drawings.

D. The Leachate Collection Pipe shall be uniformly sloped to drain towards the leachate collection sumps. The overall pipe invert slope shall not deviate more than +/- 0.2 percent from the slope shown on the Drawings.

E. All other earthwork shall be constructed to within +/- 0.3 feet of the specified lines and elevations shown on the Drawing, except as approved by the Design Engineer.

PART 2: PRODUCTS

2.01 EARTH LINER

A. Earth Liner shall be naturally available soil or blends of naturally available soil meeting the following specifications:

1. Compacted hydraulic conductivity less than or equal to 1 x 10^{-7} centimeters per second (cm/sec) as determined by ASTM D5084,

2. At least 50 percent fines passing the U.S. No. 200 sieve as determined by ASTM D422,

3. Liquid Limit between 10 and 50, and Plasticity Index between 5 and 35, as determined by ASTM D4318, and

4. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and stones/clods greater than 3-inches. Localized areas containing less than an estimated 5 percent by volume of visible organics and clay clods may be accepted as approved by the Design Engineer on a case-by-case basis.

A. Material that does not meet the above-criteria may be used as Earth Liner only upon completion of a Test Liner that successfully demonstrates that the material meets the hydraulic conductivity criteria.

B. Compacted Earth Liner shall exhibit an average unconfined compressive strength of at least 1.8 tons per square foot as determined by ASTM D2166.

1.00 COMPACTED CLAY FILL

A. All earth fill placed beneath the landfill floor Earth Liner shall meet the criteria for Compacted Clay Fill.

B. Compacted Clay Fill shall be naturally available soil or blends of naturally available soil meeting the following specifications:

1. Average compacted hydraulic conductivity less than or equal to 1 x 10^{-7} centimeters per second (cm/sec) as determined by ASTM D5084,

2. At least 50 percent fines passing the U.S. No. 200 sieve as determined by ASTM D422,

3. Liquid Limit between 10 and 50, and Plasticity Index between 5 and 35, as determined by ASTM D4318, and

4. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and stones/clods greater than 3-inches. Localized areas containing less than an estimated 5 percent by volume of visible organics and clay clods may be accepted as approved by the Design Engineer on a case-by-case basis.

C. Compacted Clay Fill shall exhibit an average unconfined compressive strength of at least 1.8 tons per square foot as determined by ASTM D2166.

2.03 FINAL COVER BARRIER SOIL

A. Final Cover Barrier Soil shall be naturally available soil or blends of naturally available soil meeting the following specifications:

1. Average compacted hydraulic conductivity less than or equal to 1 x 10^{-7} centimeters per second (cm/sec) as determined by ASTM D5084,

0. At least 50 percent fines passing the U.S. No. 200 sieve as determined by ASTM D422,

0. Liquid Limit between 10 and 50, and Plasticity Index between 5 and 35, as determined by ASTM D4318, and

0. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and stones/clods greater than 3-inches. Localized areas containing less than an estimated 5 percent by volume of visible organics and clay clods may be accepted as approved by the Design Engineer on a case-by-case basis.

B. Final Cover Barrier Soil shall exhibit an average unconfined compressive strength of at least 1.8 tons per square foot as determined by ASTM D2166.

2.04 RANDOM FILL

Random Fill shall be naturally available soil or blends of naturally available soil meeting the following specifications:

A. Liquid Limit no greater than 60 as determined by ASTM D4318,

B. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and stones/clods greater than 5-inches diameter. Localized areas containing less than an estimated 5 percent by volume of visible organics and clay clods may be accepted as approved by the Design Engineer on a case-by-case basis.

C. Random Fill placed in the first lift above geosynthetic materials (geomembranes, geonets, geotextiles, etc.) shall not contain stones greater than 2-inches diameter, sharp objects, or other materials that could damage the underlying geosynthetic material.

2.05 SAND DRAINAGE LAYER

Sand Drainage Layer material is specified for use as a leachate drainage blanket just above the geomembrane base liner. Sand Drainage Layer material shall meet the following specifications:

F. Hydraulic conductivity at least 3 x 10^{-2} cm/sec, as determined by ASTM D2434 test methods,

A. Particles are hard and non-friable,

B. Exhibit no adverse reaction to dilute hydrochloric acid. The aggregate that exhibits no visible reaction with dilute hydrochloric acid in accordance with the test procedures described in ASTM D2488 are deemed to meet this criterion. Aggregate that displays a visible reaction shall be further tested prior to use in accordance with ASTM D3042, and shall not exhibit more than a 15% carbonate loss.

C. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and other deleterious materials. Localized areas containing less than an estimated 5 percent by volume of visible organics may be accepted as approved by the Design Engineer on a case-by-case basis.

D. Exhibit the following gradation as determined by ASTM D422:

Particle Size (U.S. Standard Sieve)	Percent Passing (by weight)
3/8 inch	100
No. 8	70 – 100
No. 16	40 – 100
No. 30	10 – 60
No. 50	0 – 15
No. 200	0 – 5

2.06 SAND BEDDING

Sand Bedding is specified for use as bedding material for buried facilities such as: leachate, condensate and gas transmission piping; condensate drain piping, stormwater letdown piping; stormwater culverts; and other underground structures that are outside or above the waste limits. Sand Bedding shall meet the following specifications:

A. Particles are hard and non-friable,

B. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and other deleterious materials. Localized areas containing less than an estimated 5 percent by volume of visible organics may be accepted if approved by the Design Engineer on a case-by-case basis.

C. Exhibit the following gradation as determined by ASTM D422:

Particle Size (U.S. Standard Sieve)	Percent Passing (by weight)
3/8 inch	100
No. 8	70 - 100
No. 16	40 – 100
No. 30	10 – 75
No. 50	0 – 30
No. 100	0 – 10

2.07 WASHED GRAVEL

Washed Gravel is specified for envelopment of the leachate collection pipe and shall meet the following specifications:

A. Particles are hard and non-friable,

B. Exhibit no adverse reaction to dilute hydrochloric acid. The aggregate that exhibits no visible reaction with dilute hydrochloric acid in accordance with the test procedures described in ASTM D2488 are deemed to meet this criterion. Aggregate that displays a visible reaction shall be further tested prior to use in accordance with ASTM D3042, and shall not exhibit more than a 15% carbonate loss.

C. Free of visible organics (roots, leaves, grass, etc.), frozen materials, and other deleterious materials. Localized areas containing less than an estimated 5 percent by volume of visible organics may be accepted if approved by the Design Engineer on a case-by-case basis.

D. Exhibit the following gradation as determined by ASTM D422:

Particle Size (U.S. Standard Sieve)	Percent Passing (by weight)
1-1/2 inch	100
1 inch	90 – 100
½ inch	30 – 60
No. 4	0 – 5

2.08 RIPRAP AND BEDDING

Riprap and Bedding shall consist of materials meeting the Quality C material specifications contained in Section 1005 of the Illinois Department of Transportation Standard Specifications for Road and Bridge Construction. Riprap and Bedding gradation are specified on the Drawings.

2.09 VEGETATIVE COVER

A. Vegetative Cover shall be naturally available soil or blends of naturally available soil meeting the following specifications:

1. At least 20 percent finer than the No. 200 sieve,

2. Free of frozen materials and stones/clods greater than 10-inches diameter.

3. Vegetative Cover placed in the first lift above geosynthetic materials (geomembranes, geonets, geotextiles, etc.) shall not contain stones greater than 2-inches diameter, sharp objects, or other materials that could damage the underlying geosynthetic material.

4. Where placed on the final cover 3:1 (horizontal to vertical) sideslopes, exhibit an unconfined compressive strength of at least 0.75 tons per square foot as determined by ASTM D2166.

B. The upper 6-inches of Vegetative Cover shall consist of natural, fertile, agricultural topsoil obtained from approved stockpiles and borrow. Alternatively, the upper 12-inches of Vegetative Cover shall be amended with approved sludge, manure, or other material as needed to ensure turf establishment.

PART 3: EXECUTION

3.01 PREPARATION

A. The Contractor shall make arrangements to locate all existing Utilities and Underground Facilities in the areas of work. If any are to remain in place, Contractor shall provide adequate means of protection during earthwork operations.

B. The Contractor shall protect structures, bench marks, survey control points, utilities, fences, monitoring wells, piezometers, gas monitoring probes, gas extraction wells, and other facilities from damage caused by direct contact, settlement, lateral movement, undermining, washout and other hazards created by earthwork operations.

C. The Contractor shall provide erosion and sediment control to prevent erosion from disturbed areas and to prevent sediment from reaching any surface water drainage features.

D. Protect existing buildings, structures, utilities, roadways, trees, slopes, and other features where temporary unbalanced earth pressures are liable to develop by utilizing bracing, shoring, underpinning, or other approved methods.

3.02 CLEARING, GRUBBING, AND STRIPPING

A. The Contractor shall clear and grub all trees, stumps, vegetation, etc. from the construction area.

B. Cleared vegetation and debris shall be properly disposed as approved by the Owner.

C. The Contractor shall strip all topsoil from the construction area and stockpile the topsoil as directed by the Owner.

3.03 EXCAVATION

A. Excavation consists of removing material encountered when 1) establishing the required elevation for the Earth Liner, structural foundations, buried piping, and underground structures, or 2) constructing or maintaining erosion, sediment, run-on or run-off control features.

B. Trenches excavated for buried piping shall be excavated deep and wide enough to allow placement of Sand Bedding or Washed Gravel material as shown on the Drawings.

C. Sloped sides of excavations shall comply with applicable laws and regulations. The Contractor shall shore or brace excavations where sloping is not possible either because of space restrictions or stability of the material excavated. The Contractor shall maintain sides and slopes of excavations in a safe condition until completion of backfilling.

D. The Contractor shall, to the extent practical, prevent surface water from flowing into excavations and from flooding the Project Site or surrounding areas. Temporary drainage ditches and other diversions outside excavation limits shall be maintained as appropriate.

E. The Contractor shall be responsible for dewatering excavations to ensure that all subsequent construction in the excavations are conducted in the dry.

F. The Contractor shall notify the CQA Officer when soil at the bottom of the excavation appears unsuitable and discontinue work in the affected area until notified to resume work by the CQA Officer.

G. The Contractor shall trim, make firm, and remove loose material and debris from structural slab and foundation excavations. Where natural soil or fill material at the bottom of a structural slab or foundation excavation is disturbed, the Contractor shall compact the disturbed soil to at least 95 percent of the SMDD, or remove the disturbed soil and refill the space as directed by the CQA Officer.

H. Some excavations, such as those for drip legs and portions of the leachate transmission piping will be into waste materials. Excavated wastes and soil contaminated by wastes shall be managed as described in Part 3.04 of this Section of the Specifications.

3.04 SOLID WASTE CONTAINERIZATION AND DISPOSAL

A. The Contractor shall segregate waste from clean earth materials as practical.

B. All waste shall be placed within covered roll-off containers, or shall be properly disposed by the end of each day.

C. The Owner will procure all required disposal permits and properly transport and dispose the waste at a permitted landfill.

3.05 EARTH LINER SUBGRADE PREPARATION, PLACEMENT AND COMPACTION

A. Subgrade Preparation

2. The Earth Liner subgrade shall be proof-rolled to the satisfaction of the CQA Officer prior to placing Earth Liner material. The subgrade shall be firm, in an unfrozen state, and free of organics, topsoil, debris, and standing or running water.

3. Unsuitable materials, as defined herein, shall be overexcavated and removed from the Earth Liner subgrade. Unsuitable materials include: saturated sand and soft soils that do not provide a firm subgrade on which to compact Earth Liner material.

4. The Earth Liner in the floor of the northern cell of Area #2 shall be founded on Berry Clay, Radnor Till, or Compacted Clay Fill extending to Berry Clay or Radnor Till.

1. Saturated sand exposed in the floor of the landfill shall be overexcavated to a minimum depth of 5 feet below the Earth Liner subgrade, or to the full thickness of the sand, whichever is shallower. Such overexcavations shall be backfilled with Compacted Clay Fill that is placed and compacted in accordance with Part 3.06 of this Section of the Specifications.

2.

5. Saturated sand less than 3 feet thick exposed in the sidewall of the landfill shall be overexcavated at least 10 feet laterally beyond the Earth Liner subgrade. The Design Engineer shall establish the minimum overexcavation extent if saturated sand greater than 3 feet thick is encountered. Such overexcavations shall be backfilled with Compacted Clay Fill that is placed and compacted in accordance with Part 3.06 of this Section of the Specifications.

6. Soft, unstable or pumping soils that do not provide a sufficiently firm subgrade so as to allow the first lift of Earth Liner to be compacted to the specified density shall be removed to such a depth so that, when backfilled, the subgrade onto which Earth Liner is to be placed is firm. Such overexcavations shall be backfilled with Compacted Clay Fill, the upper 12 inches of which shall be compacted to at least 90 percent of the material's SMDD. The use of geotextile at the bottom of the overexcavation to minimize the depth of the required overexcavation is allowed only with the express approval of the CQA Officer. Geotextile materials and placement shall be in accordance with the requirements provided in Section 02640 of these specifications.

B. The Contractor shall place Earth Liner material in horizontal lifts not exceeding 12 inches in loose thickness, and 9 inches following compaction.

C. The Contractor shall ensure that Earth Liner material gradation, texture and moisture content are reasonably uniform throughout each lift.

D. The Contractor shall maintain Earth Liner material moisture content between 0 and 4 percentage points above the material's optimum moisture content.

E. The Contractor shall compact each lift of Earth Liner material to at least 95 percent of the SMDD. Compaction shall be achieved using a compactor and procedures (i.e. number of passes per lift) as those used while constructing a successful Test Liner. Compaction equipment not deemed equivalent by the CQA Officer, or an alternative minimum number of passes, shall only be used following completion of a Test Liner that successfully demonstrates that the compactive effort results in the Earth Liner meeting the hydraulic conductivity criteria.

F. Each lift shall be well bonded with the underlying lift. If the compacted surface of any layer of fill is determined by the CQA Officer to be too smooth to bond properly with succeeding lifts, the Contractor shall scarify the surface to a depth of at least 1 inch before the succeeding lift is placed.

G. Except as authorized by the CQA Officer, the Contractor shall not place successive lifts until the CQA Officer has approved the previous lift.

H. The Contractor shall implement measures to protect the in-place Earth Liner material from disturbance (e.g. rutting), excess moisture, dessication, etc. The Contractor shall reconstruct areas that become disturbed, excessively wet, or dessicated as directed by the CQA Officer.

3.06 COMPACTED CLAY FILL SUBGRADE PREPARATION, PLACEMENT AND COMPACTION

A. Subgrade Preparation

0. The Compacted Clay Fill subgrade shall be proof-rolled to the satisfaction of the CQA Officer prior to placing Compacted Clay Fill. The subgrade shall be firm, in an unfrozen state, and free of organics, topsoil, debris, and standing or running water.

0. Unsuitable materials, as defined herein, shall be overexcavated and removed from the Compacted Clay Fill subgrade. Unsuitable materials include: saturated sand and soft soils that do not provide a firm subgrade on which to compact Compacted Clay Fill material.

B. Soft, unstable or pumping soils that do not provide a sufficiently firm subgrade so as to allow the first lift of Compacted Clay Fill to be compacted to the specified density shall be removed to such a depth so that, when backfilled, the subgrade onto which Compacted Clay is to be placed is firm. Such overexcavations shall be backfilled with Compacted Clay Fill, the upper 12 inches of which shall be compacted to at least 90 percent of the material's SMDD. The use of geotextile at the bottom of the overexcavation to minimize the depth of the required overexcavation is allowed only with the express approval of the CQA Officer. Geotextile materials and placement shall be in accordance with the requirements provided in Section 02640 of these specifications.

C. The Contractor shall place Compacted Clay Fill material in horizontal lifts not exceeding 12 inches in loose thickness, and 9 inches following compaction.

D. The Contractor shall ensure that Compacted Clay Fill material gradation, texture and moisture content are reasonably uniform throughout each lift.

E. The Contractor shall maintain Compacted Clay Fill material moisture content between 0 and 4 percentage points above the material's optimum moisture content.

F. The Contractor shall compact each lift of Compacted Clay Fill material to at least 95 percent of the SMDD.

G. Each lift shall be well bonded with the underlying lift. If the compacted surface of any layer of fill is determined by the CQA Officer to be too smooth to bond properly with succeeding lifts, the Contractor shall scarify the surface to a depth of at least 1 inch before the succeeding lift is placed.

H. Except as authorized by the CQA Officer, the Contractor shall not place successive lifts until the CQA Officer has approved the previous lift.

I. The Contractor shall implement measures to protect the in-place Compacted Clay Fill material from disturbance (e.g. rutting), excess moisture, dessication, etc. The Contractor shall reconstruct areas that become disturbed, excessively wet, or dessicated as directed by the CQA Officer.

3.07 FINAL COVER FILL PLACMENT AND COMPACTION

B. Final Cover Barrier Soil

1. The Contractor shall proof roll the Final Cover Barrier Soil subgrade (12-inch minimum Random Fill) to the satisfaction of the CQA Officer. The Final Cover Barrier Soil subgrade shall be firm, in an unfrozen state, and free of organics, topsoil, debris, and standing or running water.

2. Soft soils that do not provide a sufficiently firm Final Cover Barrier Soil subgrade so as to allow the first lift of the Final Cover Barrier Soil to be compacted to the specified density shall be overexcavated and replaced as required to provide a firm Final Cover Barrier Soil subgrade. The use of geotextile at the bottom of the overexcavation to minimize the depth of the required overexcavation is allowed only with the express approval of the CQA Officer. Geotextile materials and placement shall be in accordance with the requirements provided in Section 02640 of these specifications.

3. The Contractor shall place Final Cover Barrier Soil material in lifts not exceeding 12 inches in loose thickness, and 9 inches following compaction.

4. The Contractor shall ensure that Final Cover Barrier Soil material gradation, texture and moisture content are reasonably uniform throughout each lift.

5. The Contractor shall maintain Final Cover Barrier Soil material moisture content as necessary to achieve the specified relative compaction and hydraulic conductivity.

6. The Contractor shall compact each lift of Final Cover Barrier Soil material to at least 90 percent of the SMDD.

7. Each lift shall be well bonded with the underlying lift. If the compacted surface of any layer of fill is determined by the CQA Officer to be too smooth to bond properly with succeeding lifts, the Contractor shall scarify the surface to a depth of at least 1 inch before the succeeding lift is placed.

8. Except as authorized by the CQA Officer, the Contractor shall not place successive lifts until the CQA Officer has approved the previous lift.

1. The Contractor shall roll or blade the surface of the Final Cover Barrier Soil prior to geomembrane placement to a smooth, undisturbed and firm surface. The geomembrane subgrade shall be free of protruding stones greater than 2 inches diameter and sharp objects.

2. The Contractor shall implement measures to protect the in-place Final Cover Barrier Soil material from disturbance (e.g. rutting), excess moisture, dessication, etc. The Contractor shall reconstruct areas that become disturbed, excessively wet, or dessicated as directed by the CQA Officer.

B. Vegetative Cover

1. The Contractor shall follow the geomembrane protection requirements of Part 3.11 of this Section while placing Vegetative Cover.

2. Vegetative Cover soils placed on slopes steeper than 4:1 shall be placed from the bottom of the slope upwards toward the top of the slope.

3. The first lift of the Vegetative Cover placed above geosynthetic materials shall be between 18 and 22 inches thick (loose thickness). Remaining Vegetative Cover shall be placed in lifts not exceeding 12 inches in loose thickness.

4. Each lift of Vegetative Cover shall be lightly compacted by one pass of a bulldozer (i.e. track-walked).

5. Topsoil, if placed, shall not be compacted.

6. Vegetative Cover soil amendment, if performed, shall be conducted in accordance with Section 02900 (Turf Establishment) of these Specifications.

3.08 MISCELLANEOUS RANDOM FILL SUBGRADE PREPARATION, PLACEMENT AND COMPACTION

C. Subgrade Preparation

1. Random Fill subgrade shall be proof-rolled to the satisfaction of the CQA Officer prior to placing Random Fill material. The subgrade shall be firm, in an unfrozen state, and free of organics, topsoil, debris, and standing or running water.

2. Soft soils that do not provide a firm subgrade on which to compact Random Fill shall be overexcavated and removed from the Random Fill subgrade.

3. Soft, unstable or pumping soils that do not provide a sufficiently firm subgrade so as to allow the first lift of Random Fill to be compacted to the specified density shall be removed to such a depth so that, when backfilled, the subgrade onto which Random Fill is to be placed is firm. Such overexcavations shall be backfilled with Random Fill, the upper 12

inches of which shall be compacted to at least 90 percent of the material's SMDD. The use of geotextile at the bottom of the overexcavation to minimize the depth of the required overexcavation is allowed only with the express approval of the CQA Officer. Geotextile materials and placement shall be in accordance with the requirements provided in Section 02640 of these specifications.

D. The Contractor shall place Random Fill material in horizontal lifts not exceeding 12 inches in loose thickness, and 9 inches following compaction.

E. The Contractor shall ensure that Random Fill material gradation, texture and moisture content are reasonably uniform throughout each lift.

F. The Contractor shall maintain Random Fill material moisture content as required to achieve the specified degree of compaction.

G. The Contractor shall compact each lift of Random Fill to at least 90 percent of the SMDD, except in embankments greater than 10 feet high, where Random Fill shall be compacted to at least 95 percent of the SMDD.

H. Each lift shall be well bonded with the underlying lift. If the compacted surface of any layer of fill is determined by the CQA Officer to be too smooth to bond properly with succeeding lifts, the Contractor shall scarify the surface to a depth of at least 1 inch before the succeeding lift is placed.

I. Except as authorized by the CQA Officer, the Contractor shall not place successive lifts until the CQA Officer has approved the previous lift.

J. The Contractor shall implement measures to protect the in-place Random Fill material from disturbance (e.g. rutting), excess moisture, etc. The Contractor shall reconstruct areas that become disturbed or excessively wet as directed by the CQA Officer.

K. The Contractor shall gently place fill materials to a uniform thickness on all sides of in-place installations to minimize the unbalanced earth pressures. Do not dump fill materials directly against or on existing installations.

L. The Contractor shall compact fill placed against in-place installations and within geosynthetic anchor trenches using hand-operated compaction equipment (i.e. vibratory plate, jumping jack, etc.).

K. Where temporary unbalanced earth pressures are liable to develop on walls or other structures, the Contractor shall erect bracing or shoring to counteract the unbalanced earth pressures as approved by the CQA Officer.

L. The Contractor shall ensure that all concrete which will be subjected to earth loads from the filling operations has cured to an adequate strength to withstand such loads.

3.09 SAND DRAINAGE LAYER PLACEMENT AND COMPACTION

B. The Contractor shall follow the geomembrane protection requirements of Part 3.11 of this Section while placing the Sand Drainage Layer.

C. The surface of the Sand Drainage Layer shall be rolled or bladed to provide a smooth surface.

3.10 LEACHATE COLLECTION TRENCH BACKFILL PLACEMENT AND COMPACTION

A. The Contractor shall follow the geomembrane protection requirements of Part 3.11 of this Section while placing Washed Gravel within the leachate collection system.

B. Washed Gravel shall be placed by dumping from a height no more than 2 feet.

C. Washed Gravel below the leachate collection pipe shall be firmly compacted prior to pipe placement using equipment-mounted or hand-operated vibratory compaction equipment, or other equipment approved by the CQA Officer.

D. Following pipe placement, Washed Gravel shall be placed to its specified grades in such a manner as to prevent damage to, and/or excessive deflection of, the leachate collection pipe to the satisfaction of the CQA Officer.

E. The Contractor shall maintain Washed Gravel free of contamination.

3.11 GEOSYNTHETIC MATERIAL PROTECTION

F. Only light-weight, low-ground pressure rubber-tired vehicles, such as all-terrain-vehicles (ATVs) as approved by the CQA Officer, shall be operated above geosynthetic materials (geomembranes, geonets, geotextiles, etc.) that are covered by less than 12 inches of fill.

G. Only rubber-tired equipment of gross weight less than 75,000 pounds and low-ground pressure (5 psi or less) bulldozers with cleats less than 2-inches high are allowed to operate above geosynthetic materials when the geosynthetic materials are covered by at least 12 inches (nominal) of fill material.

H. Other equipment shall only operate above geosynthetic materials when the geosynthetic materials are covered by at least 18 inches (nominal) of fill material.

I. The first 12 inches of fill placed above geosynthetic materials shall be free of stones greater than 2-inches diameter and sharp objects.

J. The first lift of fill over geosynthetic materials shall be at least 12-inches thick (nominal, loose thickness).

K. The Contractor shall place the first lift of fill over geosynthetic materials in such a manner as to maintain geomembrane wrinkles less than 4 inches in height, and to prevent geomembrane wrinkles from folding. To this end, the first lift shall be placed by vertically dropping the fill onto the geosynthetic materials to the extent practical. Where geomembrane wrinkles exceeding these criteria are unavoidable, the wrinkles shall be repaired prior to filling in accordance with the procedures described in Section 02650 of these Specifications.

L. All equipment operating above geosynthetic materials that are covered by less than 24 inches of fill shall be operated at low speeds, with no sharp turns, and no quick stops or starts.

3.12 MISCELLANEOUS TRENCH BACKFILL PLACEMENT AND COMPACTION

B. Sand Bedding shall be placed as shown on the Drawings.

C. Sand Bedding shall be moisture conditioned as necessary to facilitate compaction.

D. Sand Bedding below pipe inverts shall be firmly compacted prior to pipe placement using equipment-mounted or hand-operated vibratory compaction equipment, or other equipment approved by the CQA Officer.

E. Following pipe placement, Sand Bedding shall be placed adjacent to, and 6 to 8 inches above, the pipe crown. The Contractor shall then firmly compact the surface of the Sand Bedding using equipment-mounted or hand-operated vibratory compaction equipment, or other equipment approved by the CQA Officer.

F. Subsequent backfill above pipes that are buried in trenches no greater than 12-inches wide and that are not overlain by pavement, a slab, or other structural component can be placed in a single lift and surface rolled.

G. Subsequent backfill above pipes that are buried in trenches greater than12-inches wide and are less than 10 feet deep shall be placed in lifts no greater than 12 inches thick (loose thickness) and firmly compacted using equipment-mounted or hand-operated vibratory compaction equipment, or other equipment approved by the CQA Officer.

H. Subsequent backfill above pipes that are buried 10 feet or more shall be placed in lifts no greater than 12 inches thick (loose thickness) and compacted to at least 95 percent of the SMDD using equipment-mounted or hand-operated vibratory compaction equipment, or other equipment approved by the CQA Officer.

3.13 RIPRAP AND BEDDING PLACEMENT AND COMPACTION

F. Riprap Bedding shall be uniformly spread along the riprap subgrade to the minimum thickness shown on the Drawings. The placement method shall such that particle size segregation does not occur to the satisfaction of the CQA Officer.

G. Compaction of Riprap Bedding is not required, but the final surface shall be reasonably uniform.

H. Riprap shall be placed in a single lift from the center outward, or as approved by the CQA Officer.

I. Where riprap is placed on slopes steeper than 5:1, placement shall start at the lower elevation and proceed upward toward the higher elevation.

J. Riprap shall be dropped from a height no greater than 2 feet and placed in such a manner as to not displace its bedding.

K. The Contractor shall ensure that the graded stone sizes within the in-place riprap are reasonably well distributed.

3.14 FIELD QUALITY CONTROL

A. The Contractor shall utilize equipment, materials and procedures which are anticipated to meet the quality requirements specified.

B. The CQA Officer is responsible for conducting quality assurance testing in accordance with the approved CQA Plan. The Contractor shall provide the CQA Officer safe and unimpeded access to the sampling and testing locations selected by the CQA Officer.

END OF SECTION

j:\projects\01-0669 tcli\construction\current specifications\earthwork spec revision 1.doc

SECTION 02640

GEOTEXTILES

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered under this Section shall include providing all materials, equipment, supervision, and labor necessary to construct complete in-place all geotextile materials as shown on the Drawings and specified herein.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. D3786 – Standard Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics – Diaphragm Bursting Tester Method.
2. D4355 – Standard Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus).
3. D4491 – Standard Test Methods for Water Permeability of Geotextiles by Permittivity.
4. D4533 – Standard Test Method for Trapezoid Tearing Strength of Geotextiles.
5. D4595 – Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method.
6. D4632 – Standard Test Method for Grab Breaking Load and Elongation of Geotextiles.
7. D4751 – Standard Test Method for Determining Apparent Opening Size of a Geotextile.
8. D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.
9. D5261 – Standard Test Method for Measuring Mass per Unit Area of Geotextiles.
10. D5321 – Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. Manufacturer: Geotextile manufacturer.

C. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, and services necessary to perform the work as detailed in this Section of the Specifications.

1.04 SUBMITTALS

A. The Installer shall submit a certification signed by an authorized representative of the Manufacturer attesting that the geotextile to be supplied is in conformance with the specifications contained in Part 2 of this Section. Such certification shall be submitted to the Owner prior to material delivery to the Site.

1.05 DELIVERY, STORAGE AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier.

B. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

C. The Owner will designate a properly drained area free of holes and protruding objects for storing geotextile and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the geotextile. The Installer accepts the area as suitable for geotextile storage upon placing the geotextile in the storage area.

D. Geotextile shall be stored elevated above the ground surface.

E. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment, except that directly caused by Owner's personnel. Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

F. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

G. Nonconforming products shall be promptly removed from the Site.

PART 2: PRODUCTS

2.01 PHYSICAL PROPERTIES

A. Geotextile shall be needle punched nonwoven sheets of polypropylene or polyester yarns.

B. Geotextiles shall exhibit the following properties in both machine direction and cross-machine direction:

PLACEMENT: 3:1 SIDEWALL LEACHATE COLLECTION SYSTEM AND WITHIN LEACHATE COLLECTION TRENCHES			
Physical Property	**Test Method**	**Minimum Average Roll Value**	
Mass per Unit Area	ASTM D5261	8	oz / sy
Apparent Opening Size (range)	ASTM D4751	70 – 100	U.S. Standard Sieve
Water Flow Rate (MD and TD)	ASTM D4491	50	gpm per ft^2
Wide-Width Tensile Strength (MD and TD)	ASTM D4595	75	lbs per inch
Grab Tensile Strength (MD and TD)	ASTM D4632	220	lbs
Grab Elongation (MD and TD)	ASTM D4632	50	percent
Puncture Strength	ASTM D4833	120	lbs
Mullen Burst	ASTM D3786	380	psi
Trapezoidal Tear (MD and TD)	ASTM D4533	95	lbs
UV Resistance	ASTM D4355	70	percent strength retained after 500 hrs.

PLACEMENT: CELL FLOOR LEACHATE COLLECTION SYSTEM, FINAL COVER DRAINAGE LAYER, AND OTHER MISCELLANEOUS LOCATIONS			
Physical Property	**Test Method**	**Minimum Average Roll Value**	
Mass per Unit Area	ASTM D5261	6.0	oz / sy
Apparent Opening Size (range)	ASTM D4751	70 - 100	U.S. Standard Sieve
Water Flow Rate (MD and TD)	ASTM D4491	50	gpm per ft^2
Grab Tensile Strength (MD and TD)	ASTM D4632	150	lbs
Grab Elongation (MD and TD)	ASTM D4632	50	percent
Puncture Strength	ASTM D4833	80	lbs
Mullen Burst	ASTM D3786	285	psi

Trapezoidal Tear (MD and TD)	ASTM D4533	60	lbs
UV Resistance	ASTM D4355	70	percent strength retained after 500 hrs.

C. Geotextiles shall meet the minimum required interface shear strength properties:

INTERFACE (by ASTM D5321)	**MINIMUM TESTING FREQUENCY**	**MINIMUM ADHESION (psf)**	**MINIMUM FRICTION ANGLE (deg)**
Bottom Liner System			
Granular Drainage Layer vs. 8 oz. Geotextile[1,3]	Once per construction season	NA	$\Phi_{secant} = 24°$
Final Cover System			
8-oz Geotextile and Geonet[2,3]	Once per construction season	Shear Strength = 195 psf (peak) or 165 psf (residual)	

Notes:

1. Testing shall be performed under flooded and consolidated conditions at normal stresses of 5,000 psf, 10,000 psf, and 20,000 psf (2.5, 5.0, and 10 tsf) using a strain rate no greater than 0.04 inches per minute to a maximum displacement of 2 inches.
2. Testing shall be performed under flooded and consolidated conditions at normal stresses of 400 psf, (0.2 tsf) using a strain rate no greater than 0.2 inches per minute to a maximum displacement of 2 inches.
3. Interface shear strength criteria may be revised upon approval of the design engineer. If the interface shear strength test results are less than the minimum values reported above, additional slope stability analyses can be performed by a qualified geotechnical engineer using the interface shear strength test results. The test results are acceptable if these analyses demonstrate adequate factors of safety.

D. Each roll of geotextile shall be labeled with the Manufacturer's name, product identification, lot number, and roll number.

PART 3: EXECUTION

3.01 PLACEMENT AND PROTECTION

A. The geotextile shall be placed carefully such that no damage occurs during installation. The Installer shall repair or replace any damaged geotextile to the satisfaction of the CQA Officer.

B. The geotextile shall be maintained clean and free of debris at all times during construction.

C. Geotextile shall be laid smooth so as to minimize tension, stress, folds, and wrinkles.

D. On slopes steeper than 5:1 (horizontal to vertical), geotextile shall be anchored as shown on the Drawings and unrolled downslope keeping the fabric in slight tension to minimize wrinkles and folds.

E. Adjacent roll widths and lengths shall be overlapped a minimum of 12 inches, except thermally bonded or sewn seams shall be overlapped at least 3 inches.

F. Thread for sewn seams shall meet the ultraviolet light stability specifications for geotextile. The thread color shall contrast with the geotextile.

G. Adequate ballasting shall be provided to prevent displacement due to wind.

H. Operation of equipment and fill placement above geotextiles shall be conformance with Section 02200 of these specifications.

3.02 REPAIRS AND PENETRATIONS

A. Holes or tears in the geotextile shall be repaired by placing a patch of geotextile extending a minimum of 12 inches beyond the edges of the hole or tear.

B. The seams around geotextile patches shall be continuously thermally bonded or sewn.

C. The machine direction of patches shall be oriented the same as the machine direction of the patched geotextile.

D. Geotextile penetration details shall be as recommended by the Manufacturer.

END OF SECTION

SECTION 02645

GEONET

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered under this Section shall include providing all materials, equipment, supervision, and labor necessary to construct complete in-place all geosynthetic drainage materials (geonet) as shown on the Drawings and specified herein.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. D792 – Specific Gravity (Relative Density) and Density of Plastics by Displacement.
2. D1238 – Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.
3. D1505 – Standard Test Method for Density of Plastics by the Density-Gradient Technique.
4. D1603 – Standard Test Method for Carbon Black in Olefin Plastics.
5. D1682 – Standard Methods of Test for Breaking Load and Elongation of Textile Fabrics.
6. D4716 – Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.
7. D5035 – Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method).
8. D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.
9. D5321 – Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. Manufacturer: Geonet manufacturer.

C. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, and services necessary to perform the work as detailed in this Section of the Specifications.

D. HDPE: High density polyethylene.

1.04 SUBMITTALS

A. The Installer shall submit a certification signed by an authorized representative of the Manufacturer attesting that the resins and manufactured geonet to be supplied are in conformance with the specifications contained in Part 2 of this Section. Such certification shall be submitted to the Owner prior to the material being delivered to the Site.

1.05 DELIVERY, STORAGE AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier.

B. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

C. The Owner will designate a properly drained area free of holes and protruding objects for storing geonet and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the geonet. The Installer accepts the area as suitable for geonet storage upon placing the geonet in the storage area.

D. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment, except that directly caused by Owner's personnel. Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

E. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

F. Nonconforming products shall be promptly removed from Site.

PART 2: PRODUCTS

2.01 PHYSICAL PROPERTIES

A. Geonet shall be formed by extruding two sets of solid HDPE strands to form a three-dimensional structure.

B. Resins used in the formulation of the geonet shall meet the following criteria:

1. Resins shall be contain no fatty acid residues, epoxy, secondary plasticizers, fillers or extenders.
2. Resins shall exhibit a density no less than 0.932 grams per milliliter, as determined by ASTM D1505 or D792B.
3. Resins shall exhibit a melt index value no greater than 1.0 gram per 10 minutes, as determined by ASTM D1238.

C. Completed geonets shall have good appearance and be free of blisters, undispersed raw materials, signs of contamination by foreign matter, or any other defect that would affect the specified properties of the geonet.

D. Geonets shall exhibit the following properties to be tested at a minimum frequency of one per lot:

Physical Property	**Test Method**	**Minimum Average Value**	
Density (compounded resin)	ASTM D1505	0.94	gm / cc
Thickness	ASTM D5199	0.200	inches
Tensile Strength (MD)	ASTM D5035	40	lbs / in
Transmissivity (1)	ASTM D4716	1×10^{-3}	m^2 / sec
Carbon Black (range)	ASTM D1603	1.5 - 3	Percent

(1) Transmissivity corresponding to hydraulic gradient of 0.1 at a confining pressure of at least 10,000 psf, seat time of at least 15 minutes, tested between steel plates.

E. The geonet shall meet the minimum interface shear strength parameters with adjoining construction materials, or as part of a geocomposite configuration:

Interface (by ASTM D5321)	Test Conditions		Min. Shear Strength	
	Max. Strain Rate (In./Min.)	Normal Stress	Peak	Residual
Final Cover System[4]				
Geonet vs. Geotextile	0.001	400 psf	195 psf	165 psf
Geonet vs. 40 mil textured HDPE Geomembrane	0.2			

Notes:

1. Additional test conditions
   a. Samples shall be flooded and consolidated under the normal stress for at least 24 hours prior to sampling
   b. Tests shall be conducted in a flooded condition

c. Strain rates may be increased by a factor of 10 after the peak shear strength is observed
d. Samples shall be sheared to a minimum 2.0 inch horizontal displacement.

2. The minimum residual shear strength criteria only apply to the interface which exhibits the lowest peak strength
3. Strength criteria may be varied upon approval of the Engineer. If the tested interface shear strength are less than the values reported above, additional slope stability analyses may be performed to check the acceptability of the test results. The slope stability analysis should be performed by an engineer experienced in geotechnical engineering.
4. Final cover system component interface shear criteria apply only to materials placed on 4:1 (horizontal to vertical) final cover slopes.
5. The testing frequency shall be once per construction season.

F. Each roll of geonet shall be labeled with the following:

- Name of Manufacturer,
- Product identification,
- Lot number,
- Roll number, and
- Roll dimensions.

PART 3: EXECUTION

3.01 PLACEMENT

A. The geonet shall be placed carefully such that no damage occurs during installation. The Installer shall repair or replace any damaged geonet to the satisfaction of the CQA Officer.

B. The geonet shall be maintained clean and free of debris at all times during construction.

C. Geonet shall be unrolled downslope keeping the net in slight tension to minimize wrinkles and folds.

D. Geonet shall be oriented to provide the maximum transmissivity downslope.

E. Adequate ballasting shall be provided to prevent displacement due to wind.

3.02 OVERLAP AND FASTENERS

A. Adjoining roll lengths shall be overlapped a minimum of 4 inches and shall be connected using HDPE or nylon ties spaced no farther than 5 feet downslope and 2 feet cross-slope. Adjoining roll lengths in anchor trenches shall be connected using HDPE or nylon ties spaced no farther than 6 inches.

B. Adjoining roll widths shall be overlapped a minimum of 12 inches and shall be connected using HDPE or nylon ties spaced no farther than 2 feet.

C. Light-colored ties shall be used to ease inspection.

D. Geonets shall not be welded to geomembrane.

E. Where more than one layer of geonet is required, joints shall be staggered. Stacked geonet layers shall be laid in the same direction to maintain transmissivity.

F. An extra layer of geonet shall be installed where overlaps between rolls are staggered in corners of sideslopes.

3.03 REPAIRS AND PENETRATIONS

A. Holes or tears in the geonet shall be repaired by placing a patch of geonet extending a minimum of 2 feet beyond the edges of the hole or tear.

B. Geonet patches shall be oriented in the same direction as the underlying geonet.

C. Geonet patches shall be fastened to the underlying geonet using nylon or HDPE ties spaced a maximum of 6 inches.

D. Geonet penetration details shall be as recommended by the Manufacturer.

END OF SECTION

SECTION 02650

GEOMEMBRANES

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered by this section includes furnishing all supervision, labor, materials and equipment required to supply, install, and/or repair geomembranes at the site including, but not limited to the following:

1. Landfill liner geomembranes, and

2. Landfill final cover geomembrane.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. D792 – Specific Gravity (Relative Density) and Density of Plastics by Displacement.

2. D1004 - Standard Test Method for Initial Tear Resistance of Plastics Film and Sheeting.

3. D1238 - Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

4. D1505 - Standard Test Method for Density of Plastics by the Density-Gradient Technique.

5. D1603 - Standard Test Method for Carbon Black in Olefin Plastics.

7. D3895 - Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry.

8. D4218 - Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique.

9. D4833 - Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products.

10. D5199 - Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

11. D5321 – Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

12. D5397 – Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test.

13. D5596 – Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics.

14. D5641 – Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.

15. D5721 – Standard Practice for Air-Oven Aging of Polyolefin Geomembranes.

16. D5820 – Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes.

17. D5885 – Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry.

18. D5994 – Standard Test Method for Measuring the Core Thickness of Textured Geomembranes.

19. D6365 – Standard Practice for the Nondestructive Testing of Geomembrane Seams Using the Spark Test.

20. D6392 – Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods.

21. D6693 – Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes.

B. The following are complete titles of Geosynthetic Research Institute (GRI) references cited in this section:

1. GM 10 – Specification for the Stress Crack Resistance of Geomembrane Sheet.

2. GM 12 – Measurement of the Asperity Height of Textured Geomembranes Using a Depth Gauge.

3. GM 13 – Standard Specification for: Test Properties, Testing Frequency and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes.

4. GM 17 – Standard Specification for: Test Properties, Testing Frequency and Recommended Warranty for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes.

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. Manufacturer: Geomembrane manufacturer.

C. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, field testing, and services necessary to perform the work as detailed in this Section of the Specifications.

D. HDPE: High density polyethylene.

E. LLDPE: Linear low density polyethylene.

1.04 SUBMITTALS

A. The Installer shall submit the following items to the Owner prior to mobilizing to the Site:

1. Manufacturer certifications that the resins and manufactured geomembrane sheets are in conformance with the material and testing specifications contained in Part 2 of this Section of the Specifications. The certification shall be accompanied by manufacturing quality control (MQC) test data demonstrating conformance.

2. Written Manufacturer's warranty that the geomembrane is free of manufacturing defects and able to withstand normal weathering for a period of at least 5 years from date of installation. The warranty shall provide for repair or replacement of defective materials on a pro-rata basis.

3. Two sets of panel layout shop drawings showing the proposed locations of all panels, field welds, anchorages, and anchorage details. The panel layout shall minimize the number and length of field welds consistent with proper methods of liner installation. Panel layout shop drawings are not required for repairs.

4. Two sets of shop drawings detailing attachment of geomembrane to structures and penetrations shown on the drawings.

5. Upon request by Owner, a list of similar installations currently in service. As a minimum, 10 geomembrane installations, with at least 5 installations of textured HDPE geomembrane (final cover Installer only), all in service at least 2 years, shall be included. The list shall include the owners' name, address, telephone number, location of project, the type(s) and square feet of product(s) installed, geomembrane thickness, and the start and completion dates.

6. Resume for each Project Superintendent assigned to the project. Each resume shall include at least two similar installation projects on which the proposed Project Superintendent served as Project Superintendent. The owners' names, addresses, telephone numbers, locations of the projects, types and square feet of products,

geomembrane thickness, and the start and completion dates of each project shall be included on the resume.

7. Written workmanship warranty covering defects in installation for a period of at least one year from date of installation completion.

B. The Manufacturer shall, prior to shipping geomembrane to the site, submit to the Owner one 1-foot wide by 6-feet long (minimum) sample of geomembrane for each 50,000 square feet (or portion thereof) of geomembrane to be supplied. The sample(s) shall be from roll(s) to be delivered and shall be labeled with the roll number(s). At least one sample shall be provided for each phase of geomembrane installation. The Owner will submit the sample(s) to a qualified laboratory independent of the Manufacturer for quality assurance testing of the following properties: thickness, density, tensile properties, puncture resistance, tear resistance, carbon content, interface shear, and any other test deemed appropriate by the Owner.

C. The Installer shall submit to the Owner all field and laboratory quality control documentation records as required by Part 3.09 of this Section of the Specifications. These records shall be submitted within 2 weeks of completion of geomembrane installation.

D. Within one week of Owner's request, the Installer shall submit one copy of the Manufacturer's and Installer's quality control manual for the manufacture and installation of geomembrane.

1.05 SEQUENCING AND SCHEDULING

A. The Installer shall coordinate geomembrane delivery date, onsite storage needs, and Installer mobilization date with Owner.

B. The Installer shall not allow or cause any of the work performed or installed to be covered up or enclosed prior to required inspections, tests or approvals.

1.06 DELIVERY, STORAGE, AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier. The geomembrane shall be rolled onto a substantial core and held firm by dedicated straps/slings, or other suitable means, during shipping.

B. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

C. The Owner will designate a properly drained area free of holes and protruding objects for storing geomembrane and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the geomembrane. The Installer accepts the area as suitable for geomembrane storage upon placing the geomembrane in the storage area.

D. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment while on site, except that directly caused by Owner's personnel. Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

E. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

F. Nonconforming products shall be promptly removed from Site.

G. The Installer shall perform an inventory of the materials delivered to verify the presence of roll numbers listed in the MQC data, as well as those from which samples were provided for Owner's quality assurance testing as described in Part 1.04B of this Section.

PART 2: PRODUCTS

2.01 MATERIALS

A. Geomembrane and Extrusion Weld Rod Resin

1. Resins shall contain no fatty acid residues, epoxy, secondary plasticizers, fillers or extenders.
2. Resins shall contain no more than 10 percent rework. If rework is used, it must originate from the same formulation and production lot as the parent material.
3. No post-consumer resin of any type shall be used.
4. HDPE resins shall exhibit a density no less than 0.932 grams per milliliter, as determined by ASTM D1505 or D792B. LLDPE resins shall exhibit a density between 0.915 and 0.926 grams per milliliter
5. Resins shall exhibit a melt index value less than or equal to 1.0 grams per 10 minutes at 2.16 kg, as determined by ASTM D1238.

B. Geomembrane Sheets

1. Geomembrane sheets shall have good appearance and be free of holes, blisters, undispersed raw materials, signs of contamination by foreign matter, or any other defect that would affect the specified properties of the geomembrane.
2. Textured geomembrane shall be textured on both sides.
3. Textured geomembrane sheets shall have a uniform textured appearance.
4. Landfill liner geomembrane shall meet the criteria listed in Table 02650-1.
5. Landfill final cover geomembrane materials shall meet the criteria listed in Table 02650-1.
6. Geomembrane materials shall meet the interface shear strength criteria listed in Table 02650-2.

7. Each roll of geomembrane shall be labeled with the following:
   - Name of Manufacturer,
   - Product type and thickness, and
   - Manufacturing batch code.

C. Metal Fasteners

1. Metal fasteners, such as bolts, battens, bandings, etc., shall be Type 304 or 316 stainless steel.

2. Metal batten strips and banding shall be at least ¼ - inch thick and 1-1/2 inches nominal width, and be provided with neoprene gaskets (or approved equivalent).

3. Bolts shall be Kwik Bolts as manufactured by Hilti Corporation, or approved equivalent.

2.02 GEOMEMBRANE MANUFACTURER'S QUALITY CONTROL

A. General manufacturing procedures shall be performed in accordance with a written manufacturer's quality control program that conforms to generally accepted industry standards at the time of manufacture.

B. Testing methods and minimum MQC sampling/testing frequencies are shown on Table 02650-1. If no sampling protocol is stipulated in the referenced test method, then test specimens shall be taken evenly spaced across the entire roll width.

PART 3: EXECUTION

3.01 PREPARATION

A. The Owner will be responsible for preparing and maintaining the geomembrane foundation to the design lines and grades in accordance with the appropriate Section(s) of these Specifications.

B. The Owner will be responsible for collecting and removing surface water from the area in which the geomembrane is to be installed.

3.02 GEOMEMBRANE SUBGRADE

A. The geomembrane subgrade shall be rolled or bladed smooth to a smooth, well compacted surface.

B. The geomembrane subgrade shall be free of hard or sharp objects that will not pass a 3/8-inch sieve.

C. The geomembrane subgrade shall be free of desiccation cracks in excess of ½-inch wide.

D. The Installer shall certify in writing that the surface on which the geomembrane is to be installed is acceptable.

3.03 GEOMEMBRANE PLACEMENT

A. Geomembrane panels shall be placed as shown on the approved panel layout drawing or as otherwise approved by the CQA Officer.

B. Geomembrane anchor trenches shall be constructed to the lines, grades, and minimum dimensions shown on the Drawings.

C. Geomembrane anchor trenches shall be free of loose or disturbed material, debris, and standing water upon geomembrane placement.

D. Geomembrane anchor trenches shall be backfilled and compacted in accordance with Part 3.08 of the Earthwork Specifications. Care shall be exercised to prevent damaging the geosynthetic materials while placing and compacting anchor trench backfill.

E. Geomembrane shall not be deployed during periods of inclement weather (rain, snow, high wind, or with ambient temperature above 95° F or below 32° F) unless demonstrated by the Installer and approved by the CQA Officer that conformance with these specifications will not be sacrificed by continuing.

F. Adjoining seams shall be overlapped a minimum of 3 inches.

G. Adjoining seams shall be shingled such that runoff flows over the overlapping geomembrane panel where practical.

H. Panels shall be installed such that slack and wrinkles are minimized except as needed to minimize stresses due to thermal expansion and contraction.

I. The Installer shall ballast the geomembrane using sand bags, tires, or other approved means as required to prevent displacement.

3.04 GEOMEMBRANE PROTECTION

A. The Installer shall provide the Owner with a list of equipment and supplies that will be used within the confines of the installed geomembrane. The CQA Officer shall approve all equipment and supplies that may contact the geomembrane.

B. The Installer shall protect the geomembrane from damage of any kind during installation. Sacrificial layers of scrap geomembrane may be used if approved by the CQA Officer.

C. All personnel whose duties require walking on the geomembrane shall wear smooth-soled shoes.

D. Only light-weight, low-ground pressure rubber-tired vehicles, such as all-terrain-vehicles (ATVs) may be used on the geomembrane where approved by the CQA Officer. Such vehicles shall be operated such that they do not impose wrinkles or significant shear stresses on the geomembrane due to sharp turns or abrupt starts or stops.

E. No equipment (except as described above) or supplies shall be rolled or dragged over the geomembrane unless the geomembrane is protected with a minimum 60 mil rub sheet and the area to be traversed is first inspected and cleared of any objects that could penetrate or otherwise damage the geomembrane.

3.05 WELDS

A. Seams to be welded shall be in a relaxed state, i.e. they shall not be under tension or exhibit wrinkles. Critical seams shall be welded during the coolest part of the day.

B. Geomembrane seams shall be thermally bonded using a double-wedge fusion weld. A single-wedge fusion weld or extrusion (fillet) weld is acceptable upon the CQA Officer's approval only where a double-wedge fusion weld is not possible.

C. Each welding equipment/operator combination shall be pre-qualified in accordance with the procedures described in Part 3.09 of this Section.

D. Automated double- and single-wedge fusion welding machines shall be used to control fusion temperature, pressure, and travel speed.

E. Seams to be extrusion welded shall first be roughened a minimum ½ inch on either side of the extrusion weld using a grinder or other appropriate tool. The overlapping edge of geomembrane to be extrusion welded shall be beveled approximately 45 degrees for geomembranes greater than 80 mils. Grinding shall be completed no more than 1 hour prior to extrusion welding.

F. Seams shall be wiped clean of moisture, dust and debris immediately prior to welding.

G. Once heated, extrudate shall be used within 15 minutes. Otherwise it shall be purged from the extrusion gun and discarded prior to the next weld.

H. A moveable protective layer may be used directly beneath panel edges to be fused to maintain the area to be fused free of dust or moisture.

3.06 DEFECT REPAIR

A. Deep (partially penetrating) scratches and creases can be repaired using a bead of molten resin extrudate. The surface shall first be roughened and cleaned as described for extrusion welding.

B. Fully penetrating holes, tears, rips, etc. shall be patched using a geomembrane patch comprised of material with a nominal thickness at least that of the geomembrane being patched. The patch shall extend at least 4 inches in all directions beyond the defect. Cross-seam tees shall be patched with a minimum patch size of 12 inches square. The entire perimeter of the patch shall be extrusion welded to the base geomembrane in accordance with Part 3.05 of this Section. The seam shall be non-destructively tested in accordance with Part 3.09 of this Section.

C. Wrinkles that in the opinion of the CQA Officer are likely to become folded when covered shall be removed by 1) cutting the crest of the wrinkle, 2) overlapping the edges, 3) extrusion welding the exposed edge, and 4) patching the ends of the cut. The seams shall be tested in accordance with Part 3.09 of this Section.

3.07 CONSTRUCTION OVER GEOMEMBRANE

A. The Owner will provide labor, equipment and materials for constructing the leachate drainage system and protective layer over the installed geomembrane.

B. The CQA Officer shall be responsible for approving the Owner's construction methods to ensure that they do not jeopardize the geomembrane integrity, Manufacturer's warranty, or Installer's warranty. The CQA Officer will be responsible for confirming that the Installer's recommended construction methods are followed.

3.08 CLEANUP

A. The Installer shall be responsible for handling and disposal of all materials, supplies, etc. that are incidental to the work.

3.09 FIELD QUALITY CONTROL

A. The Installer shall inspect both sides of each geomembrane sheet surface as the geomembrane is deployed. Any defects shall be repaired or replaced in a manner approved by the CQA Officer, and at the expense or the Manufacturer or Installer, whichever party caused the defect.

B. Each welding equipment/operator combination shall undergo pre-qualification testing at the Installer's expense in accordance with the following procedures:

1. Pre-qualification test welds shall be conducted at the start and midpoint of each shift, and following a 1-hour or longer interruption in welding activities during the shift.

2. Pre-qualification test welds shall be at least 3 feet long, and be conducted on scraps of the material being production welded. The test materials shall have been stored under conditions similar to those used for the geomembrane.

3. If production welding is to be conducted on slopes, the pre-qualification welds shall also be conducted on a slope of the same steepness.

4. A minimum of five weld coupons shall be cut from each test seam, and subjected to 3 field peel and 2 shear tests conducted in accordance with the most recent edition of ASTM D6392. A certificate of calibration less than 12 months old shall be provided by the Installer for the field tensiometer equipment. The serial number on the tensiometer unit must correspond to the serial number of the unit represented on the certificate of calibration. The test seam shall meet the following criteria:

   i. Shear and Peel strength values provided in Table 02650-2, and

ii. The weld visually appears continuous and homogeneous.

5. The test weld can be repeated until the operator and equipment pass the pre-qualification testing.

C. All welded seams shall be non-destructively tested at the Installer's expense as described below:

1. Double-wedge fusion welds shall be pressure-tested in accordance with the most recent edition of ASTM D5820. Test pressures and maximum allowable pressure differentials are provided in Table 02650-4

2. Extrusion and single-wedge fusion welds shall be vacuum box tested in accordance with the most recent edition of ASTM D5641.

3. Where either pressure testing or vacuum box testing is not practical due to seam location and/or geometry, upon the CQA Officer's approval, the Installer may spark test the seam in accordance with the most recent edition of ASTM D6365.

D. Samples of each type of seam shall be collected and destructively tested as described below:

1. Sample locations shall be selected randomly by the CQA Officer at a frequency no less than one sample per 500 lineal feet of seam, or one per each day during which field welding occurs, whichever provides the greatest number of samples. Note that the CQA Plan allows the CQA Officer to waive daily testing under certain conditions when only a limited footage of seaming occurs.

2. Additional samples shall be collected in areas where, in the CQA Officer's judgement, seam integrity is questionable.

3. Sample and sample locations shall be marked to allow identification of the location from which each sample was collected.

4. The Installer shall collect the sample specimens. Each specimen shall be at least 1 foot wide by 4 feet long (parallel to the seam), with the seam centered in the sample. If desired, the Installer may retain another specimen for field testing. Such field testing shall solely be for the Installer's convenience.

5. Each sample location shall be patched in accordance with Part 3.06B of this Section. Patching shall occur the same day as sample removal.

6. The Installer shall submit one specimen to a qualified laboratory approved by the Owner. Five coupons of each specimen shall be tested for peel and tensile strength in accordance with the most recent edition of ASTM D6392. The Owner will archive the remaining specimen.

7. The seam shall be deemed to have successfully passed the destructive testing provided the following criteria are achieved based on the laboratory testing in accordance with ASTM D6392:

i. Strength, elongation and separation (incursion) values provided in Table 02650-2, and

ii. Unacceptable Locus-of-Break Codes for single or double wedge welded seams: AD and AD-Brk > 25 %, and

iii. Unacceptable Locus-of-Break Codes for extrusion (fillet) welded seams: AD1, AD2, and AD-WLD.

E. Seams between a failed weld and the closest passing weld on both sides of the failed weld are considered failed. The Installer may conduct additional testing to minimize the length of seam that must be repaired. The seam to be repaired must extend a minimum of 10 feet in both directions from the failed sample location.

F. Failed seams shall be repaired by patching over the failed seamed in accordance with the procedures detailed in Part 3.06B of this Section. Double-wedge fusion welded seams that fail the non-destructive test only can alternatively be repaired by extrusion welding the free edge of the overlying sheet to the base sheet in accordance with Part 3.05 of this Section. All repairs shall be subjected to the Field Quality Control procedures described in Part 3.09 of this Section.

3.10 DOCUMENTATION

A. The Installer shall prepare a panel placement log. The log shall, at a minimum, document the placement date, panel number, roll number, panel length, and panel width.

B. The Installer shall prepare an as-built panel layout drawing. The as-built panel layout drawing shall be to scale and include the following: panel edges and numbers, fusion welds, extrusion welds, repairs (including type of repair), destructive sample location with sample identification, and liner penetrations.

C. The Installer shall document all pre-qualification testing. Documentation shall include chronological pre-qualification test number, date and time, weather conditions/ambient temperature, welding equipment operator name, welding apparatus identification, type of weld, operating parameters (e.g. wedge temperature and roller speed for double-wedge fusion, and extrusion temperature and pre-heat temperature for extrusion gun), peel resistance and shear strength test results

D. The Installer shall document all field seaming activities. The field seaming documentation shall include date and time, , type of weld, welding equipment operator, seam and adjoining panel designations, welding apparatus identification, and corresponding pre-qualification test number.

E. The Installer shall maintain a non-destructive testing log. The non-destructive testing log shall include test date, start and end time of the test, test seam identification (including the extent of the test), type of test, and test results (pass/fail). Pressure tests shall include initial pressure and final pressure.

F. The Installer shall maintain a destructive sample log. The sample log shall include sample identification, sample date and time, and a description of the sample location including seam number and adjoining panels. In addition, results of any field testing performed on the sample shall be included.

G. The Installer shall maintain a repair log. The repair log shall include repair date, repair number, repair location, , type of repair, and date that the repair was tested. Each repair shall have a corresponding seaming documentation, non-destructive testing log, and destructive sample log, as appropriate.

TABLE 02650-1

HDPE GEOMEMBRANE SHEET PROPERTIES –LINER AND FINAL COVER

PROPERTY	TEST METHOD	REQUIRED VALUE 60 mil Smooth	REQUIRED VALUE 60 mil Textured	MQC TESTING FREQUENCY[1]
Thickness: Minimum average[2]: Minimum value:	ASTM D5199	60 mils 57 mils	80 mils 76 mils	Each roll
Density (minimum)	ASTM D1505/D792B	0.94 g/cc	0.94 g/cc	200,000 lb.
Tensile Properties (MD & XMD)[3]: Yield Strength (min. average): Break Strength (min. average): Yield Elongation (min. average): Break Elongation (min. average):	ASTM D6693 (1.3" gauge) (2.0" gauge)	126 lb/in 228 lb/in 12% 700%	126 lb/in 90 lb/in 12% 100%	20,000 lb.
Tear Resistance (min. average):	ASTM D1004	42 lbs	42 lbs	45,000 lb.
Puncture Resistance (min. average):	ASTM D4833	108 lbs	90 lbs	45,000 lb.
Stress Crack Resistance (min. ave.):	ASTM D5397-Appendix	300 hrs	300 hrs	Per GRI GM-10
Carbon Black Content (range):	ASTM D1603[4]	2.0-3.0%	2.0-3.0%	20,000 lb.
Carbon Black Dispersion:	ASTM D5596	(Note 5)	(Note 5)	45,000 lb.
Oxidative Induction Time (OIT)[6]: Standard OIT (min. average): High Pressure OIT (min. ave.):	ASTM D3895 ASTM D5885	100 min. 400 min.	100 min. 400 min.	200,000 lb.
Oven Aging at 85^0 C[6, 7]: Standard OIT (min. ave.): High Pressure OIT (min. ave.):	ASTM D5721 ASTM D3895 ASTM D5885	55% 80%	55% 80%	Each formulation
UV Resistance[8] High Pressure OIT (min. average % retained after 1600 hours):	GRI – GM11 ASTM D5885	50%	50%	Each formulation

Notes:
1. Minimum Manufacturer's Quality Control (MQC) testing frequencies.
2. Average calculated according to procedures cited in the reference test method.
3. MD = Machine direction; XMD = Cross-machine direction. Average values shall be based on 5 test specimens each direction. Gage length in accordance with GRI GM-13.
4. Other methods may be acceptable if an appropriate correlation with this method can be established per GRI GM-13.
5. Determine for 10 different views with a minimum of nine values in Category 1 or 2, and a maximum of one in Category 3.
6. Manufacturer has option to select either Standard or High Pressure OIT methods.
7. Required value expressed as the percent retained after 90 days.
8. Test condition: 20 hour UV cycle at 75^0 C followed by 4 hour condensation at 60^0 C.

TABLE 02650-2

GEOMEMBRANE SEAM CRITERIA

SEAM PROPERTY (by ASTM D6392)	MINIMUM VALUES 60 MIL HDPE
Shear Strength (lb/in):	
4 of 5 coupons	120
5 of 5 coupons	96
Shear Elongation at Break (%):	
5 of 5 coupons	50
Peel Strength (lb/in):	
4 of 5 coupons	
Hot Wedge Seams:	91
Extrusion Fillet Seams:	78
5 of 5 coupons	
Hot Wedge Seams:	73
Extrusion Fillet Seams:	62
Peel Separation (%):	
5 of 5 coupons	25

Notes: 1. Shear Elongation (E) = $(L/L_0) \times 100$
L = Extension at end of test (in.)
L_0 = Original average length (in.)

2. Peel Separation (incursion) (S) = $(A/A_0) \times 100$
A = Average area of separation or incursion (sq. in. or sq. mm)
A_0 = Original bonding area (sq. in. or sq. mm)

TABLE 02650-3

GEOMEMBRANE INTERFACE SHEAR STRENGTH CRITERIA

INTERFACE (by ASTM D5321)	MINIMUM TESTING FREQUENCY	MINIMUM ADHESION (psf)	MINIMUM FRICTION ANGLE (deg)[5]
Landfill Floor Liner and Sideslope System[1]			
Clay Liner vs. 60 mil HDPE Geomembrane	Once per construction season	NA	$\Phi_{secant} = 24°$
60 mil HDPE Geomembrane vs. Geocomposite	Once per construction season	NA	$\Phi_{secant} = 24°$
60 mil HDPE Geomembrane vs. GCL	Once per construction season	NA	$\Phi_{secant} = 24°$
60 mil HDPE Geomembrane vs. Leachate Collection System Material	Once per construction season	NA	$\Phi_{secant} = 24°$
Final Cover System			
Clay Liner vs. 40 mil textured LLDPE Geomembrane'[24]	Once per construction season	Shear Strength = 195 psf (peak) or 165 psf (residual)	
40 mil textured LLDPE Geomembrane vs. Geocomposite[2,4]	Once per construction season	Shear Strength = 195 psf (peak) or 165 psf (residual)	

Notes:

1. Landfill liner system testing shall be performed under flooded and consolidated conditions at normal stresses of 5,000, 10,000, and 20,000 psf (2.5, 5, and 10 tsf) using a strain rate no greater than 0.04 inch/min to a maximum displacement of 2 inches.

2. Final cover system testing shall be performed under flooded and consolidated conditions at a normal stress of 400 psf (0.2 tsf) using a strain rate no greater than 0.04 inch/min to a maximum displacement of 2 inches.

3. Secant friction angle is determined from a best-fit line assuming no adhesion.

4. Final cover system component interface shear criteria apply only to material place on 4:1 (horizontal to vertical) final cover slopes.

4. Interface shear strength criteria may be revised upon approval of the design engineer. If the interface shear strength test results are less than the minimum values reported above, additional slope stability analyses can be performed by a qualified geotechnical engineer using the interface shear strength test results. The test results are acceptable if these analyses demonstrate adequate factors of safety.

5. The minimum residual shear strength criteria only apply to the interface which exhibits the lowest peak strength.

TABLE 02650-4

DOUBLE WEDGE WELD AIR TESTING CRITERIA

INITIAL TEST PRESSURES *

GEOMEMBRANE THICKNESS (mils)	MINIMUM TEST PRESSURE (psi)	MAXIMUM TEST PRESSURE (psi)
40	24	30
60	27	35
80	30	35
100	30	35

*Initial pressure settings are read after a two-minute "relaxing period." The purpose of this "relaxing period" is to permit the air temperature and pressure to stabilize.

MAXIMUM PERMISSIBLE DIFFERENTIAL PRESSURES

GEOMEMBRANE THICKNESS (mils)	MAXIMUM PRESSURE DIFFERENTIAL (psi)
40	4 psi
60	3 psi
80	2 psi
100	2 psi

Differential Pressure equals the Initial Test Pressure minus the pressure at the end of the test. The test shall extend at least 5 minutes after the reading of the Initial Test Pressures.

END OF SECTION

SECTION 02660

GEOSYNTHETIC CLAY LINER

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered under this Section shall include providing all materials, equipment, supervision, and labor necessary to complete in-place all geosynthetic clay liner (GCL) as shown on the Drawings and specified herein.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. ASTM D 4632, "Standard Test Method for Grab Breaking Load and Elongation of Geotextiles"
2. ASTM D 4643, "Determination of Water (Moisture) Content of Soil by the Microwave Oven Method"
3. ASTM D 5084, "Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"
4. ASTM D 5261, "Standard Test Method for Measuring Mass Per Unit Area of Geotextiles"
5. ASTM D 5321, "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"
6. ASTM D 5887, "Measurement of Index Flux Through Saturated Geosynthetic Clay Liner Specimens Using a Flexible Wall Permeameter"
7. ASTM D 5888, "Standard Guide for Storage and Handling of Geosynthetic Clay Liners"
8. ASTM D 5889, "Standard Practice for Quality Control of Geosynthetic Clay Liners"
9. ASTM D 5890, "Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners"
10. ASTM D 5891, "Standard Test Method for Fluid Loss of Clay Component of Geosynthetic Clay Liners"

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. GCL: geosynthetic clay liner

C. Manufacturer: GCL manufacturer.

D. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, and services necessary to perform the work as detailed in this Section of the Specifications.

1.04 SUBMITTALS

A. The Installer shall submit a certification signed by an authorized representative of the Manufacturer attesting that the manufactured GCL to be supplied is in conformance with the specifications contained in Part 2 of this Section. Such certification shall be submitted to the Owner within 2 weeks of notice to proceed. The certification shall identify the Lot and Roll Numbers that are covered by the certification.

1.05 DELIVERY, STORAGE AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier.

B. All GCL rolls shall be packaged in moisture resistant plastic sleeves. The cores shall be sufficiently strong to resist collapse during transit and handling.

C. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

D. The Owner will designate a properly drained area free of holes and protruding objects for storing GCL and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the GCL. The Installer accepts the area as suitable for GCL storage upon placing the GCL in the storage area.

E. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment, except that directly caused by Owner's personnel. Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

F. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

G. Nonconforming products shall be promptly removed from Site.

PART 2: PRODUCTS

2.01 PHYSICAL PROPERTIES

A. The GCL shall comprise a natural sodium bentonite core between two durable geotextile layers. The top geotextile layer shall be a nonwoven geotextile; the bottom geotextile shall be either a slit film woven geotextile or a scrim reinforced nonwoven geotextile.

B. The GCL shall be manufactured by mechanically bonding the geotextiles using a needlepunching process to enhance frictional and internal shear characteristics.

C. The GCL shall exhibit the following properties:

Physical Property	ASTM Test Method	Minimum MQC Testing Frequency	Minimum Average Roll Value	
Geotextile Properties				
Weight	D 5261		2.5	oz / sy
Bentonite Properties				
Swell Index	D 5890	100,000 lbs	24	ml / 2 g (min.)
Moisture Content	D 4643	100,000 lbs	12	% (max.)
Fluid Loss	D5891	100,000 lbs	18	ml (max)
Finished GCL Properties				
Bentonite Mass	D 5993	40,000 ft^2	0.75	lbs / ft^2
Grab Strength	D 4632	40,000 ft^2	80	lbs.
Grab Elongation	D 4632	40,000 ft^2	30	lbs. (typical)
Peel Strength	D 4632	40,000 ft^2	5	lbs.
Permeability	D 5084	100,000 ft^2	5×10^{-9}	cm / sec (max)
Index Flux	D 5887	weekly	$.1 \times 10^{-8}$	$m^3 / m^2 / s$ (max)
Internal Shear Strength	D 6243	NA	50	psf (typical)

D. Each roll of GCL shall be labeled with the following:
- Product identification,
- Lot number,
- Roll number, and
- Roll dimensions.

E. A minimum overlap guide-line and a construction match-line delineating the overlap zone shall be imprinted with non-toxic ink on both edges of the GCL panel.

F. Any accessory bentonite used for sealing seams, penetrations, or repairs shall be the same type of granular bentonite as used in the production of the GCL itself.

PART 3: EXECUTION

3.01 PLACEMENT

A. The CQA Officer shall approve the area to receive the GCL prior to GCL deployment.

B. The GCL shall only be deployed during weather conditions that prevent the GCL from becoming hydrated.

C. The GCL shall be placed carefully such that no damage occurs during installation. The Installer shall repair or replace any damaged GCL to the satisfaction of the CQA Officer.

D. GCL panels shall be placed with the nonwoven geotextile up, except as approved by the CQA Officer.

E. Where practical, all slope panels shall be installed parallel to the maximum slope while panels installed in flat areas require no particular orientation.

F. The Installer shall minimize dragging GCL panels to the maximum extent practical.

G. Overlaps shall be a minimum of 6 inches and be free of wrinkles, folds or "fish mouths."

H. The Installer shall only install as much GCL as can be covered at the end of each day. No GCL shall be left exposed overnight. The exposed edge of the GCL shall be covered by a temporary tarpaulin or other such water resistant sheeting.

3.02 SEAMING

A. Adjoining roll lengths shall be overlapped a minimum of 6 inches.

B. Adjoining roll widths shall be overlapped a minimum of 12 inches.

C. The addition of bentonite to the seam is optional.

3.03 REPAIRS AND PENETRATIONS

A. Rips or tears shall be repaired by completely exposing the affected area, removing all foreign objects or soil, and by then placing a patch cut from a GCL panel. The patch can be placed over the damaged area (i.e. the damaged area does not need to be removed) and shall overlap undamaged edges a minimum of 12 inches. Accessory bentonite shall be placed in a 6-inch wide (nominal) fillet between the patch edges and repaired material at a rate of at least one-quarter pound per lineal foot of edge.

B. Rips or tears on slopes steeper than 7 horizontal to 1 vertical shall be repaired as described above, except the edges of the patch shall be adhered to the repaired panel with an adhesive to ensure the patch remains in position.

C. Displaced panels shall be repositioned and inspected by the CQA Officer for any geotextile damage or bentonite loss. Damaged panels shall be repaired as described above.

D. The Installer shall notify the CQA Officer in the event that GCL becomes prematurely hydrated. The CQA Officer shall determine appropriate corrective actions.

END OF SECTION

j:\projects\01-0669 tcli\construction\current specifications\gcl spec.doc

SECTION 02646

GEOCOMPOSITE DRAINAGE LAYER

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered under this Section shall include providing all materials, equipment, supervision, and labor necessary to construct complete in-place all geocomposite drainage layer materials (geocomposite) as shown on the Drawings and specified herein.

1.02 REFERENCES

A. The following are complete titles of ASTM references cited in this section.

1. D1505 – Standard Test Method for Density of Plastics by the Density-Gradient Technique.
2. D1603 – Standard Test Method for Carbon Black in Olefin Plastics.
3. D4355 – Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus.
4. D4491 – Standard Test Methods for Water Permeability of Geotextiles by Permittivity.
5. D4533 – Standard Test Method for Trapezoid Tearing Strength of Geotextiles.
6. D4632 – Standard Test Method for Grab Breaking Load and Elongation of Geotextiles.
7. D4716 – Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.
8. D4751 – Standard Test Method for Determining Apparent Opening Size of a Geotextile.
9. D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.
10. D5035 – Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method).
11. D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.
12. D5261 – Standard Test Method for Measuring Mass per Unit Area of Geotextiles.

13. D5321 – Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

14. D7005 – Standard Test Method for Determining the Bond Strength (Ply Adhesion) of Geocomposites.

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. Manufacturer: Geocomposite manufacturer.

C. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, and services necessary to perform the work as detailed in this Section of the Specifications.

D. HDPE: High density polyethylene.

1.04 SUBMITTALS

A. The Installer shall submit a certification signed by an authorized representative of the Manufacturer attesting that the resins and manufactured geonet to be supplied are in conformance with the specifications contained in Part 2 of this Section. Such certification shall be submitted to the Owner prior to the material being delivered to the Site.

B. The Manufacturer shall, prior to shipping geocomposite to the site, submit to the Owner one 1-foot wide by 6-feet long (minimum) sample of geocomposite drainage layer material for each 50,000 square feet (or portion thereof) of geocomposite drainage layer material to be supplied. At least one sample shall be provided for each phase of geocomposite installation.

1.05 DELIVERY, STORAGE AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier.

B. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

C. The Owner will designate a properly drained area free of holes and protruding objects for storing geocomposite and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the geocomposite. The Installer accepts the area as suitable for geonet storage upon placing the geonet in the storage area.

D. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment, except that directly caused by Owner's personnel.

Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

E. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

F. Nonconforming products shall be promptly removed from Site.

PART 2: PRODUCTS

2.01 PHYSICAL PROPERTIES

A. Geocomposite drainage layer material shall consist of an HDPE geonet bonded on both sides to a nonwoven needlepunched geotextile.

B. Resins used in the formulation of the geonet portion of the geocomposite shall meet the following criteria:

1. Resins shall be contain no fatty acid residues, epoxy, secondary plasticizers, fillers or extenders.
2. Resins shall exhibit a density no less than 0.91 grams per milliliter, as determined by ASTM D1505 or D792B.
3. Resins shall exhibit a melt index value no greater than 1.0 gram per 10 minutes, as determined by ASTM D1238.

C. Completed geocomposite drainage layer material shall have good appearance and be free of blisters, undispersed raw materials, signs of contamination by foreign matter, or any other defect that would affect the specified properties of the geocomposite.

D. Geocomposite drainage layer material shall exhibit the properties provided in Table 02646-1.

E. Geocomposite drainage layer material placed as part of the 3:1 (horizontal to vertical) sidewall liner leachate drainage system or the 4:1 (horizontal to vertical) final cover slope shall conform to the interface shear strength criteria provided in Table 02646-2.

F. Each roll of geocomposite shall be labeled with the following:

- Name of Manufacturer,
- Product identification,
- Lot number,
- Roll number, and
- Roll dimensions.

PART 3: EXECUTION

3.01 PLACEMENT

A. The geocomposite shall be placed carefully such that no damage occurs during installation. The Installer shall repair or replace any damaged geonet to the satisfaction of the CQA Officer.

B. The geocomposite shall be maintained clean and free of debris at all times during construction.

C. Geocomposite shall be unrolled downslope keeping the net in slight tension to minimize wrinkles and folds.

D. Geocomposite shall be oriented to provide the maximum transmissivity downslope.

E. Adequate ballasting shall be provided to prevent displacement due to wind.

3.02 OVERLAP AND FASTENERS

A. Adjoining roll lengths shall be overlapped a minimum of 4 inches and shall be connected using HDPE or nylon ties spaced no farther than 5 feet downslope and 2 feet cross-slope. Adjoining roll lengths in anchor trenches shall be connected using HDPE or nylon ties spaced no farther than 6 inches. Geotextile components of the geocomposite shall be continuously sewn.

B. Adjoining roll widths shall be overlapped a minimum of 12 inches and shall be connected using HDPE or nylon ties spaced no farther than 2 feet. Geotextile components of the geocomposite shall be continuously sewn.

C. Light-colored ties shall be used to ease inspection.

3.03 REPAIRS AND PENETRATIONS

A. Holes or tears in the geocomposite shall be repaired by placing a patch of geocomposite over the hole or tear.

B. Geocomposite patches shall be oriented in the same direction as the underlying geonet.

C. Geocomposite patches shall be fastened to the underlying geocomposite using nylon or HDPE ties spaced a maximum of 6 inches.

D. Geocomposite penetration details shall be as recommended by the Manufacturer.

TABLE 02646-1

GEOCOMPOSITE DRAINAGE LAYER MATERIAL PROPERTIES

PROPERTY	TEST METHOD	MINIMUM AVERAGE ROLL VALUE	
		FINAL COVER	SIDEWALL LINER
Nonwoven Geotextile Fabric			
Fabric Weight	ASTM D5261	6.0 oz/yd^2	8.0 oz/yd^2
Apparent Opening Size	ASTM D4751	70 – 100 U.S. Sieve	70 – 100 U.S. Sieve
Grab Tensile Strength (MD and TD)	ASTM D4632	150	220
Grab Elongation	ASTM D4632	50%	50%
Puncture Resistance	ASTM D4833	80 lbs.	120 lbs.
Trapezoid Tear Strength (MD and TD)	ASTM D4533	60 lbs.	95 lbs.
Permittivity	ASTM D4491	1.5 sec^{-1}	1.5 sec^{-1}
Water Flow Rate	ASTM D4491	100 gpm/ft^2	100 gpm/ft^2
UV Resistance	ASTM D4355	70% strength retained after 500 hours	70% strength retained after 500 hours
Geonet Core			
Polymer Density	ASTM D1505	0.94 g/cm^3	0.94 g/cm^3
Thickness	ASTM D5199	0.200 inches	0.200 inches
Tensile Strength (MD)	ASTM D5035	40 lbs/inch	40 lbs per inch
Transmissivity	ASTM D4716	1×10^{-2} m^2 / sec	1×10^{-2} m^2 / sec
Carbon Black Content	ASTM D1603	1.5 - 3 %	1.5 - 3 %
Geocomposite (Two Sided Geotextile/Geonet)			
Transmissivity	ASTM D4716	1×10^{-4} m^2/sec	1×10^{-4} m^2/sec
Peel Adhesion	ASTM D7005	1.0 lb/inch	1.0 lb/inch

Note: Transmissivity corresponding to hydraulic gradient of 0.1 at a confining pressure of at least 10,000 psf, seat time at least 15 minutes, tested between two steel plates.

TABLE 02646-2
GEOCOMPOSITE INTERFACE SHEAR STRENGTH CRITERIA

INTERFACE (by ASTM D5321)	TEST CONDITIONS[1]		MIN. SHEAR STRENGTH[2, 3]	
	MAX. STRAIN RATE (IN./MIN.)	NORMAL STRESS	PEAK	RESIDUAL
Final Cover System[4]				
Geocomposite Drainage Layer vs. Final Cover Barrier Soil	0.001	400 psf	195 psf	165 psf
Geocomposite Drainage Layer vs. 40 mil textured HDPE Geomembrane	0.2			

Notes:

1. Additional test conditions:
   i. Samples shall be flooded and consolidated under the normal stress for at least 24 hours prior to shearing
   ii. Tests shall be conducted in a flooded condition
   iii. Strain rates may be increased by a factor of 10 after the peak shear strength is observed
   iv. Samples shall be sheared to a minimum 2.0 inch horizontal displacement

2. The minimum residual shear strength criteria only apply to the interface which exhibits the lowest peak strength.

3. Strength criteria may be varied upon approval of the Engineer. If the tested interface shear strengths are less than the values reported above, additional slope stability analyses may be performed to check the acceptability of the test results. The slope stability analysis should be performed by an engineer experienced in geotechnical engineering.

4. Final cover system component interface shear criteria apply only to materials placed on the 4:1 (horizontal to vertical) final cover slopes.

END OF SECTION

t:\projects\91-118 cli\permit applications\cli #3 initial bol application log 2005-070\specifications\cli 3 geocomposite drainage layer spec.doc

SECTION 02900

TURF ESTABLISHMENT

PART 1: GENERAL

1.01 DESCRIPTION OF WORK

A. Work covered in this Section includes providing all supervision, labor, equipment and materials, and performing all operations necessary to establish turf as set forth in these Specifications.

1.02 REFERENCES

A. No references cited.

1.03 SUBMITTALS

A. Contractor shall submit to the CQA Officer the ingredients and application rates of the seed mix, fertilizers and soil amendments to be used.

1.04 SEQUENCING AND SCHEDULING

A. Seed shall be sown only at times of the year when temperature, moisture, and climatic conditions will promote germination and plant growth. Normal seed application dates are between March 1 and May 31, or between August 10 and September 30. The Contractor shall obtain the CQA Officer's approval to apply seed during other time periods.

PART 2: PRODUCTS

2.01 SEED

A. Seed shall be labeled in accordance with the latest federal, state and local laws and regulations.

B. Seed shall be furnished in sealed standard containers unless exception is approved in writing.

C. Seed that has become wet, moldy, or otherwise damaged in transit or in storage, will not be acceptable.

D. The pure live grass seed mixture to be applied at the following rates, or as otherwise approved by the Design Engineer:

GRASS	MINIMUM APPLICATION RATES(lbs per acre)
KY 31 Tall Fescue	70
Perennial Ryegrass	20
Timothy	10
Redtop	5

2.02 SOIL AMENDMENTS

A. Fertilizer shall be commercial grade, free flowing, uniform in composition and shall conform to applicable local, state and federal regulations. Granular fertilizer shall contain a minimum percentage by weight of 10 percent nitrogen (of which 50 percent shall be organic), 10 percent available phosphoric acid, and 10 percent potash. Agricultural ground limestone shall be measured by weight in tons.

E. The quantities and application rates of fertilizer and agricultural ground limestone shall be established by a knowledgeable person based on soil test data.

F. Soil amendment by sludges shall be conducted in accordance with the permitting and regulatory requirements of the IEPA Bureau of Water.

2.03 MULCH

A. Mulch shall consist of either of the following:

1. Clean, unweathered, small grain straw or grass hay, in air-dry condition and suitable for placing with blower or other suitable equipment, or

2. Excelsior blanket, jute netting, paper fabric, or similar materials, as approved by the CQA Officer.

PART 3: EXECUTION

3.01 SEED BED PREPARATION

A. Seed bed preparation shall not be started until the topsoil, soil amendments, and seed mixture have been approved by the CQA Officer.

B. Low-ground pressure equipment shall be used to prepare the seedbed. Ruts shall be repaired prior to seeding.

C. The final surface to be seeded shall be graded to prevent ponding of water and to the lines and grades on the Drawings.

D. Limestone and/or fertilizer shall be uniformly spread over the areas to be seeded at the rates recommended by the Local Co-Operative Extension Service Agricultural Advisor or other qualified person.

E. The areas to be seeded shall be worked to a minimum depth of 3 inches immediately following placement of soil amendments with a disk or other appropriate equipment, reducing all soil particles to a size not larger than 2 inches in the largest dimension. The prepared surface shall be relatively free from all weeds, clods, stones, roots, sticks, depressions, rivulets, gullies, crusting and caking.

3.02 SEEDING

A. No seed shall be sown during high winds or when the ground is not in a proper condition for seeding. All legumes not pre-inoculated shall be inoculated within 12 hours of seeding with inoculant specific to the species being seeded.

B. Drill or Broadcast Methods: The designated seed mixture and rate shall be applied uniformly at a depth of 1/4 to 1/2 inch with a drill (band seed) or cultipacker type seeder. For broadcast seeding, broadcast seed uniformly and cover to 1/4 to 1/2 inch depth with a cultipacker, harrow or similar tool. For both methods, one half of the seed shall be sown in one direction and the remainder shall be sown at right angles to the first sowing.

C. Immediately after seeding, the entire area shall be firmed with an approved smooth-wheeled roller not exceeding 112 pounds for each foot of roller width. If seeding is performed with a cultipacker-type seeder or if seed is applied in combination with hydromulching, rolling may be eliminated.

D. Hydroseeding: When seed or fertilizer is applied with a hydraulic seeder, the rate of application shall be not less than 1,000 gallons of slurry per acre. This slurry shall contain the proper quantity of seed or fertilizer specified per acre. When using a hydraulic seeder, the fertilizer nutrients and seed shall be applied in two separate operations.

E. Companion Seeding: To reduce erosion and weed growth, seed a companion crop of 1 bushel spring oats per acre for a spring seeding or 20 pounds per acre of wheat or cereal rye for later summer seedings. These seeding rates shall not be exceeded as heavier rates will result in excessive competition to the regular seeding. Companion crops shall be mowed in the early stage.

3.03 MULCH

Mulch shall be applied immediately after seeding, except in the case of hydroseeding, which includes mulch.

A. Grain straw or grass hay shall be applied to new seedings at the rate of 2 to 2-1/2 tons of air-dry material per acre. Grain straw and grass hay shall be applied by any approved method that will result in uniform application on the soil surface. Press straw or hay into the soil to a 2-inch depth by use of a serrated straight disk, or a dull farm disk set straight (not required if hydroseeded areas).

B. Netting or other commercial mulch products may be applied in lieu of straw or hay upon approval by the CQA Officer. Excelsior blankets, jute netting, paper fabric, or similar commercial materials shall be applied by hand according to manufacturer's directions.

END OF SECTION

j:\projects\01-0669 tcli\construction\current specifications\turf spec.doc

SECTION 15105

HIGH DENSITY POLYETHYLENE (HDPE) PIPE AND FITTINGS

PART 1: GENERAL

1.01 DESCRIPTION

A. Work covered under this Section shall include providing all materials, equipment, supervision, and labor necessary to construct complete in-place, and test all high density polyethylene (HDPE) piping and fittings as shown on the Drawings and specified herein. This Section specifically includes all HDPE piping and fittings for the following:

1. Leachate collection piping,

2. Leachate monitoring and collection sumps,

3. Leachate transmission piping,

4. Gas transmission piping,

5. Condensate driplegs,

6. Condensate lift stations, and

7. Condensate drain and transmission piping.

1.02 REFERENCES

Work covered under this Section shall be in accordance with the latest available version of the following references unless otherwise noted:

A. ASTM F-714: "Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter."

B. ASTM D-1248: "Specification for Polyethylene Plastics Molding and Extrusion Materials."

C. ASTM D-2513: "Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings."

D. ASTM D-3261: "Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing."

E. ASTM D-3350: "Standard Specification for Polyethylene Plastics Pipe and Fittings Materials."

1.03 DEFINITIONS

A. CQA Officer: Designated Construction Quality Assurance Officer, including CQA Officer-in-Absentia.

B. Installer: Contractor responsible for furnishing all materials; providing all labor, supervision, administration, and management; and supplying all construction equipment, materials, field testing, and services necessary to perform the work as detailed in this Section of the Specifications..

C. Manufacturer: HDPE pipe and fittings manufacturer.

D. Supplier: HDPE pipe and fittings supplier.

E. HDPE: High density polyethylene.

1.04 SUBMITTALS

A. The Supplier shall submit a certification signed by an authorized representative of the Manufacturer attesting that the supplied pipe and fittings conform to the specifications in this Section prior to material delivery to the Site.

B. The Installer shall submit to the Owner all field quality control documentation records as required by Part 3.02E of this Section of the Specifications.

1.05 DELIVERY, STORAGE, AND HANDLING

A. The Manufacturer shall package products for shipment in a manner suitable for safe transport by commercial carrier. The pipe and fittings shall be held firm by dedicated straps/slings, or other suitable means, during shipping.

B. The Installer shall be responsible for unloading, handling and storing all materials, supplies and equipment in accordance with the Manufacturer's recommendations.

C. The Owner will designate a properly drained area free for storing pipes, fittings and other supplies and equipment. The Installer shall inspect the area for proper subgrade, drainage, etc. prior to unloading the pipe and fittings. The Installer accepts the area as suitable for pipe and fittings storage upon placing the pipe and fittings in the storage area.

D. The Installer is responsible for loss (including by theft) or damage (including by vandalism) to any materials, supplies and equipment, except that directly caused by Owner's personnel. Shelter or security for materials, supplies or equipment, if required, shall be provided by the Installer.

E. Materials shall be inspected by the Installer at the delivery point for loss or damage in transit. Materials damaged in transit shall be identified and set aside. The Owner shall be provided with a complete assessment of the extent of damage and suggested repair methods as approved by the Manufacturer. Damaged materials shall either be repaired as approved by the Manufacturer or replaced at the discretion of the Owner. All costs to repair or replace damaged materials shall be the Installer's responsibility.

F. Damaged and nonconforming products shall be promptly removed from Site.

PART 2: PRODUCTS

2.01 PHYSICAL PROPERTIES

A. The polyethylene pipe and fittings shall meet the following physical property requirements:

Property	Test Method	Required Value	
PPI Material Listing	PPI TR-4	PE 3408	
Material Classification	ASTM D-1248	III C 5 P34	
Cell Classification	ASTM D-3350	345434C	
Density	ASTM D-1505	>0.94	g/cm3
Resin Melt Index [E]	ASTM D-1238	<0.15 @ 2.16 kg	g/10 min
Flexural Modulus	ASTM D-790	>110,000 and <160,000	psi psi
Compressive Strength @ yield	ASTM D-695	>1600	psi
Elongation at yield	ASTM D-638	>6	%
Tensile Strength @ yield	ASTM D-638	3000 to 3500	psi
Elongation @ break	ASTM D-638	>700	%
Tensile Strength @ break	ASTM D-638	>4500	psi
ESCR [C]	ASTM D-1693	f_0 >5000	hours
Hydrostatic Design Basis	ASTM D-2837	>1600 psi @ and >800 psi @	73.4°F. 140°F
Carbon Black	ASTM D-1603	2 to 3	%
Elastic Modulus	ASTM D-638	>110,000	psi
Brittleness Temperature	ASTM D-746	<-180	°F
Vicat Softening Temperature	ASTM D-1525	>255	°F
Linear Thermal Expansion	ASTM D-696	<1.5 x 10^{-4}	in/in/°F
Hardness	ASTM D-2240	64	Shore D

B. Where possible, pipe and fittings should be produced by the same manufacturer from identical materials. Special or custom fittings may be exempted from this requirement.

C. The pipe and fittings shall be homogenous throughout and free from visible cracks, holes, foreign inclusions or other injurious defects. The pipe and fittings shall be as uniform as commercially practical in color, opacity, density and other physical properties.

D. Clean rework or recycled material generated by the Manufacturer's own production may be used so long as the pipe and fittings produced meet all the requirements of this Specification.

2.02 PIPE AND FITTINGS

A. Dimensions:

1. Pipe Dimensions: Nominal pipe diameter shall be as shown on the Drawings. The nominal inside diameter of the pipe shall be true to the specified pipe size in accordance with ASTM D-2513. Alternatively, the nominal outside diameter of the pipe shall be true to the specified pipe size in accordance with ASTM F-714.

2. Fitting Dimensions: Fittings such as coupling, wyes, tees, adapters, etc. for use in laying pipe shall have standard dimensions that conform to ASTM D-3261.

3. Minimum wall thickness:

- Leachate collection pipe:	SDR 11
- Leachate transmission primary pipe:	SDR 11
- Leachate transmission secondary pipe:	SDR 11
- Leachate collection sump pipe:	SDR 21
- Gas transmission pipe:	SDR 17
- Condensate drain pipe:	SDR 17
- Condensate transmission primary pipe:	SDR 11
- Condensate transmission secondary pipe:	SDR 17

B. Molded fittings shall meet the requirements of ASTM D-3261 and this specification. At the point of fusion, the outside diameter and minimum wall thickness of fitting shall meet the diameter and wall thickness specifications of the mating system pipe. Fitting markings shall include a production code from which the location and date of manufacture can be determined.

C. Marking: Each standard and random length of pipe and fitting in compliance with this Specification shall be clearly marked with the following information:

1. ASTM Standard Designation
2. Pipe Size
3. Class & Profile Number
4. Production Code
5. Standard Dimension Ratio

2.03 MANUFACTURER'S QUALITY ASSURANCE AND QUALITY CONTROL

A. The Manufacturer shall have an established quality assurance program responsible for inspecting incoming and outgoing materials. At a minimum, incoming polyethylene materials shall be routinely tested for density per ASTM D-1505, and melt index per ASTM D-1238, and shall be visually inspected for contamination. All incoming polyethylene materials shall be certified by the supplier. Certification shall be verified by the pipe and fittings Manufacturer's Quality Assurance Program.

B. The Manufacturer shall have an established quality control program responsible for assuring the long term performance of materials and products. Representative samples of pipe and fittings shall be tested against the physical property requirements of this Section. Each extrusion line and molding machine shall be qualified to produce pressure rated products by taking representative production samples and performing sustained pressure tests in accordance with ASTM D-1598.

C. All outgoing materials shall be inspected for diameter, wall thickness, length, straightness, out-of-roundness, concentricity, toe-in, inside and outside surface finish, markings, and end cut. The pipe and fittings Manufacturer shall routinely perform tests of density, melt index, carbon content, and carbon dispersion. All fabricated fittings shall be inspected for fusion quality and alignment.

D. The Manufacturer shall maintain permanent QC and QA records, which shall be available for review by the Owner or CQA Officer.

E. Inspection Requirements:

1. Notification: If inspection is requested by CQA Officer or the Owner, the Manufacturer shall notify CQA Officer or the Owner in advance of the date, time and place of testing of the pipe.

2. Access: CQA Officer or the Owner shall have reasonable access to the inspection area of the Manufacturer's plant. The Manufacturer shall make available to CQA Officer and the Owner without charge, all reasonable facilities for determining whether the pipe meets the requirements of this Specification.

PART 3: EXECUTION

3.01 INSTALLATION

A. The Installer shall excavate, backfill and compact trenches in accordance with Section 02200 of these Specifications.

B. Heat Fusion of Pipe:

1. All welds shall be performed in accordance with the Manufacturer's recommendations for butt fusion methods. Provide fusion operators certified by the pipe Manufacturer or Supplier.

2. Butt fusion equipment for joining procedures shall be capable of meeting conditions recommended by Manufacturer including, but not limited to, temperature requirements, alignment, and fusion pressures.

3. Pipe ends shall be clean and in the appropriate condition conducive to pipe butt-welding. For cleaning pipe ends, solutions such as detergents and solvents, when required, shall be used in accordance with Manufacturer's recommendations.

4. The Installer shall not bend pipe to a greater degree than the minimum radius recommended by Manufacturer for type and grade.

5. The Installer shall not subject pipe to strains that will overstress or buckle the piping or impose excessive stress on joints or fittings.

6. Branch saddle fusions shall be joined in accordance with Manufacturer's or Supplier's recommendations and procedures. Branch saddle fusion equipment shall be of size to facilitate saddle fusion within the trench as required.

7. Use compatible fusion techniques when polyethylenes of different melt indexes are fused together. Refer to Manufacturer's specifications for compatible fusion techniques.

8. Electrofusion couplers, where used, shall be installed in conformance with the manufacturer's specifications.

9. Before butt fusing pipe, inspect each length for presence of dirt, sand, mud, shavings, and other debris or animals. Remove all such foreign objects and debris from pipe.

10. Cover open the ends of fused pipe at the end or each working day to prevent entry by animals or debris.

C. Flange Jointing:

1. Flange jointing shall only be used at the locations shown on the Drawings, or as otherwise approved by the Design Engineer.

2. Backup flanges shall be of ductile iron or stainless steel, and shall be connected with stainless steel nuts and bolts.

3. All flanges installed below ground shall be connected using stainless steel bolts, washers, and nuts. Above-ground flanges can be connected using zinc-plated or stainless steel bolts, washers, and nuts.

4. The Installer shall observe the following precautions in connection of flange joints.

   a. Align flanges or flange/valve connections to provide tight seal. Provide nitrile-butadiene gaskets to achieve seal.

   b. Place round washers as may be required on flanges in accordance with manufacturer's recommendations. Bolts shall be lubricated in accordance with manufacturer's recommendations.

c. Tighten flange bolts in sequence and accordance with Manufacturer's recommendations. <u>*CAUTION:*</u> *Do not over-torque bolts.*

d. Retorque all flange bolts in sequence and in accordance with Manufacturer's recommendations at least 1hour following the previous tightening.

5. Protect non-stainless steel metalic below-grade components (e.g. backup flanges) by covering with a 5-mil polyethylene wrap. Duct tape wrap to HDPE pipe.

D. Barb Jointing:

1. The leachate collection pipe, leachate transmission pipe, condensate drain pipe and condensate transmission pipe can be connected using approved barb joints designed for at least 100 psig pressure.

2. Barb joints are not allowed for the gas transmission pipe.

3. Barb joints shall be installed in accordance with the manufacturer's recommendations.

E. Coupling Jointing:

1. Pipe sections can be jointed using mechanical couplings only where specifically approved by the Design Engineer.

2. Mechanical couplings shall, at a minimum, be jointed using 3 stainless steel screws of appropriate size.

F. Pipe Placement:

1. Grade control equipment shall be of type to accurately maintain design grades and slopes during installation of pipe.

2. Dewatering: Remove standing water in trench before pipe installation.

3. Maximum lengths of joined pipe to be handled as one section shall be according to Manufacturer's recommendations as to pipe size, pipe SDR, and topography so as not to cause excessive gouging, deflection, stresses, or surface abrasion; however, in all cases, do not exceed 400 feet.

4. Notify CQA Officer prior to installing pipe into trench and allow time for CQA Officer's inspection. Contractor shall correct irregularities and deficiencies found during inspection.

5. Allow pipe sufficient time to adjust to trench temperature prior to testing, segment tie-ins or backfilling.

6. To reduce branch saddle stress, install saddles at slope equal to and continuous with lateral piping.

7. Coordinate construction of pipes near access roads with Owner to limit impediment of site ingress/egress.

8. Support all above-ground piping sections as shown on Drawings or as recommended by pipe Manufacturer.

3.02 FIELD QUALITY CONTROL

A. Pipe may be rejected for failure to conform to Specifications or the following at the discretion of CQA Officer:

1. Fractures or cracks passing through pipe wall. All pipes within one shipment shall be rejected if defects exist in more than 5% of shipment or delivery.

2. Cracks or gouges sufficient to impair strength, durability or serviceability of pipe.

3. Defects indicating improper proportioning, mixing, and molding.

4. Damaged ends, where such damage prevents making satisfactory joint.

B. Acceptance of pipe fittings, stubs, and specifically fabricated pipe sections shall be based on visual inspection at job site and documentation of conformance to these Specifications.

C. The Installer shall pressure-test all leachate, gas, and condensate transmission pipe sections and fittings after placement in trench in accordance with federal, state and local laws and regulations and the following procedures (leachate recirculation piping within the waste boundary is exempt from these testing requirements):

1. Installer shall supply all air required for testing and provide and install the necessary piping connections, test pressure equipment, pressure gauges, and all other equipment, materials, labor and supervision required to perform the specified tests.

2. All openings shall be sealed prior to testing. Brace seals as required to prevent blowout.

3. Cover and brace pipe at intervals as required to hold the pipe in place during the test. All connections and fittings shall remain exposed and accessible during the test.

4. Provide a regulator set to avoid over-pressurizing and damaging piping.

5. Provide pressure gauge capable of accurately measuring pressures to a precision of 1 psi or better.

6. Slowly apply 20 psig air pressure to section to be tested. Monitor and record the pressure drop in approximately 10-minute intervals.

7. After at least 30 minutes or when the pressure drop due to pipe expansion stabilizes, whichever is longer, return air pressure to 20 psig. Monitor and record the pressure drop and ambient temperature in approximately 10-minute intervals for at least 1 hour.

8. Pipe will be considered to be satisfactorily air-tight if less than 2 psig pressure drop is observed during the 1-hour test period.

E. The Installer shall document all pressure tests. Documentation shall include the following:

- Pipe section being tested,
- Date and time of test,
- Weather conditions, including ambient temperature at time of test,
- Air pressure and time at beginning of test, and
- Air pressure and time at end of test.

END OF SECTION

APPENDIX K.2

TWO-STAGE BOUTWELL PERMEAMETER TEST METHODOLOGY

Shaw®

THE STEI TWO-STAGE FIELD PERMEABILITY TEST

JANUARY, 1991 *

SYNOPSIS

The Two-Stage Field Permeability Test is a falling-head infiltration test conducted in a cased borehole, typically 4 inches in diameter. The first stage is performed with the bottom of the hole flush with the bottom of the casing for maximum effect of vertical permeability (Kv). After steady-state is achieved, the hole is advanced some 6 to 8 inches below the bottom of the casing so that horizontal permeability (Kh) has a greater effect. The two stages yield two equations which can then be solved for (Kh, Kv). Procedures are available for reduction of the data in the cases of both above and below water table testing.

The major test precautions include proper sealing of the casing along the outside, accounting for temperature effects, and correcting for sidewall smear during the second stage. The test is quick, simple, and relatively inexpensive. It allows results in days, rather than months. Multiple installations are feasible so that statistical confidence can be achieved. It is recognized in the literature, including U.S. EPA publications.

I. BASIC CONCEPTS

1.1 Anisotropy. In general, the hydraulic conductivity (permeability) of soils is anisotropic. The horizontal value ($Kx = Ky = Kh$) is normally larger than the vertical ($Kz = Kv$), even in compacted materials (Boutwell & Rauser, 1990). This phenomenon affects all current field permeability test procedures; if the observed "permeability" is taken to be the vertical permeability, then the result is too high by factors on the order of 2 to 5.

Which is the proper value (Kh or Kv) to use in evaluating a compacted clay liner? On the relatively horizontal bottom, the flow potential is obviously vertical, i.e., normal to the liner surface and thus the plane of compaction. The "vertical" permeability ($Kn = Kv$) obviously governs. On the sides, the situation is less clear. However, flow net studies have shown that the mean angle of flow deviates from the normal (perpendicular to liner face) by angles of 30 to 40 degrees using typical side slopes [1(V):3 to 4(H)] and anisotropies (Kh/Kv = 2 to 10). The permeability along the flow path ($K\theta$) can then be calculated from the permeability ellipsoid equation:

$$K\theta/Kv = (Kh/Kv) / \sqrt{1 + [(Kh/Kv)^2 - 1] \cos^2\theta} \qquad (1)$$

θ = Angle Between Flow Path and Line Normal to Slope

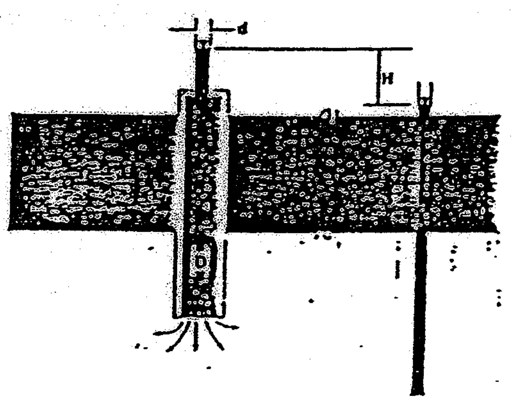
* Minor modifications June, 1991

The results show that even if (Kh/Kv) approaches infinity, (Kθ/Kv) will be less than 2.0 for angles (Θ) up to 60 degrees. As an example, at (Kh/Kv = 10) and (Θ = 45 degrees), (Kθ/Kv = 1.4) but (Kθ/Kh = 0.14). Thus, (Kθ) is always much closer to (Kv) than to (Kh), even on the side liners.

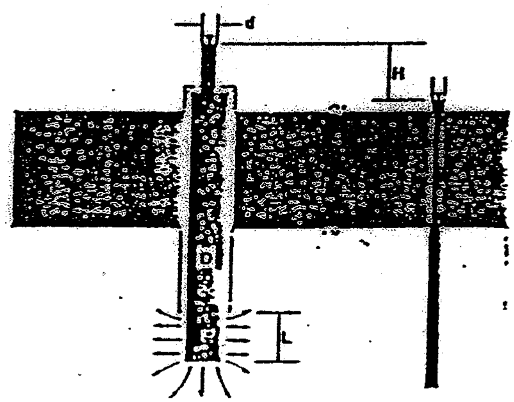
The proper measure of clay barrier performance is thus (Kv). Yet, anisotropy affects all field tests to some degree. The two-stage test was therefore developed to separate these effects so that (Kv) can be determined. Naturally, it also yields (Kh).

1.2 Theory of Test. The Two-Stage Test is a field infiltration test, conducted in a cased borehole so that the geometry of the infiltrating zone can be controlled. It is normally conducted as a falling-head test. Although a constant-head procedure could be used, measurement of the small flow volumes would be a problem. The test was first developed in 1982 for evaluating a liner during Adjudicatory Hearings. It was first published in Boutwell & Derick, 1986.

The basic idea is to vary the geometry of the infiltrating area so as to vary the relative effects of (Kh) and (Kv). In the first stage, the geometry is chosen so that (Kv) has its maximum effect. The second stage geometry is such that (Kh) has its maximum effect. The results of the two stages yield two equations in two unknowns (Kh, Kv), which can then be solved. This concept is illustrated below:



FLUSH-BOTTOM TEST



CYLINDRICAL TEST

Stage 1 is normally conducted using a flat bottom flush with the base of the casing. Infiltration proceeds until a steady-state condition is achieved. Then, the borehole is advanced some 6 to 8 inches below the bottom of the casing. The apparatus is refilled, and infiltration in this Stage 2 continues until it achieves steady-state flow.

1.3 Hvorslev Equations. Attached as Figure A-1 is a figure from Juul Hvorslev's 1951 paper where the equations for flow from various geometries in an anisotropic mass are given. These equations form the basis for the current method of data reduction. Figure A-1 illustrates several geometries not normally used in the Two-Stage Test, but illustrates that the technique is not limited to the simple case presented in the current literature (e.g., EPA, 1988; Daniel, 1989; Sai, 1990). However, these equations are based on a cross-anisotropic (Kx=Ky=Kr=Kh≠Kz=Kv) infinite or semi-infinite medium, with no vertical gravitational gradient within the flow field. They are therefore most applicable to very thick layers below the groundwater level.

1.4 Modifications for Lower Boundary. These tests are commonly performed in test pads or real liners which are:

- Finite in Thickness (36"-48" Typical)
- Underlain by a Drainage Blanket

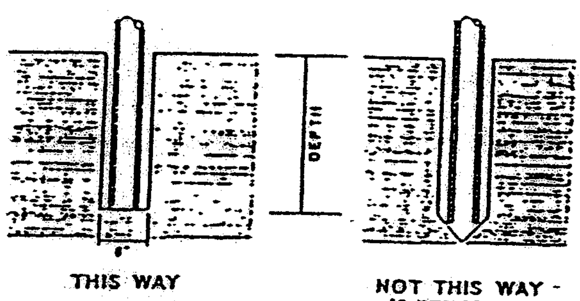
The finite thickness problem can be handled as described in Section 2.1.C. The underlying drainage blanket, usually kept dry or at virtually an atmospheric head level, distorts the flow patterns by creating a gravitational downwards gradient (i=1.0).

The vertical gradient problem cannot be totally overcome by the clearances of Section 2.1.C. Rather, new equations have been developed to describe the flow field, using the Image Potential method. The new equations and their application are discussed in Section V. They will henceforth be termed the Hvorslev-Image ("H-I") equations.

II. FIELD PROCEDURES

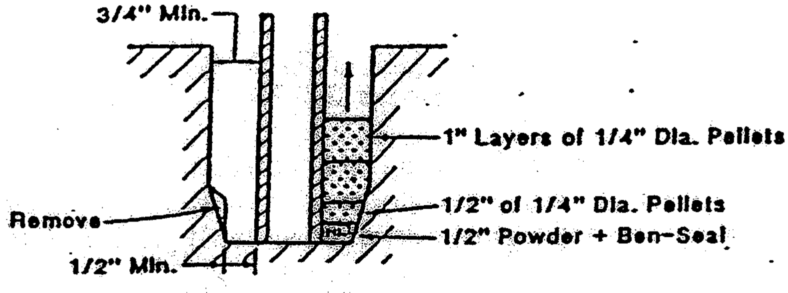
2.1 Installation. The geometry of the infiltrating area must be known for any of the Hvorslev or H-I equations to apply. Hence, the casing must be properly sealed against the walls of the borehole. Also, the boundary conditions (bounded, semi-infinite, or infinite medium) must be approximated. These considerations are handled as illustrated below.

2.1.A Bottom. In Stage 1, the bottom of the borehole should be flat and flush with the bottom of the casing in order to correspond with Hvorslev's (or H-I) case "B" or "C" (See Figure A-1 for the Hvorslev equations, Section V for the H-I equations). This is accomplished with a special "flat auger" and measurement from the top of the casing. If the bottom of the hole is above the bottom of the casing, Hvorslev's "D" or "E" (or the equivalent H-I) should apply but there is a strong possibility of leakage along the boundary between the encased soil and the inside of the casing. Hvorslev's (or H-I) Cases "F" or "G" would apply if the hole extends past the bottom of the casing.



BOTTOM CONDITIONS

In practice, the diameter of the basic borehole should be at least 2 and preferably 3 inches larger than the OD of the casing. The borehole is advanced by hand or mechanical auger until the point of the auger is about 1 inch above the testing level. Then, the large flat auger is used to advance the hole to the testing level. The large flat auger should cut a hole at least 1 1/2 inches larger in diameter than the casing OD to allow the annular seal (see Section 2.1.B) to penetrate to the testing level. The inside walls of the hole are hand-trimmed so that there is a fairly constant slope from the basic borehole (maximum) diameter to that cut by the flat auger.

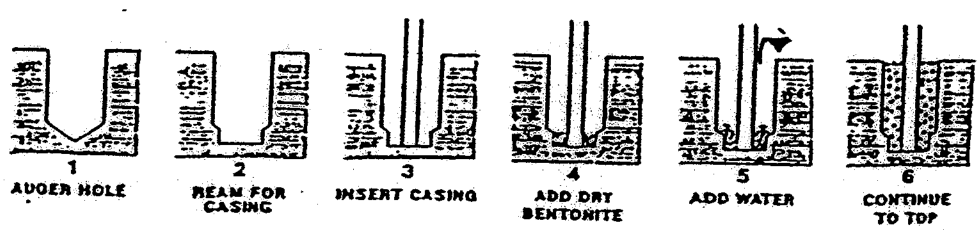


2.1.B Sealing. The annular space between the casing and the wall of the borehole is sealed with bentonite. Best results have been attained using 1/4" (not 3/8" or larger) bentonite pellets. Crushed bentonite (Baroid "Hole-Plug" or equivalent) has also been satisfactory. The procedure is:

* Crush sufficient pellets, "Ben-Seal", or "Hole-Plug" to fill about 1/2 inch of the annulus. This should have about 1/16" size fragments with some powder.
* Place this material into the annular space.
* Place about 1/2 inch of bentonite pellets or "Hole-Plug" into hole,
* Tamp the bentonite pellets,
* Add water until it shows above the bentonite,
* Repeat the process (but using only the pellets) in 1 inch increments to the ground surface.

When seals have been made in this manner, no water (even that added for hydration) enters the casing.

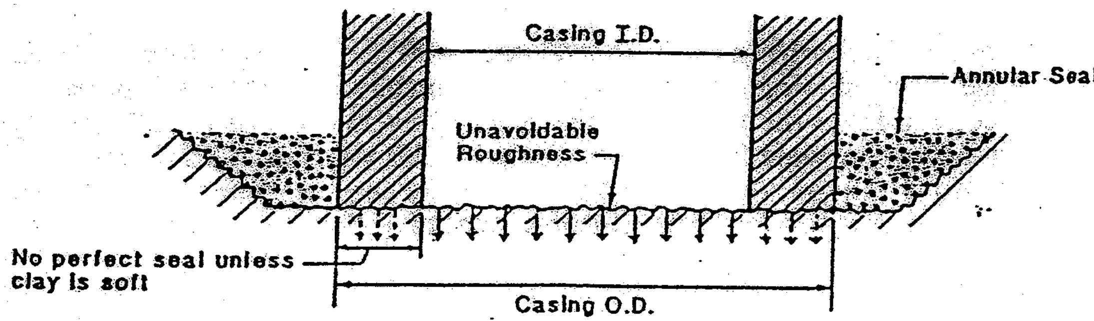
The bentonite seal is then allowed to hydrate overnight before any head is applied to the system.



SETTING THE CASING

It is virtually impossible to seal the flat bottom of the casing against the bottom of the hole, although the annular space between the wall of the casing and that of the borehole can be fully sealed. STEI conducted some laboratory tests on this phenomenon; clay liner material was compacted, trimmed smooth, and a smooth-bottom casing pressed against the trimmed soil surface with a force of some 50+ pounds. No external seal was applied. When water was introduced into the casing, there was always leakage at the casing-soil interface, until the compacted material was medium to stiff in consistency (shear strength <2000 lb./sq.ft.). The sample corresponded to 95% Modified Proctor and 4 percentage points over optimum. The laboratory-prepared soil surface was, of course, much smoother than could be achieved in the field, especially with material containing a significant proportion of large particles. The high vertical force is not maintained in the field.

A field test for determination of which test diameter (D) to use for the first stage is performed. A borehole is prepared as outlined in Paragraph (2.1.A). The casing is then inserted into the hole and seated firmly against the bottom soil. Then, water is introduced into this test casing. If outward seepage is noted, the OD (rather than the ID) of the casing should be used for the Stage 1 (D). *



The obvious inferences are:

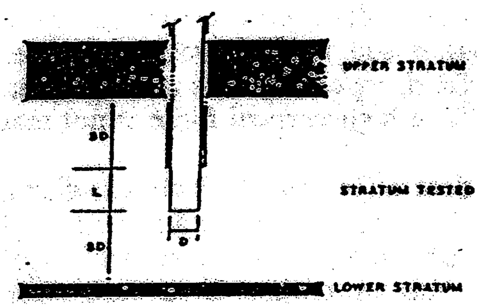
- If the casing bottom is flat, the OD of the casing should be used for the test diameter during Stage 1, depending on the field test casing's results.*

- This phenomenon could be overcome by tapering the bottom of the casing on its outside.

The downhole activity associated with preparing for Stage 2 apparently seals this disk-shaped infiltrating area. Also, the total infiltrating area of Stage 2 is some 6 to 8 times that of Stage 1, so that any remaining effect of the "disk" would be minor. The actual borehole diameter (Casing ID) should therefore be used in reducing the data for Stage 2.

* NOTE: One can also check the <u>inside</u> of each casing for inflow of the water added to hydrate the bentonite.

2.1.C Boundaries. A typical liner or natural deposit is not an infinite medium; it has a finite thickness. The U.S. Bureau of Reclamation (USBR, 1987) recommends that field permeability tests have a clearance of at least 5 test diameters from any boundary (region of significantly higher or lower permeability). The typical Two-Stage Test has a 4 inch diameter and is extended 6 to 8 inches for Stage 2. The USBR clearance is thus (4 x 5 = 20 inches) above the top of the test and below its bottom. Following this recommendation; the bottom of the casing should therefore be 20 or more inches below the liner surface and 26 to 28 inches above the bottom of the liner.



EMBEDMENT

These embedments have been evaluated with the H-I equations of Section V for Stage 2, which would be closest to the boundary. The Stage 2 permeabilities as calculated from the basic Hvorslev equations would be 10 to 15% too high if the remaining clay were 2.5 diameters, only 4 to 7% too high at 5.0 diameters. The H-I equations can be used for geometries where the remaining clay exceeds 1 to 2 diameters, but the maximum possible remaining clay is still recommended.

Another boundary concern is the horizontal distance to a boundary. Both the Hvorslev and the H-I equations assume an infinite horizontal extent of the tested stratum. A criterion used successfully in the past by STEI is to multiply the 5-diameter vertical clearance by a factor of 5 to 10 in order to account for anisotropy. Typical (Kh/Kv) ratios for compacted materials range from 2 to 10. A 50-diameter horizontal clearance equates to 16 feet for a 4-inch diameter test.

STEI tries to maintain at least 15 feet clear between tests and between any test and the crest of a test pad. However, there have been successful tests in a bench cut into the side of a levee, where the clearance at test level was about 9 feet (26 diameters).

2.1.D. Protecting the Infiltration Surface. STEI has received a report that during some very-long-term tests (over 2 months), the Stage 2 permeability increased suddenly. Excavation showed that the sidewalls of the Stage 2 cylindrical hole had collapsed, increasing the infiltration area. This problem can be overcome by a simple pervious support: a gravel-filled "sock". The sock is a rigid cylinder of open-mesh plastic, lined with a filter geofabric. The cylinder is some 1/4 inch smaller in diameter than the casing ID (and thus the Stage 2 hole), and an inch or so longer than the extension for Stage 2. It is fitted with retrieving lines and not left in the hole. The sock also protects the infiltration surface from erosion when water is introduced into the casing, so is also used in Stage 1. The effect of the sock (K>10(-1) cm/sec) is negligible when testing a typical liner material (K<10(-6) cm/sec). If testing a high-permeability material, Hvorslev Cases "D" or "E" as appropriate could be used.

2.1.E. Hydraulic Fracturing. This can occur if the water pressure exceeds the overburden pressure; it is a well known phenomenon in oil-field work. The effect is a horizontal separation of the stratum which yields a falsely high horizontal permeability. Theoretically, it could affect either stage or both stages. Note that this is strictly a test phenomenon. In a real-life surface impoundment, for example, the water pressure becomes part of the total overburden pressure since it is an area load.

STEI has conducted several tests where hydraulic fracturing should have occurred based on the simple concept above. No effects have been noted. In reality, the head dissipates rapidly with distance away from the test point. While the pressure may exceed overburden, the force available is insufficient to cause hydraulic fracturing. Calculations for a typical set up (4-inch diameter) show that fracturing will not occur with a head up to 8 embedment depths using a shear strength in the fill of 250 lb./sq.ft. However, it is still recommended that the water pressure at the test point not exceed 1.5 times the overburden pressure. The applied head should therefore be less than about 3 times the depth to the bottom of the casing.

2.2 Measurement/Pressure System. The falling-head procedure allows close measurement of both flow and pressure. The usual apparatus is a 1/2 to 1 inch ID clear plastic standpipe (clear Schedule 40 PVC seems best) with a scale (aluminum yardstick) permanently attached. The bottom of the yardstick should be at a level which can easily be re-determined if, for some reason, the yardstick falls off. Such a system can be read to 1/32 inch, which equates to 0.10 cc for a half-inch pipe. The standpipe system is attached to the cap for the casing. After the casing seal has hydrated, the casing and standpipe system are filled with water and the test begins. The "plumbing" system is carefully checked for leaks, and any found are repaired. The system is illustrated on the attached Figure A-2. A plastic elbow ("Ell") is attached to the top of the standpipe to prevent entry of rainwater. Evaporation losses are minimized by covering the open end of the Ell with aluminum foil, held in place with a rubber band, and having a pinprick hole in the foil for air pressure equalization.

Measurements are taken frequently on the first day. The rates of flow are usually slow enough so that readings thereafter can be on a twice-a-day basis, or even daily. When the fluid level in the standpipe approaches the bottom of the measurement scale, the standpipe is refilled and a new test increment begins. Caution is needed for overnight readings. The rate of fall should be checked against the overnight time increment (usually 13 to 15 hours). If it appears that the standpipe might run dry, it should be refilled after the last afternoon reading.

2.3 Apparent Permeabilities. The Hvorslev equations on Figure A-1 and the H-I equations in Section V all have a common format (See Figures A-1, A-4, and A-5 for nomenclature):

$$q = G\,Kh \quad \text{or} \quad K = q/(Gh) \tag{2}$$

for the constant-head case and

$$K = (Ap/G)\,Ln(H1/H2)/(t_2-t_1) \tag{3}$$

for the falling-head case, where:

K	=	Permeability
t_1,t_2	=	Time at Beginning and End
H1,H2	=	Heads at (t_1,t_2)
Ap	=	Standpipe Area
G	=	Geometric Factor (function of m, b, L, D)
m	=	$\sqrt{Kh/Kv}$
b	=	Remaining clay below test

All of the factors of Equation (3) are known during the test, except (m) and, of course, (K).

If the water table is above the base of the test, there is no question of how to measure the head: it is the vertical distance from the top of the water column in the standpipe to the water table (before the test began). Where the water table is below the test, the head should be calculated in the same manner. If there is an unsaturated drainage blanket at some depth (b) below the test, the head should be taken as the vertical distance from the top of the water column in the standpipe to the top of the drainage blanket. However, in no case should the depth to water below bottom of test exceed 20 to 40 test diameters.

The lowest likely value for (m) is 1, which is not only the most conservative for (Kv) but also simplifies the field calculations. Keeping up with the data in terms of apparent permeabilities has a physical meaning and so yields a better "feel" for the test than does merely plotting the ratio of logarithm divided by time. In the "normal" situation, Case "C" applies to Stage 1 and Case "G" to Stage 2. Setting (m=1) into the equations for the "normal" situation, one has for Stages 1 and 2, respectively:

Direct Hvorslev:

$$K1 = (\pi d^2/11D)\,Ln\,(H1/H2)/(t_2-t_1) \tag{4}$$

$$K2 = (d^2/8L)\,Ln\,(L/D + \sqrt{1 + (L/D)^2})\,Ln\,(H1/H2)/(t_2 - t_1) \tag{5}$$

Hvorslev - Image (H-I):

$$K1 = (\pi d^2/11D)[1 - (D/4b)]\,Ln(H1/H2)/(t_2-t_1) \tag{6}$$

$$K2 = (d^2/16L)\,Ln[g(L/D,b)]\,Ln(H1/H2)/(t_2-t_1) \tag{7}$$

$$g = \frac{(\sqrt{1+(L/D)^2} + L/D)\,(4b/D-L/D + \sqrt{1+(4b/D-L/D)^2})}{(\sqrt{1+(L/D)^2} - L/D)\,(4b/D+L/D + \sqrt{1+(4b/D+L/D)^2})} \tag{8}$$

The function for (K2) can also be written with the simpler notation of Section V as:

$$K2=(\pi d^2/16L)\ [Ln\ [u(1,r,0)/u(1,r,2b)]\ ]\ Ln(H1/H2)/(t_2-t_1) \qquad (8A)$$

Note that the remaining clay (b) will be different in Stage 1 and Stage 2. Also, the acting diameter of Stage 1 may be greater than that of Stage 2 (See Section 2.1.B.).

The H-I equations have only a small effect on the geometric constants used in computing (K1, K2), but the heads should be the distance from the top of the standpipe water column to the potentiometric level in the underlying drainage blanket (the latter usually being zero). Returning to the nomenclature of Equations (2 and 3), and taking (b_2) as the clay thickness remaining below the test during Stage 2, the following comparisons can be made.

Ratio of H-I Values to H Values

	L/D = 1.5			L/D = 2.0		
b_2/D	F1	F1*	F2	F1	F1*	F2
1.0	0.967	0.962	0.954	0.967	0.965	0.950
5.0	0.962	0.956	0.945	0.964	0.960	0.942
4.0	0.955	0.949	0.934	0.958	0.953	0.931
3.0	0.944	0.938	0.916	0.950	0.944	0.913
2.0	0.929	0.920	0.886	0.938	0.930	0.884
1.0	0.900	0.887	0.820	0.917	0.906	0.825

Note: F1* is F1 using the OD of the casing.

It must be emphasized that neither (K1) nor (K2) is "the" permeability, but rather a convenient notation. Obviously, the geometric portions do not change during a test stage. For field use, these complex equations are solved once for the constants (F1,F2) so that the field calculations are simply:

$$K1 = F1\ Ln(H2/H1)/(t_2-t_1) \qquad (9)$$

$$K2 = F2\ Ln(H2/H1)/(t_2-t_1)^* \qquad (10)$$

*Note: F2 should contain the correction for small (L/D) given in Equation (27), Section 3.2.

2.4 Steady-State. Whether one uses the Laplacian or the Green-Ampt model for groundwater flow, there are still transient effects at the beginning of every type of field or laboratory permeability test. The observed effect is to indicate a high permeability, gradually decreasing to some relatively constant value corresponding to a steady-state flow condition. Such an effect is usually noted in the Two-Stage Test. Therefore, the test must be conducted "long enough" to achieve virtually the steady-state condition or the results will be not only too high but also erratic.

There is no reliable method for pre-calculating the length of time required to achieve steady-state. Rather, the observational method is used. The appropriate apparent permeability (K1 or K2) is calculated for each the increment, and/or over longer periods of time; when these appear to be stable, they are checked using arithmetic time - weighted averages, e.g.,

$$K' = \Sigma\,(T_iK_i)/\Sigma\,(T_i) \tag{11}$$

where K' = Arithmetic Time-Weighted Average (ATWA) Permeability
Ti = Time Duration of Test Increment (i)
Ki = Permeability Measured during Test Increment (i)

This is theoretically exact for a single run (between refills). Since the test stabilizes with increasing times, the (K') values are computed beginning with the last test increment and proceeding towards the initial increments.

2.5 Ambient Conditions. At slow rates of flow, the field readings are affected by temperature, as has been noted on many such projects. Rising temperature causes the water column in the pressure/measurement standpipe to expand, so that the drop in water level is less than flow alone would produce. The net effect is a lower apparent permeability. Conversely, falling temperature produces a higher apparent permeability. A normal day's temperature variations can easily cause a 0.5 to 1 order of magnitude change in the apparent permeability. These effects have been much stronger for smaller-diameter standpipes, since a given change in overall volume creates a larger change in height with a smaller area. They are very strong for 1/2 inch standpipes, but still noticeable with 3/4 inch standpipes. Since the total water column is partially exposed and partially below grade, any calculations for the volumetric change would be a crude approximation.

Therefore, a complete "dummy" test setup is installed but with the bottom of the casing sealed with a cap. This dummy, or temperature effect gauge (TEG) is of the same construction and embedded to the same depth as the regular test setups. Since there is no flow from the TEG, any change in its readings must be due to changes in the ambient conditions; such changes would affect the regular test setups to exactly the same degree.

This correction is applied to the regular tests by:

- Reading the TEG at the same times as readings are taken on the regular tests.
- Determining any increase (decrease) in water levels in the TEG between regular test readings.
- Subtracting any increase (adding any decrease) at the TEG from the readings at the regular tests for the ends of the time increments.

The third step of this procedure is not theoretically precise. The theoretical solution yields a complex implicit equation in which the true permeability is a function of its own logarithm. However, for the geometry of the test setups and the observed magnitudes of increases/decreases, the apparent permeabilities calculated in this manner differ from the true permeabilities by no more than 2 to 5 percent. The net result is to "smooth" the apparent permeabilities. This smoothing is most apparent (and most useful) when the soil permeability is less than about 5x10(-7) cm/sec.

An alternate procedure is to calculate the apparent permeability (K1, K2) over roughly 24-hour periods so that the temperatures are about the same at the beginning and end of the test. This method yields adequate results, but takes far longer because of the number of 24-hour periods required to verify steady-state.

2.6 Freezing. These tests can be conducted in very cold weather, but there is a possibility of the water in the exposed standpipe freezing. Insulation would not prevent freezing if the mean daily temperature is less than 32°F, and could interfere with readings. Heating could be employed, but would be difficult to control to the degree necessary to prevent erratic and uneven expansion of water in the various standpipes.

Some form of antifreeze is indicated but it should not affect the test or pollute the test area permanently. STEI has used grain alcohol (normally 100 Proof Vodka) for this purpose. A mixture of 1 part Vodka to 3 parts water will prevent freezing to about 20°F, * and 1(Vodka):2(Water) to 10°F. Withstanding 0°F requires a 1(Vodka):1(water) ratio. The viscosity (u) of ethyl alcohol is about 1.3 times that of water at temperatures of 20 degrees to 100 degrees F. Its specific gravity is about 0.8, and of 100-Proof (0.9). Using the proper equation to account for kinematic effects, the ratio of observed permeabilities with respect to pure Vodka (Ka) and Water (Kw) should be:

$$\frac{K_a}{K_w} = \frac{u_w}{u_a}\,\frac{G_a}{G_w} = \frac{1.0}{1.15}\,\frac{0.9}{1.0} \qquad (12)$$

$$= 0.78$$

The kinematic effect of using a small amount as an antifreeze should be small (5 to 6%).

There are, however, chemical effects on the absolute permeability which are independent of the kinematic effects. A review of the literature does not disclose any tests at present using grain or ethyl alcohol (ethanol). There are tests on illites and montmorillonites using wood or methyl alcohol (methanol). These indicate for illite an increase in permeability of 3 orders of magnitude using reagent grade methanol. After repermeation with water, the residual effect was an increase of 1.5 orders of magnitude. In the STEI procedure, the concentration of ethanol is very small by the time the fluid reaches the soil. Analogy with the results of testing with high and low concentrations of other organic solvents indicates that the effect of the ethanol should be small.

Automobile antifreeze (ethylene glycol) has been used. However, this chemical should be limited to test pads where the affected soil can be removed and treated. Kinematic effects must be considered.

* NOTE: Double these Vodka proportiond for a given temperature.

2.7 Kinematic Effects of Temperature. Permeability is normally reported as the value for water at 20°C (68°F). The density and viscosity of liquids, including water, are affected by temperature. The effect on permeability is in direct ratio to the kinematic viscosity (v), which is the viscosity divided by the density. The kinematic viscosity decreases at higher temperatures. The net effect is that the apparent permeability is greater than the 68°F value at low temperatures.

The kinematic viscosity (vo) of water at 68°F is 1.06x10(-5) sq.ft./sec. Using this value as a base and the normal kinematic correction for flow,

$$Kc/K = v/vo \qquad (13)$$

where Kc = Corrected permeability
K = Measured permeability
v = Kinematic viscosity at Temperature other than 68°F *

The required corrections are illustrated on Figure A-3 for the case of pure water. They are small for typical laboratory tests, but can be significant (20 to 50%) for field tests in very cold or very hot conditions. These corrections should be applied to the (K1, K2) values from the field in determining (K1', K2').

2.8 Special Items - Stage 2. The casing should be emptied of water (siphon and/or bailing) before any of the following operations commence. An undisturbed "Shelby Tube" sample is normally secured from the borehole as part of advancing that hole for Stage 2. This sample is than tested in the laboratory for classification (Atterberg Limits and/or Particle Size), moisture, density, plus horizontal and vertical permeability. Such sampling is not advised when the liner material has a significant content of large-sized particles such as gravel. The sampling process can loosen the walls of Stage 2 in soils which contain gravel.

Extreme caution is needed to minimize sidewall smear effects. The final reaming to full diameter should be done with an undersize device having full diameter only at the cutting edge. It is still good practice to roughen the sides of the hole with a wire brush.

III. DATA REDUCTION - GENERAL

3.1 Basic Procedure. The real values (Kh, Kv) can be determined once the final values for (K1', K2') are determined using the ATWA procedure described in paragraph (2.4). These two apparent permeabilities were computed using ($m = \sqrt{Kh/Kv} = 1.0$). The problem is to find the true (m), then (Kh) or (Kv) can be calculated from either (K1') or (K2'). Returning to the nomenclature of equation (2),

$$K1 = [Ap/G1(1)] \ Ln \ (H1/H2)/(t_2-t_1) \qquad (14)$$

$$K2 = [Ap/G2(1)] \ Ln \ (H1/H2)/(t_2-t_1) \qquad (15)$$

Where G(1) means taking (m=1) in the proper equation, either Hvorslev or H-I.

* NOTE: Use a thermometer or thermocouple to the bottom of the TEG to obtain the temperature of the infiltrating water.

Thus

$$Kv = [Ap/G1(m)] \, Ln\, (H1/H2)/(t_2-t_1) \quad (16)$$
$$= [G1(1)/G1(m)]K1' \quad (17)$$

$$Kv = [Ap/G2(m)] \, Ln\, (H1/H2)/(t_2-t_1) \quad (18)$$
$$= [G2(1)/G2(m)]K2' \quad (19)$$

$$\text{or } K2'/K1' = [G2(m)/G2(1)] \, [G1(1)/G1(m)] \quad (20)$$

As an illustration, assume the "normal" case in which (K1) was computed using Hvorslev Case "C" and (K2) from Case "G". Then:

$$Ap/G1 = \pi \, d^2 \, m \, / \, 11 \, D \quad (21)$$

$$Ap/G2 = (d^2/8L) \, Ln\, (mL/D + \sqrt{1 + (mL/D)^2}) \quad (22)$$

and

$$K2'/K1' = \frac{m Ln(L/D + \sqrt{1 + (L/D)^2}\,)}{Ln(mL/D + \sqrt{1 + (mL/D)^2})} \quad (23)$$

Which is the procedure cited in current literature. Obviously, it is a special case of the generalized case given above as Equation (20). Since (m) is an implicit function of its own logarithm, solution is by trial-and-error. Once (m) is determined, it is introduced into Equation (17) or (19) to obtain (Kv), and ($Kh = m^2Kv$).

<u>3.2 Non-Convergence.</u> Reference to Figure A-1 shows that Hvorslev Case "G" should reduce to Case "C" if (L=0). It does not; rather, it converges to the solution for a spherical discharge geometry.

$$\text{Lim "G"} = (md^2/8D) \quad (24)$$
$$\text{"C"} = \pi(md^2/11D) \quad (25)$$

$$\text{Ratio "G"/"C"} = 1/8 \div \pi/11 = .438 \quad (26)$$

This is accounted for using a correction factor, necessary only at small (L/D) for Stage 2. The Stage 1 value from Case "C" is taken as correct since it is quite close to Case "B". An exact theoretical solution for Case "B" is available and confirms Hvorslev's value. Another part of Hvorslev's 1951 paper gives the proper value for (L/D = 1), so that an exponential transition could be applied to Stage 2; it becomes:

$$F = [1.0 - 0.5623 \, Exp\, (-1.566 \, L/D)] \quad (27)$$

and (K2) is replaced by (K2/F). This correction is normally carried in the field (see Section 2.3), and applied to both Hvorslev and H-I equations for Stage 2.

3.3 Soil Suction. The pore-water pressure of unsaturated clay is below atmospheric, a phenomenon which produces "soil suction". The effect on a permeability test is to create a negative water pressure at the wetting front (i.e., where saturation reaches 100%). The actual hydraulic gradient is therefore greater than would be calculated without suction. The permeability determined by disregarding suction is therefore too high. Soil suction is accounted for in the one-dimensional Green-Ampt analysis, often applied to surface infiltrometer testing. Mathematically, the effect is the same as adding the suction value to the applied head.

During a (field) permeability test, the location of the wetting front is constantly changing; the radius to the wetting front increases with the volume of flow. Hence, the effect of suction on the test is constantly decreasing, at least until the wetting front reaches a pervious boundary.

In the case of a spherical flow source in an infinite isotropic medium, it can be shown that the observed test permeability (Ko) will differ from the real, saturated permeability by:

$$Ko/Ks = [1 + (hs/ht)][1/(1 - ro/R)] \qquad (28)$$

where: hs = Head due to Soil Suction
ht = Head Applied at Test Level
ro = Radius of Test Casing
R = Radius to Wetting Front

NOTE: This is a very approximate procedure for a cylindrical source (i.e. Stage 2). Correct equations have beer derived but are not yet included.

The first term becomes (1.0) if the (ht) is replaced by (ht + hs) when (Ko) was calculated. The remaining second term does not depend on suction. Hence, if quasi-steady state flow is reached during the test, the second term becomes essentially (1.0).

Typical liner soils are compacted wet of optimum, and hence will have air voids of around 2 to 4 percent of their total volume. A water flow of 200cc during the test will thus saturate 5000 - 10000 cc (300-600 cu.in.) of soil. For a 4-inch diameter test, this equates to (ro/R = 0.3), so that the observed permeability should be some 1.4 times the saturated value. In practice, both (K1) and (K2) become quite steady after total flows less than 200 cc, and do not exhibit the continually decreasing observed permeability predicted by the Green-Ampt Model.

The effects of soil suction can therefore be taken into account by adding the suction value to the applied head. In most tests, the applied head (measured with respect to the drainage layer) is on the order of 7 feet. Soils compacted wet of optimum have comparatively low soil suctions, on the order of 1 to 2 feet. Hence, the total effect of soil suction on the test is on the percentage level, not at the order-of-magnitude level.

3.4 Outliers. Experience with this test procedure has shown that some (one out of 5, on the average) will leak enough to affect the results but with no surface expression. Since the testing is usually performed in groups of 3 or more (preferably 5 or more), such an occurrence is usually quite clear by comparison with the other tests. A numerical evaluation can be made statistically, as shown below. However, a bad test may indicate a bad area of the tested unit. If it is clear that a test is behaving significantly different from the others, it should be replaced. If the replacement test follows the original test's behavior, there is something wrong in that area. The test for significance is:

$$\frac{\text{Log K' - Log Kj}}{S} > 2.5 \qquad (29)$$

where: K = Logarithmic Mean K of other tests
Kj = K for suspect test
S = Logarithmic standard deviation of other tests

IV. DATA REDUCTION (HVORSLEV)

4.1 Applicability. The basic Hvorslev equations apply most directly to infinite, isotropic or anisotropic, masses below the water table. Where the test is above the water table, the Hvorslev-Image equations in Section V should be used. The nomenclature for the following Section is illustrated on Figure A-4.

4.2 Basic Solution. The first step is to obtain the time-weighted values of apparent permeability, (K1') from Stage 1 and (K2') from Stage 2 - See Section (3.1). Then, Equation (20) or the more specialized Equation (23) is solved by trial-and-error for (m), leading to (Kh, Kv) through Equation (17) or (19). However, in many tests the ratio (K2'/K1') is so low that Equation (23) fails to converge.

4.3 (K2'/K1') Less Than 1.0 (Hvorslev Equations). Physically, (Kh > Kv), and therefore (K2'/K1') should be greater than 1.0. However, on many field tests in several states (LA, MI, NJ, OH, PA, SD, TX) ratios less than 1.0 have been observed. The reason is normally sidewall smear, which reduces the effective (Kh) acting near the sidewalls during Stage 2.

Mathematically, (K2'/K1' < 1.0) can lead to a condition where no solution of Equation (20) or the more specialized and common Equation (23) is possible. In the case of Equation (23), for example, the limit as (m) approaches zero is:

$$\text{Lim (23)} = (D/L)\,\text{Ln}\,(L/D + \sqrt{1 + (L/D)^2}) \qquad (30)$$

For (L/D = 1.5), the limit is (K2'/K1' = 0.797). On the other hand, if (m = 0), (Kv) is infinite. Hence, (K2'/K1') values less than predicted by Equation (30) cannot exist. They are test artifacts due to sidewall smear.

4.4 Smear Corrections. From the concepts of Section (4.3), it appears that some correction is necessary for sidewall smear, especially when (K2'/K1' < 1.0). There are two basic approaches to accounting for smear effects:

4.4.A. Purely Empirical. Barron (1948) proposed using an effective diameter of one-half the true diameter to account for sidewall smear in the case of sand drains (L/D approaching infinity). The mathematical effect is the same as replacing Hvorslev Case "G" (Infinite Medium) with Case "F" (Semi-Infinite Medium).

4.4.B. Smear Equation. The case of flow from a lined cylindrical hole in a semi-infinite anisotropic medium was solved by Boutwell, Adams, and Brown (1980). This solution is easily converted to a falling-head test in an infinite anisotropic medium having a smeared zone along its sidewalls. Various radiographic studies on "undisturbed" samples indicate that the smeared zone is probably around 1/4 inch thick. The ratio (p=Kh/Ks) of the natural horizontal permeability (Kh) to that of the smeared zone (Ks) is not determined in the regular test (although a 3rd stage might do so). Back calculations from numerous projects in various materials indicate that this ratio is between 10 and 20, i.e., that the horizontal permeability of the smeared zone is about 5 to 10% that of the natural soils. The smear equation for the normal situation Hvorslev Equation (K1' from "C", K2' from "G") is:

$$\frac{K2'}{K1'} = \frac{m\,Ln(L/D + \sqrt{1 + (L/D)^2})}{Ln(A) + p\,Ln(B)} \qquad (31)$$

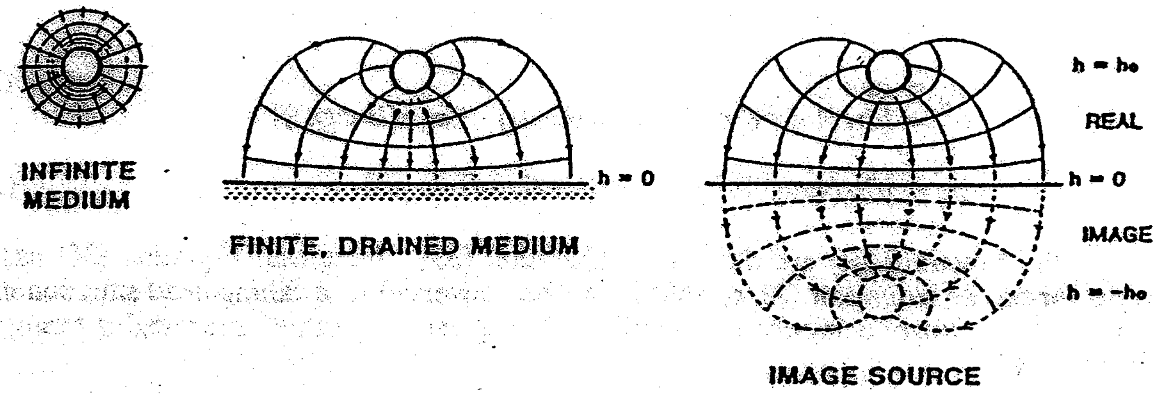
where
$A = mL/(D+2T) + \sqrt{1+[mL/(D+2T)]^2}$
$B = 1 + 2T/D$
L = Height of Cylindrical Cavity
Ks = Permeability of Smeared Zone
Kh = Natural Horizontal Permeability
T = Thickness of Smeared Zone
D = Inner Diameter of Cavity = $2r_2$
$m = \sqrt{Kh/Kv}$

V. HVORSLEV/IMAGE EQUATIONS

As noted previously, the basic Hvorslev equations apply most directly to masses of infinite depth and below the groundwater level. Neither test pads nor liners often meet these criteria. Therefore, results calculated by using the Hvorslev equations directly for such cases will not be correct. For a given permeability, both proximity to a drainage zone and the vertical gradient due to gravity cause the flow to be greater than the basic Hvorslev equations would predict. The basic Hvorslev equations therefore predict a higher permeability than the material really has. A method for accounting for these effects was needed.

5.1 Image Potential Technique. The method of image wells has been used in geohydrology for years. The classic example is the solution for a well near a river, found in many textbooks. However, the method is not limited to two-dimensional situations such as this illustration. Any solution for an infinite or semi-infinite medium which describes the potential field (head distribution) can be converted to a solution for a finite medium bounded by a plane by using the Image Potential technique.

The basic idea is that halfway between a source and a sink of equal but opposite strength will be a plane of zero potential. So, if there is a plane of zero potential (head), its effect can be replaced by an "image" source/sink located twice as far away from the sink/source as is the plane. If the test (source) is set a distance (b) above the drainage blanket, the flow field will be the same as if there were no blanket but there was an image test (sink) with negative head at a distance of (2b) below the real test. Since the drainage blanket is at zero head, the head at the test is taken as the total head lost: (b) plus the excess pressure (ht) applied at the infiltration point of the test.



The Image Potential technique thus accounts both for the less-than-infinite drainage path lengths in the real world and for the gravitational gradient (i=1.0).

The generalized procedure is to describe the head at a point where head is known in terms of the heads induced at that point by flows from the real and image sources, i.e.,

Known Head At Point	=	Head at Point as Function of Real Flow	-	Head at Point as Function of Image Flow

This procedure has been applied to several applicable cases, as described below. The nomenclature for the following Sections is illustrated on Figure A-5.

5.2 H-I Equations for Stage 2 (No Smear). The basic Hvorslev equation approximates the flow from a cylindrical source (such as Stage 2) by that from an ellipsoidal source. The head distribution for the anisotropic, infinite medium is given by (Harr, 1962):

$$h(r,z) = [Q/(4\pi m^2 KvL)]\ \mathrm{Ln}\left[\frac{(mz/r)+(mL/2r) + \sqrt{1+[(mz/r)+(mL/2r)]^2}}{(mz/r)-(mL/2r) + \sqrt{1+[(mz/r)-(mL/2r)]^2}}\right] \quad (32)$$

where: z = Vertical distance from center of ellipsoid
r = Radial distance from center of ellipsoid
L = Length of Ellipsoid (cylinder)
Q = Flow from Ellipsoid (cylinder)

For simplicity, one can define the function

$$u(m,r,z) = \frac{(mz/r)+(mL/2r) + \sqrt{1+[(mz/r)+(mL/2r)]^2}}{(mz/r)-(mL/2r) + \sqrt{1+[(mz/r)-(mL/2r)]^2}} \quad (33)$$

And

$$h(r,z) = [Q/(4\pi m^2 KvL)]\ \mathrm{Ln}[u(m,r,z)] \quad (34)$$

The head at the center of the cylinder (h_o) is the sum of the positive head (hr) due to the real source and the negative head (-hi) due to the image source. The vertical distance (z) from the real source's center is zero and that from the image well (2b). The vertical line (r=o) is a mathematical singularity. Therefore, the evaluation must be done at the test radius ($r=r_2$), i.e., the wall of the test, to avoid divisions by zero. Thus:

$$h_o = hr - hi \quad (35)$$
$$= [Q/(4\pi m^2 KvL)] [Ln(u(Real)) - Ln(u(Image))]$$

$$h_o = [Q/(4\pi m^2 KvL)] \, Ln \, [u(Real)/u(Image)] \quad (36)$$

where the functions (u) are defined in Equation (33). Note that Equation (36) has the same format as Equation (2), so that it can be converted to a falling-head situation using Equation (3). Introducing the real (z=0) and image (z=2b) values, rearranging terms, and simplifying,

$$Kv = [d^2/(16m^2 L)] \, Ln[u(m,r_2,o)/u(m,r_2,2b_2)] \, Ln(H2/H1)/(t_2-t_1) \quad (37)$$

And (K2) is obtained by setting (m=1) in Equation (37).

<u>5.3 H-I Equations for Stage 1.</u> Concerning the flush-bottom (Stage 1) configuration, Hvorslev states "a...formal mathematical solution is not known." However, one can invoke St. Venant's principle that the further away from a disturbance, the less the exact manner of its application matters to its effect. The head due to a spherical source is given by:

$$h = h_w + (Q/4\pi K)[(1/r)-(1/r_o)] \quad (38)$$

At a distance from the flush-bottom image source, then:

$$h_i = h_w + [(Q/5.5K)((1/R) - (1/r_o)] \quad (39)$$

where: r = Radius from center of Real test
R = Radius from center of Image test
r_o = Radius of both test sources

At the real (test) source, the head (h_o) is the sum of the applied head (h_w) and the negative image head (h_i), leading to:

$$h_o = (Q/(5.5K)((1/r_o)-(1/2b_1)) \quad (40)$$

Again, rearranging, using Equation (2) for the falling-head test, and introducing anisotropy,

$$Kv = (\pi d^2/11Dm)[1-(D/4mb_1)] \, Ln(H1/H2)/(t_2-t_1) \quad (41)$$

And (K1) is obtained by setting (m=1) in Equation (41). Of course, the proper (D) to use in Stage 1 (ID or OD) should be determined - see Section (2.1.B.).

5.4 Final Calculations: H-I Equations, No Smear. The procedure is as outlined in Section (3.1), especially Equation (20):

$$K2'/K1' = [G2(m)/G2(1)][G1(1)/G1(m)] \quad (20)$$

Following the format of Equation (2) and the results of Section (5.3),

$$G1(1) = 5.5r_1/[1-(r_1/2b_1)] \quad (42)$$

$$G1(m) = 5.5mr_1/[1-(r_1/2mb_1)] \quad (43)$$

where r_1 = Radius during Stage 1
b_1 = Clay remaining under bottom of Stage 1

In the same format from Section (5.2)

$$G2(1) = 4\pi L/Ln[u(1,r_2,0)/u(1,r_2,2b_2)] \quad (44)$$ See b_2 definitions below

$$G2(m) = 4\pi m^2L/Ln[u(m,r_2,0/u(m,r_2,2b_2)] \quad (45)$$ "

As in previous sections, Equation (20) is solved by trial-and-error until some value of (m) yields the correct (K2'/K1'). The actual (Kh,Kv) are determined from Equations (17) or (19) as described in Section (3.1).

5.5 H-I Equations for Stage 2 (With Smear). In this case, smear is taken as affecting a thin zone around Stage 2, in a manner similar to that described in Section (4.4.B). Letting (Ks) again be the (horizontal) permeability of the smeared zone, the Image Potential technique yields:

$$Q = \frac{4\pi L\ m^2Kv\ \ h}{(Kh/Ks)\ Ln[u(m,r_2,0)/u(m,r_2+T,0)]+Ln[u(m,r_2+T,0)/u(m,r_2,2b_2)]} \quad (46)$$

Which, in the format of Equation (2), becomes

$$G = \frac{4\pi L\ m^2}{Ln[u(m,r_2+T,0)/u(m,r_2,2b_2)] + (Kh/Ks)\ Ln[u(m,r_2,0)/u(m,r_2+T,0)]} \quad (47)$$

$$= G2T(m)$$

where L = Length of Stage 2 Extension
r_2 = Radius of Stage 2
b_2 = Distance from Center of Stage 2 cylinder to underlying boundary.
T = Thickness of Smeared Zone

And the other terms are as defined previously. The smear effect is not normally taken into account in the field calculations for (K1,K2). Therefore, data reduction following Equation (20) becomes:

$$K2'/K1' = [G2T(m)/G2(1)][G1(1)/G1(m)] \quad (48)$$

where G2T(m) = Equation 47
G2(1) = Equation 44
G1(1) = Equation 42
G1(m) = Equation 43
u(m,r,z) = Equation 33

The normal trial-and-error solution of Equation (48) yields the proper (m) for Equation (17) or (19).

5.6 Limitations. As mentioned in Section (5.1), the plane (drainage blanket) at (z=b) below the test is at zero head with respect to the head (h_o) at the test. Therefore, the head at the test is the head applied by the standpipe (ht=Rt+Ra+Z) plus the elevation change to the plane (b). As (b) becomes infinite, so does the flow predicted by the H-I equations. Or, alternatively, as (b) becomes infinite the predicted (K) becomes zero. This problem does not affect two-dimensional solutions, where the area through which flow occurs is proportional to (b); in three-dimensional solutions, the flow area is proportional to (b^2).

As an analogy, Two-dimensional flow from a well into a medium bounded in depth approaches zero as the radius of the medium approaches infinity; no solution is possible. Yet, geohydrology uses these solutions by assuming an "effective" radius of influence of the well which is less than infinity. The effective radius is taken as 200-500 times the well radius. Taking these limits to the 2/3 power (to account for 3 vs 2 dimensions), the maximum value for (b) should be 20 to 40 test diameters.

V. ADVANTAGES/LIMITATIONS

6.1 Advantages. The Two-Stage Test has several positive features:

6.1.A. Cost. Compared with other field permeability tests, it is relatively inexpensive. The equipment for one test costs less than $100.00.

6.1.B. Speed. The entire test normally takes 1 to 3 weeks, not 3 to 5 months. However, since (K1) is the maximum possible real value for (Kv), the liner or test pad can usually be given "Pass" or "Fail" within 48 hours.

6.1.C. Multiplicity. There is really little extra cost in running 5 tests as opposed to 1 test. A greater number of tests allows more confidence in the results.

6.1.D. Low-K. The test has successfully measured permeabilities as low as 2x10(-9) cm/sec, and could probably evaluate even lower values.

6.1.E. Simplicity. While the computations are quite involved, the test concept and execution are simple. The test is performed with readily available materials and uses physical measurements.

6.1.F. Acceptability. Although not the only procedure so described, the test is positively cited in the U.S. EPA's manual "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities", 1988.

6.1.G. Side Liners. The test can be performed on a slope, with some minor benching.

6.1.H. Field Correlations. The results, both (Kh) and (Kv), have compared quite closely with the results from laboratory testing on undisturbed "plugs" from the liners. The test has also correlated well with Infiltrometer tests and long-term (4+ years) Pan Lysimeter installations.

6.2 Limitations. Two limitations of the procedure are apparent:

6.2.A. Volume Tested. The infiltration area is small compared with a full-size surface infiltrometer. However, the major advantage to large volume is that secondary structure is more likely to affect the results. The Two-Stage Test does a similar evaluation through multiple installations.

6.2.B. Soil Suction. The Hvorslev Equations are derived basically from the Steady-State Laplacian Model, not the Green-Ampt (Transient) Model which accounts for soil suction. The latter phenomenon is mathematically the same as adding head at the infiltration point. Surface infiltrometers use a head of around one to two feet. The Two-Stage uses an applied head (ht) of 4 to 7 feet, so that any suction effect is relatively far less.

Approximate solutions for the effects of non-saturation (distance to wetting front and value of soil suction) are included herein. A full procedure has been developed and is forthcoming.

REFERENCES

Barron, R.A. (1948), "Consolidation of Fine-Grained Soils by Drain Wells", Trans. ASCE, Vol. 113.

Boutwell, G.P., R.B. Adams, and D.A. Brown (1980), "Hazardous Waste Disposal in Louisiana", Capitol Section, ASCE, Washington, DC.

Boutwell, G.P., and R.K. Derick (1986), "Groundwater Protection for Sanitary Landfills in the Saturated Zone", Waste Tech '86, NSWMA, Chicago, IL.

Boutwell, G.P., and C. L. Rauser (1990), "Clay Liner Construction", Proc. ASCE-PaDOT Geotechnical Seminar, Hershey, PA.

Daniel, D.E. (1989), "In-Situ Hydraulic Conductivity Tests for Compacted Clay", Journal of the Geotechnical Engineering Division, ASCE, Vol. 115, No. 9, September, 1989, pp. 1205-1226.

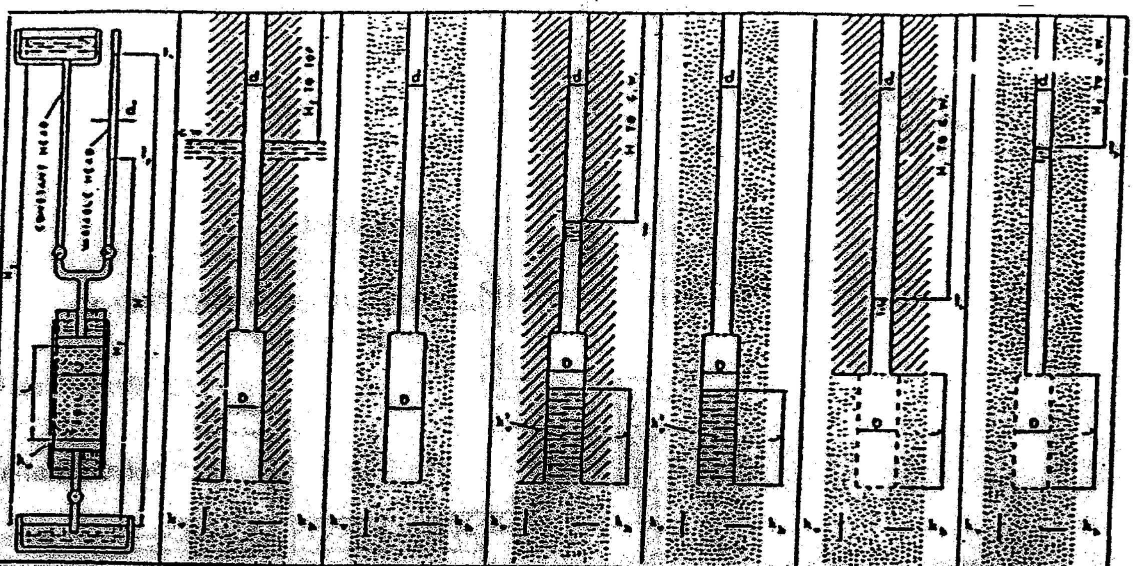
EPA - Goldman, L.J., and L.I. Greenfield, (1988), Design, Construction and Evaluation of Clay Liners for Waste Management Facilities, EPA/530/SW-86/007F, U.S. EPA, November, 1988, pp. 3-57 through 3-61.

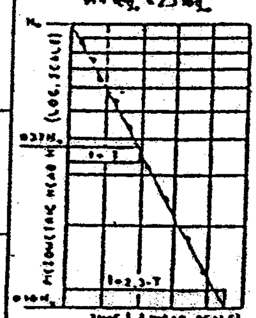
Harr, M.E. (1962), Groundwater and Seepage, McGraw-Hill, New York, NY, pp. 261-262.

Hvorslev, M.J. (1951), "Time Lag in the Observation of Ground Water Levels and Pressures", Bulletin No. 36, USA/COE Waterways Experiment Station, Vicksburg, MS.

Sai, J.O., and D.C. Anderson (1990), "Field Hydraulic Conductivity Tests for Compacted Soil Liners", ASTM Geotechnical Testing Journal, Vol. 13, No. 3, September, 1990, pp. 215-225.

U.S. Bureau of Reclamation (1987), Design of Small Dams, Third Edition, U.S.G.P.O., Denver, CO, 1987, p. 176.

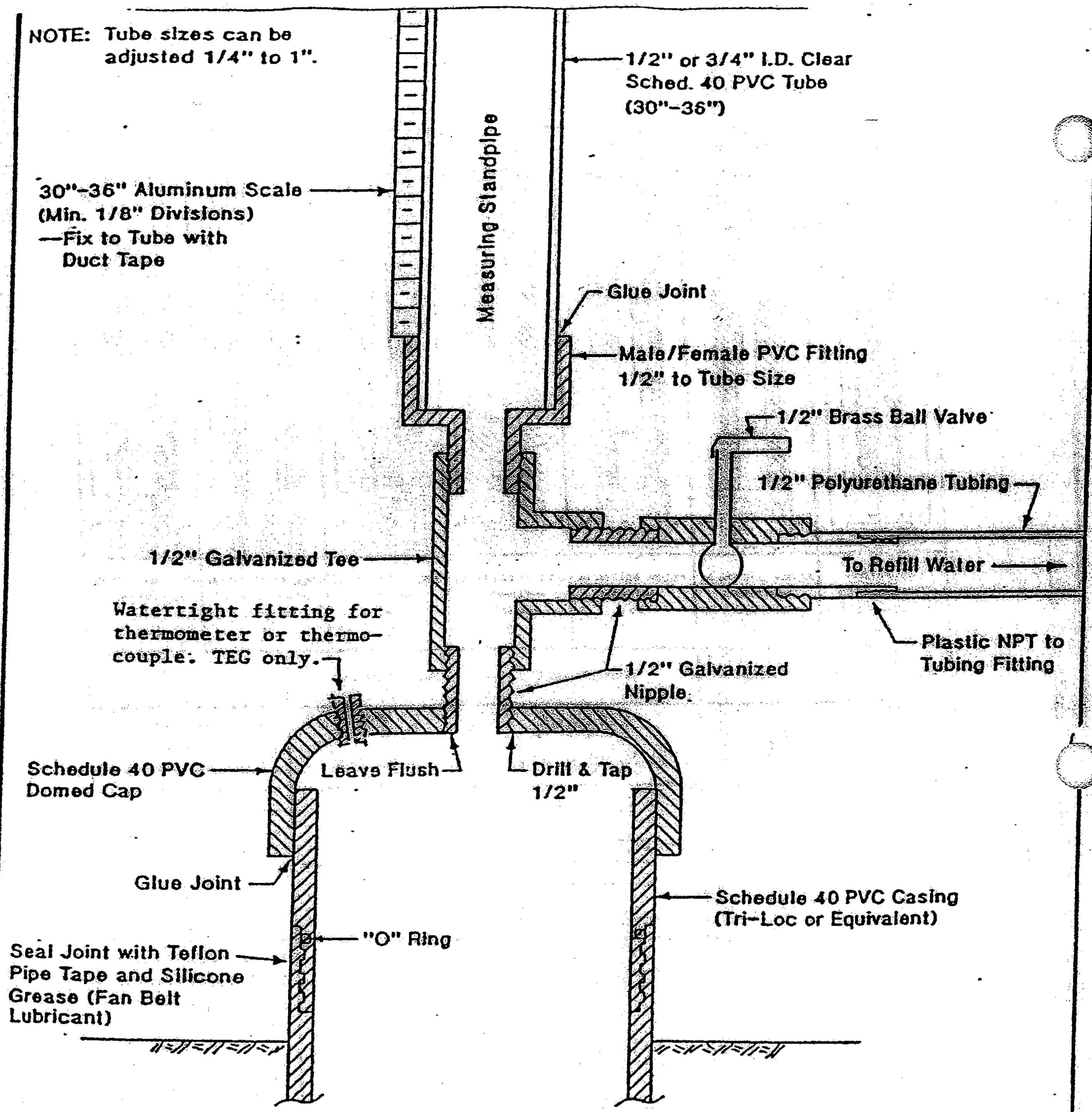


CASE	CONSTANT HEAD	VARIABLE HEAD	BASIC TIME LAG	NOTATION
A	$k_v = \frac{4 \cdot q \cdot L}{\pi \cdot D^2 \cdot H_c}$	$k_v = \frac{d^2 \cdot L}{D^2 \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_v = \frac{L}{t_2 - t_1} \ln\frac{H_1}{H_2}$ for $d = D$	$k_v = \frac{d^2 \cdot L}{D^2 \cdot T}$ $k_v = \frac{L}{T}$ for $d = D$	D – DIAM., INTAKE, SAMPLE, CM d – DIAMETER, STANDPIPE, CM L – LENGTH, INTAKE, SAMPLE, CM
B	$k_m = \frac{q}{2 \cdot D \cdot H_c}$	$k_m = \frac{\pi \cdot d^2}{8 \cdot D \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_m = \frac{\pi \cdot D}{8 \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ for $d = D$	$k_m = \frac{\pi \cdot d^2}{8 \cdot D \cdot T}$ $k_m = \frac{\pi \cdot D}{8 \cdot T}$ for $d = D$	H_c – CONSTANT PIEZ. HEAD, CM H_1 – PIEZ. HEAD FOR $t = t_1$, CM H_2 – PIEZ. HEAD FOR $t = t_2$, CM q – FLOW OF WATER, CM^3/SEC.
C	$k_m = \frac{q}{2.75 \cdot D \cdot H_c}$	$k_m = \frac{\pi \cdot d^2}{11 \cdot D \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_m = \frac{\pi \cdot D}{11 \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ for $d = D$	$k_m = \frac{\pi \cdot d^2}{11 \cdot D \cdot T}$ $k_m = \frac{\pi \cdot D}{11 \cdot T}$ for $d = D$	t – TIME, SEC. T – BASIC TIME LAG, SEC. k_v' – VERT. PERM. CASING, CM/SEC. k_v – VERT. PERM. GROUND, CM/SEC.
D	$k_v' = \frac{4 \cdot q \left[\frac{\pi}{8} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{\pi \cdot D^2 \cdot H_c}$	$k_v' = \frac{d^2 \cdot \left[\frac{\pi}{8} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{D^2 \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_v = \frac{\frac{\pi}{8} \frac{D}{m} + L}{t_2 - t_1} \ln\frac{H_1}{H_2}$ for $k_v' = k_v$, $d = D$	$k_v' = \frac{d^2 \cdot \left[\frac{\pi}{8} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{D^2 \cdot T}$ $k_v = \frac{\frac{\pi}{8} \frac{D}{m} + L}{T}$ for $k_v' = k_v$, $d = D$	k_h – HORZ. PERM. GROUND, CM/SEC. k_m – MEAN COEFF. PERM., CM/SEC. m – TRANSFORMATION RATIO $k_m = \sqrt{k_h \cdot k_v}$ $m = \sqrt{k_h / k_v}$
E	$k_v' = \frac{4 \cdot q \left[\frac{\pi}{11} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{\pi \cdot D^2 \cdot H_c}$	$k_v' = \frac{d^2 \cdot \left[\frac{\pi}{11} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{D^2 \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_v = \frac{\frac{\pi}{11} \frac{D}{m} + L}{t_2 - t_1} \ln\frac{H_1}{H_2}$ for $k_v' = k_v$, $d = D$	$k_v' = \frac{d^2 \cdot \left[\frac{\pi}{11} \cdot \frac{k_v'}{k_v} \cdot \frac{D}{m} + L\right]}{D^2 \cdot T}$ $k_v' = \frac{\frac{\pi}{11} \frac{D}{m} + L}{T}$ for $k_v' = k_v$, $d = D$	$\ln = \log_e = 2.3 \log_{10}$ 
F	$k_h = \frac{q \cdot \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{2 \cdot \pi \cdot L \cdot H_c}$	$k_h = \frac{d^2 \cdot \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{8 \cdot L \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_h = \frac{d^2 \cdot \ln\left(\frac{4mL}{D}\right)}{8 \cdot L \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ for $\frac{2mL}{D} > 4$	$k_h = \frac{d^2 \cdot \ln\left[\frac{2mL}{D} + \sqrt{1 + \left(\frac{2mL}{D}\right)^2}\right]}{8 \cdot L \cdot T}$ $k_h = \frac{d^2 \cdot \ln\left(\frac{4mL}{D}\right)}{8 \cdot L \cdot T}$ for $\frac{2mL}{D} > 4$	
G	$k_h = \frac{q \cdot \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{2 \cdot \pi \cdot L \cdot H_c}$	$k_h = \frac{d^2 \cdot \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{8 \cdot L \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ $k_h = \frac{d^2 \cdot \ln\left(\frac{2mL}{D}\right)}{8 \cdot L \cdot (t_2 - t_1)} \ln\frac{H_1}{H_2}$ for $\frac{mL}{D} > 4$	$k_h = \frac{d^2 \cdot \ln\left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2}\right]}{8 \cdot L \cdot T}$ $k_h = \frac{d^2 \cdot \ln\left(\frac{2mL}{D}\right)}{8 \cdot L \cdot T}$ for $\frac{mL}{D} > 4$	DETERMINATION BASIC TIME LAG T

ASSUMPTIONS

SOIL AT INTAKE, INFINITE DEPTH AND DIRECTIONAL ISOTROPY (k_v AND k_h CONSTANT) – NO DISTURBANCE, SEGREGATION, SWELLING OR CONSOLIDATION OF SOIL – NO SEDIMENTATION OR LEAKAGE – NO AIR OR GAS IN SOIL, WELL POINT, OR PIPE – HYDRAULIC LOSSES IN PIPES, WELL POINT OR FILTER NEGLIGIBLE

Fig. 18. Formulas for determination of permeability



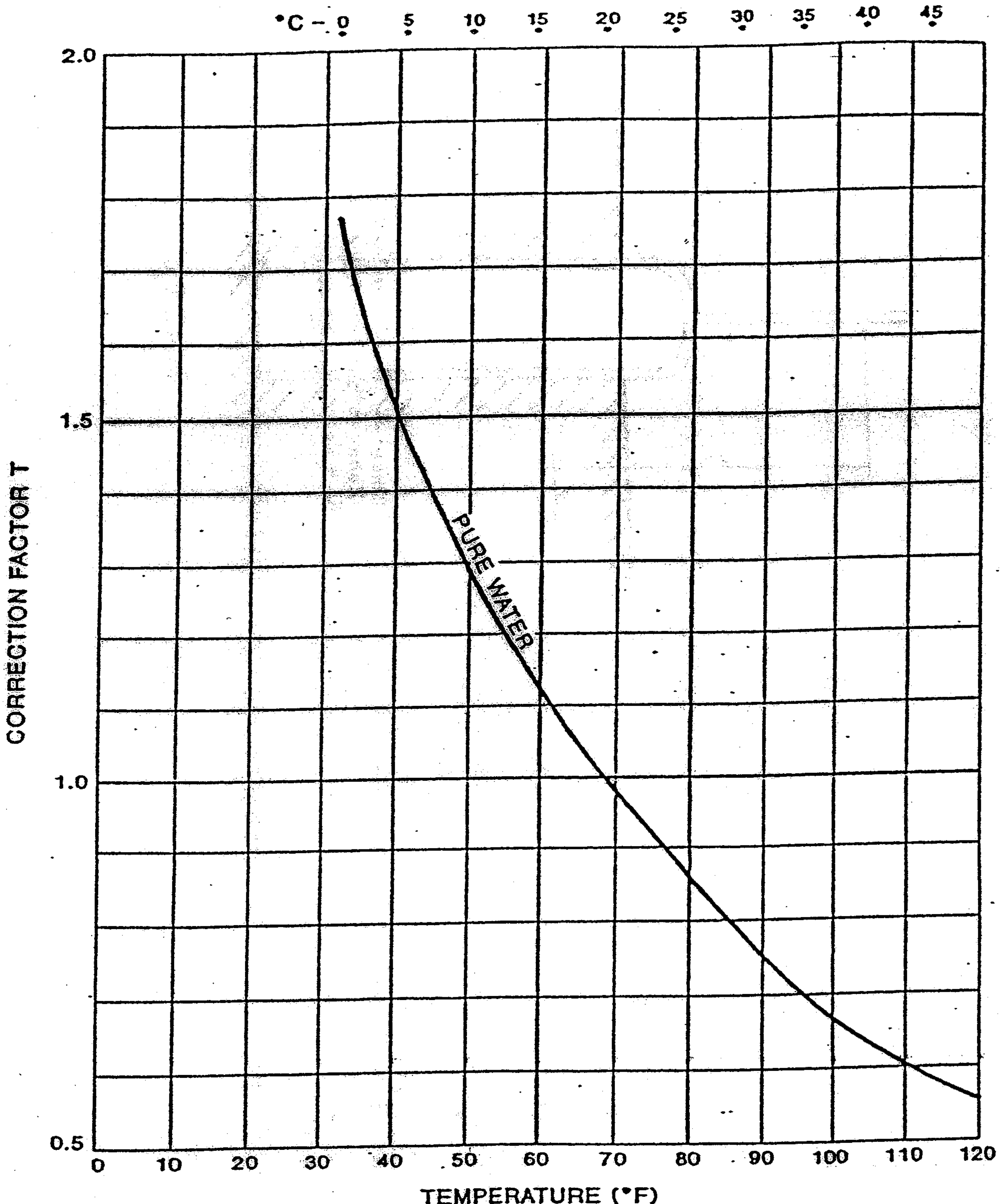
FLOW MEASURING SYSTEM

NOTE: Use Teflon Tape and Silicone Grease on all piping joints.

SOIL TESTING ENGINEERS, INC.

FIGURE NO.: A-2

DATE: 12/90

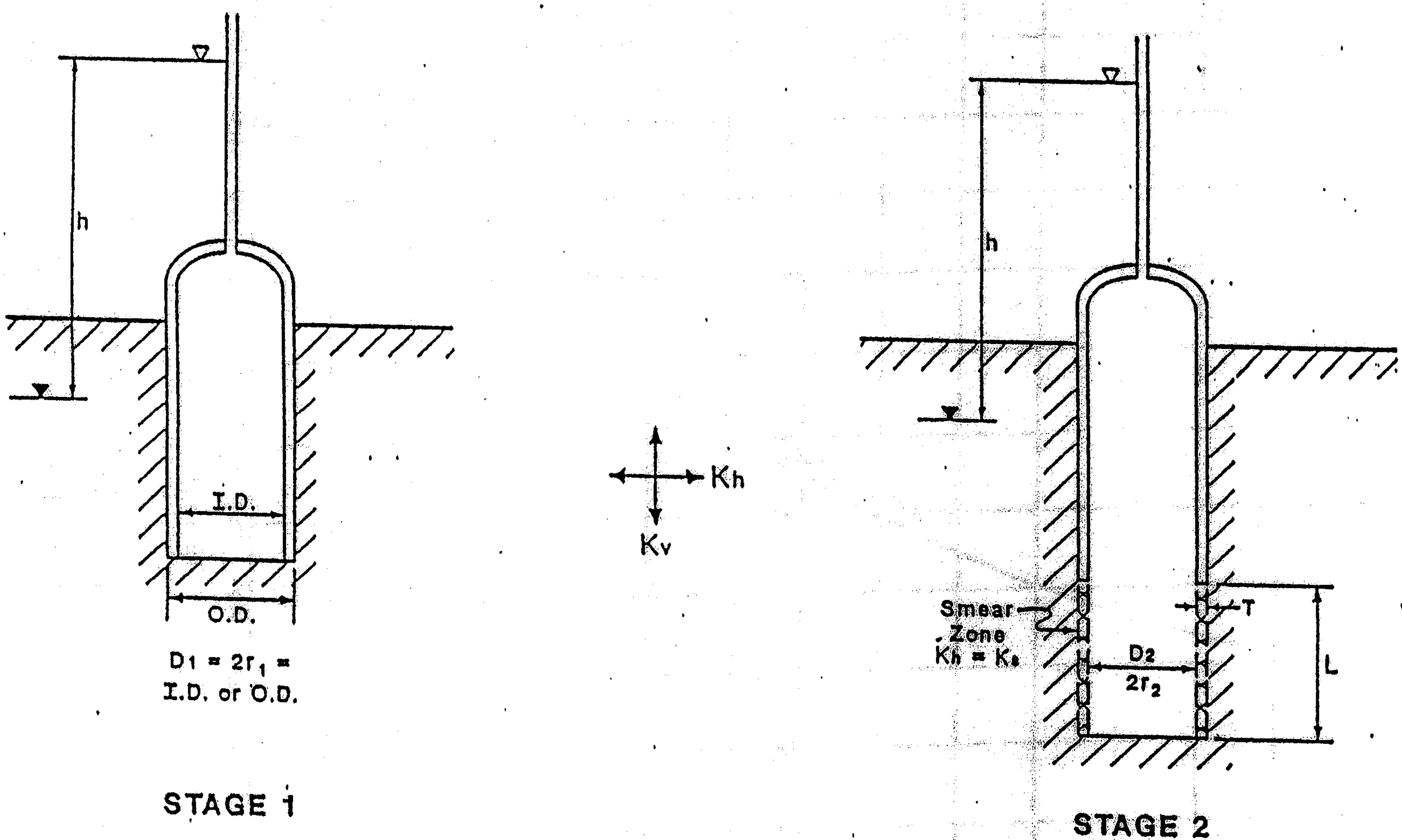


$K_{CORR} = T \cdot K_{MEAS}$

TEMPERATURE CORRECTIONS FOR PERMEABILITY

FIGURE A-3

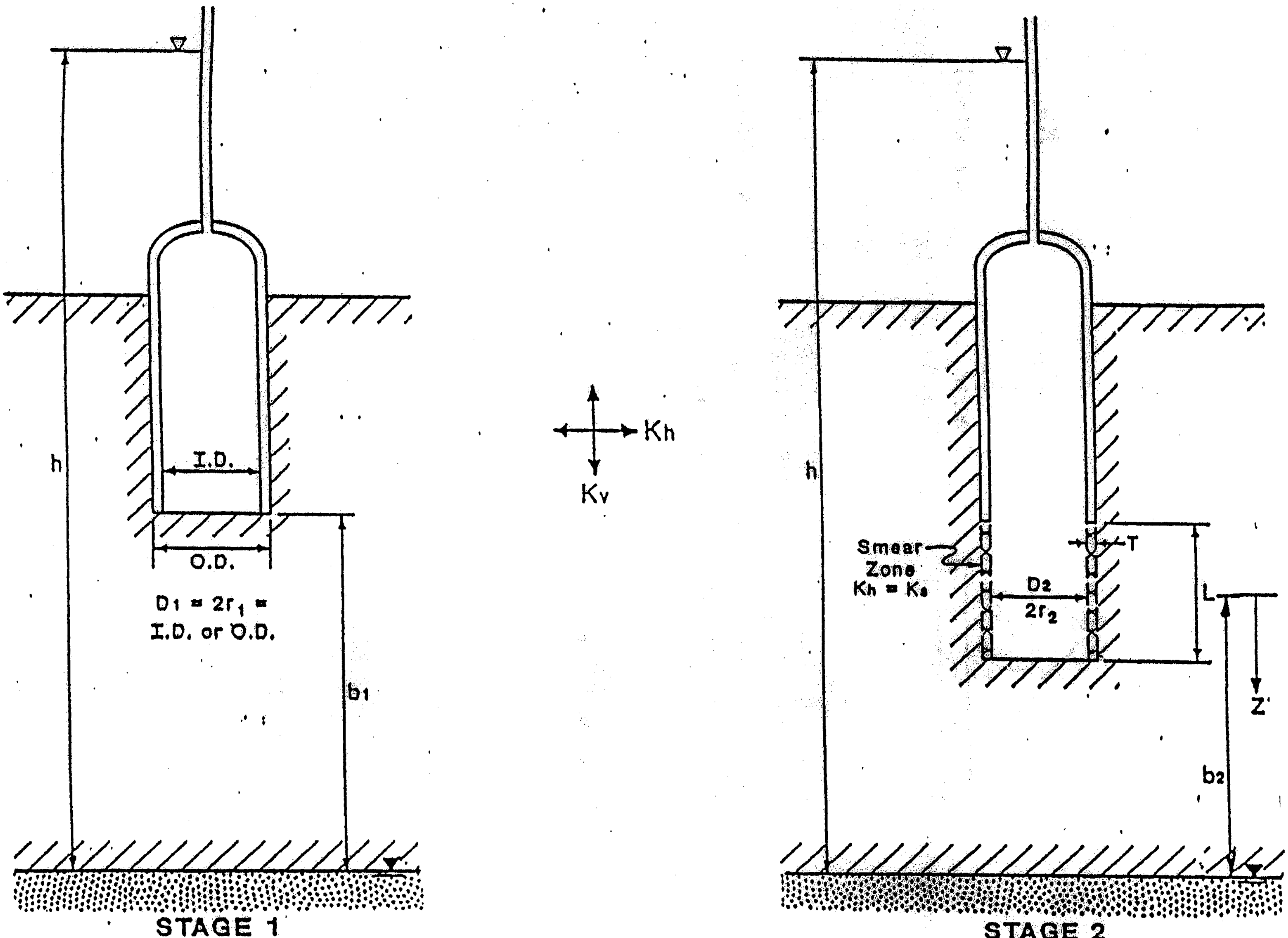
SOIL TESTING ENGINEERS, INC.



NOMENCLATURE

BASIC HVO[illegible]EV CASE

FIGUR[illegible]-4



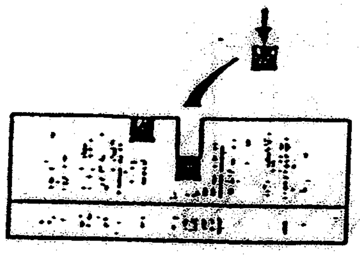
NOMENCLATURE

HVORSLEV – IMAGE CASE

FIGURE I

TEST IMPOUNDMENT
HW SITE – LA

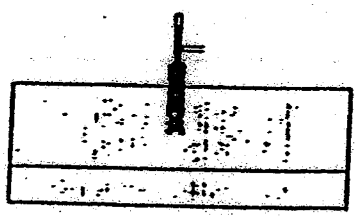
KN



LAB TESTS
ON PLUGS

1 WEEK
7 TESTS

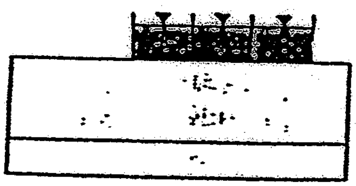
3x10(–9)



TWO–STAGE
FIELD TEST

4 WEEKS
6 TESTS

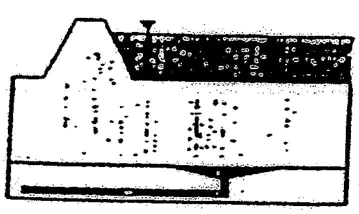
4x10(–9)



SDRI

5 MONTHS
1 TEST

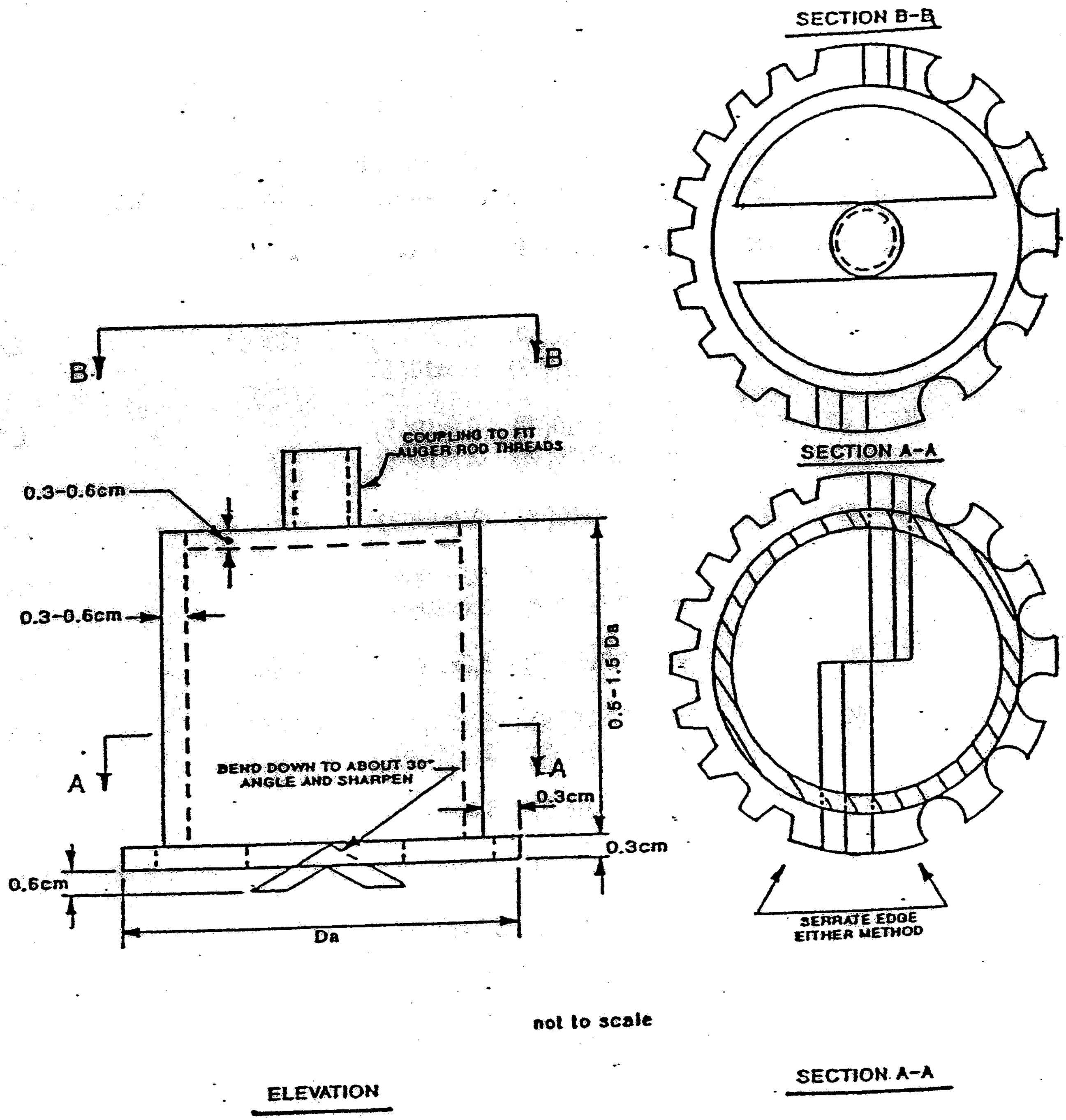
4x10(–9)



PAN
LYSIMETERS

4 YEARS
6 TESTS

2x10(–9)



NOTE: FOR FLAT AUGER, Da=D+5cm
FOR REAMER, Da=D -0.1 cm

SOIL TESTING ENGINEERS, INC.

REPRESENTATIVE TWO-STAGE PROJECTS
LINERS AND TEST PADS
AS OF 7 AUGUST 91

Project No.	Soil Type	LL (%)	Fines (%)	Kv or Kh	Mean Permeability (cm/sec) UD Plugs	2-Stage	SDRI	AEP	State	Year
Aa	CH	101	98	V	3.5x10(-9)	1.6x10(-8)	2.6x10(-8)	-	LA	1991
				H	4.0x10(-9)	1.5x10(-7)				
A	CH	85	97	V	4.4x10(-9)	9.0x10(-9)	5.0x10(-9)	-	LA	1991
				H	2.8x10(-9)	9.5x10(-8)				
B	CH	62	97	V	3.5x10(-9)	9.9x10(-9)	-	-	LA	1983
				H	3.5x10(-8)	2.7x10(-8)				
C	CH	59	96	V	1.4x10(-8)	2.2x10(-8)	-	-	LA	1982
D	CH	56	95	V	8.8x10(-9)	9.5x10(-9)	-	-	LA	1987
				H	2.5x10(-8)	3.6x10(-8)				
E	CH	54	?	V	1.7x10(-8)	5.8x10(-9)	2.7x10(-8)	-	PA	1991
F	CH	50	96	V	7. x10(-9)	5. x10(-9)	4. x10(-9)	-	LA	1980
				H	1. x10(-8)	2. x10(-8)				
G	CL	48	85	V	4.6x10(-9)	8.6x10(-9)	-	-	OH	1990
H	CL	48	84	V	1.1x10(-7)	1.6x10(-7)	I.P.	2.2x10(-8)	CA	1991
I	CL	45	-	V	1.8x10(-8)	2.9x10(-8)	-	-	SD	1988
J	CL	41	98	V	1.6x10(-8)	2.7x10(-8)	-	-	OH	1990
K	CL	41	94	V	1.6x10(-8)	9.3x10(-9)	-	-	LA	1983
				H	3.7x10(-8)	3.7x10(-8)				
L	CL	41	-	V	2.6x10(-8)	2.3x10(-7)	3.1x10(-7)	9.3x10(-7)	CA	1988
La	CL	39	86	V	1.3x10(-8)	1.4x10(-8)	I.P.	-	PA	1991
M	CL	36	91	V	1.3x10(-8)	9.8x10(-9)	-	-	LA	1990
				H	1.1x10(-8).	3.3x10(-8)				
N	CL	36	92	V	1.6x10(-8)	1.1x10(-8)	1.2x10(-8)*	-	LA	1991
Na	CL	36	83	V	1.4x10(-8)	4.6x10(-8)	-	-	NJ	1990

REPRESENTATIVE TWO-STAGE PROJECTS
LINERS AND TEST PADS
AS OF 7 AUGUST 91
(CONTINUED)

Project No.	Soil Type	LL (%)	Fines (%)	Kv or Kh	Mean Permeability (cm/sec) UD Plugs	2-Stage	SDRI	AEP	State	Year
Nb	CL	34	?	V	2.8x10(-8)	2.8x10(-8)	-	-	OH	1991
0	SC-G	34	44	V	1.1x10(-7)	5.9x10(-8)	-	-	PA	1990
Oo	CL	33	95	V	5.8x10(-8)	6.1x10(-8)	-	-	OH	1991
P	CL	33	?	V	5.7x10(-8)	4.3x10(-8)	4.7x10(-8)	-	PA	1990
Pa	CL	33	?	V	8.1x10(-9)	8.7x10(-9)	-	-	LA	1991
				H	1.0x10(-8)	2.8x10(-8)	-	-		
Q	SC	30	49	V	6.7x10(-8)	5.8x10(-8)	-	-	OH	1990
R	SC-G	31	30	V	3.8x10(-7)	1.0x10(-7)	-	-	PA	19[illegible]
S	CL	28	-	V	1.5x10(-8)	1.7x10(-8)	-	-	LA	1988
T	SC	28	31	V	6.8x10(-8)	1.4x10(-7)	6.7x10(-7)	4.8x10(-8)	CA	1989
U.	SC	28	30	V	2.6x10(-8)	1.9x10(-7)	5.3x10(-8)	1.2x10(-7)	CA	1989

* PDRI Test
IP - Test in Progress