Technical Reference Document for Liquid Manure Storage Structures

COMPACTED CLAY LINERS

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Depending on the site hydrogeology, an earthen manure storage may require a compacted clay liner.

SECTION 1 - PURPOSE AND SCOPE

1.1. Purpose of the Technical Reference Document – The Technical Reference Document for the *Design and Construction of Compacted Clay Liners* provides specifications and construction procedures to Engineers for the design of compacted clay liners for the conditions of Manitoba.

1.1.1. This Technical Reference Document is intended as a supplement to the Technical Reference Document *Earthen Manure Storage Structures*.

1.1.2. In Manitoba, the regulatory agency is Manitoba Conservation.

1.1.3. The general information that is required by the regulatory agency for obtaining a construction permit for an earthen manure storage structure comprising of a compacted clay liner is specified or referenced herein.

1.2. Requirement for a Compacted Clay Liner – Depending on the site's geological and hydrogeological features, an earthen manure storage structure may be required to contain a liner. The construction of a compacted clay liner is an option.

1.3. Definition of a Compacted Clay Liner – A compacted clay liner is a seepage free barrier constructed of a cohesive soil that is compacted to increase its bulk dry density and homogeneity. The purpose is to reduce porosity and decrease soil permeability. Within the earthen manure storage structure, the compacted clay liner is designed to impede seepage of the liquid manure.

SECTION 2 - RESPONSIBILITIES OF THE ENGINEER

2.1. Qualifications - The Engineer responsible for the design, inspection and certification of an earthen manure storage structure comprising of a compacted clay liner shall be licensed to practice engineering by the Association of Professional Engineers and Geoscientists of the Province of Manitoba.

2.2. Responsibilities – The above Engineer shall comply with the Technical Reference Document *Role and Responsibilities of the Engineer (RRoE)*.

2.2.1. Notwithstanding the requirements outlined in this Technical Reference Document, the Engineer must ensure that the design meets any other technical standards or documents of the Technical Reference Manual for Liquid Manure Storage Structures that apply.

2.2.2. It is the responsibility of the client and the developer, where applicable, to ensure that the contract between the developer and the Engineer is adequately covering the design, supervision and construction requirements set out herein and any other standards or document in the Technical Reference Manual for Liquid Manure Storage Structures that apply.

2.3. Completeness of Design – The Engineer whose professional seal appears on the design drawings is responsible for both the completeness of data acquired and the design of the compacted clay liner.

2.4. Other Acts and Regulations – The Engineer is responsible for complying with all of the relevant Acts and regulations in force in Manitoba.

2.5. Other Standards – Provincial, national and international standards and their respective abbreviations are listed in Section 10. In all cases, the most current edition of the referenced standard is implied. Additional relevant documents are also referenced in Section 10.

SECTION 3 - INFORMATION REQUIREMENTS

3.1. Submissions – The information required for the evaluation of an application for a new, expanded or modified earthen manure storage structure is outlined in the Technical Reference Document *Earthen Manure Storage Structures*. For the purpose of evaluating an application for an earthen storage structure that is comprised of a compacted clay liner, the Engineer shall submit to the regulatory agency additional information including, but not limited to the following details of the compacted clay liner design and site characteristics:

3.1.1. Site plan showing the location of the earthen manure storage structure, proposed clay borrow area, stockpile areas for waste material and distances to:

- bore holes for soil and site evaluation;
- access lanes; and,
- proposed system for detecting pollution or leaks.

3.1.2. A design summary including:

- compacted clay liner design section and method of construction as given in Section 7.1;
- erosion control provisions for the exposed surfaces of the liner;
- details of erosion control around pipe inlets, pumping or agitation pads and overflow or transfer devices;
- transportation patterns, vehicular loading and any limitations to vehicular traffic;
- requirements for installation;
- construction notes;
- details of monitoring well design; and,
- site specific operational notes (if the design is dependent on specific operation and management factors).

3.1.3. Geotechnical information including:

- bore hole logs for the clay borrow pit;
- material specifications;
- description of soil testing and analyses;
- all applicable soil testing results; and
- depth to seasonal high ground water.

3.1.4. Recommendations for regular inspection, maintenance and repair of the liner, including:

- the frequency of inspection, critical features to inspect and method of inspection (visual, monitoring data etc.);
- procedures for regular maintenance and preventative repairs; and

- contingency plans which include procedures for the repair of damaged features.

3.1.4.1. Annual Inspections – Annual inspections by a qualified professional are necessary to ensure the integrity of the compacted clay liner is maintained. The inspections should include:

- monitoring of stand pipes;
- walls for erosion or cracking;
- pipe inlets and outlets;
- subsurface drains or secondary containment systems for accumulation of leachate; and
- signage for adequacy and visibility.

SECTION 4 - DESIGN CRITERIA

4.1. General Design Criteria – Compacted clay liners shall be designed to have a saturated hydraulic conductivity of 1 x 10^{-9} metres/second or less.

4.1.1. The regulatory authority may require calculations of the specific discharge through the structure and liner system.

4.2. Thickness – The minimum acceptable thickness of a compacted clay liner shall be 1.0 metre as measured normal to the slope and floor of the storage structure.

4.3. Water Table – Compacted clay liner systems shall not be constructed below the seasonal high water table or saturated conditions unless the Engineer can show that the drainage system or the liner ballast will counteract any deterioration of the liner due to hydraulic pressure.

SECTION 5 - MATERIAL SUITABILITY

5.1. Specifications for Liner Material **-** The Engineer shall collect samples of the material to be used for the construction of the compacted clay liner to establish its suitability.

5.1.1. For any compacted clay liner, the borrow area shall be sampled for material suitability. The regulatory agency may require a specific number of samples depending on the variability of the soil and geologic conditions at the site.

5.1.2. The Engineer shall be responsible for ensuring that adequate testing is carried out to accurately characterize the material to be used to construct the compacted clay liner.

5.2. Laboratories – Only laboratories approved by the regulatory authority shall be utilized to analyze materials to be used in the construction of compacted clay liners for particle size distribution, Atterberg limits and hydraulic conductivity.

5.3. Testing Requirements for Material Characterization – In order for the material to be approved for use in the construction of a compacted clay liner without the need for additional testing as described in Section 5.5, it must meet the criteria described in Subsections 5.3.1 and 5.3.2. Materials that do not meet these requirements will require the additional testing as described in Section 5.5.

5.3.1. All materials to be used in the construction of a compacted clay liner shall be analyzed for particle size distribution following ASTM D2487 and ASTM 422-63, and Atterberg Limits following ASTM D4318, or any other method pre-approved by the regulatory agency.

5.3.2. If the distribution of the particle size classes and the Atterberg limits fall within the ranges given in Subsection 5.3.2.1 and 5.3.2.2, the material is considered acceptable for compacted clay liner construction without the need for additional laboratory testing, provided that it is installed using the recommended equipment as described in Section 6.1. The use of materials as defined above with the appropriate construction methodologies and equipment are expected to produce compacted clay liners with hydraulic conductivities of 1 x 10^{-9} metres/second or less.

5.3.2.1. Acceptable Particle Size Ranges (by weight):

- Percent Fines ≥ 50 %;
- Clay Content ≥ 20 %;
- Sand Content ≤ 45 %; and

where the fines are defined as the soil fraction which passes through a No. 200 (75-µm) US standard sieve, and clay and sand are defined in the ASTM D2487-00 standard.

5.3.2.2. Acceptable Atterberg Limits:

- Plasticity Index (PI): PI ≥ 20%
- Liquid Limit (LL): LL ≥ 30 %

5.3.2.3. Poorly graded materials with high silt content may not be considered acceptable. Such materials do not compact well and are highly erodible.

5.3.3. If the distribution of the particle size classes and the Atterberg limits **do not** fall within the acceptable ranges given in Subsection 5.3.2.1. and 5.3.2.2,

Tow behind Sheepsfoot Roller

additional testing (as described in Section 5.5) will be required.

5.4. Required Testing for All Materials – The Engineer must complete standard Proctor density tests following ASTM D698 to determine the maximum dry unit weight and optimum soil moisture content for each soil type used for construction of a compacted clay liner.

5.4.1. The Engineer shall specify the final maximum dry bulk density and the optimum soil moisture content for compacting the liner material.

5.5. Additional Testing – When the material to be used for the construction of a compacted clay liner does not meet all of the criteria in Subsections 5.3.2.1 and 5.3.2.2, additional testing is required to demonstrate that the "as-constructed" clay liner will have a field hydraulic conductivity of 1 x 10^{-9} metres/second or less as given in Section 8.3.

5.5.1. Laboratory hydraulic conductivity shall be determined following ASTM 5084 on no less than three samples after compaction to at least 95% standard Proctor maximum dry density following ASTM 698.

5.5.1.1. Hydraulic conductivities required in Section 5.5.1 shall be 5 x 10^{-10} metres/second or less for the material to be considered suitable for construction of the clay liner.

5.5.1.2. The Engineer shall specify the standard Proctor maximum dry density and the optimum soil moisture content for compacting the liner material.

5.5.2. Additional post-construction tests, as described under Section 8.3.1, may be required by the regulatory agency on all liners constructed of materials that did not meet the requirements of Subsections 5.3.2.1 and 5.3.2.2.

SECTION 6 - CONSTRUCTION EQUIPMENT

6.1. Recommended Equipment – The recommended compaction equipment for the construction of a compacted clay liner is the Sheepsfoot Roller Compactor. Many different models of Sheepsfoot Roller Compactors are available. Only those meeting the following criteria shall be considered acceptable:

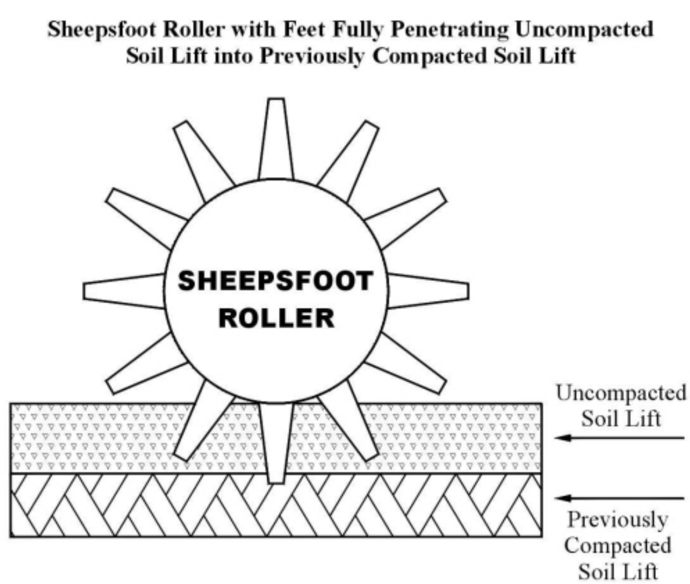
6.1.1. Soil Contact Pressures – The compaction equipment or rollers shall be ballasted to attain soil contact pressures of at least 2400 kPa.

6.1.2. Soil Contact Pressure Measurement – Contact pressures shall be measured by dividing the total mass of the roller by either the total area of the maximum number of tamping feet in one row parallel to the axis of the roller; or by calculating 5 % of the total foot area, whichever is the greater.

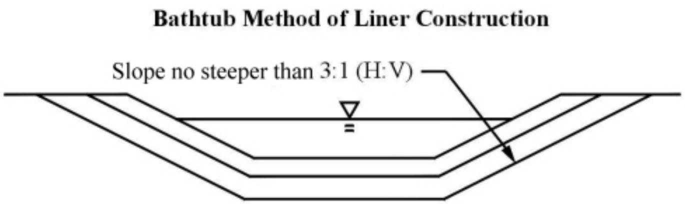
6.1.3. Tamping Feet Requirement – The tamping feet shall be 200 mm to 250 mm in length from the cylindrical surface of the roller. The tamping feet shall have a face area between 4500 and 6000 mm^2. The compactor feet shall be spaced to provide at least 4 tamping feet for each 0.25 m^2 of cylindrical surface.

6.1.4. Equipment Cleaning – The roller shall be equipped with cleaning fingers to prevent the accumulation of material between the tamping feet and to allow full penetration of the feet through the lift being compacted.

6.2. Other types of Compaction Equipment – Other



Contact pressure and sheepsfoot length are two key parameters for proper compaction with sheepsfoot rollers



“Bathtub” type compacted clay liner

compaction equipment can only be used after obtaining a written approval from the regulating authority. Smooth drum steel rollers are not acceptable as compaction equipment.

SECTION 7 - CONSTRUCTION

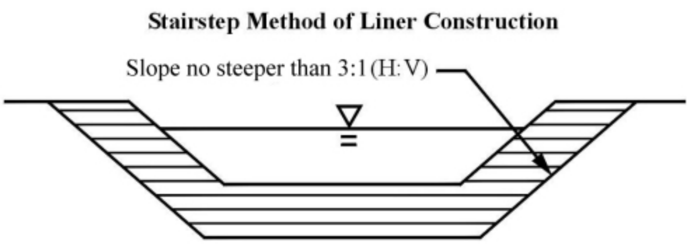
7.1. Methods of Construction – Compacted clay liners for earthen manure storage structures may be constructed by either the “Bathtub” or “Stairstep” method.

7.1.1. The Bathtub Liner Method – Using this method, the liner is constructed by placing a continuous layer of clay across an excavation to construct an impervious clay liner. When using this method the following criteria shall be met:

7.1.1.1. The inside side slopes of the earthen manure storage structure shall be no steeper than 3:1 (horizontal:vertical). Steeper side slopes could result in unacceptable liner quality due to the shearing action of heavy compaction equipment. The Engineer may recommend flatter slopes or specify the use of procedures or equipment to ensure proper compaction of the liner.

7.1.2. The Stairstep Method – These liners are constructed by continuously placing horizontal lifts of clay to construct an impervious clay liner. Liners are constructed by placing horizontal lifts of material upward along each of the side slopes. Using this method the following criteria must be met:

7.1.2.1. The side slopes of the earthen manure storage structure shall be no steeper than 3:1 (horizontal:vertical) when employing the stairstep method.



The “Stairstep” method for compacted clay liners

7.1.2.2. To avoid improper sealing between lifts the interface surface of lower lifts shall be properly disced or scarified, as described in Section 7.3.4, before placement of subsequent lifts of material.

7.2. Excavation and Materials Management

7.2.1. Plan Drawings – Excavation and placement of materials shall be made to the elevations and grades shown on the earthen manure storage structure plan drawings.

7.2.1.1. Amendments to the Plan – Any alterations made to the earthen manure storage plans must preserve the original intent of the project. The contractor shall obtain approval of the Engineer for any proposed or required changes to the plan. Where major alterations are made, the Engineer shall obtain approval from the appropriate regulatory agency.

7.2.2. Prior to excavating clay material from borrow pits, the existing subgrade shall be cleared of all stones, topsoil, silt, sand, gravel, organic deposits and other debris.

7.2.3. Material Stockpiles – All excavated materials whether from the manure storage area or borrow pits, shall be categorized by the Engineer as topsoil, waste material or liner material and stockpiled.

7.2.4. Clay Materials – Clay material deemed suitable for compacted clay liner construction (as described in this Technical Reference Document) may be placed in the designated stockpile area or transported immediately onto the subgrade for compaction.

7.2.5. Subgrade Inspection – Prior to placement of the material for liner construction within the excavation, the Engineer shall inspect the subgrade of the excavated area. The area requiring clay lining shall be proof rolled with one or two passes of the compaction equipment to detect any pockets of soft or overly wet materials. These materials shall be removed and replaced with compacted clay lining material. All rocks greater than 75 mm in diameter shall be removed.

7.2.5.1. Where the depth of cut exceeds 2 m in “cut & fill” earthen manure storage structures, dry density measurements of the undisturbed native material shall be measured.

7.2.5.2. Where the dry bulk density of the native material in the excavated portion of an earthen manure storage structure is found to be less than 95% of the maximum Proctor dry density, the soil in the entire cut surface shall be over-excavated to

0.3 m and replaced in 0.15 m lifts and compacted to 95% of its maximum Proctor dry density.

7.2.6. Ponded Water – Any ponded water in the area of liner construction shall be removed. No liner material shall be placed in freestanding water prior to compaction.

7.3. Liner Placement and Compaction – The clay material shall be installed in the earthen manure storage structure according to the following:

7.3.1. Compaction Specifications – The clay liner shall be compacted compacted to within 95 % of maximum proctor density (ASTM D698) at a moisture content between 0.9 and 1.2 optimum.

7.3.1.1. Moisture Management – If additional moisture is required for compaction, water shall be applied by sprinkling directly on the liner material or by irrigation of the burrow pit in a manner approved by the Engineer. The quality of the water shall be subject to the approval of the Engineer and shall be free from undesirable quantities of organic matter and mineral salts. Water application pressures shall be controlled to prevent erosion of the liner and to prevent freestanding water on the surface.

7.3.2. Liner Lift Placement – Liner material shall be deposited in the areas requiring a compacted clay liner as shown on the design drawings or in areas specified by the Engineer. Liner materials shall be spread by a motor grader or other means approved by the Engineer to obtain a uniform lift thickness prior to compaction. In the bottom of the excavation, the liner material shall be first placed in the lowest elevations.

7.3.3. Lift Thickness – The foot length of the compaction equipment will govern the thickness of the loose lift that can be compacted. The thickness of each uncompacted lift shall be at least 25 mm less than the foot length of the compaction equipment. This is to ensure full penetration through the uncompacted lift and into the previous compacted liner layer or subgrade on the first pass of the compaction roller feet.

7.3.4. Bonding Between Lifts – If the surface prior to placing the next lift is too hard for the feet on the sheepsfoot roller, or that of other compaction equipment, to penetrate, the surface shall be disced or scarified.

7.3.4.1. If the lift surface is deemed too wet or eroded from runoff, the affected material shall be removed and replaced with new material and recompacted.

Heavy duty offset disc harrows may be used to scarify soil between lifts placement.

7.3.5. Foreign Materials – All rocks greater than 75 mm in diameter, roots and other organic debris shall be removed from the liner material prior to compaction.

7.3.6. Construction Below Freezing – Excavation and compaction shall be completed only when soil temperatures are above freezing.

7.3.7. Liner Desiccation – Each compacted lift shall be protected from drying out to prevent cracking due to shrinkage.

7.3.8. Material Preparation – Compacted clay liner materials shall be adequately mixed and manipulated to break up and blend the materials in order to produce the required homogeneity for soil texture and moisture content, as approved by the Engineer.

7.3.9. Overlap of Equipment Passes – The overlap between equipment passes shall not be less than 10 % of the width of the equipment being used to ensure lateral bonding between placed materials.

7.3.10. Areas with Limited Access – Portions of the fill not accessible for compaction by the compaction equipment, such as around pipes and manholes, shall be placed in 100 mm layers and compacted with manually guided mechanical compactors. All materials shall be at the desired moisture content range and homogeneity prior to compaction.

7.4. Compaction Monitoring - Compaction should be monitored at frequent intervals during construction of the liner to ensure that target material dry bulk density values are achieved. Frequency of monitoring shall be greater where fill material properties change as excavation proceeds.

7.4.1. Dry bulk density measurements shall be collected a minimum of two (2) times during the construction of a clay liner.

7.4.2. Where soil properties are variable, representative soil samples shall be collected at the location where dry bulk density measurements are made, and analyzed for soil particle size distribution.

7.5. Post-Construction Management – If a newly constructed earthen manure storage structure is left empty for extended periods of time, the engineer shall inspect the liner to ensure that its integrity is maintained.

7.5.1. Damaged Liners – If cracks due to shrinkage or any other damage to the liner or any of its component lifts are observed, the damage shall be repaired prior to commencement of service. Repairs shall be determined by the Engineer in a manner that is acceptable to the regulatory agency. All repairs shall be made such that replacement material can be recompacted to the above standards.

7.5.2. Soil Covers – At the Engineer's discretion, a temporary soil cover may be used to prevent desiccation cracking of the clay liner.

SECTION 8 - QUALITY ASSURANCE

8.1. Inspection – During construction, the compacted clay liner shall be inspected by the Engineer to ensure that it was built as designed and is in compliance with all applicable technical reference document, standards, codes and regulations.

8.2. Quality Control - During construction of the liner, the Engineer shall measure the soil moisture content and dry density at sufficient representative locations in the floor and sides of the liner.

8.2.1. Nuclear methods for soil dry density and soil moisture content can be used provided the procedures and equipment used are in accordance with ASTM D2922 for soil dry density measurements and D3017 for soil moisture measurements.

8.2.2. Dry density and soil moisture content can be determined from laboratory analyses of undisturbed soil cores taken following either ASTM D1587 or ASTM D2937. Other ASTM soil sampling procedures can be used subject to pre-approval by the regulatory authority.

8.2.3. All core and probe entry holes shall be sealed by backfilling with bentonite.

8.3. Regulatory Discretion – Although this technical reference document recommends a testing protocol based on the acceptability of the materials and construction equipment to be used, the regulatory agency has the authority to require additional testing including the post construction tests, compaction tests and permeability tests irrespective of material and equipment suitability (as described in Section 5.3.2).

8.3.1. When the material to be used for the construction of a compacted clay liner does not meet the criteria in Section 5.3.2, or when compaction equipment other than that recommended in Section 6.1 is used, additional post-construction tests may be required by the regulatory agency. Quality control tests including, but not limited to the those under this section, may be requested after the compacted clay liner has been installed:

8.3.1.1. A minimum of two undisturbed soil cores per cell of storage structures or as required by the regulatory agency shall be submitted to an approved laboratory for hydraulic conductivity measurements following ASTM 5084. These soil cores shall be collected to the full thickness of the liner and taken in representative locations of the floor and sides of the earthen manure storage structure.

8.3.1.1.1. The laboratory hydraulic conductivity of the undisturbed soil cores shall be 1×10^{-9} metres/second or less.

8.3.1.2. All soil core holes shall be sealed by backfilling with bentonite.

8.4. Liner Thickness – The Engineer shall measure the thickness of the compacted clay liner after construction.

8.5. Final Inspection – The Engineer shall make arrangements with the regulatory agency for a joint final inspection after completion of the construction and before commissioning of the manure storage structure.

SECTION 9 - ISSUANCE OF CERTIFICATES

9.1. Certificate – The Engineer shall provide the appropriate regulatory agency with a final letter of certification indicating that the manure storage structure has been completed in conformance with submitted **engineering plans** and **meets required codes, regulations and Technical Reference Document mentioned herein.**

9.1.1. The letter of certification shall be affixed with the Engineer's seal in a manner acceptable to the guidelines of the Association of Professional Engineers and Geoscientists of the Province of Manitoba.

9.2. Construction Report - The letter of certification must be accompanied with a prepared construction report.

9.2.1. In the case of compacted clay liner, the construction report must provide accurate information on the following aspects of the construction work:

- all laboratory reports on soil sample testing;
- "As Built" drawings;
- nuclear densometer results;
- complete hydraulic conductivity report;
- soil core sample locations; and,
- physical verification of liner depth.
- monitoring well construction logs
- top of dike and storage bottom elevations
- monitoring well water elevations
- background water quality results

9.2.2. Certification can be provided if construction details do not conform to engineering plans submitted provided these details were approved by the regulatory agency and referenced in a construction report.

SECTION 10 - RESOURCE INFORMATION

Reference	Abbreviation
Tri-Provincial Standard *Earthen Manure Storage Structures*	
Tri-Provincial Standard *Role and Responsibilities of the Engineer*	RRoE
National Building Code of Canada (Parts 3 & 4)	NBC
National Farm Building Code of Canada	NFBC
ASAE EP470 *Manure Storage Safety*	ASAE 470
ASAE S441.2 *Safety Signs*	ASAE 441.2
ASCE 7-95 *Minimum Design Loads for Buildings and Other Structures*	ASCE 7-95
ASAE EP393.2 *Manure Storages*	ASAE 393.2
ASTM D422-63 Standard Test Method for Particle-Size Analysis of Soils	ASTM D422-63
ASTM D698-00a *Standard Test Method for Laboratory Compaction Characteristics of Soil using Standard Effort*	ASTM 698
ASTM D1587-94 *Standard Practice for Thin-Walled Tube Geotechnical Sampling of Soils*	ASTM D1587
ASTM D2487-00 *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)*	ASTM 2487
ASTM D2922-96e1 *Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)*	ASTM D2922
ASTM D2937-94 *Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method*	ASTM D2937
ASTM D3017-96 *Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)*	ASTM D4318
ASTM D4318-00 *Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils*	ASTM 4318
ASTM 5084-90 (1997) *Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Material using a Flexible Wall Permeameter*	ASTM 5084