U.S. Environmental Protection Agency

National Environmental Publications Information System

Serving Environmental Scientists, Students, Citizens, and the World

Print Version

Document Image

Simple Search

Enhanced Search

Publication Number/Title Search

User's Guide

1. 540R92073 Technical Guidance Document: Const Management for Remedial Action and Remedial Des Containment Systems

Next Page | Enlarge Image | Shrink Image

United States
Environmental Protection
Agency

Office of Solid Waste and
Emergency Response
Washington, DC 20460

Superfund

EPA/540/R-92/073

EPA

Technical Guidance Document

Construction Quality Management for Reme Action and Remedial D Waste Containment Sy

This is page 1 of 108.

Choose a command for displaying the current document: (*Help for Commands*)

Next Page | Go to Page | Specify page: 108 | Enlarge Image | Shr

Prepare Document for Printing

New search of publications for

NEPIS Home || EPA Site Search || Order Hardcopy Documents || NEPIS Feedback

CLARITweb: done processing form on Mon Nov 1 18:40:47 2004

United States Environmental Protection Agency
Office of Solid Waste and Emergency Response Washington, DC 20460
Office of Research and Development Washington, DC 20460
Superfund
EPA/540/R-92/073
October 1992

EPA

Technical Guidance Document

Construction Quality Management for Remedial Action and Remedial Design Waste Containment Systems

EPA/540/R-92/073
October 1992

Technical Guidance Document

CONSTRUCTION QUALITY MANAGEMENT FOR REMEDIAL ACTION AND REMEDIAL DESIGN WASTE CONTAINMENT SYSTEMS

by

Gregory N. Richardson

Hazen and Sawyer, P.C.
Raleigh, North Carolina 27607

Contract No. 68-C0-0068

Project Officer

Robert Landreth

Waste Minimization, Destruction & Disposal Research Division
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Superfund Technical Support Center for Engineering and Treatment
Technology Innovation Office
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington, D.C. 20460

In Cooperation With

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

DISCLAIMER

The preparation of this document has been funded wholly by the United States Environmental Protection Agency. It has been subjected to the Agency's peer and administrative review, and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Risk Reduction Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the U.S. Environmental Protection Agency; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibility and economically.

This document provides design guidance on final cover systems for hazardous waste landfills and surface impoundments. We believe that the final cover, if properly designed and constructed, can provide long-term protection of the unit from moisture infiltration due to precipitation. The cover system presented herein is a multilayer design consisting of a vegetated top layer, drainage layer, and low-permeability layer. Optional layers which may be required for site-specific conditions are also discussed. Rationale is provided for the design parameters to give designers and permit writers background information and an understanding of cover systems.

This document is intended for use by organizations involved in permitting, designing and constructing hazardous and non-hazardous waste land disposal facilities and in remediating uncontrolled hazardous waste sites.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

This Technical Guidance Document is intended to augment the numerous construction quality control and construction quality assurance (CQC and CQA) documents that are available for materials associated with waste containment systems developed for Superfund site remediation. In general, the manual is oriented to the remediation project manager (RPM) who must administer these projects.

This document reviews the significant physical properties associated with the construction materials used in waste containment designs and reviews the sampling and acceptance strategies required for Construction Quality Management. The first chapter reviews the minimum Federal regulatory requirements for waste containment systems. Key elements of these systems are identified. The second chapter reviews the key physical properties and conformance tests required to verify these properties. The third chapter reviews sampling methods and acceptance criteria that are used to verify key physical properties during construction.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS

List of Figures

List of Tables

SECTION 1.0

Construction Quality Management

The purpose of this document is to define procedures that ensure construction materials and practices used in waste containment installations meet the project specifications and the requirements of related remedial settlement orders. The specific objectives are:

- Define Construction Quality Management (CQM) and the responsibility of the parties involved in the project
- Define and list the waste containment systems described in 40 CFR 240 and 300
- Identify components used to construct the waste containment systems
- Identify the elements that are used to assemble these components and the key properties of these elements that require testing in the field to measure the quality of the construction
- Present sampling methods to obtain unbiased representative samples from these key elements
- Present examples of how to implement these sampling methods on selected elements.

This document is written for the design engineer responsible for preparation of project plans, specifications, and the CQM program, and the EPA remedial project manager (RPM) charged with implementing the CQM program. The document focuses on those factors most susceptible to field construction problems. It is assumed that the materials to be used at each site have been designed (thickness, type, etc.) and evaluated (EPA Method 9090, etc.) by others. These elements are assumed to meet the applicable or relevant and appropriate requirements (ARAR) for the site as determined in the remedial investigation and feasibility studies (RI/FS) process under CERCLA (1).

CQM is defined as the pro-active planning, development and implementation of both Construction Quality Assurance (CQA) and Construction Quality Control (CQC) throughout the project. In order to ensure a functional and safe waste containment system, quality must be present in all phases of the project, including:

- *Pre-construction phase*
  - conceptual design
  - design
  - preparation of project specifications
  - preparation of CQA/CQC documents

- Construction phase
  - material property testing
  - installation testing

- Post-Construction phase
  - care of installation until it goes into service
  - inspection and maintenance of the facility
  - *operations*

While CQM must be included in every phase of the project and a system of testing and oversight must be used throughout the project, the focus of this document is CQM during the construction phase of the development of a waste containment system.

1.1 CQA/CQC Objectives

Construction Quality Assurance (CQA) consists of a planned series of observations and tests to ensure that the final product meets project specifications. CQA plans, specifications, observations, and tests are used to provide quantitative criteria with which to accept the final product.

On routine construction projects, CQA is normally the concern of the owner and is obtained using an independent third party testing firm. For the waste containment applications covered by this guide, the CQA program is also commonly a certification tool used by EPA to ensure that the project is properly implemented. The independence of the third party inspection firm is therefore of great importance. This is particularly true when the owner is a corporation or other legal entity that has under its corporate 'umbrella' the capacity to perform the CQA activities. Although these CQA personnel may be registered professional engineers, there may exist a perception of misrepresentation if the activity is not performed by an independent third party.

The CQA officer should fully disclose any activities or relationships with the owner which may impact his impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA officer's objectivity. Regulatory representatives can then evaluate whether these mechanisms are sufficient to ensure an acceptable CQA product.

Construction Quality Control (CQC) is an ongoing process of measuring and controlling the characteristics of the product in order to meet manufacturer's or project specifications. CQC is a production tool that is employed by the manufacturer of materials and contractor installing the materials at the site. CQA, by contrast, is a verification tool employed by the facility owner or regulatory agency to ensure that the materials and installations meet project specifications. CQC is performed independently of the CQA Plan. For example, while a geomembrane liner installer will perform CQC testing of field seams, the CQA program will require independent CQA testing of those same seams by a third party inspector.

The CQA/CQC plans are implemented through inspection activities which include visual observations, field testing and measurements, laboratory testing and the evaluation of the test data. Inspection activities are typically concerned with four separate functions:

> Quality Control (QC) Inspection by the Manufacturer provides an in-process measure of the product quality and its conformance with the project plans and specifications. Typically, the manufacturer will provide CQC test results to certify that the product conforms to project plans and specifications.
>
> Construction Quality Control (CQC) Inspection by the Contractor provides an in-process measure of construction quality and conformance with the project plans and specifications. This allows the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans.
>
> Construction Quality Assurance (CQA) Testing by the Owner (Acceptance Inspection) performed by the owner usually through the third party testing firm, provides a measure of the final product quality and its conformance with project plans and specifications. Due to the size and costs of a typical remedial action/remedial design (RA/RD) project, rejection of the project at completion would be costly to all parties. Consequently, CQA testing takes place throughout the construction process. This allows deficiencies to be found and corrected before they become too large and costly. CQA represents an important tool to EPA to ensure that the remediation is properly implemented.
>
> Regulatory Inspection is often performed by a regulatory agency to ensure that the final product conforms with all applicable codes and regulations. In some cases the regulatory agency will use the CQA documentation and the as-built plans or 'record drawings' to confirm compliance with the regulations.

EPA Report 530-SW-86-031 (NTIS PB87-132825) entitled "Construction Quality Assurance for Hazardous Waste and Land Disposal Facilities" sets forth key items that should be included in the CQA/CQC Plan:

1) **Responsibility and Authority** - The responsibility and authority of the various organizations and personnel involved in permitting, designing, and building the facility should be described.

2) **Personnel Qualifications** - The qualifications of the CQA officers and supporting CQA inspection personnel should be presented.

3) **Inspection Activities** - The observations and tests that will be used to ensure that the construction or installation meets or exceeds all design criteria, plans, and specifications for each component should be described.

4) **Sampling strategies** - The sampling activities, sample size, methods for determining sample locations, frequency of sampling, acceptance and rejection criteria, and methods for ensuring that corrective measures are implemented should be presented.

5) **Documentation** - Reporting procedures for CQA activities should be described in detail in the CQC/CQA plans.

The responsibility and authority of project organizations and personnel (item 1 above) are included in the above EPA Report and will not be discussed here. Guidelines for the qualification of personnel (item 2) are also included in the EPA report, but are being revised and will be presented in an upcoming document. Currently, a program to certify CQA inspectors is administered by the National Institute for Certification of Engineering Technicians (NICET). Inspection activities for specific components of a waste containment system have been presented in a variety of EPA papers and Technical Guidance Documents (TGDs) (2, 3, 4, 5, 6, 7) and will only be summarized in this report.

This guidance document begins with a brief overview of waste containment systems and components along with the key physical properties that require monitoring during construction and installation. A major focus of this document is the sampling strategies and acceptance criteria which are used in the CQA plan (item 4). Suggested CQA documentation requirements are provided in several EPA TGDs detailing waste containment components (8, 9, 10).

1.2 Regulatory Waste Containment Systems and Objectives

Under current RCRA and CERCLA regulations, there are four distinct waste containment systems: surface impoundments, waste piles, landfills, and on-site isolation. Each containment system is built of components with distinct engineering functions, (e.g. moisture barrier, reinforcement, drainage, etc). In turn, each component is composed of elements , i.e., individual materials or products, that have particular field inspection requirements. This chapter provides a brief overview of the four waste containment systems and their major components. Chapter 2 describes the elements and their respective CQA field testing requirements. Chapter 3 reviews common field sampling strategies and acceptance criteria and provide examples of their application.

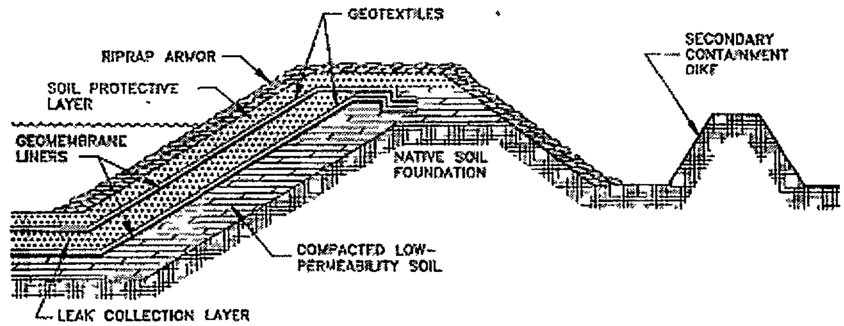
Surface Impoundments

These are basins used to store or dispose of primarily liquid wastes. If the system is planned to be removed after the operating life and the site cleaned of all contamination, then it is considered a storage unit. If the waste is stabilized, the free liquid is removed, and the system is closed and monitored, then it is a disposal unit. Surface impoundments can include liners, leachate collection systems, leachate detection systems, and gas collection systems. If the facility is designed as a disposal unit, then a closure system is necessary.

Under the Federal requirements for the design and operations for surface impoundments (40 CFR 264 subpart K, 264.220 to 264.231) and EPA's design, construction and operation guidelines (Technical Resource Document 530-SW-91-054) (10), a surface impoundment must include the components and elements shown on Figure 1-1. A typical cover profile used when a surface impoundment is closed without waste removal is also shown on Figure 1 2.

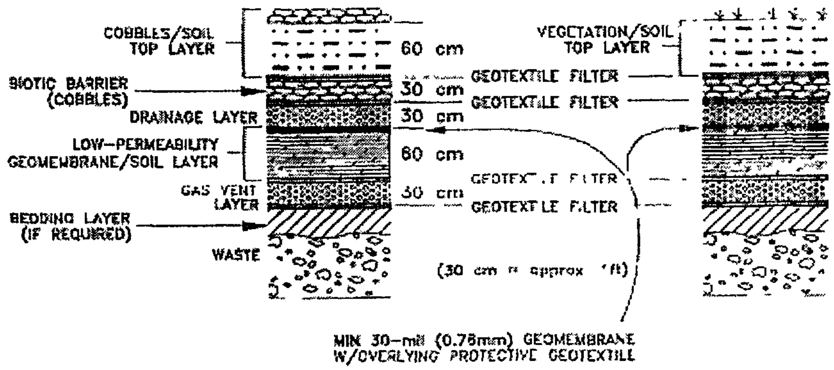
Waste Piles

These are structures in which waste can be treated and/or stored temporarily. A waste pile system must have a similar bottom liner system as the surface impoundment but will not have a final cover since it is only a temporary structure. However, waste piles must be covered by a structure which keeps precipitation, wind and surface water run-on away from the waste. Typically, these protective structures are simple metal buildings, although other protective cover may be used. For example, a geomembrane can be used to cover the waste. The various components and elements of waste piles as required by Federal regulations (40 CFR 264 subpart L, 264.250 to 264.259) are shown on Figure 1-3.



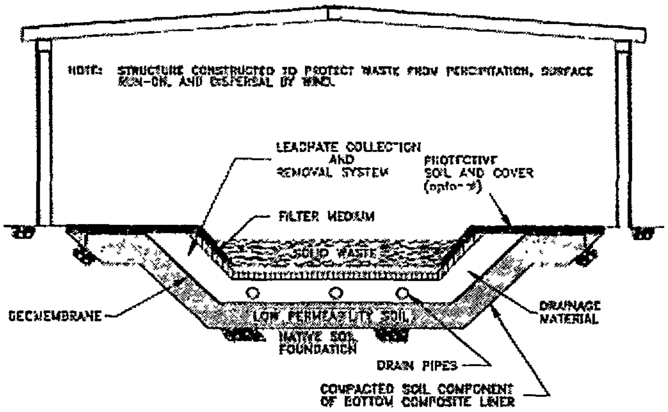
SURFACE IMPOUNDMENT COMPONENTS AND ELEMENTS REFERENCES: 40 CFR 264, SUBPART K TRD/EPA 530-SW-91-054	COMPONENT	ELEMENT
LINER SYSTEM CONSISTING OF ONE OR MORE OF THE FOLLOWING:	•	
• COMPACTED SOIL LINER		•
• BENTONITE MODIFIED ON-SITE SOILS		•
• GEOSYNTHETIC CLAY LINER (GLC)		•
• GEOMEMBRANE		•
LEACHATE COLLECTION SYSTEM or LEAK DETECTION SYSTEM	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• PIPES,		•
• SUMPS, AND		•
• PUMPS		•
GAS VENTING SYSTEM IF ORGANIC SOILS ARE PRESENT BENEATH THE LINER	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• VENT PIPES OR FLAPS		•
• GEOTEXTILE FILTER TO PROTECT DRAINAGE LAYER		•
LINER PROTECTION COVER TO PROTECT IT FROM CONSTRUCTION, WEATHER, AND OPERATIONAL DAMAGE	•	
• SOIL OR GEOTEXTILE PROTECTIVE LAYER OVER LINER		•
• STONE OR RIP-RAP ABOVE LIQUID LEVEL TO PREVENT EROSION AND DAMPEN WAVE ACTION		•
SURFACE WATER MANAGEMENT SYSTEM	•	
• DIVERSION DITCHES AND BERMS,		•
• INLETS, PIPES, MANHOLES		•
• AND RETENTION/DETENTION BASINS		•
VOLATILE ORGANIC COUMPOUND EMISSION CONTROL SYSTEM	•	
• COMPLETE ENCLOSURE, E.G AIR BUBBLE	•	
• SURFACE BARRIER OR FLOATING COVER OF FOAM, OIL, OR GEOMEMBRANE	•	•
• WIND DIVERSION FENCE	•	•
STABLE FOUNDATION	•	•
GROUND-WATER MONITORING WELLS	•	
LIQUID LEVEL CONTROL SYSTEM CONSISTING OF EITHER AN <u>ACTIVE SYSTEM</u> USING PUMPS OR A <u>PASSIVE SYSTEM</u> USING A SPILLWAY	•	
SECONDARY CONTAINMENT SYSTEM SURROUNDING ENTIRE SURFACE IMPOUNDMENT	•	

FIGURE 1-1 SURFACE IMPOUNDMENT USED FOR STORAGE



SURFACE IMPOUNDMENT AND LANDFILL COVER SYSTEM REFERENCES: 40 CFR, SUBPART K TRD/EPA 530-SW-91-054	COMPONENT	ELEMENT
PROTECTIVE COVER WITH VEGETATIVE OR HARDENED EROSION CONTROL SURFACE	•	
• VEGETATIVE LAYER OF TOPSOIL VEGETATION OR		•
• HARDENED LAYER OF RIP-RAP, ASPHALT, OR CONCRETE		•
• PROTECTIVE SOIL LAYER		•
BIOTIC BARRIER TO LIMIT PENETRATION OF BURROWING ANIMALS AND TAP ROOTS	•	
• COBBLES, STONES OR HARDENED BARRIER SYSTEM		•
• GEOTEXTILE FILTER TO CONTAIN ADJACENT SOILS		•
SURFACE WATER DRAINAGE LAYER	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• GEOTEXTILE FILTER		•
LOW PERMEABILITY BARRIER CONSISTING OF ONE OR MORE OF THE FOLLOWING	•	
• COMPACTED SOIL LINER		•
• BENTONITE AMENDED ON-SITE SOILS		•
• GEOSYNTHETIC CLAY LINER (GCL)		•
• GEOMEMBRANE		•
GAS COLLECTION SYSTEM IF WASTE WILL GENERATE GAS	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• VENT PIPES		•
• GEOTEXTILE FILTER TO PROTECT DRAINAGE LAYER		•
BEDDING LAYER OVER WASTE TO PROVIDE STABLE WORKING PLATFORM	•	
• ON SITE SOIL		•
• GEOTEXTILE FILTER TO PROTECT BEDDING LAYER		•

FIGURE 1-2 COVER SYSTEM FOR SURFACE IMPOUNDMENT/LANDFILL CLOSURE



WASTE PILES FOR INTERIM HAZARDOUS WASTE STORAGE REFERENCES: 40 CFR 264, SUBPART L, 264.250 TO 264.259	COMPONENT	ELEMENT
LINER SYSTEM CONSISTING OF ONE OR MORE OF THE FOLLOWING:	•	
• COMPACTED SOIL LINER		•
• BENTONITE MODIFIED ON-SITE SOILS		•
• GEOSYNTHETIC CLAY LINER (GLC)		•
• GEOMEMBRANE		•
LEACHATE COLLECTION SYSTEM or LEAK DETECTION SYSTEM	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• PIPES,		•
• SUMPS, AND		•
• PUMPS		•
GAS VENTING SYSTEM IF ORGANIC SOILS ARE PRESENT BENEATH THE LINER	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• VENT PIPES OR FLAPS		•
• GEOTEXTILE FILTER TO PROTECT DRAINAGE LAYER		•
LINER PROTECTION COVER TO PROTECT IT FROM CONSTRUCTION, WEATHER, AND OPERATIONAL DAMAGE	•	
• SOIL OR GEOTEXTILE PROTECTIVE LAYER OVER LINER		•
• STONE OR RIP-RAP ABOVE LIQUID LEVEL TO PREVENT EROSION AND DAMPEN WAVE ACTION		•
SURFACE WATER MANAGEMENT SYSTEM	•	
• DIVERSION DITCHES AND BERMS,		•
• INLETS, PIPES, MANHOLES		•
• AND RETENTION/DETENTION BASINS		•
VOLATILE ORGANIC COUMPOUND EMISSION CONTROL SYSTEM	•	
• COMPLETE ENCLOSURE, E.G. AIR BUBBLE	•	
• SURFACE BARRIER OR FLOATING COVER OF FOAM, OIL, OR GEOMEMBRANE	•	•
• WIND DIVERSION FENCE	•	•
STABLE FOUNDATION	•	•
GROUND-WATER MONITORING WELLS	•	
LIQUID LEVEL CONTROL SYSTEM CONSISTING OF EITHER AN ACTIVE SYSTEM USING PUMPS OR A PASSIVE SYSTEM USING A SPILLWAY	•	
SECONDARY CONTAINMENT SYSTEM SURROUNDING ENTIRE SURFACE IMPOUNDMENT	•	

FIGURE 1-3 WASTE PILE USED FOR INTERIM WASTE STORAGE

Landfills

These are final disposal units for solid and hazardous wastes. Landfills have the same components and elements as the surface impoundment disposal units. Under the requirements for the design and operation of landfills (40 CFR 264 subpart N, 264.300 to 264.317) and the design, construction and operations guidelines presented in EPA seminar publications (11, 12), a landfill should include the components and elements shown on Figure 1-4.

On-Site Waste Isolation

Remedial actions to isolate uncontrolled releases of contaminates are described in 40 CFR 300 "Appendix D - Appropriate Actions and Methods of Remediating Releases." Waste isolation systems include caps built over waste to minimize infiltration of rainwater, and both horizontal barriers under the waste and vertical barriers at the lateral extent of the waste to prevent uncontrolled release of leachate (12, 13, 14). These are systems which are constructed on remediation sites to isolate and allow for the treatment of an uncontained waste.

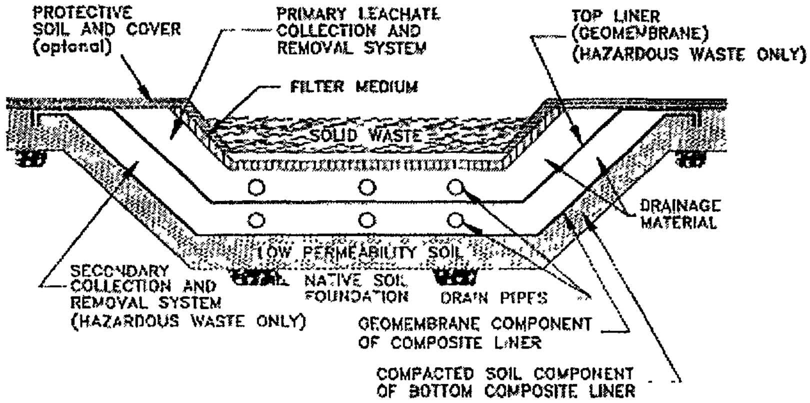
Caps --

Waste facility caps reduce water infiltration, control gas and odor emissions, improve the aesthetics, and provide a stable surface over the waste. A composite barrier capping system (Figure 1-2), is required for the closure of hazardous waste storage facilities (12, 13). A hardened cap is typically required in an arid climates where a vegetative cover will not survive, in urban areas where vegetation may be undesirable, or at industrial facilities where it would be advantageous to continue using the site. The hardened cap integrates the vegetative layer, protective layer (biotic) and drainage layer into one layer as shown in Figure 1-5. The hardened cap can be constructed using "hard" elements, such as graded stone, asphalt, or concrete. *Note that the use of a hardened surface layer does not eliminate the need for the geomembrane/clay moisture barrier components in the cap.*

Horizontal Barriers --

Horizontal barriers are installed below an existing waste mass to contain the waste and prevent the movement of contaminate into the surrounding soil and water. Horizontal barriers are very difficult to inspect due to the overlying waste.

Horizontal barrier techniques involve the injection of grout under the waste using one of the following methods:



LANDFILLS – LONG-TERM HAZARDOUS WASTE DISPOSAL REFERENCES: 40 CFR 264, SUBPART N EPA 625/4-91-025, EPA 625/4-89-022	COMPONENT	ELEMENT
LINER SYSTEM CONSISTING OF ONE OR MORE OF THE FOLLOWING:	•	
• COMPACTED SOIL LINER		•
• BENTONITE MODIFIED ON SITE SOILS		•
• GEOSYNTHETIC CLAY LINER (GLC)		•
• GEOMEMBRANE		•
LEACHATE COLLECTION SYSTEM or LEAK DETECTION SYSTEM	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• PIPES,		•
• SUMPS, AND		•
• PUMPS		•
GAS VENTING SYSTEM IF ORGANIC SOILS ARE PRESENT BENEATH THE LINER	•	
• GRANULAR SOIL OR GEOSYNTHETIC DRAINAGE LAYER		•
• VENT PIPES OR FLAPS		•
• GEOTEXTILE FILTER TO PROTECT DRAINAGE LAYER		•
LINER PROTECTION COVER TO PROTECT IT FROM CONSTRUCTION, WEATHER, AND OPERATIONAL DAMAGE	•	
• SOIL OR GEOTEXTILE PROTECTIVE LAYER OVER LINER		•
• STONE OR RIP-RAP ABOVE LIQUID LEVEL TO PREVENT EROSION AND DAMPEN WAVE ACTION		•
SURFACE WATER MANAGEMENT SYSTEM	•	
• DIVERSION DITCHES AND BERMS,		•
• INLETS, PIPES, MANHOLES		•
• AND RETENTION/DETENTION BASINS		•
WIND DISPERSAL CONTROL SYSTEM	•	
• COMPLETE ENCLOSURE, E.G. AIR BUBBLE	•	
• SURFACE BARRIER OF FOAM OR GEOMEMBRANE		•
• WIND DISPERSION FENCES		•
STABLE FOUNDATION	•	•
GROUND-WATER MONITORING WELLS	•	
LIQUID LEVEL CONTROL SYSTEM CONSISTING OF EITHER AN ACTIVE SYSTEM USING PUMPS OR A PASSIVE SYSTEM USING A SPILLWAY	•	
SECONDARY CONTAINMENT SYSTEM SURROUNDING ENTIRE SURFACE IMPOUNDMENT	•	

FIGURE 1-4 LANDFILL USED FOR HAZARDOUS WASTE STORAGE

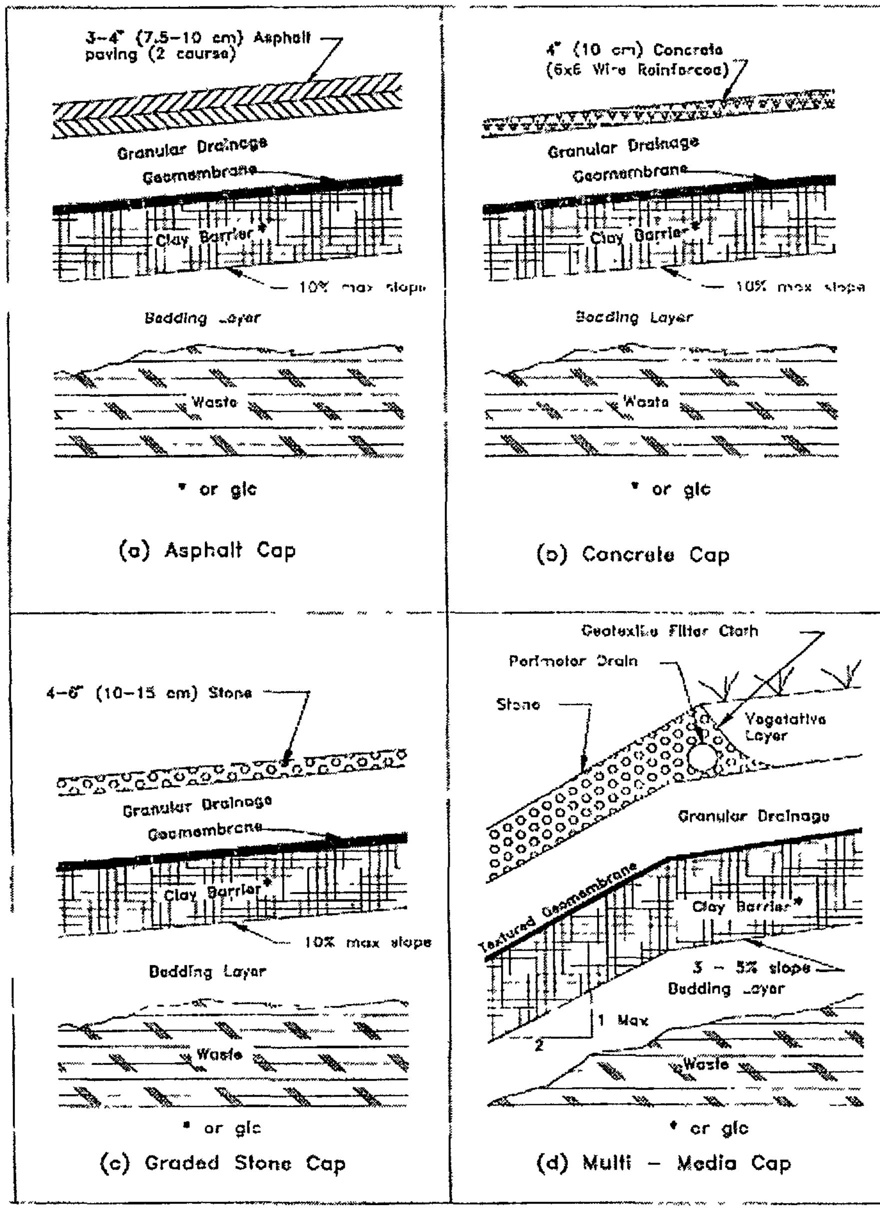


FIGURE 1-5 HARDENED CLOSURE SYSTEM

- vertical borings drilled through the waste and pressure injection or rotary jetting of the grout beneath the waste,

- horizontal borings drilled below the waste from trenches and pressure injection of the grout beneath the waste,

- block displacement method which surrounds the waste with a vertical grout wall and then injects low pressure grout beneath the waste. The entire waste block is raised in this process (15).

All of these methods require that the borings be spaced close enough together that the grout bulbs or lenses overlap and form a continuous barrier. Verification of the overlap is critical but very difficult. Potential inspection methods are limited to test excavations, exploratory borings, and observed impact on ground water if the barrier is placed beneath the ground water table.

Vertical Barriers --

Vertical barriers are wall-like systems used to isolate any contaminates that have leached from the waste and that are moving laterally. To be effective, these barriers should intercept a continuous impervious horizontal layer below the waste. This bottom layer can be a naturally occurring layer such as an aquiclude, or a horizontal barrier. Several types of vertical barriers are commonly used, including:

- Slurry wall. A trench surrounding the waste, filled with a soil bentonite and/or concrete-bentonite slurry.

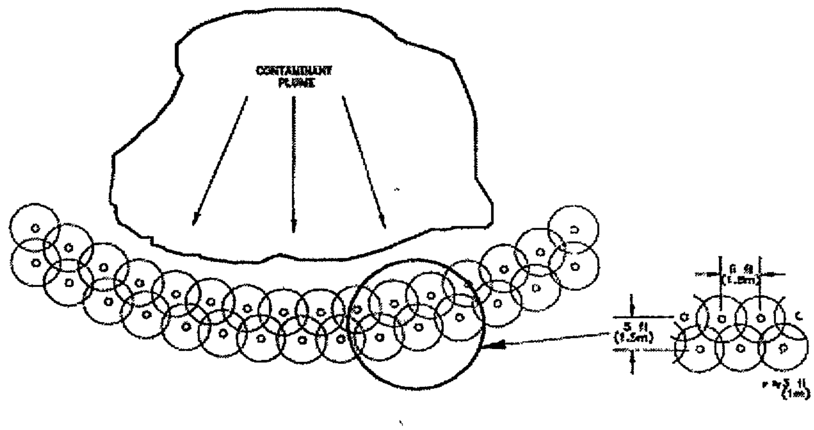
- Grout curtain. Grout is injected in a series of vertical columns that surround the waste, creating a continuous curtain.

- Geomembrane curtain. Interlocking geomembrane panels are placed in a vertical trench surrounding the waste. In some cases the geomembrane is used in conjunction with the slurry wall to form a composite liner system.

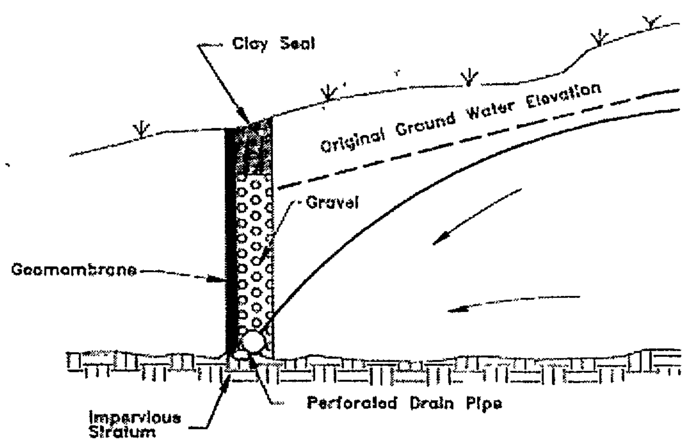
Schematics of grout curtains and geomembrane curtains are shown in Figure 1-6.

1.3 Components and Elements in Waste Containment Systems

The regulatory waste containment systems reviewed in Section 1.2 are constructed using a small family of functional components. These functional components include:



a. GROUT CURTAIN VERTICAL BARRIER



b. GEOMEMBRANE VERTICAL BARRIER

FIGURE 1-6 VERTICAL BARRIER SYSTEMS

- Hydraulic Barriers
- Hydraulic Conveyances
- Filter Layers
- Erosion Control Layers
- Protective Layers
- Earthwork

Each of these basic building blocks is in turn composed of distinct physical elements as listed on Table 1-1. It is important to understand that project specifications and the construction quality management program will focus on elements and not components. Thus project specifications for a hydraulic barrier will provide guidance for clay or geomembrane properties but will not identify functional properties of the overall hydraulic barrier. This document therefore examines construction quality management at an elemental level.

TABLE 1-1 WASTE CONTAINMENT COMPONENTS AND ELEMENTS

COMPONENT	ELEMENTS

Hydraulic Barriers	Geomembranes
	Geomembrane Interlocking Panels
	Grouts
	Compacted Soil
	Bentonite Products
	    Soil-Bentonite Blends
	    Geosynthetic Clay Liner
	    Bentonite Slurries
	    Concrete/Bentonite Slurry

Hydraulic Conveyances (Both Liquid and Gas Conveyance)	Natural Sand/Gravel Drain/Collector Geosynthetic Drain/Collector Pipe Sumps Pumps
Filter Layers	Sand/Gravel Filter Geotextile
Erosion Control Layers	Stone and Rip-Rap Vegetation and Topsoil Geosynthetic Erosion Control Products
Protective Layers	Hardened Layer Biotic Layer Geotextile Soil Layer
Earthwork	Soil Foundation or Bedding Layer Soil Embankments Geotextile Separator

1.4 References

1-1 - U.S. EPA. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final, Office of Emergency and Remedial Response, Washington, DC 20460.

1-2 - U.S. EPA. 1984. Quality Assurance Handbook for Air Pollution Measurement Systems: Volume 1 Principles. EPA 600/9-76/005, Environmental Monitoring Systems Laboratory, Research Triangle Park, NC 27711.

1-3 - U.S. EPA. 1986. Construction Quality Assurance for Hazardous Waste Land Disposal Facilities. Technical Guidance Document EPA 530-SW-86-031, Office of Solid Waste and Emergency Response, Washington, DC 20460.

1-4 - U.S. EPA. 1987. Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments. EPA 625/4-89/022, Hazardous Waste Engineering Research laboratory, Office of Research and Development, Cincinnati, OH 45268.

1-5 - U.S. EPA. 1989. Requirements for Hazardous Waste Landfill Design, Construction, and Closure. Seminar Publication EPA 625/4-89/022, Center for Environmental Research Information, Office of Research and Development, Cincinnati, OH 45268.

1-6 - U.S. EPA. 1991. Inspection Techniques for the Fabrication of Geomembrane Field Seams. Technical Guidance Document EPA 530/SW-91/051, Risk Reduction Engineering Laboratory, Cincinnati, OH 45268.

1-7 - U.S. EPA. 1989. The Fabrication of Polyethylene FML Field Seams. Technical Guidance Document EPA 530/SW-89/069, Office of Solid Waste and Emergency Response, Washington, DC 20460.

1-8 - U.S. EPA. 1988. Guide to Technical Resources for the Design of Land Disposal Facilities. Technology Transfer Document EPA 625/6-88/018, Risk Reduction Engineering Laboratory, Cincinnati, OH 45268.

1-9 - U.S. EPA. 1984. Permit Applicants' Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities - Final Draft EPA 530 SW-84-004, Office of Solid Waste and Emergency Response, Washington, DC 20460.

1-10 - U.S. EPA. 1983. Handbook for Evaluating Remedial Technology Plans, Municipal Environmental Research Laboratory, Research and Development Document EPA-600/2-83-076, Office of Research and Development, Cincinnati, OH 45268.

1-11 - U.S. EPA. 1991. Design, Construction, and Operation of Hazardous and Non-Hazardous Waste Surface Impoundments. Technical Resource Document EPA 530/SW-91/054, Office of Research and Development, Washington, DC 20460.

1-12 - U.S. EPA. 1991. Design and Construction of RCRA/CERCLA Final Covers. Seminar Publication EPA 625/4-91/025, Office of Research and Development, Washington, DC 20460

1-13 - U.S. EPA. 1989. Final Covers on Hazardous Waste Landfills and Surface Impoundments. Technical Guidance Document, EPA 530/SW-89/047, Risk

Reduction Engineering Laboratory, Cincinnati, OH 45268.

1-14 - U.S. EPA. 1991. *Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites.* Technical Guidance Document EPA 540/P-91/001, Office of Emergency Remedial Response, Washington, DC 20460.

1-15 - U.S. EPA. 1987. Block Displacement Method Field Demonstration and Specifications, EPA 600/2-87/023, Risk Reduction Engineering Laboratory, Cincinnati, OH 45268.

SECTION 2.0

Summary of Construction Elements and Key Properties

Construction elements are commonly used as pay units on construction projects and as such are readily identified. For example, the contractor may be paid based on the square footage of geomembrane installed or the cubic yardage of compacted clay, sand, etc. installed. Specific references to these elements are made in the project specifications.

This chapter reviews the elements common to components used in waste containment systems. Each element will have physical properties defined in the project specifications. Some of these properties must be verified in the field as part of the construction quality management program. However, many of the physical, mechanical and chemical properties cannot be verified in the field. In these cases, the construction quality management program must rely either on certification by the manufacturer or supplier that the material meets project specifications or conformance testing by an independent laboratory. Key properties or installation parameters that require verification and corresponding test methods are discussed in this chapter. Standard test methods to quantify material properties are identified in Appendix A.

2.1 Hydraulic Barriers

A site manager should realize that the performance of a barrier system can exceed the sum of the elements that comprise it. A well constructed composite liner system, for example, will have less infiltration than what is expected from independent evaluations of the clay liner and geomembrane. Such synergistic interaction between elements is not accounted for in project specifications or the construction quality management program. Table 2-1 identifies hydraulic barrier systems and elements that require field testing.

Geomembranes

Geomembranes are used as low permeability barriers in both the bottom liners and caps of waste containment systems. In a hazardous waste landfill, geomembranes can be used alone as the upper or primary liner, and in conjunction with a low permeability soil layer to form the lower or secondary composite liner. Manufacturers and fabricators of geomembranes are responsible for the quality control of both the raw materials, such as plastic resin, and the finished sheets. Their internal quality control (QC) incorporates routine testing of the polymer and the finished product. Test results must be submitted with each lot of geomembranes shipped to the site. In addition, certification must be presented with the geomembranes

TABLE 2-1 BARRIER SYSTEM ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES/POST-CONSTRUCTION CARE	TEST	INSTALLATION QUALITY VERIFICATION	FIELD TEST
Geomembrane	• Polymer properties: - Melt Flow Index - Carbon Black Content - Carbon Black Dispersion - Environmental Stress Crack - Notched Constant Load Test • Mechanical Properties - Thickness - Density - Tensile Properties Post Construction: Upon completion, the geomembrane should be covered or weighted using sandbags to prevent damage from wind. Additionally, the geomembrane is vulnerable to construction and weather related damage if left exposed.	 ASTM D1238 ASTM D1603 ASTM D3015 ASTM D1693(a) GRI GM5 ASTM D751 ASTM D792 (A-1) ASTM D638 (M)	* Placement Considerations - Preparation of surface, E.G. no sharp items, rocks, etc. - Stable foundation - Anchor trenches have proper dimensions and location - Geomembrane panels placed per panel placement drawing - Measure overlap of seams * Seaming - Adequate surface preparation: clean, dry, extent grinding - Temperature, Pressure, Speed of Seaming - Adequate curing time prior to testing (if applicable) - Document start & stop locations, crews, repairs and weather - 100% non-destructive seam testing: Air lance, Mechanical Point Stress, Electric Spark, Vacuum Chamber, Dual Seam - Destructive Seam Testing: Peel(ASTM D413), Shear(ASTM D882) or ASTM D3083 - 1" Wide	 Visual Proof Roll Survey Visual Visual Visual Certification Visual/Test Visual Per Spec. Per Spec.
Geomembrane Interlocking Panels	* Polymer Properties of Geomembrane (As Above) * Interlock Sealing Element * Mechanical Properties of Geomembrane(As Above) Post Construction: Verification of the integrity of the interlock seal is difficult. No known field verification strategies	As Above Certification As Above	* Placement Considerations - Adequate depth of placement(slurry trench or vibration) - Interlock panels placed per panel location drawing - Continuous meshing of interlock seal * Seaming - Presence of interlock sealing element	 Visual Visual Visual Visual
Grouts	* Grout Material Properties - Viscosity of Grout - Graded % of Sand Unit Weight - Compressive Strength	 ASTM D4016 Certification ASTM D4380 ASTM D4832	* Placement Considerations - Spacing of drill pipe used to inject grout - Depth of drill pipe during injection - Quantity of grout injected - Pressure of grout during injection	 Visual Visual Bulk Measure Visual
Bentonite Amended Soil (Also Bentonite Slurry) (Also Cement-Bentonite)	* Bentonite Material Properties: Bentonite Type, Atterberg Limits, Percent Impurities * Soil Properties: Grain Size Distribution Atterberg Limits * Bentonite Amended Soil: % Bentonite Water Content Post Construction: Same as Clay Below	 Certification ASTM D422 ASTM D4318 Methylene Blue ASTM D4959	* Placement Considerations - Thoroughness of blending, e.g. % Bentonite (May require Pugg Mill or Asphalt Grinder for a uniform mixture of soil and Bentonite)	 Methylene Blue
Geosynthetic Clay Liner (GCL)	* Bentonite Properties: Atterberg Limits, Type Percent Impurities, Mass per Unit Area of Board * Geotextile Properties: AOS, Trap Tear, Polymer Post Construction: Protect from free water	ASTM D4318 Certification Certification	* Placement Consideration - Minimum 6-inch overlap of adjacent panels - Subgrade free of rocks, ruts, etc. that could penetrate board - Stable foundation	 Visual Visual Proof Roll
Compacted Clay Liner (CCL)	* Clay Properties: Atterberg Limits Grain Size Distribution Moisture-Density Relationship Maximum Clod Size < 2 inch Post Construction: Clay liners can be damaged from either desiccation or freezing. Soil liner must be protected from drying or freezing.	ASTM D4318 ASTM D422 ASTM D1557 or D698 Visual	* Placement Considerations - Soil water content as specified - Soil density as specified - Water content adjustment not made 24 hr. prior to placement - Sheepsfoot roller with fully penetrating feet - Scarify between lifts	 ASTM D4959 ASTM D2922 Visual

stating that the materials are in compliance with manufacturer's published information and/or the project specifications.

A sample of each lot (production run) of geomembrane material that arrives at the site should be taken. Tests on these samples should confirm that they have the same polymer properties required by project specifications. This is known as *conformance testing* and should be performed by an independent laboratory. A series of samples, instead of one, may be necessary to provide all responsible parties with a sample. Testing of the geomembrane in the field is typically limited to verification of membrane thickness, visual inspection for physical defects, and a thorough testing of all field seams.

Non-Destructive Testing (NDT) of seams is required for the entire length of the seam. Such testing is performed using the vacuum box test for single bonded seams or the pressurized air channel test for those seams that have two lines of bonding separated by an air channel. The vacuum box test applies a moderate vacuum to a seam previously wetted with soapy water. Leaks are indicated by bubbles. The test must be repeated over the entire length of the seam. The pressurized air channel test inflates the seam and checks for a loss of pressure. Samples for destructive testing are commonly taken at a minimum of every 500 feet of seam, with at least one sample taken per seam. Additionally, samples must be cut at least every four hours or when seaming conditions change to provide samples for destructive testing and to monitor variations in seam quality due to variations in operator or seaming equipment. The reader is referred to the Technical Guidance Document EPA/530/SW-91/051 entitled "Inspection Techniques for the Fabrication Geomembrane Field Seams. Specific test requirements may be part of the Construction Quality Assurance Manual prepared for the project.

Geomembrane Interlocking Panels

Geomembrane interlocking panels are installed in vertical trenches to construct a low permeability barrier. The panels consist of membrane panels that connect along their lengths much like conventional steel sheet piles. The panels are pre-fabricated and assembled at the site by locking the panels together and placing them into the trench.

Geomembrane interlocking panels have two physical elements; high density Polyethylene (HDPE) panels with interlock fittings along their vertical edge, and a soft plastic sealing medium within the interlock that provides a hydraulic seal to the interlock fittings. The HDPE interlock closely resembles that used in conventional steel sheet files: A female channel on one panel that engages a male edge of an adjacent panel. Field inspection of the HDPE panels and hydraulic seal material is generally identical to that required for geomembrane materials. Field testing of the geomembrane panels is typically limited to verification of panel thickness. The interlock seal material is hydrophilic and swells in the presence of the groundwater to establish a seal. The manufacturer should be required to provide certification of the long-term chemical stability of the hydraulic seal material when exposed to the site-specific contaminant.

Geomembrane interlocking panels can be installed in open trenches, slurry trenches, or vibrated into sandy soils using a steel mandrel. Care must be taken to insure that the hydraulic interlock and seal material properly seat along the entire length of the interlock channel. This verification can be difficult in slurry wall and vibrated installations. The continuity of the interlock is tested during installation of a new panel using a "runner". The runner consists of a 3 1/2 inch section of the female portion of the interlock that is secured to a rope. The runner is installed ahead of the panel to be installed so that it is pushed down the interlock by the panel being installed. The rope is knotted to show final installation depth. If the runner comes to a halt before the full insertion depth is reached, the panel must be removed and redriven. The hydraulic seal is marked in a similar manner and is not accepted if the seal advance depth is less than 85% of the panel depth.

Grouts

The grout used in a waste containment system is usually a mixture of cement and bentonite. Grouts are, however, available with silica, acrylate, urethane, and Portland cement binders. Grout can be injected in horizontal or vertical borings using a variety of pressures. The suppliers of the grout materials must provide material property data sheets and a certification that the materials conform to their specifications. During the mixing of the grout, the quantities of materials used in the mix should be measured and recorded. Once the grout is mixed, it must be tested to confirm that it meets project specifications for viscosity (Marshal funnel test), setting time, and strength.

Grout is pressure injected into the ground by specialty contractors. Field monitoring requirements include documentation of the injection location, depth, pumping rate, and total grout volume used (see Table 2-1).

Bentonite Products

Bentonite provides an effective moisture barrier. Available as either sodium bentonite mined in several western states or a less active calcium bentonite from Georgia, commercial bentonite is purchased in powder or pellet form. The permeability of bentonite ranges from 10^{-8} cm/sec for calcium bentonite to as low as 10^{-10} cm/sec for sodium bentonite. Bentonite can be used by itself to form a moisture barrier or blended with on-site soils to form an acceptable soil liner. Bentonite is available from commercial suppliers who must provide a summary of the material properties of the bentonite shipped to the project site and certification that the materials meet their specifications.

Bentonite Amended Soil--

When there is not an adequate supply of low permeability soil on site for the construction of a soil barrier layer, a bentonite soil amendment can be used to lower the permeability of the on-site soils. Typically, a 3 to 6% bentonite amendment by dry weight is sufficient to achieve a permeability of 1 x 10^{-7} cm/sec using on-site soils. Sands, however, may require as much as 10 to 15% bentonite amendment. The percent bentonite required is evaluated in the laboratory using site specific soils. Project specifications are then prepared to ensure that the soil and the bentonite used in the field replicate that used in the laboratory. Once the bentonite is mixed with the soil, it should be tested to evaluate the thoroughness of the mixing and the concentration of the bentonite (12). A uniform mixing of bentonite is essential to the performance of the soil-bentonite liner. This mixing may require a pug mill or asphalt pavement surfacer to adequately blend the bentonite with on-site soils.

The installation methods and evaluation of the bentonite soil liner is the same as that for an unamended clay liner. If the bentonite is mixed with the soil in place using a disk, careful visual observation of the depth of mixing and the coverage of the bentonite over the liner area must be made.

Geosynthetic Clay Liner (GCL)--

A GCL is essentially a pre-fabricated low permeability soil layer. The bentonite is usually sandwiched between two geotextiles or adhered to a geomembrane. GCL's are manufactured in 8 ft. and wider sheets and are shipped to the site in rolls. Typically the weight of bentonite (or bentonite and adhesive) per square foot is specified and must be field verified.

The GCL barrier is installed by simply unrolling the sheets over a prepared subgrade. The subgrade should be free of large rocks, ruts, and objects that could penetrate through the GCL. Additionally, the subgrade must be stable, which can be checked by proof-rolling. Seaming of the GCL barrier is typically limited to a minimum 6-inch overlap of adjacent sheets. The water seal at the seam forms when the bentonite hydrates and "oozes" out from between the geotextiles. Additional dry bentonite powder may be spread between the overlaps to improve the seal.

Bentonite Slurries--

Bentonite slurries are used in vertical barrier walls to displace the natural soils and construct a low permeability barrier. Bentonite slurries are mixtures of 4 to 7% bentonite and water. Quantities of materials used in the mix should be measured and recorded. After the mixing, the bentonite slurry should be tested for gel strength using a Fann Viscometer. Typical gel strengths exceed 15 psf (240 kg/m^2).

The bentonite slurry can be used "as is" to prevent the collapse of cut-off wall excavations or blended with on-site soils to form a soil-bentonite slurry used in permanent barrier walls. The soils should have 20-40% fines and are blended with the bentonite slurry until a paste is formed. This paste should have the consistency of fresh mortar or concrete and flow easily.

Slurry uniformity is poor when dozers are used to blend the soil and bentonite. If dozers are used, increased visual inspection and bentonite concentration testing may be required.

Concrete-Bentonite Slurries--

Concrete-bentonite slurries are used on sites where adequate soils to form soil-bentonite slurries are not available or when increase strengths are needed. The concrete-bentonite slurries are mixtures of approximately 18% concrete, 6% bentonite, and 76% water. The concrete bentonite slurry is similar to the bentonite slurry above and the test methods used in that section also apply to this material.

Because of the concrete, the concrete-bentonite slurry will hydrate and begin setting in 2-3 hours. The installation must be monitored to ensure that the slurry has not hydrated prior to placement.

Compacted Clay Liners (CCL)

A CCL may be used as the primary moisture barrier in both waste liner and cover systems. Achieving a low permeability in a clay liner requires a suitable clayey soil and proper preparation and compaction of the soil. Test data (4,11) clearly demonstrate that the permeability of a clay liner can be increased 100 to 1000 times if a single parameter in preparation or compaction is neglected. Soil selected for use as a clay liner is specified using soil plasticity (Atterburg Limits) and grain size distribution. Both parameters can be easily monitored during actual field placement of the liner.

Construction of a clay liner requires proper soil preparation and correct compaction equipment and technique. Soils used for clay liners should be processed to ensure that the soil water content is as specified, the soil clods are no larger than 1 to 2 inches, and the maximum particle size is less than required by the project specifications. For composite liners, the maximum rock size in the last lift is frequently less than 1.0 inch (2.54 cm) to minimize potential damage from rocks to the overlying geomembrane. Liner soil preparation is usually done as the soil liner material is placed in a stockpile. Significant moisture adjustment should not be attempted in the 24 hours preceding placement of the soil.

Key construction guidelines for installing clay liners are related to both equipment and operations. Compaction equipment must have feet that penetrate completely through a loose layer of fill. Alternately, the loose lift thickness can be adjusted to maximize the efficiency of the available compaction equipment. Compacted effort (compactor speed and number of passes) should be consistent with the minimum effort established in a test strip. Additionally, bonding between the layers of compacted clay must be enhanced by scarifying the surface of the previous lift. The as-built clay liner must be tested to verify that it meets project compaction criteria. This requires a field sampling program to measure soil moisture content and density.

A clay liner is very susceptible to damage due to either desiccation or freezing. Clay liners left exposed must be protected from desiccation using a surface sealant (acrylic sprays or light membranes) or an additional layer of "sacrificial" soil. Soil cover also serves to prevent freezing of the clay liner. Even a single cycle of freezing can significantly increase the permeability of a clay liner. Testing a suspect soil liner for permeability requires either a large-scale double-ring infiltrometer test or laboratory testing of undisturbed (UD) samples taken from the soil liner.

2.2 Hydraulic Conveyances (Both Liquid and Gas)

Drainage layer components are designed to collect leachate beneath the waste or to collect gas above the waste. Both functions require the drainage layer to be significantly more permeable than the adjacent waste or soils. Thus filter systems, discussed in Section 2.3, are required with all drainage systems. Newer geocomposite systems provide both the drainage media and filter layer in a single commercial product. Field testing requirements for hydraulic conveyance systems are presented on Table 2-2.

<u>Natural Drains and Collectors</u>

A sand or gravel drainage layer can be used as part of the leak detection component of a waste containment system, as the primary drainage layer above the bottom liner, and as an infiltrating storm water drain in the capping system. Soil drains provide a high permeability medium into which liquids can easily drain to a network of collection pipes. The soil drain usually consists of clean sand or gravel sorted to specific particle sizes by a quarry. In some cases suitable sands or gravels are found on site, but this is unusual.

TABLE 2-2 HYDRAULIC CONVEYANCE SYSTEM ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES/POST CONSTRUCTION CARE	FIELD TEST	INSTALLATION QUALITY VERIFICATION	FIELD TEST
Send/Gravel/Drain Collector	- Material Properties: Natural Water Content Grain Size Distribution Laboratory Hydraulic Conductivity Moisture-Density Relationship Post Construction: Natural drainage layers must be protected from fines related to sedimentation	ASTM D2218 ASTM D422 ASTM D2434 ASTM D1557 or ASTM D698	* As Placed Properties - Water Content - In Place Density - Lift Thickness * Visual observation of compactive effort as measured by number of passes with a given compaction equipment	 ASTM D2216 ASTM D2922 Visual Visual
Geosynthetic Drain/ Collector	- Material Properties: Weight per sq foot, transmissivity under load, polymer properties (see geomembrane) Post Construction: Geosynthetic drainage layers must be protected from damage by direct trafficking of vehicles, and movements caused by wind or men	Certification	* Placement Considerations - Measure width of panel overlap Avoid folds, wrinkles, or damage to panels - Provide temporary anchorage, e.g. sandbags	 Visual Visual Visual
Pipes	- Material Properties: Polymer properties, pipe rating - Mechanical Properties: Wall thickness and diameter Post Construction: Pipes must be protected from damage by direct trafficking of vehicles and movements prior to burial	Certification per ASTM D1248 Visual	* Placement Considerations Verify pipe perforations, placement, and connectors in perforated pipe - Verify location and grade of pipe - Hydrostatic pressure test solid pipe joints - Verify bedding material satisfies specifications * Grain Size Distribution In-Place Density	 Visual Survey See Pipe Manual 'Butt Fusion Visual ASTM D422 ASTM D2922
Sumps	- Material Properties: Polymer properties (see geomembrane) - Mechanical Properties (prefabricated sump) * Diameter and wall thickness * Pipe penetrations per specs.	Certification Visual Visual	* Placement Considerations - Subgrade perpared free of rocks or sharp objects - Bedding layer required for prefabricated sumps Verify location and grade of sump * Seaming (see geomembrane)	 Visual Visual Survey
Pumce	- Mechanical Properties * Flow Rating Post Construction: Verify rated capacity with hydro test	Certification	* Placement Considerations Installation per manufacturer's recommendation	 Visual

Drain materials are specified using a particle size distribution and samples should be taken for laboratory grain size and permeability conformance testing. Soil drains typically require only moderate to light compaction and the as-installed drain layer thickness should be verified. Natural drainage layers must be protected by diversion berms or geotextiles from the introduction of water borne fines from surface erosion of adjacent slopes.

Geosynthetic Drains and Collectors

A geocomposite drain consists of a core material that provides a pathway for drainage and a surrounding geotextile that prevents clogging of the core. Geocomposite drains can be used as part of the leak detection component of a waste containment system, as the primary drainage layer above the bottom liner, and as a lateral drain in the capping system. Similar to the soil drain, a geocomposite drain provides a high transmissivity core through which liquids can easily drain into a network of collection pipes. Geocomposite drains are pre-fabricated and come in rolls or panels up to 300 ft. in length.

Geocomposite drains are available from suppliers who must certify that the materials supplied meets the manufacturer's minimum specifications. The CQA officer must compare the manufacturer's specifications with the project specifications. Laboratory conformance testing should be performed on the drains under service conditions if differences exist between the two specifications. The material delivered to the site should be inspected for general compliance with project specifications and to check for damage during shipping.

Installation of the geocomposite drain requires no field testing. The drain should be inspected to confirm that it is installed according to manufacturer's and project specifications. Overlaps between adjacent roll ends or panels are particularly important with the proper overlap length, orientation, and plastic ties used to bind the overlap. Geosynthetic drainage layers must be protected from damage by vehicle traffic, wind or other disturbances. The layer should also be protected from fines carried by surface erosion during construction.

Plastic Pipes

Both perforated collection and solid transmission pipes are used in the leak detection systems, the primary leachate collection drain, the lateral drain in the cap, and to carry stormwater and leachate away from the waste containment system. Collection and transmission pipes are constructed from a variety of plastics and can be designed for gravity flow lines as well as low or high pressure lines, depending upon the application.

Collection and transmission pipes are available from suppliers who must certify that the materials meet manufacturer's specifications. The material delivered to the site should be inspected for general compliance with the project specifications and to check for damage during shipping.

Installation of collection and transmission pipes should be field inspected to verify that the location and grades of the pipe and joints, and the bedding material and backfill meet project specifications. Perforated pipes require additional inspection of the perforations (hole diameter and spacing) and pressure pipes require hydrostatic pressure testing (see Appendix A).

Sumps

Leachate sumps are located in both the primary leachate collection layer and the bottom/lower leak detection layer. Sumps are located at low points in the liner and act as basins in which the leachate can be collected. From the sumps, the leachate is either drained out of the waste containment system by gravity or pumped out. The sumps can be a simple depression in the composite liner or a pre-manufactured plastic basin that is set in the clay liner so that its top is flush with the geomembrane liner. The geomembrane is fusion-welded to a flange on the upper edge of the sump. Pre-manufactured sumps eliminate difficult-to-test field seams or complex grading.

If leachate sumps are fabricated on site, then they will be made from the same materials as the liner system, so certification of the liner materials will already have been provided. If the leachate sumps are pre-fabricated then the supplier must certify that they meet project specifications. The sumps delivered to the site should be inspected for general compliance with the project specifications and any damage.

Sumps are the only area of a waste containment system that will continuously receive leachate. As such, any defect in the sump may result in a continuous long-term leak. The seams made at this location are difficult to test due to their short length and tight angles. Destructive samples should be kept to a minimum due to the difficulty of repairs in the vicinity of the sumps.

Pumps

The leachate can be drained by gravity from the waste containment system or it can be pumped out the system using a submersible pump. The pumps used to move leachate are manufactured for harsh environments and can be powered by electricity or compressed air. Leachate pumps are available from suppliers who must certify the pumps meet the manufacturer's specifications. The pumps should be inspected when delivered to the site to confirm that they were not damaged during shipment.

Installation of the pumps should be done in accordance with the manufacturer's instructions. All electrical connections, power requirements, insulation, grounding, and piping should be installed and used as specified by the manufacturer. These items should be inspected during installation to verify that they follow the manufacturer's recommendations. The pump should be tested, using water, to verify that it is working properly.

2.3 Filters

Filter layers must provide for long-term movement of water through the layer while at the same time limit the movement of waste or soil particles across the layer. Too tight a filter will quickly clog while too loose a filter will result in an excessive loss of solids through the filter. Biological growth can also impact filter layer performance and is currently being studied by the EPA. Field verified material properties and installation factors are given in Table 2-3.

Sand/Gravel Filter

A soil filter is used to prevent very fine soil and waste particles from entering into a drain, accumulating, and eventually clogging the drain. Typically, soil filters consist of sand and/or gravel which has been screened to a specified particle size. The sand/gravel filter should have a particle size smaller than the drain particle but larger than the infiltrating particle. The filter may consist of one layer or several successively graded layers depending upon the performance objectives of the designer. A soil gradation requirement will be provided for each sand/gravel filter layer in the project specifications.

The sand and gravel filter should be laboratory tested to ensure that the grain size distribution meets the project specifications. Individual filter layers are also field tested to ensure that the installed filters meet compaction and thickness specifications.

Geotextile Filter

A geotextile filter is used to prevent very fine soil and waste particles from entering into a drain, accumulating and eventually clogging the drain. The geotextile filter is selected by the designer based on its opening size and permittivity. Suppliers of geotextile filters must certify that the materials meet the published manufacturer's specifications. Published manufacturer specifications must also satisfy the specific geotextile specifications for the project. Conformance testing of the geotextile is recommended for critical filter applications (see Table 2-3). The geotextile arrives on the site in rolls for installation. The material delivered to the site should be inspected to ensure compliance with the project specifications and to check for damage during shipping.

TABEL 2-3 FILTER SYSTEM ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES/POST CONSTRUCTION CARE	FIELD TEST	INSTALLATION QUALITY VERIFICATION	FIELD TEST
Sand/Gravel Filter	* Material Properties:		* Placement Considerations	
	- Natural Water Content	ASTM D4959	- Soil water content if specified	ASTM D4959
	- Grain Size Distribution	ASTM D422	- Soil density if specified	ASTM D2922
	- Laboratory Hydraulic Conductivity	ASTM D2434	- Lift thickness	Visual
			- Verify compactive effort if density specified	Visual
	Post Construction: Natural filter must be protected from surface water sediments prior to burial			
Geotextile Filter	* Polymer Properties. Density, Denier, Polymer Type, UV Stability	Certification	* Placement Considerations	
			- Verify overlap of geotextile panels	Visual
	* Mechanical Properties.		- Verify no folds or wrinkles exist	Visual
	- Weight per square yard	Weigh	- Verify use of temporary anchorage if required	Visual
	- Tensile Strength (grab tensile)	ASTM 4632	- Verify sewn seams	Visual
	- Permittivity	ASTM D4491		
	- AOS	ASTM D4751		
	- Puncture Strength	ASTM D4833		
	Post Construction: Protect geotextile from surface water sediments and from wind or man caused movement			

The installation of the geotextile should be inspected to verify that panel overlap or sewn seams meet manufacturer's requirements. Additionally, any folds or wrinkles or damage to the panels must be eliminated and temporary restraint provided if necessary.

2.4 Erosion Control

Final cover systems on waste containment systems must be designed to limit the infiltration of surface water while at the same time require only limited maintenance for an extended period of time. Maintenance on such cover systems is significantly influenced by the degree of erosion that is allowed. For example, the EPA suggests that erosion be limited to less than 2 tons of soil per acre per year. The selection of a final cover system may also be influenced by the end use of the cover, e.g. park, or climatic conditions, e.g. lack of rain. Field inspection requirements for erosion control systems are presented on Table 2-4.

Vegetation and Topsoil

Surface vegetation may be the most economical erosion control system in those regions where rainfall exceeds evapo-transpiration. The vegetation will typically be a native grass tolerant of local climatic conditions. It should also limit spontaneous vegetation by non-desirable plants, germinate rapidly, and be compatible with the cap profile. Vegetation having exceptionally aggressive tap roots should be avoided.

Vegetation is usually bid on a cost per acre basis with a minimum weight of seed per acre specified. The seed placement cost should include required soil preparation (tilling, fertilizers, etc.), hydromulching, and any additional short-term erosion control required until the vegetation is established. Suppliers of fertilizer and seeds must certify that the fertilizer and seed meet project specifications. Placement of the seeds should be made in accordance with the supplier's instructions. The application rate, time of year, soil preparation, hydromulching, and watering schedule should be observed and documented.

Topsoil is used to support the growth of the vegetation on the cap and other locations that require vegetation. The topsoil is usually obtained on site from a stockpile cut from the construction area or from a nearby borrow area. Project specifications are typically vague regarding topsoil properties, but the organic content of the topsoil should be at least 3 to 5 percent, to support plant growth. Field monitoring is commonly limited to verification of the final layer thickness.

TABLE 2-4 EROSION CONTROL ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES/POST-CONSTRUCTION CARE	FIELD TEST	INSTALLLATION QUALITY VERIFICATION	FIELD TEST
Vegetation	* General Properties: Seed Blend, % Wood, etc..	Certify	* Placement Considerations	
	Post Construction. Watering schedule must be maintained, protect from erosion and traffic prior to full growth.		- Time of placement per specs	Visual
			- Soil preparation per specs or seed supplier	Visual
			- Hydromulching per specs or seed supplier	Visual
			- Watering schedule per specs or seed supplier	Visual
Topsoil	* General Properties: (if given in project specifications)		* Placement Considerations	
	- Natural Water Content	ASTM D4959	- Lift Thickness	Visual
	- Grain Size Distribution	ASTM D422	- Water Content (if specified)	ASTM D4959
	- Soil PH	ASTM D4972	- Density (if specified)	ASTM D2922
	- Organic Content, and	ASTM C311	- Surface Preparation (if specified)	Visual
	- Nutrient Content			
	Post Construction. Protect from surface erosion prior to crop development			
Asphalt Cap	* Asphalt Mixture Properties		* Placement Considerations	
	- Percent Asphalt	ASTM D915	- Verify thickness of asphalt being placed	Visual
	- Grain Size Distribution of Aggregate (if specified)	ASTM D422	- Verify weather is acceptable during placement	Visual
	- Compressive Strength	ASTM D1074	Density of asphalt (field test)	ASTM 2950
	Typically use certification by batch plant		- Ensure continuity of joints start of each day	Visual
			Verify temperature of asphalt during placement	Visual
Concrete Cap	* Concrete Mixture Properties		* Placement Considerations	
	- Measure temperature of the mix	ASTM C143	- Observe placement to ensure that aggregate is not separated from fines in the concrete mix	Visual
	- Determine how long truck has been on road			
	- Slump test	ASTM C231	- Verify vibration of concrete to remove voids	Visual
	Test for amount of entrained air in concrete	ASTM C31	- Measure location of construction and expansion joints	Visual
	- Make test cylinders for compression strength testing	ASTM C39	- Observe application rate of curing compound applied over fresh concrete surface	Visual
	- Obtain batch ticket for each truck			
	- Inspect Rebar	Visual		
Rip-rap Cap	* General Properties		* Placement Considerations	
	- Rock Size Distribution	ASTM D422	- Verify lift thickness	Visual
			- Check that geotextile is beneath rip-rap specified	Visual
			- Observe placement of stone to confirm maximum drop height and 'rolling' of stones	Visual

Hardened Layers

Hardened covers provide an alternative to vegetative systems in arid regions that lack sufficient natural moisture. Additionally, hardened systems have been used to provide traffic and parking areas after closure of the waste containment facility. Asphalt and concrete hardened covers are normally limited to slopes less than 10 degrees.

Asphalt Cap --

An asphalt cap can be used to protect a capping system and provide a potentially usable area over a waste containment system (e.g. a parking lot). The asphalt cap can replace the vegetation, topsoil, drainage layer, and the biotic layer in the cap. In this application, the asphalt layer must provide the erosion resistance of the vegetation/topsoil, the lateral flow capacity of the drainage layer, and the protection of the biotic layer. The porous asphalt layer consists of an asphalt pavement system similar to that used in roadway construction. The asphalt supplier must certify that the materials meet the project specifications. Asphalt delivered to the site should be inspected for general compliance with these specifications. The temperature of the delivered asphalt mix should be measured and the batch ticket for each truck load should be filed for future reference.

During installation, the thickness, temperature, and density of the asphalt should be measured. Additionally, the weather must be monitored to avoid rain or cold temperatures that would hurt asphalt placement.

Concrete Cap--

Like asphalt, a concrete cap can protect a capping system and provide a potentially usable area over a waste containment system (e.g. a parking lot). The concrete cap replaces the vegetation, topsoil, drainage layer and the biotic layer in the cap. The concrete layer is similar to that used in roadway construction. Concrete suppliers must certify that the concrete meets project specifications.

The concrete delivered to the site should be inspected to determine how long the trucks have been on the road and if the concrete can be used. Material properties identified in the project specifications should be verified (see sample specifications in Table 2-4). The foundation below the concrete should be inspected for levelness, strength and the presence of water.

The concrete pour should be observed to verify that the aggregate is not separated from the fines in the concrete mix, and that the construction and expansion joints are properly located. The application rate of a curing compound over the concrete surface should be measured.

Rip-Rap Cap --

Rip-rap consists of natural stones ranging in size from approximately 1 inch to stones that weigh hundreds of pounds. Layers of these stones provide a significant impediment to wind and water related erosion. Rip-rap layers are commonly underlain with a geotextile filter to limit potential erosion of underlying fines. Field testing is typically limited to verifying that the delivered rip-rap meets project specifications for particle size.

The installation should be monitored to verify that thickness of the rip-rap layer meets project specifications. Placement of stone or rip-rap should be monitored to ensure that drop heights are limited. An underlying geotextile should be inspected for damage due to stone placement. When larger stones (>60 pounds) are placed over a geotextile fabric, drop height stone is commonly limited to 18 inches (45 cm). Alternately, a soil layer of 6 inches (15 cm) can be placed over the geotextile to provide a cushion and protect it from damage during rip-rap placement.

2.5 Protective Layers

Waste containment systems and covers frequently include layers that are intended to protect functional layers. Outer protective layers include the surface erosion control layers discussed above (section 2.4). This section discusses interior protective layers that function even after they are buried within the system. While some of the protective functions may be short-term or seasonal, e.g. a protective soil layer placed over a liner to protect it from freezing, most protective functions are long-term and are essential to the success of the waste containment system. Table 2-5 presents field tests that should be conducted to ensure material integrity and installation quality of protective layers.

Biotic Barrier

A Biotic barrier is used in the cap of a waste containment system to prevent small burrowing animals and plant roots from penetrating the drainage layer or the low permeability barrier. The biotic barrier usually consists of a 3 foot (1 m) thick layer of stone or cobbles. Vegetative intrusion can also be limited by herbicide impregnated geotextiles that provide time release protection. Field inspection is typically limited to verifying that the stone particle size and layer thickness meet project specifications.

TABLE 2-5 PROTECTIVE LAYER ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES/POST CONSTRUCTION CARE	FIELD TEST	INSTALLATION QUALITY VERIFICATION	FIELD TEST
Biotic Barrier	* Mechanical Properties - Grain Size Distribution	ASTM D422	* Placement Considerations - Verify lift thickness - Verify specified soil/geotextile beneath ston - Observe placement of stone per specs	 Visual Visual Visual
	Post Construction: Protect from stormwater sediments			
Geotextile	* Polymer Properties: Density, Denier * Mechanical Properties: Per project specifications - Mass per Unit Area - Thickness	Certification Measure	* Placement Considerations Verify overlap of adjacent rolls Eliminate fold or wrinkles during installation - Provide temporary anchorage per specs.	 Visual Visual Visual
	Post Construction: Protect from wind damage			
Soil Protective Layer	* Material Properties - Natural Water Content - Grain Size Distribution	 ASTM D4959 ASTM D422	* Placement Considerations Water Content In-place Density - Lift Thickness - Visual Observation of Compaction Effort	 ASTM D4959 ASTM D2922 Visual Visual
	Post Construction: Protect layer from surface water erosion and dessication			

Geotextile Protective Layer

A protective layer over the bottom liner, leachate detection layer and the primary leachate collection layer is required to protect these components from damage during construction and waste placement. The geotextile protective layer is normally a nonwoven material selected according to its unit weight (ounces/yard^2). The heavier the nonwoven material, the more cushion it provides. Suppliers of geotextile protective layer materials must certify that the geotextile meets the manufacturer's specifications.

The geotextile arrives on the site in rolls for installation. The material delivered to the site should be inspected for general compliance with project specifications and damage from shipping.

Soil Protective Layer

A soil protective layer over the liner, leachate detection layer and the primary leachate collection layer is required to protect these components from damage during waste placement and from the extremes in the weather. The soil should be selected for its resistance to erosion, strength, and stability on the side slopes of the waste containment system. Typically, an on-site soil can be used as the protective layer. The soil should be laboratory tested to verify that they meet the project specifications. Typical soil protective layer specification considerations are given in Table 2-5.

Special attention should be given to the installation of a soil protective layer over a geomembrane liner. Such installations require less rigorous compaction specifications for the first lift to avoid damaging the geomembrane during compaction.

2.6 Earthworks

Construction or closure of waste containment systems typically requires construction of earthen containment structures, such as dikes and berms, and the development of stable working benches (surfaces) over weak wastes or contaminated soils. Due to cost restrictions, earth work is usually done with either on-site or local soils. In view of the diverse nature of this material, close monitoring during construction is often necessary to achieve design conditions. Weak or soft spots in compacted soil are commonly detected by proof-rolling using a loaded dump truck. Any soil experiencing excessive rutting should be recompacted or excavated and replaced. Common field tests of earthwork are shown on Table 2-6.

TABLE 2-6 EARTHWORK ELEMENT TESTING/INSPECTION

ELEMENT	MATERIAL PROPERTIES, POST CONSTRUCTION CARE	FIELD TEST	INSTALLATION QUALITY VERIFICATION	FIELD TEST
Structural Fill	* Mechanical Properties		* Placement Considerations	
	Natural Water Content	ASTM D4959	- Soil water content as specified	ASTM D4959
	Grain Size Distribution	ASTM D422	Soil density as specified	ASTM D2922
	Moisture Density Relationship	ASTM D1557/698	- Lift thickness verified	Visual
	- Atterburg Limits	ASTM D4318		
	Post Construction - Protect layer from surface water erosion			
Soil Bedding Layer	* Mechanical Properties		* Placement Considerations	
	- Natural Water Content	ASTM D4959	- Soil water content as specified	ASTM D4959
	Grain Size Distribution	ASTM D422	- Soil density as specified	ASTM D2922
			- Lift thickness verified	Visual
			- Verify final grade	Survey
Geotextile/Geogrid Bedding Layer	* Polymer Properties	Certification	* Placement Considerations	
			- Verify overlap of adjacent rolls	Visual
	* Mechanical Properties		- Eliminate fold or wrinkles during installation	Visual
	- Weight per square yard	Measure	- Provide temporary anchorage if required	Visual
	- Strength	ASTM D4632		
	- Wide-Width Strength	ASTM D4595		

Structural Fill

A structural fill is designed to support its own weight and that of any overlying systems without experiencing excessive deformation. Such fills are typically placed to develop a minimum shear strength or compressibility as assumed in design. Laboratory shear strength or compaction tests, made prior to construction, are used to establish acceptable moisture/density requirements for such fills.

Fill soils must be inspected at the site to ensure that they are suitable and have low plasticity (i.e., plasticity index <10) and no large stones (<6 inches). Compacted soils should be tested to verify that they achieve the minimum dry density established by the project specifications.

Soil Bedding Layer

A soil bedding layer is used to level the waste surface immediately below the cap. The bedding layer provides a smooth and stable working surface for the construction of the cap and is usually made from an on-site soil with good strength properties. Other than proof-rolling and measuring the final grade, little field testing is performed on bedding soils.

Geotextile or Geogrid Bedding Layer

A geotextile or geogrid bedding layer is used to level the waste surface and bridge any voids immediately below the cap. Additionally, the bedding layer provides a smooth and stable working surface for the construction of the cap. The geotextile or geogrid must have high tensile strength and be puncture resistant. Suppliers of geosynthetic bedding materials must certify that the materials supplied meet the manufacturer's specifications. The geosynthetics, which are delivered to the site in rolls, should be inspected to ensure general compliance with the project specifications and to check for damage.

The installation is usually monitored to confirm that geotextile or geogrid overlaps meet the manufacturer's specifications. Six (6) inch (15 cm) overlaps are common. Conformance testing of the geotextiles or geogrids can be performed as indicated in Table 2 6.

2.7 References

2-1 - U.S. EPA. 1991. Design and Construction of RCRA/CERCLA Final Covers. Seminar Publication EPA 625/4-91/025, Office of Research and Development, Washington, DC 20460.

2-2 - U.S. EPA. 1991. Design, Construction, and Operation of Hazardous and Non-

Hazardous Waste Surface Impoundments. Technical Resource Document EPA 530/SW-91/054, Office of Research and Development, Washington, DC 20460.

2-3 - U.S. EPA. 1989. The Fabrication of Polyethylene FML Field Seams. Technical Guidance Document EPA 530/SW-89/069, Office of Solid Waste and Emergency Response, Washington, DC 20460. (Superseded by REF 2-5)

2-4 - U.S. EPA. 1989. Requirements for Hazardous Waste Landfill Design, Construction, and Closure. Seminar Publication EPA 625/4-89/022, Center for Environmental Research Information, Office of Research and Development, Cincinnati, OH 45268.

2-5 - U.S. EPA. 1991. Inspection Techniques for the Fabrication of Geomembrane Field Seams. Technical Guidance Document EPA 530/SW-91/051, Risk Reduction Engineering Laboratory, Cincinnati, OH 45268.

2-6 - U.S. EPA. 1987. Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments. EPA/600-S2-87/097, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, Cincinnati, OH, 45268.

2-7 - Koerner, R.M., Designing with Geosynthetics, Prentice-Hall, Englewood Cliffs, NJ, 1990.

2-8 - Standards for Specifying Construction of Airports, Advisory Circular 150/5370-10A, U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 2/17/89.

2-9 - ACI Manual of Concrete Practice, Part 2, Construction Practices and Inspection Pavements, Detroit, Michigan 48219, 1984.

2-10 - Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, PA 19103, 1990.

2-11 - Elsbury, B.R., et al., "Lessons Learned from Compacted Clay Liners," J. Geotechnical Engineering, ASCE, November 1990, 1641-1660.

2-12 - U.S. EPA. 1987. Construction Quality Control and Post-Construction Performance Verification for Gilson Road Hazardous Waste Site Cutoff Wall. EPA/600/2-87/065.

SECTION 3.0

Field Sampling Strategies

Key elements of a waste containment system should be sampled and tested to verify that the materials meet project specifications and that they are being installed in accordance with the design drawings. Sample tests can also be used to monitor the construction process, predict trends in the quality of the installation, and detect sub-quality construction trends. A field sampling strategy in its simplest form can be implemented by "randomly" picking out a half dozen or so samples for testing, and accepting the area or lot if all the tests fall within the limits of the project specifications. A "lot" is a clearly defined production unit such as a given days batch of grout or a clearly identified production run of a geosynthetic product. While this may be an appropriate sampling plan in some cases, the risks associated with this plan should be known before implementing it. If factors such as sample size, sample location, and acceptance criteria are not correctly applied, the test results may not represent the quality of the area or lot being tested.

A sampling plan, whether it is implemented in the field or in a manufacturing plant, has several distinct parts:

1) Delineation of the sample area;

2) Determination of the number of samples by one of the following methods:
   a) Following the project specifications;
   b) Using the Sample Density Method, which specifies a minimum number of tests per unit length, area or volume;
   c) Using an Error of Sampling Method, such as ASTM E-122;
   d) Using Sequential Sampling;

3) Selection of the sample locations by one of the following methods:
   a) Include every potential sample location -- Census or one-hundred percent (100%) sampling of the area or lot;
   b) Select locations using the judgement of the project inspector -- Judgmental Sampling;
   c) Include every "nth" potential sample location starting with a randomly selected starting location corresponding to a randomly selected number less than "n". (For example, select every 10th location starting with the 9th location, ie. locations corresponding to 9, 19, 29, etc.) -- Fixed Increment Sampling;
   d) Selecting sample locations completely at random using a random number generator -- Strict Random Selection;
   e) Subdividing the test area into logical subareas and randomly selecting locations within each subarea -- Stratified Random Selection;

4) Obtaining and testing the samples using the appropriate methods;

5) Acceptance or rejection of the area or lot based on either:
   a) comparison of the sample statistics (mean, variance, etc. of the test values) with the limits presented in the project specifications;
   b) comparison of the sample statistics with pre-determined limits calculated to keep the construction process in control.

6) Development of a remedial action plan to change the construction process if the quality of the construction declines

7) A clear method of historical documentation so that all of the original records, including the sample locations, test results, and the analysis of the test results (sample statistics), are available for project certification or future litigation.

3.1 Delineating the Area or Lot Being Tested

The area or lot being tested must be divided into potential test locations that can be clearly identified at a later time. The test area or lot should therefore be tied to an easily identified fixed reference point such as a manhole or the crest of a slope (see Figure 3 1a). Distance from the fixed location to the sample can be measured along a linear axis or using a pair of coordinate axes. For most sample selection schemes it is necessary that a numbering system be used to reference the potential sample locations or items. For example, samples from a geomembrane seam are referenced by measuring distance along the seam. Destructive testing of pipe, however may require samples of a specific length (e.g. 3 feet). The pipe can be marked off in 3-foot intervals with each segment given a number that identifies the sample (see Figure 3-1b). In delineating an area for sampling, a coordinate pair of axes must be used instead of a single axis. The sample locations can be delineated by distance measurements along both axes, or by assigning numbers to sample areas corresponding to subdivisions of an overall grid (see Figure 3-1c). Each sample should be marked or tagged to provide clear documentation of the test location.

3.2 Determining the Number of Sample Locations

The number of sample locations required for testing a given element is normally included in the project specifications. Sometimes, specifications for sample locations determine the number of

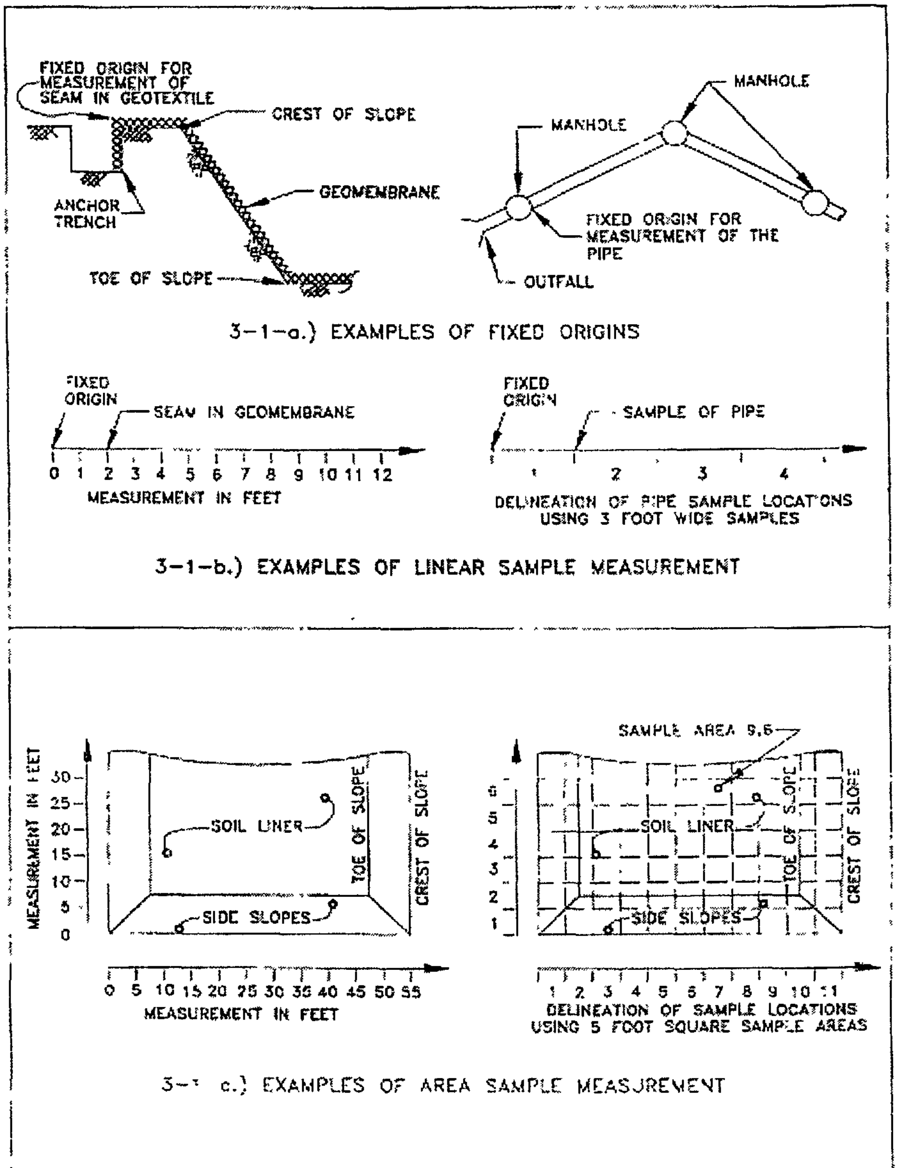


FIGURE 3-1 EXAMPLES OF DELINEATION AND MEASUREMENT OF LOT OR AREA BEING SAMPLED

samples, e.g. every 't' section of a seam in a flexible membrane liner must be tested. Apart from these instances, three methods -- sample density, error of sampling, sequential sampling -- are used to determine the number of samples to be tested.

Sample Density Method

The sample density method specifies the minimum number of sample locations per unit of measure (sample density) for a given element. This method is popular with regulatory agencies since it is readily applied and verified. It can be applied to linear systems (e.g. seams), surface areas (e.g. geomembranes), and volumes (e.g. grout). Table 3-1 shows typical sampling densities for all three of these element types. Note that sampling densities can be given in either area or volume units. For example, clay liner testing can be specified as number of tests/acre fill or number of tests/volume of fill. Common sampling densities for waste containment elements are presented in Appendix A.

Error of Sampling Method

The error of sampling method is used to determine the number of test samples required to represent the quality of the entire area or lot with an acceptable sampling error. The sampling error is defined as the maximum allowable difference between the sample estimate of lot or area quality and the measure of quality that would be determined by 100% sampling. Calculation of the number of tests needed to estimate the proportion of defective areas of a soil liner, using ASTM E-122, is shown in Figure 3-2.

The number of samples required by ASTM E-122 is a function of the importance of the element being tested (K), the allowable difference between actual and indicated quality (E), and an estimate of the actual number of defects in the area or lot (P). Calculations for a minimum number of tests for a clay liner are shown on Figure 3-2. Since a clay liner is a very critical element of a waste containment system, the K factor is 3. The allowable difference between the actual quality and the sample estimate of quality is set at 5 percent or P=0.05. An estimate of the actual number of defective tests in a given lot or area (P) requires some prior knowledge of similar applications which may require reviewing past records. This estimate can be adjusted as the project progresses to reflect actual site experience.

A minimum of 171 tests must be performed on the example clay liner to satisfy our assumed requirements. Note that ASTM E-122 does not incorporate the size of area or lot. In the case of a two foot thick clay liner, the test density (yd^3/test) is a function of the size of the liner as shown in Figure 3-2. Thus the 171 tests reflect approximately 1 test per 300 cubic yards of clay for a 15 acre site and 1 test per 500 cubic yards for a 25 acre site. Common sampling densities for clay liners range from 1 test per 250 to 500 cubic yards of clay (see Appendix A).

TABLE 3-1 EXAMPLES - SAMPLE DENSITY METHOD

ELEMENT/SYSTEM TYPE	PARAMETER	TEST METHOD	MINIMUM TESTING FREQUENCY*
Geomembrane/Linear	DT Seam Test	ASTMD413 ASTMD3083	1/500 Ft. Seam
Clay Liner/Area	Density	ASTMD2922 or ASTMD2937	5/acre/6" lift
Clay Liner/Volume	Density	ASTMD2922 or ASTMD2937	1/500 YD^3
Grout/Volume	Slump	ASTMC143	1/500 YD^3

* For landfill liners - the minimum testing frequency may be decreased (e.g. 1/1000 ft of seam) for caps or temporary applications as required.

REFERENCE: ASTM E–122 ERROR OF SAMPLING METHOD

DEFINE NUMBER OF TESTS (n)

$$n = (K/E)^2 P(1-P)$$

WHERE P = ESTIMATE OF THE FRACTION OF DEFECTIVE TESTS PER UNIT

E = MAXIMUM ALLOWABLE DIFFERENCE BETWEEN THE ESTIMATES OF QUALITY FROM n SAMPLES AND 100% TESTING

K = A FACTOR CORRESPONDING TO THE PROBABILITY THAT THE SAMPLING ERROR WILL EXCEED E. (SEE TABLE)

TABLE – k FACTOR

K	PROBABILITY OF ERROR EXCEEDING E.	IMPORTANTCE OF ELEMENT
3	0.003 (3 in 1000)	VERY CRITICAL
2.58	0.01 (10 in 1000)	CRITICAL
2	0.045 (45 in 1000)	↑
1.96	0.05 (5 in 100)	|
1.64	0.10 (10 in 100)	NOT CRITICAL

EXAMPLE APPLICATION

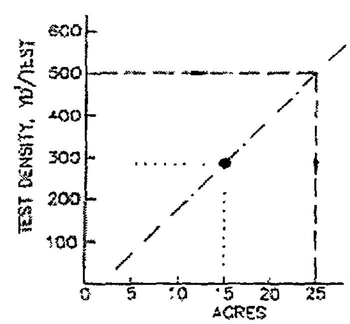
DEFINE NUMBER OF MOISTURE/DENSITY TESTS FOR SOIL LINER

ASSUMPTIONS:

P = 5% ⟹ 5 OUT OF 100 TESTS ARE DEFECTIVE
E = 5% ⟹ ALLOWABLE DIFFERENCE = ±5%
K = 3 ⟹ VERY CRITICAL ELEMENT

$$n = (3/0.05)^2\, 0.05\ (1-0.05) = 171 \text{ TESTS}$$

NOTE: ACTUAL TEST DENSITY IS A FUNCTION OF VOLUME OF SOIL LINER, e.g. 15 ACRE SITE WITH 2 ft. LINER



TEST DENSITY = 48642 YD³/171 = 248 YD³/TEST

FIGURE 3-2 NUMBER OF SAMPLES-ERROR OF SAMPLING METHOD

Sequential Sampling

The Sequential Sampling scheme is designed to minimize the required sample number when the quality of the area or lot is either exceptionally good or very poor. Most sampling plans require a fixed sample size (determined prior to construction) which is independent of the results observed at the first sample locations. Sequential sampling uses the results of the tests as they are conducted to adjust the number of samples required and the acceptance criteria. Areas or lots with high or low quality require a smaller number of tests than those with marginal quality. Note that the sequential sampling method defines both the number of samples and the acceptance criteria which depend on the results of earlier sample test results.

A sequential sampling plan requires that after each sample location, or small group of locations, is evaluated that one of three decisions is made about the test area or lot from which the sample(s) was(were) taken:

- The test area is accepted
- The test area is rejected
- The evidence is not sufficient to make a decision without an unacceptable risk of error

These three decisions are illustrated by the three regions on the chart shown on Figure 3-3. If the last decision is made, more sample locations must be selected and evaluated. This process is continued until the test area is accepted or rejected or a limit on the number of test is reached e.g. all. Typically a graph as shown in Figure 3-3 is used to implement this sampling scheme.

Four variables must be determined to implement this sampling plan. These variables include:

P_1	=	acceptable proportion of defective sample locations in a test area;
P_2	=	unacceptable proportion of defective sample locations in a test area;
α	=	the probability of rejecting an acceptable test area. (the quality of the test area is acceptable but the sample results indicate that it is unacceptable);
β	=	the probability of accepting an unacceptable test area. (the quality of the test area is unacceptable but the sample results indicate that it is acceptable).

These values, which are selected by the person designing the sampling plan, should reflect the desired precision of the test results, the importance of the tested element and the cost and delays due to sampling and testing. The consequences of a wrong decision are key

REFERENCES (6,7,8)

DEFINE ACCEPTANCE CRITERIA

P_1 = % DEFECTS ACCEPTABLE

P_2 = % DEFECTS UNACCEPTABLE

δ = % PROBABILITY OF REJECTING A TEST AREA WITH QUALITY GREATER THAN P_1

β = % PROBABILITY OF ACCEPTING A TEST AREA WITH QUALITY LESS THAN P_2

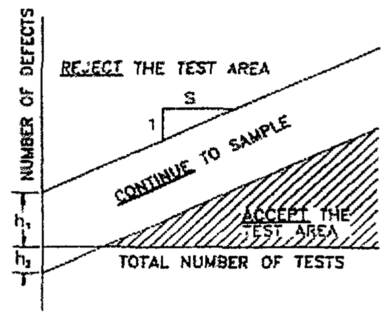
DEFINE ACCEPTANCE/REJECTION CHART

$$A = \log((P_2/P_1) \cdot ((100-P_1)/(100-P_2)))$$

$$h_1 = \log((100-\delta)/\beta)/A$$

$$h_2 = \log((100-\beta)/\delta)/A$$

$$S = \log((100-P_1)/(100-P_2))/A = \text{SLOPE}$$



EXAMPLE APPLICATION

DEFINE ACCEPTANCE CRITICAL FOR DRY DENSITY OF STRUCTURAL FILL.

ASSUMPTIONS:

$P_1=5$ $P_2=10$ $\delta=10$ $\beta=20$

$A = \log((10/5) \cdot ((100-5)/(100-10))) = 0.32$

$h_1 = \log((100-10)/20)/A = 2.04$

$h_2 = \log((100-20)/10)/A = 2.82$

$S = \log((100-5)/(100-10))/A = 0.07$

∴ MINIMUM OF 40 TESTS

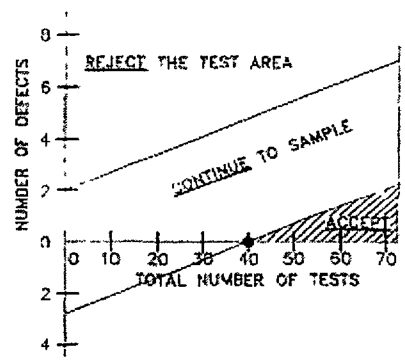


FIGURE 3-3 NUMBER OF SAMPLES-SEQUENTIAL SAMPLING

consideration when selecting these values or limits. If the constraints are too rigid, the required sample size (number) will be so large that the associated costs are prohibitive. Hence it is necessary to tradeoff up-front costs for sampling, the costs of redoing a lot rejected in error (the sample gave misleading results indicating a good lot was defective), and the costs of failing to detect a faulty lot until much time has passed. If the cost of rejecting good material is high then δ should be small. If on the other hand acceptance of inferior material is high, the typical situation for environmental materials, then β should be small.

An application of sequential sampling acceptance criteria to structural fill is given in Figure 3-3. Structural fill is an element that, while important, is less critical to the success of a waste containment system than such elements as clay or geomembrane barriers. Hence in this situation the decision maker may be willing to tolerate more defects (larger P_1 and P_2) and be less concerned about incorrect decisions (larger δ and β). If so, the number of required samples will be less than for materials which are more critical to the success of a fill. The importance of an element is reflected in the selection of the four variables required to define the acceptance chart.

Example (Figure 3-3)

The percent defects in an unacceptable fill (P_2) is assumed to be 10%. This is twice as tolerant as the criteria used in the previous example for clay liner material. The percent defects in an acceptable area (P_1) was selected as the mean of the acceptance range (<10%). Percent probabilities for accepting a defective test area (β) or rejecting an acceptable test area (δ) are selected in the example to reflect the lower importance of the structural fill. For a critical element, β will be smaller and δ could be larger since it is more important that a defective critical element not be accepted.

A minimum of 40 density tests must be performed to get acceptance of the structural fill using the sequential sampling chart developed above. If no defective density tests occur in these forty (40) tests, then the structural fill is accepted. If two (2) or more defective locations are found the lot is rejected. If one (1) defective location is found then additional sample locations must be selected and evaluated. Testing must continue until the chart indicates that the lot is acceptable or must be rejected.

3.3 Selection of Sample Locations

Field sampling strategies for selecting a single sample location may follow several sample location criteria. This is particularly true for critical elements such as the seams of geomembrane liners. The protocol for locating test samples on seams includes all of the following criteria:

For Non-Destructive Testing
- 100% Testing

For Destructive Testing
- 1 per 500 Feet (Incremental)
- Judgmental
- Minimum 1 per seam (Stratified)

Thus the sample location strategies presented in this section may be combined for a given element.

100% Sampling

In theory, determining the true quality of a product would require sampling the entire product -- which is known as 100 percent sampling. Although non-destructive testing methods can be used to sample and test all of the product or test area, this requires a significant investment of time and capital. For these reasons, a 100% sampling plan is used only to test the most critical elements in waste containment structures; the seams in the synthetic liners used in landfills, waste piles and waste ponds. Because a defect in the seam will allow a release of waste, 100% testing is considered necessary.

Since a 100% sampling plan is rigorous, the sampling and testing program should be designed to minimize inspector fatigue. A sufficient number of testing crew breaks and shift changes should be used to avoid errors in the sampling and testing program.

The 100% Sampling Plan:

Step 1 Develop a means of delineation and measurement that can be used to determine the sample locations over the entire test area. Since this a 100% sampling plan, the delineation will not be used for sample selection but will serve to ensure that all locations are tested and to locate any defective locations.

Step 2 Test the entire area or lot using a non-destructive test method (see Appendix A). Careful documentation must be made of the starting and stopping locations, material batch numbers, installation crews, and other variables that may affect the testing results. Compare the results of testing to the project specifications. All areas that do not meet the project specifications will be rejected and removed or repaired (and re-tested).

Example -- Installation of a 60-mil HPDE geomembrane liner. The 100% Sampling Plan would be implemented as follows: