United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Research and Development

EPA/600/SR-93/182 September 1995

EPA

Summary

Quality Assurance and Quality Control for Waste Containment Facilities

David E. Daniel and Robert M. Koerner

It is generally agreed that both quality assurance (QA) and quality control (QC) are essential to the proper installation and eventual performance of environmentally safe and secure waste containment systems. Even further, there are both manufacturing and construction aspects to many of the natural and synthetic materials that are involved. At issue, however, is the appropriate level of QA and QC, the specific measures to be taken, the particular test methods to be used, the frequency of these test methods and the interrelationships of the various personnel that may be involved. This technical guidance document (TGD), or "manual", has been prepared in an effort to address these issues.

The manual is not design oriented. It presumes that a separate set of plans and specifications has been, or will be, prepared for the specific site in question. Instead, the manual is focused on the preparation and necessary ingredients of a QA plan (synonymously called a QA document). This EPA technical guidance document presents information that can be used to craft a site-specific plan for QA (and QC) purposes.

The opening chapter is focused on the organizational concepts of a typical project and presents an overview of QA/QC activities. It is an updated and greatly expanded version of an earlier EPA technical guidance document on the same topic, i.e., EPA/530-SW-86-031. Following the opening chapter they are separate chapters on the specific components of waste containment systems. In the order of their presentation they are as follows:

- **compacted soil liners**
- **geomembranes**
- **geosynthetic clay liners**
- **soil drainage systems**
- **geosynthetic drainage systems**
- **vertical cutoff walls**
- **ancillary materials, appurtenances and other details**

This Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to communicate the salient points of the state of the practice for construction quality at waste containment facilities that are fully documented in a separate report of the same title (see Report ordering information at back).

Chapter 1 - Concepts and Overview

Upon defining the interrelated terms of manufacturing quality control (MQC), manufacturing quality assurance (MQA), construction quality control (CQC) and construction quality assurance (CQA), a flow chart describing the organizational structure of a typical project is presented, see Figure 1. Within this flow chart and its description are a number of contentious issues. For example, the corporate association between owner/operator, design engineer and QA organization must be kept separate so that a constant set of checks and balances can result. If such separateness is challenged the interrelations between organizations can be requested by the permitting agency. Also, the geosynthetics manufacturer/fabricator must have at least 10,000,000 ft^2 (250 acres) of experience. This may be difficult for new suppliers/installers, but the requirement is considered to be necessary. Lastly, both CQC and CQA organizations must have a minimum number and experience level of "certified" personnel on projects by Jan 1, 1996. The following

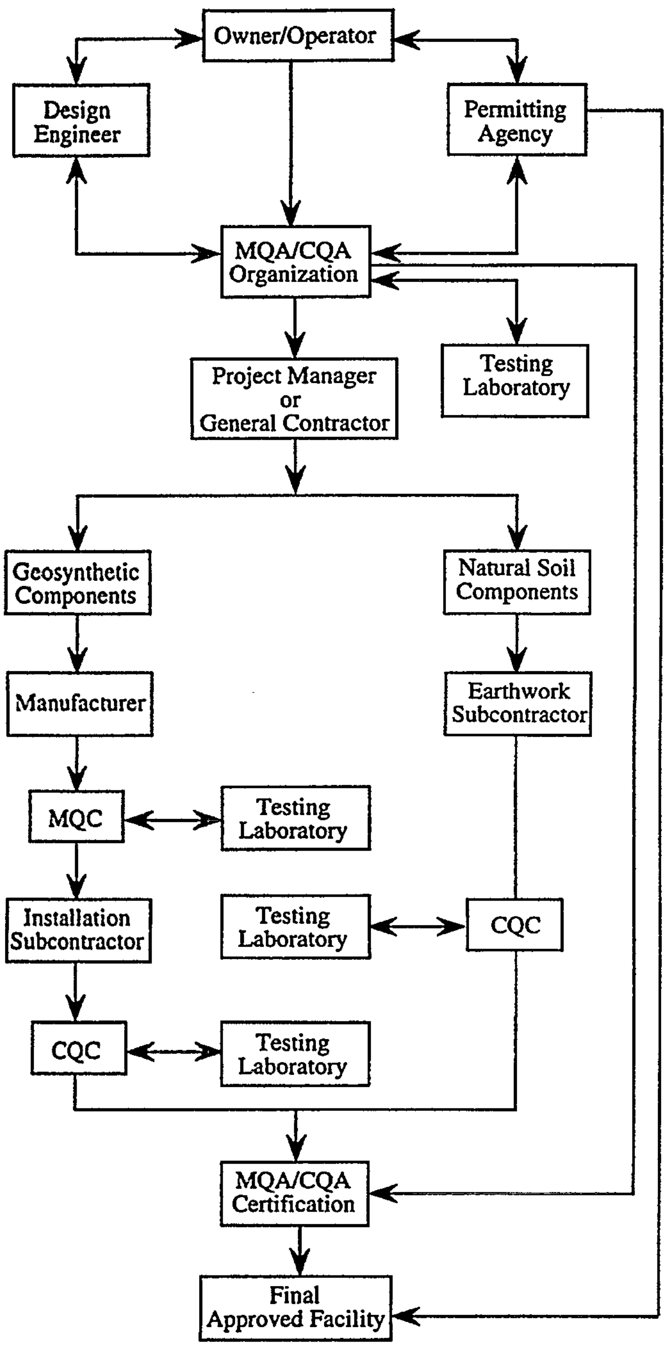


Figure 1. *Organizational structure of QA/QC inspection activities.*

schedules are recommended (Tables 1 and 2). A certification program is ongoing and is available through the National Institute for Certification in Engineering Technologies (NICET), at 1420 King Street, Alexandria, VA 22314.

Interspersed throughout the opening chapter is the critical nature of the QA plan. The chapter clarifies and elaborates upon all issues and details that are not included in the project-specific plans and specifications. As with the project plans and specifications, the QA plan is always site specific. The QA plan must be submitted to, and approved by, the regulatory agency before a construction permit is issued. The QA plan should also be available for all construction organizations (i.e., general contractor, earthwork contractor, geosynthetic manufacturer and geosynthetic installer) to review before the project is bid. This is necessary so that the level of proposed QA effort is clearly known and anticipated by all parties involved with manufacturing, construction and installation of the various materials.

Chapter 2 - Compacted Soil Liners

Compacted soil liners consist of natural clay materials or amended soil liners (usually with bentonite) to achieve the regulatory required value of the hydraulic conductivity. Generally the value must be equivalent to, or lower than, 1 X 10^{-7} cm/sec. The chapter provides detailed information concerning critical variables, field measurements, inspection of borrow services and their excavation, preprocessing of materials, placement of loose lifts, remolding and compaction, protection of the compacted soil, test pads and final approval. The critical relationship between clay soil moisture content and density are explained thoroughly as illustrated in Figures 2 and 3. Soils must be compacted at the proper water content to achieve the desired low hydraulic conductivity. For the soil illustrated in Figures 2 and 3, the optimum water content is 17%. The soil shown in Figure 2 was compacted with standard Proctor energy at a water content of 16%, which left large voids between clods of clay and which produced an unsatisfactorily large hydraulic conductivity. When the soil was wetted up to a water content of 20%, the chunks of clay were softened sufficiently to enable good remolding during compaction; hydraulic conductivity was adequately low. Specific guidance on test methods, procedures, sampling frequency, accept/reject considerations and field experiences are described throughout the chapter.

Construction guidelines are included whenever appropriate since much of the routine testing in installation of compacted soil liners is provided by the CQA personnel who must interact with the CQC personnel on a continuous basis.

Chapter 3 - Geomembranes

Geomembranes, also called flexible membrane liners (FMLs) in many state regulations, are factory manufactured synthetic liner materials made from various polymers. As such, there are both manufacturing and construction aspects to be considered. This chapter addresses the types and manufacturing of the most commonly used geomembranes. They are listed in Table 3 along with their appropriate formulations. Elements of manufacturing are described so as to develop adequate MQC/MQA protocol for geomembranes made from extrusion processes as well as calendered types.

The chapter also focuses on the construction aspects of geomembranes, i.e., CQA and CQC, insofar as proper seaming and joining is concerned. Emphasis is placed on the various field seaming methods as noted in Table 4. All types are described in a complete manner.

A complete description of seam tests (shear and peel) is presented with appropriate guidelines on sampling strategies and generally accepted minimum values. The various nondestructive test (NDT) methods given in Table 5 are addressed with detailed descriptions of each method.

Handling, storage, backfilling and covering of geomembranes are also addressed. Included in the chapter are the commonly referenced test methods, insight into the recommended test frequencies and the necessary information with which to formulate a QA plan.

Chapter 4 - Geosynthetic Clay Liners

The newest of liner, or barrier, materials are called geosynthetic clay liners (GCL's). These materials are composed of geosynthetics (either geotextiles or geomembranes) with an encapsulated or associated layer of bentonite. While the layer of bentonite is much thinner than a compacted soil liner, the hydraulic conductivity of bentonite is the lowest of any naturally occurring soil material, e.g., it typically varies from 1×10^{-9} to 5×10^{-9} cm/sec. Cross sections of the various commercially available types of GCL's are illustrated in Figure 4.

The chapter describes the type and composition of GCLs followed by salient features of the manufacturing process. Bentonite tests and their recommended frequencies are suggested. Sufficient detail as to the associated geotextiles or geomembranes are presented. This is followed by sections on handling, installation, and backfilling/covering. Included are recommended test methods for manufacturing and construction and the recommended frequency of testing for the formation of an appropriate QA plan.

Chapter 5 - Soil Drainage Layers

Both sands and gravels are utilized in waste containment facilities for leachate collection layers beneath the waste, leak detection layers between two liners beneath the waste, and for surface water drainage layers above the waste in the final cover. Thus it is necessary to include them as an essential part of a waste containment liner system.

The chapter presents an introduction, the relevant soil types, control of materials, location of borrow sources, processing of materials, placement, compaction and protection of granular drainage soils and filters. Both sands and gravels are considered. Test methods and frequencies are presented, e.g., see Table 6. Concerns are also addressed. The use of limestone sources is critiqued and some identification materials and controls are offered.

Chapter 6 - Geosynthetic Drainage Systems

So as to counterpoint the natural soil drainage and filter layers just described, this chapter presents geosynthetic drainage and filter materials. The decision to use natural soil materials or geosynthetics is a design decision and is not addressed in this manual.

Geonets are generally made from high density polyethylene (HDPE) and the typical formulation along with the variations in manufacturing are presented. Handling, storage, acceptance/conformance testing, placement, joining, and backfilling are addressed in a sequential manner.

Other types of drainage cores made from columns, prisms, cuspations (single or double), meshes and mats are also described. As with other chapters, the requisite test methods, their suggested frequencies and construction details are presented.

Insofar as geosynthetic drainage materials are concerned (i.e., they all provide for in-plane flow of leachate or water) geonets and geocomposite drainage cores have open spaces to allow the liquid to flow within them. Necessarily, they have a geotextile covering attached to their exposed surface(s). The geotextile acts as both a filter and a separator. Geotextiles are described in this chapter with respect to their resin types, formulations and manufacturing. Protection (via wrapping), handling, storage, placement, seaming and backfilling/ covering are all described. Seam types and tests, along with the relevant geotextile tests are described.

Chapter 7 - Vertical Cutoff Walls

While most of the topics discussed in this manual have the barrier material in a horizontal or gently sloped orientation, there is also a pressing need at some sites for vertical barriers. Many sites (both abandoned and newly constructed) require vertical cutoffs which are either extended into a low hydraulic conductivity layer beneath it (an aquiclude), or are deep enough to thwart underlying seepage. These cutoff walls are generally constructed using the slurry wall method and are then backfilled with a low permeability material, e.g., soil/bentonite. Figure 5 shows the concept.

The chapter progresses through an introduction, the concept of vertical cutoff walls, construction issues, various types of cutoff walls, specific CQA requirements and post construction tests to assure continuity of the completed wall against seepage losses. The inclusion of a geomembrane within the final backfill soil/ material is also described insofar as the various types available and the methods for joining the individual panels together.

Chapter 8 - Ancillary Materials, Appurtenances and Other Details

Clearly, waste containment systems are a juxtaposition of an array of elements, all of which are necessary to have an environmentally safe and secure waste containment system. Thus, the concluding chapter of the manual describes the "other" details and materials necessary to achieve the final goal of a complete waste containment system.

Included in the chapter are plastic pipe (aka "geopipe") which is used for leachate collection and removal systems, leak detection systems and peripheral drainage around the perimeter of the site for surface water removal being shed from cover systems. The pipes are made from either HDPE or PVD and both smooth wall and corrugated plastic pipe systems are in use. The types of pipe, handling and conformance testing are included in this subsection.

Sumps, manholes and risers to remove leachate and to assess leak detection are also included. Various strategies used by designers are noted with appropriate commentary. Necessary in this regard are penetrations of various barrier layers. Different types of compacted clay liner, geomembrane, and geosynthetic clay liner penetrations are presented, although the final decision and its appropriate design is obviously at the discretion of the design engineer.

Anchor trenches are illustrated with pros and cons of the various configurations.

Access ramps are critically important for below-grade waste containment facilities. Numerous problems have arisen by improper design and/or construction practices. Selected comments and precautions are given.

Geosynthetic reinforcement materials are seeing an increased use in waste containment facilities. Veneer reinforcement of leachate collection systems and cover soils represents a major need for the use of geogrids or high strength geotextiles. The growing tendency of vertical and lateral expansions of existing landfill facilities for additional waste placement also uses geogrids and high strength geotextiles. Both of these applications are illustrated in Figure 6 and are described in this subsection.

The exposed surface of the landfills and waste piles must necessarily be resistant to water and wind erosion. Thus a subsection on the use of geosynthetic erosion control systems is included.

Lastly, the use of geomembranes as floating covers for surface impoundments is included in the manual. Details of their installation and inspection are included.

In conclusion, this technical guidance document (or "manual") addresses QC and QA for all facets of the individual components of a waste containment system for landfills, surface impoundments and waste piles. Not only are the liner and cover systems addressed, but vertical barriers as well. Note that the QA plan is not written in a "cook book" fashion since the final QA plan is clearly site specific and material specific. However, the essential items for a successful QA plan are presented and with judicious use of the manual, coupled with the experience of the designer and CQA organization, a proper QA plan can be written.

Accompanying this technical guidance document are numerous references, most of which are EPA manuals or ASTM test methods. The EPA manuals are available either from the Agency or NTIS. To assist the reader in gathering the various test methods, a companion document published by the American Society of Testing and Materials (ASTM) is available which reprints all of the test methods referenced in the manual. Included are 79 separate ASTM test methods and 10 additional referenced test methods by other standardization group.

Footnotes:

1. This EPA manual is available from NTIS at a cost of $44.50 each. The NTIS Number is PB94-159100.
2. The companion document of 89 test methods referenced in the manual is available from ASTM for $77.00. The ASTM member price is $69.00. The ASTM Pub lication Code Number (PCN) is 03-435193-38.
3. An expanded and somewhat modified version of the manual is available from ASCE Sales De partment at the list price of $48.00 and the ASCE member price of $36.00.

Table 1. *Recommended Implementation Program for Construction Quality Control (CQC) of Geosynthetics* (Beginning Jan 1, 1993)*

No. of Field Crews** At Each Site	End of 18 Mo (i.e., June 30, 1994)	End of 36 Mo (i.e, Jan 1, 1996)
1-4	1 - Level II	1 - Level III***
≥ 5	1 - Level II 2 - Level I	1 - Level III*** 1 - Level I

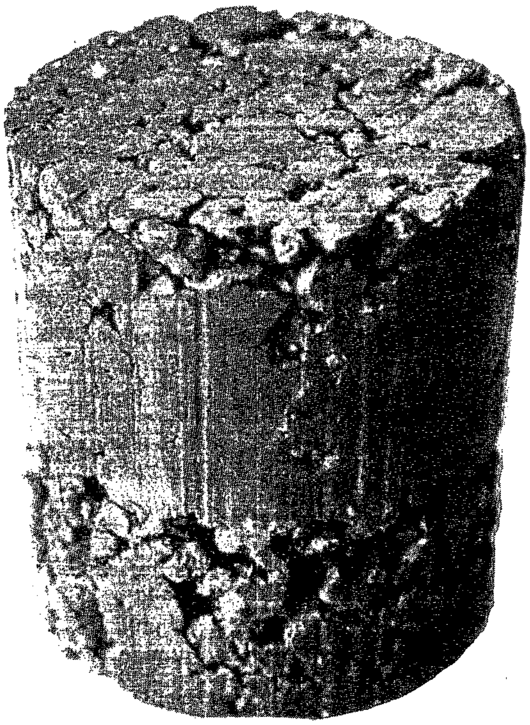
Table 2. *Recommended Implementation Program for Construction Quality Control (CQA) of Geosynthetics* (Beginning Jan 1, 1993)*

No. of Field Crews** At Each Site	End of 18 Mo (i.e., June 30, 1994)	End of 36 Mo (i.e, Jan 1, 1996)
1-2	1 - Level II	1 - Level III***
3-4	1 - Level II 1 - Level I	1 - Level III*** 1- Level I
≥5	1 - Level II 2 - Level I	1 - Level III*** 1 - Level II 1 - Level I

* Certification for natural materials is under development as of this writing.
** Performing a Critical Operation; Typically 4 to 6 People/Crew.
*** Or PE with applicable experience.

Table 3. *Types of Commonly Used Geomembranes and Their Approximate Weight Percentage Formulations**

Geomembrane Type	Resin	Plasticizer	Filter	Carbon Black or Pigment	Additives
HDPE	95-98	0	0	2-3	0.25-1.0
VLDPE	94-96	0	0	2-3	1-4
Other Extruded Types	95-98	0	0	2-3	1-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE-R	40-60	0	40-50	5-40	5-15
Other Calendered Types	40-97	0-30	0-50	2-30	0-7



16 %

STANDARD PROCTOR

Figure 2. Photograph of highly plastic clay compacted with standard proctor effort at a water content of 16% (1% dry of optimum).

20 %

STANDARD PROCTOR

Figure 3. Photograph of highly plastic clay compacted with standard proctor effort at a water content of 20% (3% wet of optimum).

Table 4. *Possible Field Seaming Methods for Various Geomembranes Listed in this Manual*

Type of Seaming Method	Type of Geomembrane					
	HDPE	VLDPE	Other PE	PVC	CSPE-R	Other Flexible
extrusion (fillet and flat)	A	A	A	n/a	n/a	A
thermal fusion (hot wedge and hot air)	A	A	A	A	A	A
chemical (chemical and bodied chemical)n/a	n/a	n/a	A	A	A	
adhesive (chemical and contact)	n/a	n/a	n/a	A	A	A

Note: A = applicable; n/a = not applicable

Table 5. *Applicability of Various Nondestructive Test Methods to Different Seam Types and Geomembrane Types*

NDT Method	Seam Types*	Geomembrane Types
1. air lance	C, BC, Chem A, Cont. A	all except HDPE
2. mechanical point stress	all	all
3. dual seam	HW, HA	all
4. vacuum chamber	all	all
5. electric wire	all	all
6. electric current	all	all
7. ultrasonic pulse echo	HW, HA C, BC, Chem. A, Cont. A	HDPE, VLDPE, PVC
8. ultrasonic impedance	HW, HA C, BC, Chem. A, Cont. A	HDPE, VLDPE, PVC
9. ultrasonic shadow	E Fil., E Flt., HW, HA	HDPE, VLDPE

* E Fil. = extrusion fillet
E Flt. = extrusion flat
HW = hot wedge
HA = hot air
C = chemical
BC = bodied chemical
Chem. A = chemical adhesive
Cont. A = contact adhesive

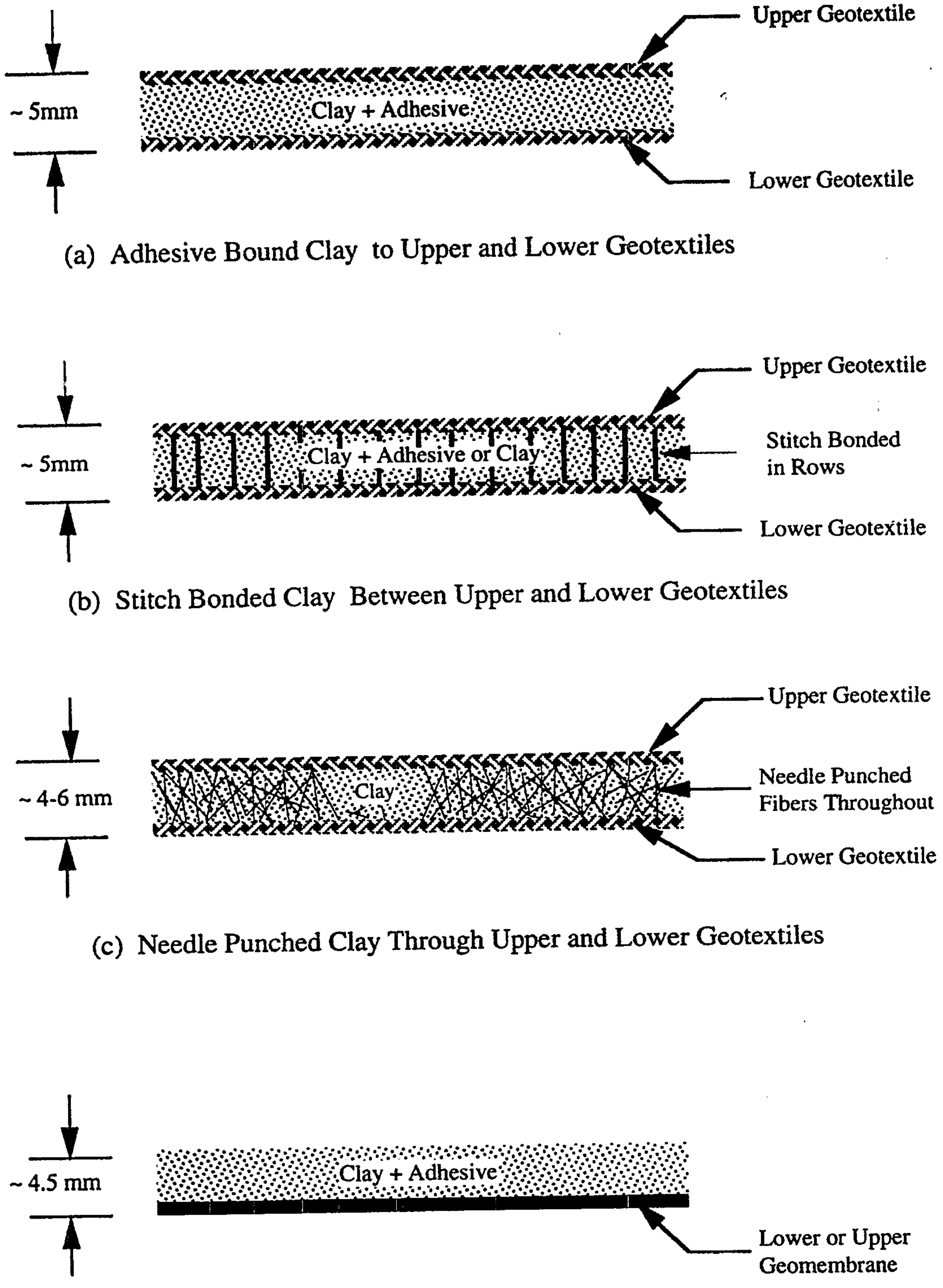


Figure 4. *Cross section sketches of currently available geosynthetic clay liners (GCLs).*

Table 6. *Recommended Tests and Testing Frequencies for Soil Drainage Materials*

Location of Sample	*Type of Test*	*Minimum Frequency*
Potential Borrow Source	*Grain Size (ASTM D-422)*	*2500 yd³*
	Hydraulic Conductivity (ASTM D-2434)	*2500 yd³*
	Carbonate Content (ASTM D-4373)*	*2500 yd³*
Onsite; After Placement and Compaction	*Grain Size (ASTM D-422)*	*1 per Hectare for Drainage Layers; 1 per 650 yd³ for Other Uses*
	Hydraulic Conductivity (ASTM D-2434)	*1 per Hectare for Drainage Layers; 1 per 650 yd³ for Other Uses*
	Carbonate Content (ASTM D-4373)*	*1 per 2500 yd³*

** The frequency of carbonate content testing should be greatly reduced to 1 per 25,000 yd³ for those drainage materials that obviously do not and cannot contain significant carbonates (e.g., crushed basalt).*

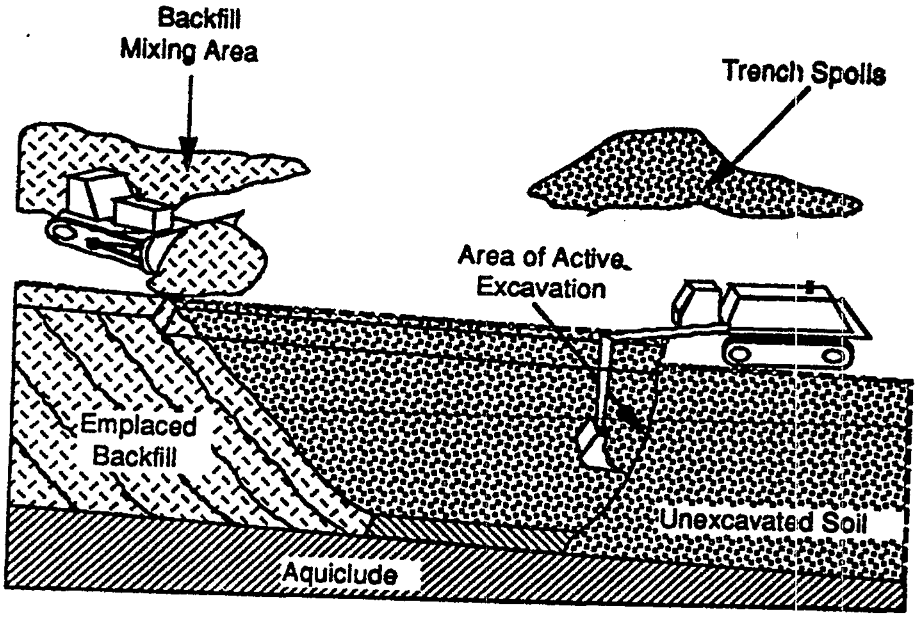
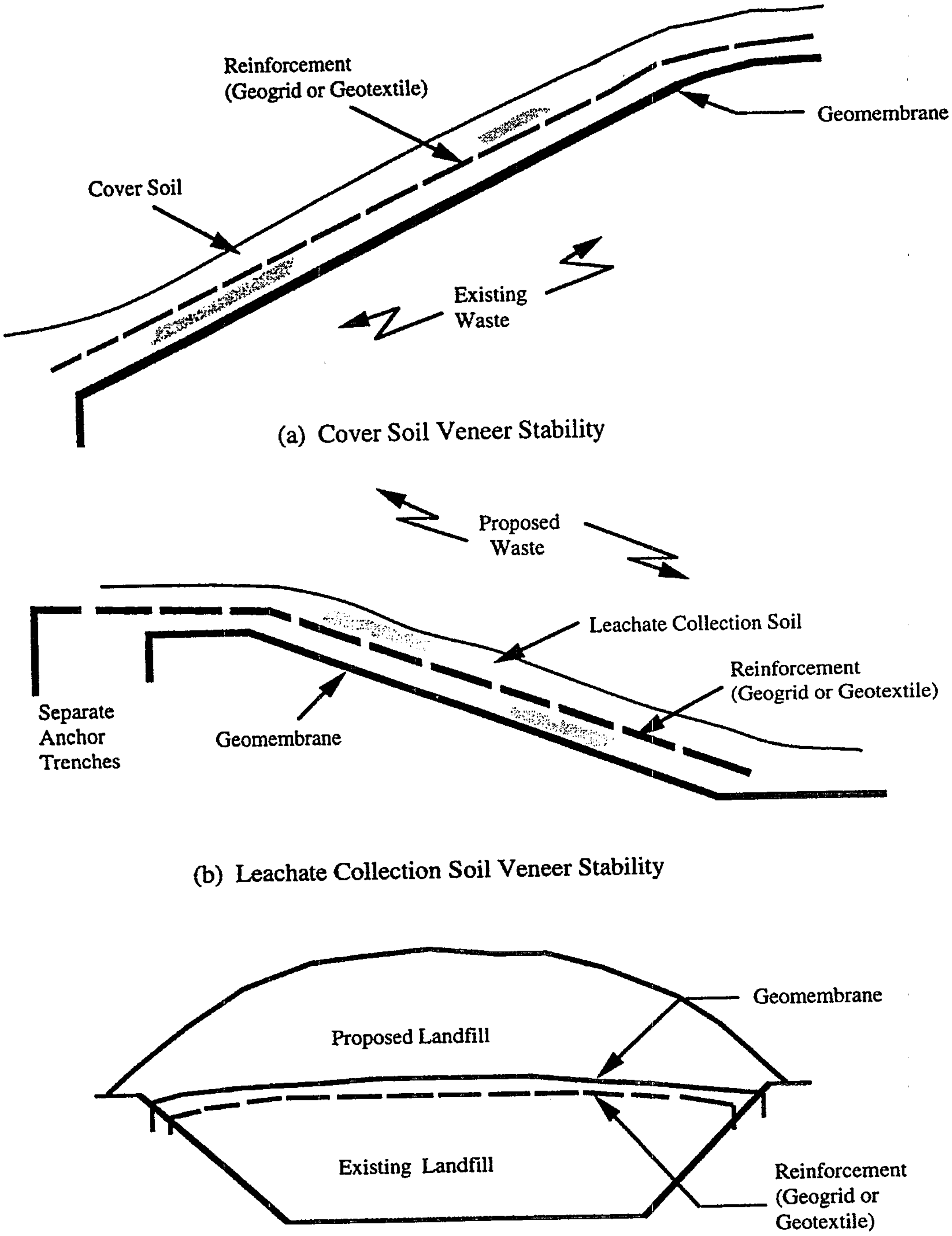


Figure 5. *Diagram of construction process for soil-bentonite-backfilled slurry trench cutoff wall.*



(a) Cover Soil Veneer Stability

(b) Leachate Collection Soil Veneer Stability

(c) Liner System Reinforcement for "Piggy backing"

Figure 6. *Geogrid or geotextile reinforcement of (a) cover soil above waste, (b) leachate collection layer beneath waste, and (c) liner system placed above existing waste ("Piggybacking").*

David E. Daniel is with the University of Texas at Austin, Department of Civil Engineering, Austin, TX 78712.
Robert M. Koerner is with Drexel University's Geosynthetic Research Institute, Philadelphia, PA 19104.
***David Carson** is the EPA Project Officer (see below).*
The complete report, entitled "Quality Assurance and Quality Control for Waste Containment Facilities," (EPA/600/R-93/182); (Order No. PB94-159 100AS; Cost: $44.50, subject to change) is available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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U.S. Environmental Protection Agency
Cincinnati, OH 45268

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