Geosynthetic Institute
475 Kedron Avenue
Folsom, PA 19033-1208 USA
TEL (610) 522-8440
FAX (610) 522-8441

GSI White Paper #26

Need for and Justification of Quality Management Systems for Successful Geosynthetic Performance

by

Robert M. Koerner, Ph.D., P.E., NAE
Director Emeritus – Geosynthetic Institute
Professor Emeritus – Drexel University
610-522-8440
robert.koerner@coe.drexel.edu

George Koerner, Ph.D., P.E., CQA
Director
Geosynthetic Institute
610-522-8440
gkoerner@dca.net

October 22, 2012

GSI White Paper #26

Need for Justification of Quality Management Systems for Successful Geosynthetic Performance

Table of Contents

GSI White Paper #26

Need for and Justification of Quality Management Systems for Successful Geosynthetic Performance

by
Robert M. Koerner and George R. Koerner
Geosynthetic Institute

1. Selected Areas of Unsuccessful Geosynthetic Field Performance

To be sure, there are countless geosynthetic and geosynthetic system projects that have been successfully accomplished over the past 30+ years. The literature is abundant with case-after-case of successful applications. Yet, there have been individual failures and even groupings of failures that are known to exist. In this regard, three groups of geosynthetic field failures follow which will hopefully set the stage for the justification of quality management systems.

1.1 Holes in Geomembranes

Using the electrical leak location survey (ELLS) method, Nosko and Touze-Foltz (2000) have located over 4000 holes in field deployed geomembranes. They were from 16 countries, more than 300 sites and approximately 3,250,000 m^2 of installed geomembrane. They report on the position of the geomembrane damage (Figure 1 and Table 1) along with the size of the damage and its causes; see Table 2.

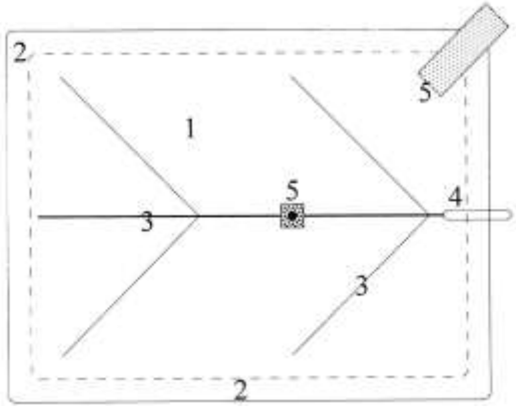


Figure 1 - Plan view of landfill with the positioning of damages.

Table 1 – Location of Damage

Amount of Damage	Flat Floor 1	Corner, Edge, etc. 2	Under a Drainage Pipe 3	Pipe Penetration 4	Other 5**
4194 100%	3261 77.8%	395 9.4%	165 3.9%	84 2.0%	289 6.9%

Table 2 – Cause of Damage vs. Size of Damage

Size of Damage (cm^2)	Stones	%	Heavy Equip-ment	%	Welds	%	Cuts	%	Worker Directly	%	Total
<0.5	332	11.1	-	-	115	43.4	5	8.5	-	-	452
0.5-2.0	1720	57.6	41	6.3	105	39.6	36	61.0	195	84.4	2097
2.0-10	843	28.2	117	17.9	30	11.3	18	30.5	36	15.6	1044
>10	90	3.0	496	75.8	15	5.7	-	-	-	-	601
Amount	2985		654		265		59		231		4194
Total	71.17%		15.59%		6.32%		1.41%		5.15%		100%

Here it is seen that stones above or below the geomembrane are the main cause, but there are others as well. Nosko and Touze-Foltz go further and estimate the rate of liquid flow due to such holes in the liner material. Others have done likewise in what can only be called an unacceptable situation insofar as leakage is concerned.

1.2 Geotextile Filter Failures

Koerner and Koerner (2008, 2012) report on seventy geotextile filter failures of which forty-one are taken from the literature, seventeen from the authors published papers, and twelve from published investigations by the authors. Of course, soil filters (usually of sand and/or gravel) can also be problematic and have been reported in the literature as well. In fact, the exact same challenging field conditions for geotextile filters also effects soil filters. Focus here, however, is only on geotextile filters.

Regarding design, the geotextile literature is quite abundant yet problems persist. Four situations of inadequate design are as follows:

- Poor fabric selection highlighted by the inadvisable use of woven silt film fabrics.
- Poor fabric design illustrated by excessive upstream coverage of geotextiles.
- Geotextile wrapped, or socked drainage pipe.
- Reversing flow conditions wherein the water is alternating its flow across the geotextile.

Regarding soil problems, four situations of difficult and challenging atypical soils are as follows:

- Cohesionless fine grained soils like rock flour, cohesionless silts, and fly ash.
- Gap-graded cohesionless soils present a similar challenge as above, however, only the fine fraction becomes mobile leaving the coarse fraction remaining in the upstream soil.
- Dispersive clays where the individual particles become fugitive.
- A major threat to geotextile filters is ferrous iron soils leading to the formation of *ochre*. It is very problematic insofar as excessive clogging is concerned.

Regarding problems with liquid permeants other than water, five types of atypical liquids are as follows:

- Oily waters and sludges have resulted in excessive clogging.
- Turbid waters with high suspended solids, mainly from dredging operations, have resulted in excessive geotextile filter clogging.
- High alkalinity water has resulted in excessive clogging.
- Landfill leachate from municipal solid wastes are often high in both suspended solids and microorganisms. A relatively large number of case histories were presented.
- Wastewater and agricultural waste liquids represent the highest bacterial count of all possible liquids and have resulted in excessive clogging.

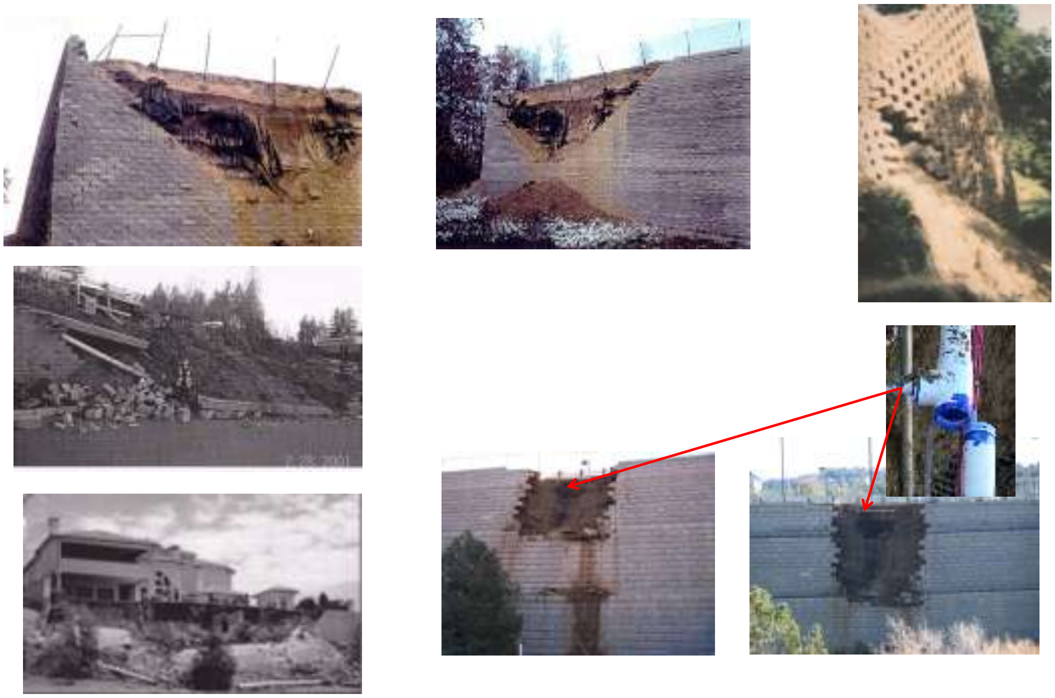
Regarding field installation, which should be quite straightforward, there are problems that have nevertheless occurred. They are the following:

- By far the greatest number of field installation problems have occurred from lack of intimate contact of the upstream soil against the geotextile filter
- Glued or blocked geotextiles have occurred, one so severe that it caused a bridge abutment failure and distortion of the superstructure.

1.3 MSE Wall Failures

Over the years, GSI has collected a data base of mechanically stabilized earth (MSE) wall failures. From 26 failures in 2001 (Koerner and Soong), to 82 failures in 2009 (GSI Report #38), to 141 failures in 2012 (Koerner and Koerner) the situation is felt to be unacceptable. The current data base of failed MSE walls and geosynthetic reinforcement consists of 34 cases of excessive deformation and 107 cases of actual collapse; see Figures 2a and 2b, respectively.

(a) Cases of Excessive Deformation



(b) Cases of Wall Collapse

Figure 2 – Two basic categories of MSE wall failures.

The main statistical findings are as follows:

1. all but one were privately (as opposed to publically) financed walls
2. 72% were in North America
3. 68% were masonry block faced (i.e., they are also called SRWs)
4. 49% were 4 to 8 m high
5. 90% were geogrid reinforced (the other 10% were geotextile reinforced)
6. 81% failed in less than four years
7. 62% used silt and/or clay backfill in the reinforced soil zone
8. 75% had poor to moderate compaction
9. 98% were caused by improper design or construction [incidentally, none (0%) were caused by geosynthetic manufacturing failures]
10. 58% were caused by internal or external water (the remaining 42% were caused by internal or external soil related issues)

In addition to presenting this factual data, the following areas are felt to be at the core of why so many of these structures are exhibiting problems:

- Fine grained soils being used as the reinforced zone backfill
- Poor placement and compaction of fine grained backfill soils
- Drainage systems not being used with fine grained soil backfill
- Inadequate surface water control

- Improperly assessed or understood design details

Concern over the situation has prompted the creation of an inspector's certification program expressly for MSE walls, berms and slopes using geosynthetic reinforcement.

2. Overview of Quality Management Systems (from Wikipedia)

A quality management system (QMS) can be expressed as the organizational structure, procedures, processes and resources needed to implement quality management. Early systems emphasized predictable outcomes of an industrial product production line, using simple statistics and random sampling. By the 20th century, labor inputs were typically the most costly inputs in most industrialized societies, so focus shifted to team cooperation and dynamics, especially the early signaling of problems via a continuous improvement cycle. In the 21st century, QMS has tended to converge with sustainability and transparency initiatives, as both investor and customer satisfaction and perceived quality is increasingly tied to these factors. The elements of a quality management system are as follows:

1. Organizational structure
2. Responsibilities
3. Data Management
4. Processes - including purchasing
5. Resources - including natural resources and human capital
6. Customer Satisfaction
7. Continuous Improvement
8. Product Quality
9. Maintenance
10. Sustainability - including efficient resource use and responsible environmental operations
11. Transparency and independent audits

The concept of quality (in a modern sense) first emerged out of the Industrial Revolution. Previously goods had been made from start to finish by the same person or team of people, with handcrafting and tweaking the product to meet 'quality criteria'. Mass production brought huge teams of people together to work on specific stages of production where one person would not necessarily complete a product from start to finish. In the late 19th century pioneers such as Frederick Winslow Taylor and Henry Ford recognized the limitations of the methods being used in mass production at the time and the subsequent varying quality of output. Birland established Quality Departments to oversee the quality of production and rectifying of errors, and Ford emphasized standardization of design and component standards to ensure a standard product was produced. Management of quality was the responsibility of the Quality department and was implemented by Inspection of product output to 'catch' defects.

Application of statistical control came later as a result of World War production methods, and were advanced by the work done of W. Edwards Deming, a statistician, after whom the Deming Prize for quality is named. Joseph M. Juran focused more on managing for quality. The first edition of Juran's Quality Control Handbook was published in 1951. He also developed the

"Juran's trilogy," an approach to cross-functional management that is composed of three managerial processes: quality planning, quality control and quality improvement. These functions all play a vital role when evaluating quality.

Quality, as a profession and the managerial process associated with the quality function, was introduced during the second-half of the 20th century, and has evolved since then. Over this period, few other disciplines have seen as many changes as the quality profession.

The quality profession grew from simple control, to engineering, to systems engineering. Quality control activities were predominant in the 1940s, 1950s, and 1960s. The 1970s were an era of quality engineering and the 1990s saw quality systems as an emerging field. Like medicine, accounting, and engineering, quality has achieved status as a recognized profession.

3. ISO 9000 and ISO 14,000 (from Wikipedia)

The ISO 9000 family of standards is related to quality management systems and designed to help organizations ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to the product. The standards are published by ISO, the International Organization for Standardization, and available through National standards bodies. ISO 9000 deals with the fundamentals of quality management systems, including the eight management principles on which the family of standards is based. ISO 9001 deals with the requirements that organizations wishing to meet the standard have to fulfill.

Third party certification bodies provide independent confirmation that organizations meet the requirements of ISO 9001. Over a million organizations worldwide are independently certified, making ISO 9001 one of the most widely used management tools in the world today. Despite widespread use, however, the ISO certification process has been criticized as being wasteful and not being useful for all organizations.

The growth in ISO 9001 certification is shown in Table 3. The worldwide total of ISO 9001 certificates can be found in the ISO Surveys of 9001 in 2003, 2007, 2008, 2009 and 2010.

In recent years there has been a rapid growth in China, which now accounts for approximately a quarter of the global certifications.

Table 3 - Top 10 Countries for ISO 9001 Certificates as of 2009

Rank	Country	No. of Certificates
1	China	257,076
2	Italy	130,066
3	Japan	68,484
4	Spain	59,576
5	Russian Federation	53,153
6	Germany	47,156
7	United Kingdom	41,193
8	India	37,493
9	USA	28,935
10	Republic of Korea	23,400

A summary of ISO 9001 content in informal language is as follows:

- The quality policy is a formal statement from management, closely linked to the business and marketing plan and to customer needs.
- The quality policy is understood and followed at all levels and by all employees. Each employee works towards measurable objectives.
- The business makes decisions about the quality system based on recorded data.
- The quality system is regularly audited and evaluated for conformance and effectiveness.
- Records show how and where raw materials and products were processed to allow products and problems to be traced to the source.
- The business determines customer requirements.
- The business has created systems for communicating with customers about product information, inquiries, contracts, orders, feedback, and complaints.
- When developing new products, the business plans the stages of development, with appropriate testing at each stage. It tests and documents whether the product meets design requirements, regulatory requirements, and user needs.
- The business regularly reviews performance through internal audits and meetings. The business determines whether the quality system is working and what improvements can be made. It has a documented procedure for internal audits.
- The business deals with past problems and potential problems. It keeps records of these activities and the resulting decisions, and monitors their effectiveness.
- The business has documented procedures for dealing with actual and potential nonconformances (problems involving suppliers, customers, or internal problems).
- The business:

    - makes sure no one uses a bad product,
    - determines what to do with a bad product,
    - deals with the root cause of problems, and
    - keeps records to use as a tool to improve the system.

ISO 14000 is a family of standards related to environmental management that exists to help organizations (a) minimize how their operations (processes etc.) negatively affect the environment (i.e. cause adverse changes to air, water, or land); (b) comply with applicable laws, regulations, and other environmentally oriented requirements, and (c) continually improve in the above.

ISO 14000 is similar to ISO 9000 quality management in that both pertain to the process of how a product is produced, rather than to the product itself. As with ISO 9000, certification is performed by third-party organizations rather than being awarded by ISO directly. The ISO 19011 audit standard applies when auditing for both 9000 and 14000 compliance at once.

The requirements of ISO 14000 are an integral part of the European Union‘s Eco-Management and Audit Scheme (EMAS). EMAS‘s structure and material requirements are more demanding, foremost concerning performance improvement, legal compliance and reporting duties.

It is important to note that both ISO 9000 and ISO 14,000 have many detractors, see Wikipedia under this heading. Perhaps most significantly from the authors perspective is that ISO auditors have little, or no expertise in the subject area that they are auditing. In short, their objective is to verify that a quality program (aka, the paperwork) is documented and followed accordingly. It is not focused on a quality product, per se, since the auditors are not expected to have expertise in assessing the idiosyncrasies of the product or its performance. While the ISO 9000 and ISO 14,000 certifications are noteworthy objectives they come at a very high financial cost.

4. CE Marking (from Wikipedia)

CE marking became legal in 1993 as being a mandatory conformity mark for products used in the European Economic Area (EEA). With this mark the manufacturer assures that the product conforms with the essential requirements of the applicable EC directives. This applies to products also made in other countries and then sold into the EEA. The self-certification process consists of the following stages:

- Identify the applicable directive(s)
- Identify the applicable requirements of the directive(s)
- Identify an appropriate route to conformity
- Assess the product’s conformity
- Complete the technical documentation
- Make a declaration and affix the CE mark

Controlling CE marked products is the responsibility of public authorities in the Member States, in cooperation with the European Commission. Citizens may contact national market surveillance authorities if the misuse of the CE marking is suspected or if a product’s safety is questioned.

5. Permitting Agencies and Engineering Licensure

All of the previous sections of this white paper dealt with self-imposed quality of products and services. There are, however, certain areas and applications where government agencies (federal, state and local) have been legally required to review and permit products, designs and installations. These include the following which directly interface with geosynthetics and geosynthetic systems.

- Environmental protection such as landfills, surface impoundments, groundwater pollution, air pollution, etc.
- Transportation facilities such as roads, railroads, walls, slopes, foundations, drainage systems, etc.
- Hydraulic structures such as dams, canals, tunnels, pipelines, etc.
- Oil and gas extraction and transportation such as water storage, wastewater storage and disposal, drill cuttings disposal, secondary containment, drill pad contamination, pipeline safety, etc.
- Coal production, usage and disposal such as deep mine and open pit safety, tailings (spoil) disposal, coal combustion residual disposal, final closure of disposed materials, etc.
- Agriculture and aquaculture such as animal waste disposal, pond liners for fresh water and waste water, containment of fish at various stages, etc.
- Treated waste water and sewage biosolids containment, usage and/or disposal

In order to grasp the involvement of permitting agencies in just one of these areas, we select worldwide federal agency regulations on landfill liners and covers. Taken from GRI Report No. 34 we find that there are regulations for landfill liners and covers in 35 different countries including the European Union (EU). There are four countries (Australia, Canada, China, and the USA) that regulate from the territorial, provincial, or state level. This adds an additional 67 regulations. Note that the 50-USA states are in a separate report (GRI Report No. 32); thus the total listed below is 52 national sets of regulations. The materials being landfilled in the containment systems of concern fall into one of three categories: hazardous solid waste (HSW), municipal solid waste (MSW), and inert solid waste (ISW). The latter is often considered to be construction and demolition (C&D) waste. All have containment systems consisting of barrier layers [geomembranes (GMs), compacted clay liners (CCLs), and/or geosynthetic clay liners (GCLs)] and drainage layers [sands, gravels, and/or geosynthetics, such as geonets (GNs) and geocomposites (GCs)]. These containment systems are located both beneath and above the waste mass. The essential findings are captured in the following two tables.

Table 4 – Various Worldwide Types of Regulated Liner and Cover Barrier Systems
(Based on a Total of 52 Countries)

(a) Liner Composition Beneath Waste Mass

Type of Waste	CCL Alone	GM Alone	GM/CCL Composite	Not Designated
Hazardous Waste (HSW)	1 (2%)	0 (0%)	34 (65%)	17 (33%)
Municipal Waste (MSW)	9 (17%)	3 (6%)	32 (62%)	8 (15%)
Inert Waste (ISW) (i.e., C&D Waste)	2 (4%)	1 (2%)	21 (40%)	28 (54%)

(b) Final Cover Liner Above Waste Mass

Type of Waste	CCL Alone	GM Alone	GM/CCL Composite	Not Designated
Hazardous Waste (HSW)	7 (14%)	1 (2%)	23 (44%)	21 (40%)
Municipal Waste (MSW)	34 (65%)	2 (4%)	4 (8%)	12 (23%)
Inert Waste (ISW) (i.e., C&D Waste)	2 (4%)	0 (0%)	0 (0%)	50 (96%)

Table 5 – Various Worldwide Types of Liner and Cover Regulated Drainage Systems
(Based on a Total of 52 Countries)

Type of Waste	Base Drainage			Cover Venting	Cover Drainage		
	Required	Thickness	Permeability	Required	Required	Thickness	Permeability
Hazardous Waste (HSW)	38 (73%)	29 (56%)	11 (21%)	3 (6%)	33 (63%)	22 (44%)	4 (10%)
Municipal Waste (MSW)	48 (92%)	33 (63%)	10 (19%)	38 (72%)	27 (71%)	27 (52%)	4 (8%)
Inert (C&D) Waste (ISW)	10 (19%)	4 (8%)	4 (8%)	0 (0%)	4 (8%)	not stipulated	

Coupled with federal, state or local regulations (such as just described) comes *professional engineering licensure*. It is established by various jurisdictions of the world to protect the safety, well-being and other interests of the general public. Also, it is to define the licensure process through which an engineer becomes authorized to provide professional services to the public. Regulations may require that only a licensed engineer can sign, seal or stamp technical documentation such as reports, drawings, and calculations for a study, estimate, valuation, or carry out design analysis or supervision of engineering works. Worldwide it is a widely varied process but usually consists of the following four requirements:

- Graduate with a degree from an Accreditation Board for Engineering and Technology accredited four-year university program in engineering, e.g., BS (Engg)/BSE/MS (Engg)/MSE Degree approved by ABET
- Complete a standard Fundamental of Engineering (FE) written examination, which tests applicants on breadth of understanding of basic engineering principles, and optionally some elements of an engineering specialty. Completion of the first two steps typically qualifies for certification in the U.S. as an Engineer-In-Training (EIT), sometimes also called an Engineer Intern (EI).
- Accumulate a certain amount of engineering experience. In most countries the requirement is four years, but in others the requirement is lower.
- Complete a written Principles and Practice in Engineering (PE) examination, testing the applicant's knowledge and skills in a chosen engineering discipline (civil, electrical, industrial, mechanical, etc.), as well as engineering ethics.

In order to maintain one's professional engineering license, ongoing and continued education is becoming necessary in many countries. It is an annual requirement which is reviewed by the licensing body for which it is granted, i.e., federal, state or local review board. It should be noted that within the ethics criteria mentioned above an engineer should not take a commission unless the requisite knowledge is known and understood. This is felt to be a limitation by many PE's insofar as geosynthetics design is concerned.

6. Geosynthetic-Specific Quality Activities

While this white paper has thus-far viewed quality management systems for a multitude of manufactured products the emphasis now shifts entirely to geosynthetics and geosynthetic systems.

6.1 Generic Geosynthetic Specifications

There is hardly a producer of geosynthetic materials that does not have an accompanying proprietary specification for their manufactured products. While this is to be expected and they are generally credible, most owners and purchasers require a generic specification. Such generic specifications encompass a class of products which are approximately equivalent to one another and can often be considered "or equal". Of course, unique characteristics and attributes are sometimes important and must be evaluated accordingly on a site-specific basis.

Geosynthetic materials specifications for geotextiles began with the U.S. Army Corps of Engineers in 1972. They were followed by those of the Federal Highway Administration and then the American Association of State Highway and Transportation Officials which resulted in the currently widely used AASHTO M288 specification. In this specification, six different common geotextile applications are included.

Regarding geomembranes, the U. S. Environmental Protection Agency commissioned the National Sanitation Foundation to develop specifications in 1983. The NSF No. 54 document listed nine geomembrane types which had revisions in 1985, 1990, and 1991 but all were discontinued (aka, depreciated) shortly thereafter. The Geosynthetic Institute, through its research arm, the Geosynthetic Research Institute (GRI), began its generic specification efforts in 1992. The process as it evolved over time is as follows:

- need is expressed by the members
- initial discussion is held within the related focus group
- development of a draft table of test methods, minimum properties and testing frequency
- intense discussion with the focus group
- addition of text to the agreed-upon tables
- more discussion within the focus group
- the draft specification is sent to all members
- the reviewed draft comes back to the focus group for modification as appropriate
- one last iteration takes place and then we daylight the original on our website
- the specification is revised and maintained on a regular basis

To date, the following is the progress of the GRI generic specifications in this regard:

Completed, Available and Regularly Updated

GM13 – HDPE Geomembranes (smooth and textured)
GM17 – LLDPE Geomembranes (smooth and textured)
GM18 – fPP and fPP-R Geomembranes
GM21 – EPDM and EPDM-R Geomembranes
GM22 – Exposed Temporary Covers
GM25 – LLDPE-R Geomembranes
GM19 – Geomembrane Seams (HDPE, LLDPE, fPP)
GT10 – Geotextile Tubes
GT12 – Geotextile Cushions
GT13 – Geotextile Separators
GCL3 – Geosynthetic Clay Liners

Working Within Focus Group

GTXX – Turf Reinforcement Mats

Delayed or Off in the Distance

GGXX – Bidirectional Geogrids
GGXX – Unidirectional Geogrids
GNXX – Geonet Drainage Composites
GCXX – Other Drainage Geocomposites
GSXX – High Strength Reinforcement Geotextiles

These specifications reference ASTM, ISO or GRI test methods and many have seen worldwide use and translation, particularly GRI-GM13 and GRI-GM17.

6.2 Geosynthetic Test Laboratory Accreditation

The Geosynthetic Accreditation Institute's (GAI) mission is focused on a Laboratory Accreditation Program (LAP) for geosynthetic test methods. The GAI-LAP was developed for accrediting geosynthetic testing laboratories on a test-by-test basis. GAI-LAP suggests that laboratories use ISO 17025 as their quality system model. In addition, the program uses the GSI laboratory as the reference test lab and operates as an ISO 17011 enterprise. In short, this means that the GSI laboratory does not conduct outside commercial testing.

It should also be made clear that GAI-LAP does not profess to offer ISO certification, nor does it "certify" laboratory results. The GAI-LAP provides accreditation to laboratories showing compliance with equipment and documentation for specific standard test methods such as ASTM, ISO or GRI standards. In addition, GAI-LAP verifies that an effective quality system exists at accredited laboratories by way of proficiency testing.

The process is described in the following flow chart:

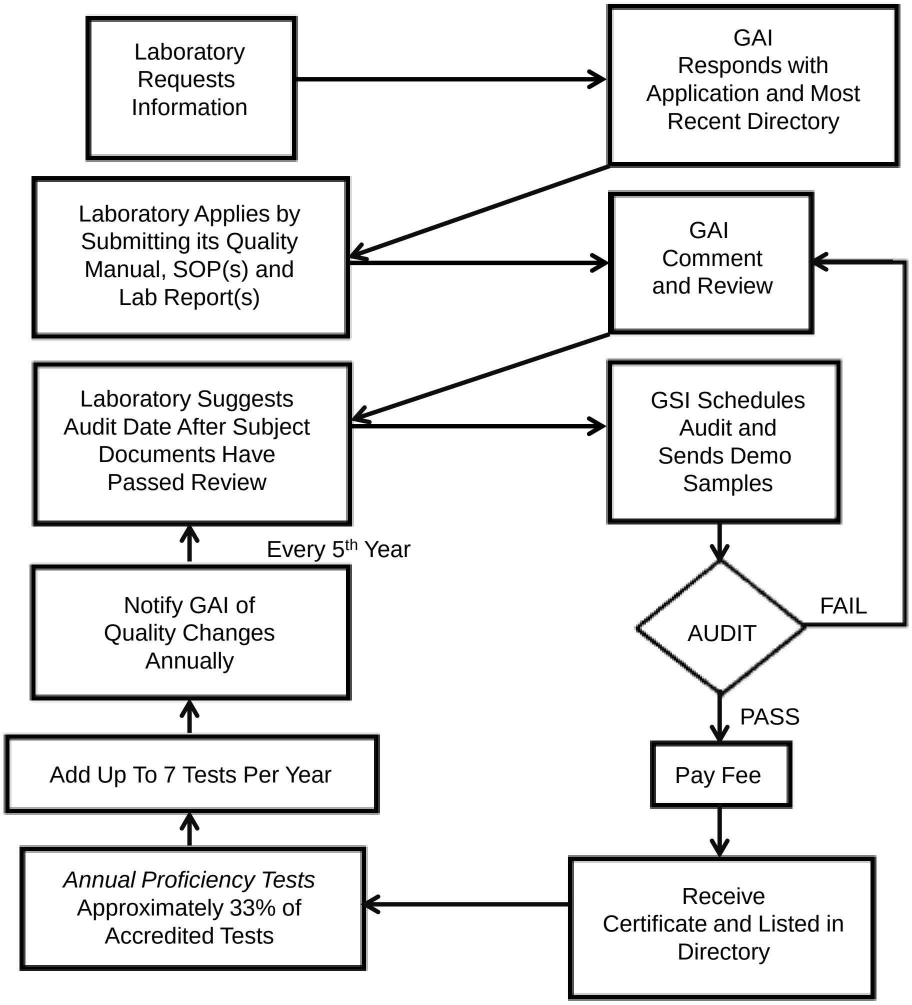


Figure 3 – Flow chart for the GAI-LAP process.

Presently, there are 230 GAI-LAP test methods available for accreditation. Please consult our home page at www.geosynthetic-institute.org for a current listing.

The program currently has 51 participating laboratories:

- independent test laboratories = 17
- manufacturers QC laboratories = 29
- institutional centers = 5

There were 1821 proficiency tests conducted in 2012 with only seven first submittal outliers. The ultimate goal of the program is to have all laboratory tests with a $c_v \leq 5\%$. The value of the program is felt to be as follows:

- upgrade the credibility of the participating test laboratories
- provide a forum for communication
- assess and critique proficiency tests and testing uncertainty
- provide conflict resolution services

6.3 Geosynthetic Field Inspector Certification Program

GSI has two separate inspector certification programs. One (begun in 2006) is focused on QA/QC of field inspection of waste containment geosynthetics and compacted clay liners. The other (begun in 2011) is focused on MSE Wall, Berm and Slope field inspection. See our website at www.geosynthetic-institute.org under "certification" for a description and information on both of them. They are both similar in that a perspective candidate must…

- Be recommended by a professional engineer who knows, and can attest to, at least six months of acceptable experience performing CQA activities with geosynthetic liner or cover systems or MSE walls, berms, or slopes using geosynthetic reinforcement.
- Submit a completed application and be approved by the Geosynthetic Certification Institute to take the examination.
- Must successfully pass a written examination (70% of the questions is the passing grade) proctored by GCI or a GCI designated organization and graded by the Geosynthetic Certification Institute to become a certified inspector.
- Must pay a one-time fee which covers a five-year period upon completion of the above items. The fee can be renewed as desired.

Program #1 – Inspection of Liner Systems for Waste Containment Systems

This program now in its sixth year has been encouraged, and in some cases required, by solid waste owners, state regulators, and design consultants for proper QCA in field installation of both geosynthetic materials and compacted clay liners. The statistics to date are as follows.

Table 6 - Inspector Certification Test Results

Year	Geosynthetic Materials		Compacted Clay Liners		Commentary
	No. of people taking exam	No. of people failing exam	No. of people taking exam	No. of people failing exam	No. of people failing both exams
2006	141	5 (3%)	128	12 (9%)	2 (1.5%)
2007	82	11 (13%)	73	12 (16%)	7 (8.5%)
2008	95	25 (26%)	89	20 (22%)	13 (14%)
2009	36	7 (19%)	36	2 (5%)	2 (6%)
2010	59	12 (20%)	54	7 (13%)	5 (8%)
2011	54	6 (11%)	53	3 (6%)	1 (2%)
2012	27	1 (4%)	21	0	0
TOTAL (to date)	**494**	**67 (14%)**	**454**	**55 (12.5%)**	**30 (6%)**

The 5-year renewal period for those having taken the exam in 2006 is at present and about 60% have renewed accordingly. This is felt to be encouraging from our perspective.

Program #2 – Inspection of MSE Walls, Berms and Slopes

The official launch of the program was on December 1, 2011 with a course and the examination afterward. More recently a somewhat revised second course on June 14, 2012 was well received. As a result there are now thirteen persons certified by GCI for the inspection of MSE Walls, Berms and Slopes.

This one-day course and an examination were developed by GSI and reviewed by a steering committee consisting of the following individuals:

- Kent von Maubeuge – NAUE Group
- Mohammed Karim – Virginia DEQ
- Bob Sabanas – NTH Consultants
- John Conturo and Maria Tanase – AECOM, Inc.
- John Lostumbo – TenCate Geosynthetics
- Mike Yako – GEI Consultants
- Steve Poirier – Geosyntec Consultants
- Willie Liew – Tensar International
- Doug Clark – CEC Consultants
- Dick Stulgis – Geocomp, Inc.
- Frank Adams, Paul Whitty, Rafael Ospina – Golder Associates
- Daniel Alzamora - FHWA
- Sam Allen – TRI Environmental Inc.
- Greg Cekander – Waste Management Inc.
- Greg Fedak – CETCO Contracting Services

Our thanks go to them in this regard.

While a field inspector cannot require proper design or instruct a contractor how to build a wall, berm or slope, flaws can be identified for possible design modification or mitigation action. Furthermore, and at minimum, construction practices can be observed and corrected if inadequate or improper.

6.4 Geosynthetic Installer Certification Program

The International Association of Geosynthetic Installers (IAGI) has two programs; one for individual personnel and one for companies. They are as follows:

- Certified Welding Technician (1999)
- Approved Installation Contractor (2006)

IAGIs mission is to advance installation and construction technologies as well as to provide a clearinghouse for worldwide installation information.

The *individual program* is focused on construction quality control personnel of different geomembrane types. This includes independent laboratory pass/fail evaluations. This is followed by a proctored written examination. The program currently has 527 certified welding technicians. The *installation contractor program* contains the following elements which must be submitted, reviewed and approved by IAGI.

- company history and information
- minimum 0.5 M ft^2 installed annually
- ability to be bonded
- general liability insurance
- workman’s compensation insurance
- automobile liability
- safety training program
- health and safety program
- drug free program
- references from engineers
- references from owners
- references from manufacturers
- all information reviewed by third party
- entire process reviewed annually

Presently there are 15 companies listed as approved installation contractors.

6.5 Geomembrane Seam Evaluation Strategies

The quality aspects of producing proper factory and field geomembrane seams is of paramount importance. Its function as a barrier to liquids and/or gases in any containment scenario is greatly challenged if improperly made; recall Table 2 in this regard. While much about seaming has been written on behalf of the U.S. EPA (1991) in this regard, the periodicity of taking destructive seam tests still follows a criterion that is over 30-years old, i.e., one destructive test per 150 m (500 ft.) of length. In the writers opinion better is a criterion based on statistical sampling. Two are presently available; GRI-GM14 (based on the method of attributes) and GRI-GM20 (based on control charts).

Even further, the entire philosophy of quality in regard to destructive and nondestructive testing of geomembranes is embodied in Figure 3. Here one can begin with using a historical criterion and then open or close the interval based on ongoing performance (the so-called “carrot and stick” approach). Other aspects of quality can also be accommodated. Most importantly, the electrical leak location system (ELLS) can be used to challenge not only the seams but the installed sheet as well. Incidentally, this was the method used to obtain the data and information of Section 1.1 of this white paper. The writers strongly recommend its use going forward.

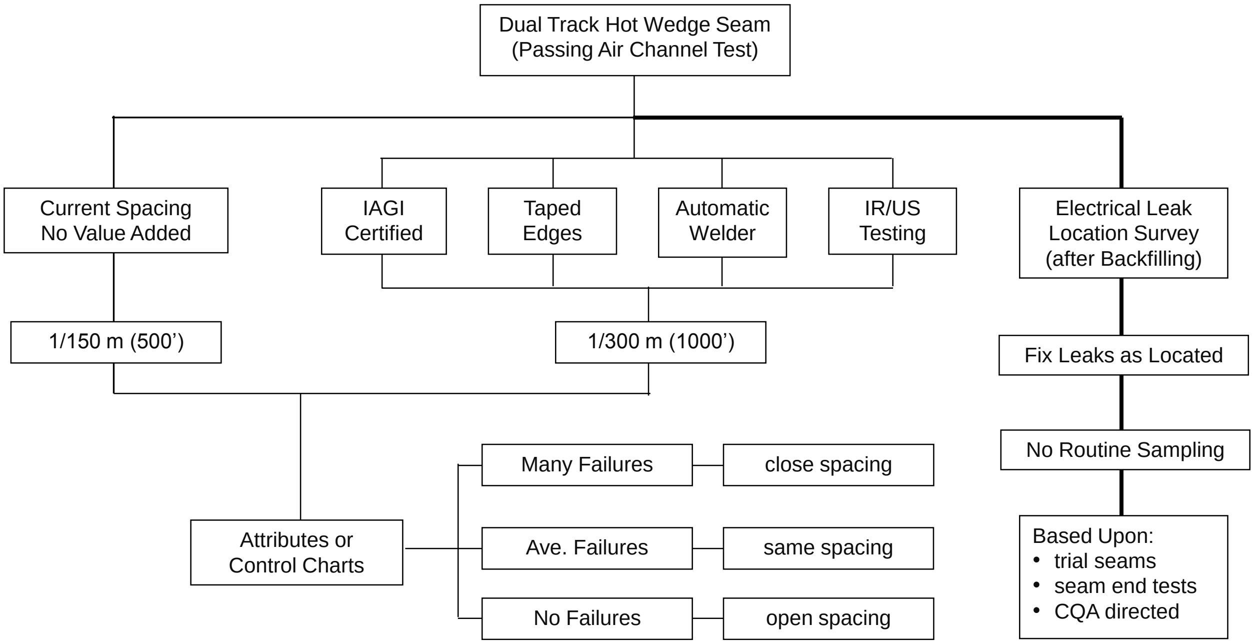


Figure 4 – Recommended strategy for testing field placed geomembranes.

7. Summary and Conclusion

The U. S. Environmental Protection Agency (EPA) has been intent on safeguarding the environment with respect to solid waste containment by issuing a series of quality management documents. The most recent is available in book form titled "MQC/MQA and CQC/CQA of Waste Containment Liner and Cover Systems". These terms refer to the following:

- *Manufacturing Quality Control (MQC):* A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer (or fabricator) of geosynthetic materials and is necessary to ensure minimum, or maximum, specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract plans and specifications.
- *Manufacturing Quality Assurance (MQA):* A planned system of activities that provide assurance that the materials were manufactured as specified in the certification documents and contract plans and specifications. MQA includes manufacturing and fabrication facility inspections, verifications, audits, and evaluation of the raw materials and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer or fabricator is in compliance with the product certification and contract plans and specifications for the project.
- *Construction Quality Control (CQC):* A planned system of inspections that are used to directly monitor and control the quality of a construction project. Construction quality control is normally performed by the geosynthetics installer to achieve the highest quality in the constructed or installed system. CQC refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project.
- *Construction Quality Assurance (CQA):* A planned system of activities that provide assurance that the facility was constructed as specified in the design. Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. CQA refers to measures taken by the CQA organization to assess if the installer or contractor is in compliance with the plans and specifications for the project.

The interaction of these four quality-related organizations can be seen in the flow chart of Figure 5.

Critical is not only the project's plans and specifications but also the *QA Document*. This is prepared by the MQC/CQA organization and presents all of the details of manufacturing, installation and inspection. It must be part of the permit process as well as being available to the contractor/installer before beginning the actual bidding process.

This project flow chart which integrates MQC/MQA and CQC/CQA as directed in the project's plans, specification and QA document lie at the heart of a quality management system for successful geosynthetic performance. While it is required for all waste containment and related environmental projects, it should be the required model for all projects containing and/or using geosynthetic materials and systems.

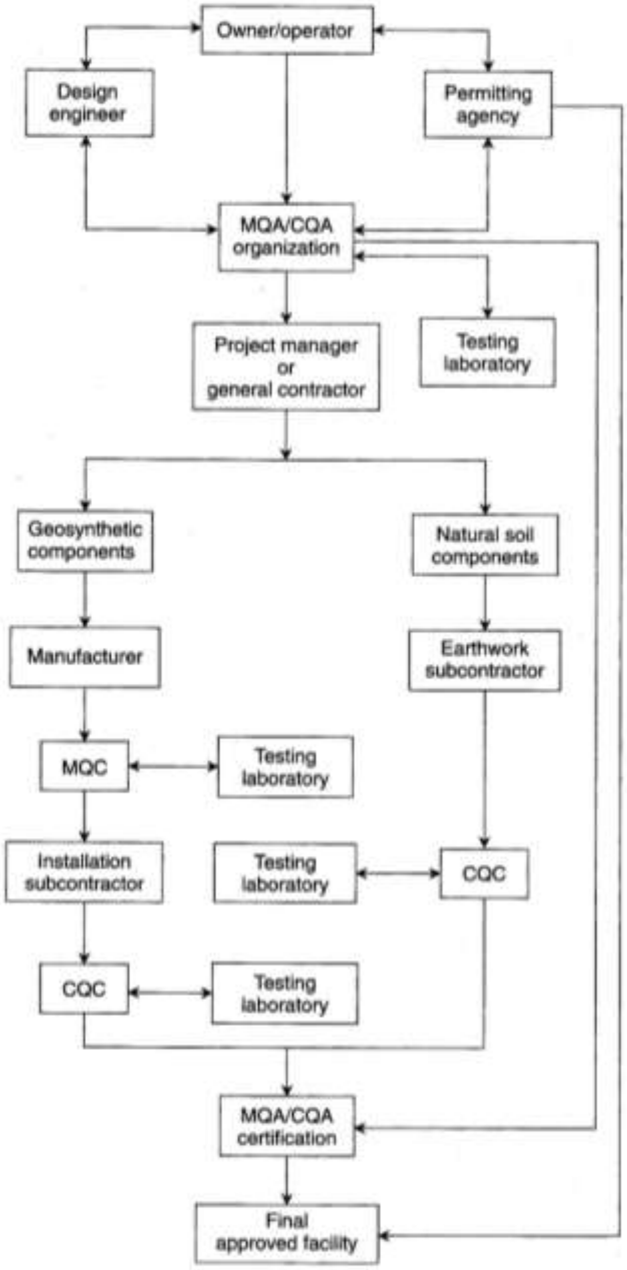


Figure 5 – Organization structure of MQC/MQA and CQC/CQA inspector activities.
(After U. S. EPA by Daniel and Koerner [1993])

8. References

GRI-GM14 (1998), "Standard Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes," Geosynthetic Institute, Folsom, PA 18 pgs.

GRI-GM20 (2003), "Standard Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts," Geosynthetic Institute, Folsom, PA, 6 pgs.

Koerner, J. R. and Koerner, R. M. (2007), "GRI's Third Survey of Solid Waste Landfill Liner and Cover Systems: Part 1, USA Status," Geosynthetic Institute, Folsom, PA, 129 pgs.

Koerner, J. R. and Koerner, R. M. (2007), "GRI's Second Worldwide Survey of Solid Waste Liner and Cover Systems," Geosynthetic Institute, Folsom, PA, 136 pgs.

Koerner, R. M. and Koerner, G. R. (2012), "A Data Base and Analysis of 141 Failed Geosynthetic Reinforced Mechanically Stabilized Earth Walls," Proc. 26th Central PA Geotechnical Conference, Hershey, PA, 21 pgs.

Koerner, R. M. and Koerner, G. R. (2011 and 2013), "Geotextile Filter Failures Under Challenging Field Conditions," 25th Central PA Geotechnical Conference, Hershey, PA and GeoCongress 2013, ASCE GeoInstitute Conference, San Diego, CA.

Koerner, R. M. and Koerner, G. R. (2009), "A Data Base Analysis of Geosynthetic Reinforced Wall Fabrics," GRI Report #38, GSI Publication, Folsom, PA, 195 pgs.

Koerner, R. M. and Soong, T.-Y. (2001), "Geosynthetic Reinforced Segmental Retaining Walls," *Journal Geotextiles and Geomembrnaes*, Vol. 19, No. 6, August, pp. 359-386.

Nosko, V. and Touze-Foltz (2000), "Geomembrane Liner Failures," Proc. EuroGeo 2, Bologna, Italy, pp. 557-560.

U. S. Environmental Protection Agency (1993), "MQA/MQA and CQC/CQA OF Waste Containment Liner and Cover Systmes," EPA/600/R-93/182, also available from ASCE Press, Reston, Virginia by D. E. Daniel and R. M. Koerner, 354 pgs.

U. S. Environmental Protection Agency (1991), "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA/530/SW-91/051, May, 173 pgs.