Costs and Benefits of Geomembrane Liner Installation CQA

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ABSTRACT

Because the cost of third-party construction quality assurance (CQA) of geomembrane liner installations is typically comparable to the cost of the geomembrane liner, CQA must be optimized to obtain the most benefit for the owner, rate payers, and environment. A regulation-based CQA protocol usually includes testing the material, observing the quality control (QC) program of the liner installer, and performing destructive tests on samples of the geomembrane seams. Another well-established type of third-party CQA is leak location surveys using an electrical leak location method.

This paper compares representative costs, benefits, and results of the two types of CQA used on geomembrane liners where both types were used. The relative merits of the two types of CQA are discussed. Examples of direct cost benefits are also presented.

A large percent of regulation-based CQA is the destructive testing of double wedge welded seams. Industry experience has shown that these welds seldom fail, and they require the test area to be repaired using a much longer length of inferior extrusion welding. Leak location surveys have shown that construction damage caused while placing protective drainage material on the geomembrane is a far more significant problem than double wedge welded seam failure. A much better cost benefit can be realized if a significant part of the resources spent on destructive testing of seams is used for electrical leak location surveys to eliminate construction damage.

INTRODUCTION

This paper examines geomembrane CQA issues, particularly for geomembranes that are heat welded, but is applicable to all geomembranes. Present conventional geomembrane CQA measures emphasize the destructive testing of geomembrane seam welds. This type of testing tests only a fraction of a percent of the length of the welds, is expensive, delays the project, and requires the test area to be repaired using much longer lengths of inferior manual seam welding. Geomembrane welds seldom fail the destructive test, and a failure of a destructive test does not necessarily mean the geomembrane would have failed in service. A much more significant problem is construction damage caused while placing protective drainage material on the geomembrane. In practice, little or no CQA resources are used to prevent or detect such actual damage and failure of the geomembrane.

Economic efficiency dictates that human, material, and capital resources will be used to produce the highest overall long term value to consumers. In the waste disposal industry, governments have mandated the use of geomembranes and CQA measures to monitor their installation. The advancement of new technologies can make these regulations outdated and even nonproductive, and a new perspective is needed produce the optimum overall benefit to owners, ratepayers, and the environment.

GEOMEMBRANE LINER CQA

Geomembrane testing methods can be divided into two categories: destructive testing and nondestructive testing. In the United States, the regulatory guidance includes testing the geomembrane material, observing the QC program of the liner installer, and performing destructive tests on samples of the geomembrane seams. In some cases, all of the CQA test methods are listed in the governmental guidelines, but the destructive tests are described in more specific details. Therefore, third party CQA has historically emphasized destructive testing and observation.

Destructive testing CQA is necessarily limited to a spot check of very limited lengths of the geomembrane seams. One destructive test every 500 feet is generally specified for double wedge welded seams, and more frequent intervals are usually specified for manual extrusion welds. For double wedge welds, usually a three-foot sample of a seam is cut out of the liner. One third of the seam is tested by a third-party CQA firm, one third is provided to the installer for QC, and the other third is saved by the owner. Multiple smaller samples of the seam are usually tested in a shear and in a peel test.

Non destructive testing methods for geomembrane seams commonly include air pressure testing, vacuum box testing, spark testing, air lance, mechanical probing, and electrical leak location testing. Table 1 lists the most-commonly used methods and features for the methods.

Leak location testing using electrical methods has become a well-established method of CQA for geomembrane liner installations, as described by Laine and Darilek (1993). This method tests all of the geomembrane liner area and seams. A voltage is impressed across the geomembrane and electrical potentials are measured to detect the points where electrical current flows through the geomembrane. In the case of landfills, the method is applied after protective drainage material is placed over the geomembrane. Therefore, the geomembrane is tested under a load, and after the potential for damage of the geomembrane has passed. A conductive media such as the prepared subgrade, geosynthetic clay liner, or a water-flooded leak detection zone must be under the geomembrane for proper operation. The leak location accuracy is typically to within a distance smaller than the depth of cover. False positive indications of a leak are not a problem if proper data sampling techniques and equipment are used. For thoroughness, areas with small marginal signals are further investigated. These areas are easily investigated so the cause of the signal is resolved or eliminated before the leak location crew leaves the site.

The electrical leak location method has been used to find a great number of leaks in installations that had regulatory CQA programs. The number of leaks, and characteristics of the leaks have been documented in several papers. Colucci and Lavagnolo (1995) reported an average of 15.31 leaks per hectare (6.20 leaks per acre) for 25 landfill liners in Italy. Of the leaks larger than 100 square millimeters, 305 out of 320 of the leaks were holes or tears probably attributed to construction damage. Laine and Darilek (1993) reported an average of 22.5 leaks per hectare (9.11 leaks per acre) for surveys of ponds filled with water in the United States. Rollin et al. (1999) reported 2.03 leaks per hectare (0.82 leaks per acre) for bare geomembranes at eleven sites in Canada and France.

Other implementations of the electrical leak location method are commonly used for testing geomembranes of ponds and tanks filled with water. A probe can be scanned over the geomembrane while the operator is wading in the water, or a probe can be towed across the liner if the water is deep or hazardous. A simplified adaptation of the method can be used on bare uncovered geomembranes. A squeegee, sponge, or water spray probe connected to an electrical power supply is used to scan the liner as it wets the dry geomembrane as described by Rollin et al. (1999). When the water from the probe makes continuity with earth ground, a circuit is established and electrical current flows. A sudden increase in the current indicates that the water from the probe has intersected the position of a leak.

ECONOMICS OF GEOMEMBRANE LINER CQA

Tedder (1997) reported primary and secondary leachate flow data from 24 landfill cells with a primary liner consisting of a 60-mil HDPE liner. These cells were constructed with a regulatory CQA program. In the 14 cells with comparable data, 4.2 percent of the leachate flowed through leaks in the primary liner before it could be pumped out.

This example raises serious questions about the cost benefit of regulatory CQA. Shepherd et al. (1992) raised questions about the true costs and benefits of the CQA efforts. They felt that if the regulatory CQA requirements are not aligned with the overall concept of obtaining significant environmental protection value, then alternatives that better meet the overall objectives should be used. They pointed out that it might be more economical to install redundant geomembrane liners instead of paying for the detailed regulatory CQA.

Table 1. Common CQA and QC Test Methods

Method	Area Tested (Percent of Liner)	Speed	Test Under Load	Test for Construction Damage	Features and Limitations
Air Lance	Seams (0.5%)	Fast, 3 to 10 m (10 to 30 ft) per minute	No	No	Economical QC test used on very flexible liners only. Tests for unbonded areas only. Requires operator skill and experience.
Air Pressure	Double wedge weld seams (0.5%)	Setup time plus about 10 minutes per seam	No	No	Economical QC test for double wedge welds only. Welds tested at a fraction of their strength.
Conductive Sheet	Primarily for panels, limited test on seams (99%)	Very rapid, 1 to 2 hectares (2 to 4 acres) per day	No	Yes, but prior to placement of drainage material	Rapid QC test of panels and areas that cannot be tested with vacuum box, requires installing proprietary geomembrane.
Destructive Seam Testing	0.2% of seams (0.0015%)	Very slow turnaround, days	Yes	No	Test for maximum seam strength, about 12 feet of inferior extrusion weld needed to repair each test point, may delay project.
Electrical Leak Location	100% of liner (100%)	About 0.5 to 1 hectare (1 to 2 acres) per person day	Yes	Yes, after drainage material placement	Only test conducted after potential for construction damage has occurred.
Vacuum Box	Primarily for extrusion welded seams (0.2%)	Slow, labor intensive	No	No	QC test, operator dependent. Cannot be used on wrinkles and corners. Leak may not be indicated with clay or water under liner. Primarily used for extrusion welds.

Shepherd et al. (1992) also reported the cost of CQA for a single composite liner constructed in 1991 to 1993 was US$31,000 to US$74,000 per hectare ($12,500 to 30,000 per acre). In one case, the cost of the geomembrane CQA only was US$22,000 per hectare ($8,900 per acre). Electrical leak location surveys for geomembrane liners typically cost US$3,700 to US$6,200 per hectare ($1,500 to $2,500 per acre). The cost for third party oversight of the electrical leak location testing is not included in these figures, but this oversight is usually accomplished in conjunction with other ongoing CQA work. The benefit of these costs in finding quality problems is examined later in this paper.

DISCUSSION OF REGULATORY REQUIREMENTS

In the United States and elsewhere, government regulations and technical guidance documents, have been promulgated for geomembrane liner construction quality assurance for landfills. The guidelines do not preclude the use of any technologies, but the guidance for some technologies is so specific that the industry has implemented those requirements and ignored others. Furthermore, some guidelines were addressed at overcoming limitations in the construction technologies at the time the guidelines were authored. This has been the case regarding the destructive testing of geomembrane seams, which was a weakness at the time. Since that time, double wedge welding machines have replaced the older technologies. In addition to providing a double weld, and a weld of superior strength with less operator skill required, the double wedge weld provides an intermediate channel that can be easily tested with air pressure for leaks through the welds. As will be shown in this paper, seam test failures are rare, and industry experience has shown that seam failures in service are practically nonexistent.

The regulations require that double-wedge welded seams be destructively tested at regular intervals. The portions of the seam where destructive test samples are removed must be repaired using the inferior manual extrusion welder. Typically, one meter (three feet) of double wedge weld is replaced with about 3.5 meters (12 feet) of manual extrusion weld. Extrusion welding requires greater operator skill and judgement for preparation and welding. The industry has recognized that manual extrusion welds fail at a far greater rate than double wedge welds. Electrical leak location surveys of geomembrane liners has also shown that extrusion welds are a significant source of small leaks. Therefore, the superior double wedge weld area under test is being replaced with about 3.5 meters (12 feet) of inferior manual extrusion weld. Even if the failure rate of extrusion welds is the same as that of double wedge welds, the destructive testing results in more than three times the exposure to seam failures. The extrusion welder requires manual grinding of the weld area, which weakens the geomembrane. The repair of the destructive test sites also requires the difficult task of making two seams over the existing double wedge weld. It is even possible that a sample of a seam with a small leak through it could pass a destructive test. The presence of a patch, and the rigidness of an extrusion weld introduce points for stress to accumulate under a load. In addition, failure of a seam during a destructive test does not even mean that seam would have failed in service. Furthermore, it is plausible that a sample of seam with a small leak could pass a destructive seam test.

Nosko et al. (1996) reported electrical leak location surveys for more than 100 sites where several thousand areas of damage were found. Of these, 73 percent were construction damage caused during the installation of the covering layer and two percent were accidentally caused after the covering layers were installed. Only 24 percent of the damage found was caused during the installation of the geomembrane. The problems with the seams were from extrusion welds at tees and around penetrations and corners. They do not mention failures in double wedge welds.

COMPARISON OF BENEFITS OF TYPES OF CQA

Questionnaire

To document the cost benefits of geomembrane liner CQA, confidential questionnaires were prepared and sent to 33 entities who have had third-party regulatory CQA, and an electrical leak location survey performed on a landfill construction project within the last three years. Eight responses were received that contained comparable information on the costs and benefits of CQA. Of these, six leak location surveys were initiated in response to a leakage problem, and two were planned as part of the initial CQA. The questionnaire asked for direct and indirect costs for the CQA and leak location, problems identified by the CQA and leak location activities, and benefits attained. It was realized that completing such a questionnaire with absolute accuracy would have been a daunting task. Although accurate data was desired, getting any response was more important than having no response. Therefore, the questionnaire was designed to elicit responses by allowing the responder to qualify the answers. Thirty-six percent of the responses were rated as "accurate, from reported data." Twenty-three percent were rated as an "estimate, based on some data," and 25 percent were rated as an "estimate." The data was tabulated and analyzed and plotted to obtain cost benefits.

Direct Cost Benefits of CQA - Identification of Problems

The primary use of geomembranes is for containment. A geomembrane liner cannot meet its intended purpose and specifications if it has bad seams or leaks, so identifying problems is an important part of CQA. Therefore, it would be instructional to quantify these benefits for the eight installations where comparable data was as obtained.

Figure 1 shows a scatter plot of the cost of the two types of CQA versus the number of problems found. The data points for the two methods are grouped together within the shaded areas. Problems included failed seam tests, and holes in the liner. The most effective CQA should find the most problems at the lowest cost. Therefore, tests represented by data points in the lower right-hand part of the graph are the most cost effective. From the plot, it can be seen that the leak location surveys located far more problems per dollar than the regulatory CQA. This is particularly significant because the leak location surveys were always conducted after the conventional CQA program. Therefore, the easier problems to identify would have been identified and eliminated before the leak location survey was performed. For conventional CQA, the average cost to find a

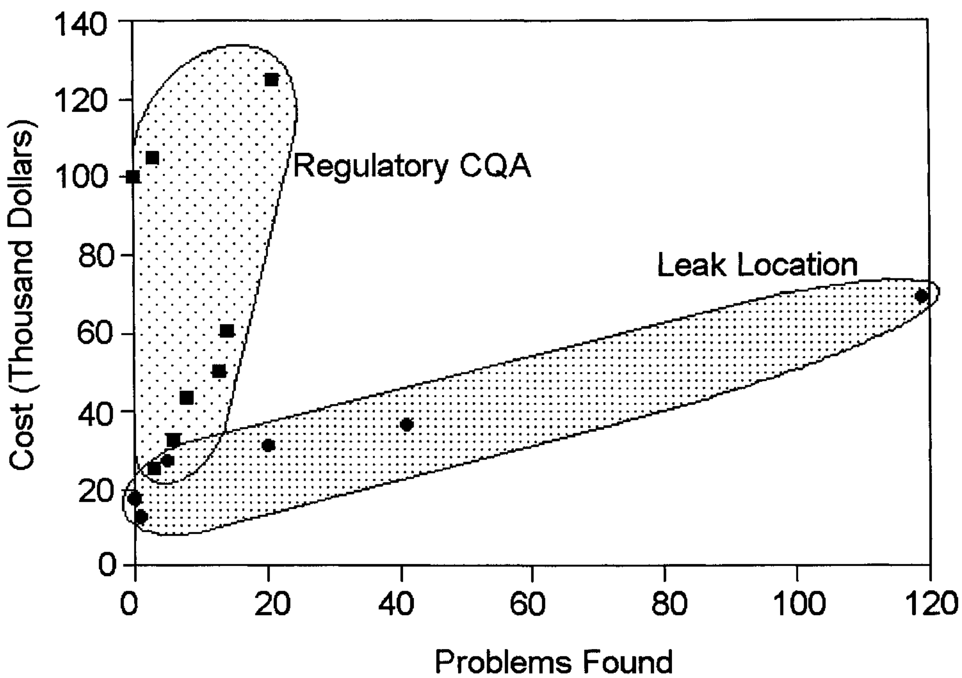

Figure 1. Cost of CQA Versus Number of Problems Found for Two CQA Methods

problem was $7,945. The average cost to find a problem using leak location was $1,186. In either case, if these problems were not detected, the future cost of these problems could make these CQA measures very cost effective.

Seam Failures

In the questionnaire, the respondents listed a total of 826 destructive tests of double wedge seams. These seam samples were taken out of the installed geomembrane, and did not include start-up samples or verification samples taken on scraps of liner. Of these 826 tests, 19 failed (or 2.3 percent) the destructive test. Each section of the seams where the destructive samples were removed had to be patched requiring about 3.5 meters (12 feet) of hand extrusion welding. This leads to the question of whether testing the resulting 826 patches times 12 meters or 2,890 meters, (9,900 feet) of extrusion welds would produce more than 19 failures. The end result is possibly that the destructive testing accomplished more harm than good.

Other Benefits

The questionnaires asked if there were any other benefits of third party CQA, and electrical leak location testing. A summary of the comments is:

Regulatory CQA

- Verified proper startup, testing, and destructive sample testing. Verified panel layout plans and documented placement procedures.

- They put the pressure on the geomembrane subcontractor to do good work

- High confidence level that construction is performed correctly and per the design.

Leak Location Testing

- Extremely useful service for owner and regulatory agency. Picks up problems with the liner that are not identified with standard CQA/QC procedures.

- Electrical leak location would be a great pre-startup tool if the cell is designed to allow for large areas to be tested.

- Caught leaks not visible to naked eye. Detected leaks created by placement of drainage layer of fill over liner.

- New York State will not approve use of cell without acceptable action leakage rate results regardless of testing. The leak detection testing eliminated one possible source of infiltration into secondary system.

- Eliminated labor to uncover liner (Alternative was to remove all the protective cover and visually inspect liner).

- Accurate. Detected defects made during placement of overlying material. Heightened contractor's awareness

<u>An Example of Cost Benefit</u>

Leachate in landfills must be treated before it can be safe for release to the environment. Depending on the nature of the leachate, the cost can be very significant. For this reason, many landfills are designed so that rainfall that falls on unused parts of the landfill is diverted from the waste so no leachate is generated and the rainwater can be discharged without treatment. However, these areas usually share the same leak detection zone with the area containing waste. Therefore, any leakage through the primary liner must undergo treatment. Treatment costs include collection and pumping for removal of landfill, hauling to the treatment plant, and treatment charges. If leaks in the primary liner can be eliminated or greatly reduced, water treatment costs can be reduced. Figure 2 shows the treatment cost for three years for a 4-hectare (10-acre) landfill for various water

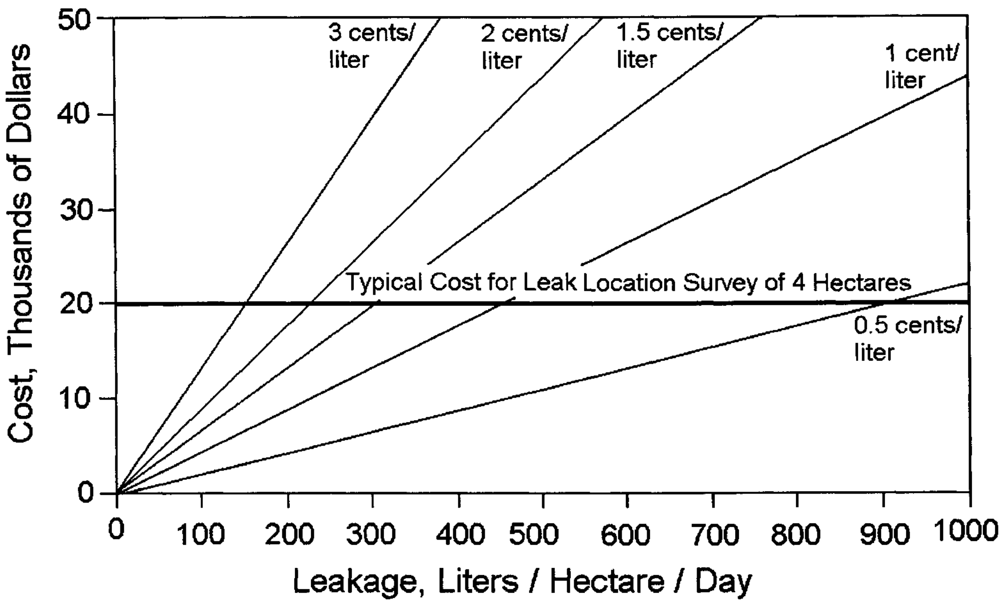

Figure 2. Leachate Treatment Costs Versus Leakage for a 4-Hectare (10-Acre) Landfill Cell for Three Years

treatment cost rates. The typical cost for a leak location survey of a 4-hectare (10 acre) landfill is also shown on the graph.

As an example, if the leakage rate was reduced 600 liters per hectare per day, and if the cost of treatment was 1 cent per liter (3.8 cents per gallon), then the cost savings would be $26,280 over a 3-year period for a 4-hectare (10-acre) landfill. Because the typical cost to perform a 4-hectare (10-acre) leak location survey is $20,000, a cost savings, for water treatment alone, would be $6,280. Tedder (1997) reported average leak detection system flow and area for 24 landfill cells in Florida. The average landfill cell size was 4.45 hectares (11 acres) and the average leakage rate was 558 liters per hectare per day (59.7 gallons per acre per day). Therefore, the above example is realistic, even for average installations.

A PLAN FOR OPTIMUM CQA COST BENEFITS

A more cost effective plan for geomembrane CQA would greatly reduce the destructive testing requirements and incorporate leak location testing after the protective drainage layer is installed. This plan would eliminate the potential for possible damage in the areas where the destructive sample sites are repaired. Destructive samples can be taken at non-critical places such as at the anchor trenches and at sites that already would require patching such as at the end of a panel or at tee junctions. However, the threat of destructive testing should be kept to positively motivate the installation crew to best workmanship. Therefore, the CQA should include a limited number of destructive tests in suspect locations, and at a very few truly random locations.

Consideration should also be given to performing pressure testing at higher pressures that do not damage the geomembrane liner seams.

For the best cost benefit, electrical leak location testing should be incorporated into the CQA program. The sump areas are the most critical parts of a liner system because they are subjected to the highest hydrostatic pressure, and because of the large amount of detailed geomembrane seaming required in these areas. As a minimum, the secondary sump areas should be tested before and after drainage gravel is installed and at least the lower parts of the primary liner should be tested for leaks after the protective drainage material is installed. In double geomembrane installations with a conductive leak detection zone such as geosynthetic clay liner or sand or gravel, and for single liner installations, the entire primary liner should be tested for leaks using the electrical leak location method.

CONCLUSIONS

The benefits of geomembrane liner CQA can be improved, and potential damage caused by destructive geomembrane seam tests can be minimized by selecting a more optimum mix of testing methods. Geomembrane seam problems have been found to be far less significant than construction damage. Valuable resources are being focused on testing a fraction of a percent of the seams, which comprise a fraction of a percent of the geomembrane. Then the entire geomembrane is subject to possible extensive construction damage in the process of installing drainage material on the liner, with no subsequent testing of the geomembrane. Geomembrane liners that had been installed with extensive regulatory CQA programs are found to leak appreciably because of construction damage caused while placing drainage material on the geomembrane. Electrical leak location testing is an efficient and effective way to locate this damage for repair.

The benefit of the regulatory-based CQA regime is to provide control of the geomembrane installation, document the geomembrane installer's QC efforts, and identify weaknesses in the installation that may lead to future leakage. In most cases, some problems were identified and corrected. The average cost to identify a problem using the regulatory CQA was US$7,945. Regulatory CQA is ineffective in identifying or preventing damage caused during the placement of protective drainage material on the geomembrane with heavy equipment.

The benefit of leak location CQA was in identifying and accurately locating a large number of actual leakage failures in the geomembrane. The leak location CQA had the ability to find construction damage not related to geomembrane installation as well as leaks caused during geomembrane installation. The average cost to identify a problem using leak location was US$1,186. The cost benefit of conducting leak location surveys using an electrical method is several times more effective than the benefit of a regulatory CQA program. Instances of using leak location surveys can be shown to provide direct and quantifiable benefits.

Now is the time to reexamine CQA requirements. Engineers, regulators, and owners must specify a CQA program that produces the most benefit. They cannot develop a false sense of security the regulations imply while ignoring more productive technologies. A significant part of the cost presently devoted to destructive testing of seams can be much better spent on leak location surveys to detect far more significant damage caused when protective drainage material is being placed on the liner. As a minimum, the most critical parts of every geomembrane liner used for waste storage should be tested using the electrical leak location method.

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