NEEDLES IN NONWOVEN GEOTEXTILES – A LANDFILL CASE HISTORY

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ABSTRACT

Engineers have been specifying geotextiles in liner systems for landfills for a number of years. While the physical properties of the geotextile are often addressed in great detail within the specifications, the engineer must also consider the manufacturing process when specifying a needle-punched, nonwoven geotextile. During the placement of the filter geotextile component of a landfill liner system in California, needles from the manufacturing process were discovered in the fabric. The potential effect of the needles on the integrity of the system was evaluated and procedures developed to determine the acceptability of the material. Following the successful completion of the project, language was developed for the specifications to minimize the potential for this problem in the future. The following paper describes the project in detail and provides the steps taken to obtain regulatory approval for the installation.

INTRODUCTION

Geotextiles have been an integral component of liner systems for landfills for a number of years. These products include woven and nonwoven fabrics composed of a variety of raw materials most typically polyester or polypropylene. In waste containment applications, nonwoven geotextiles are commonly utilized as a filter or a protective layer. While other manufacturing processes are available, mechanical needle punching is the standard process used to produce nonwoven geotextiles for landfill liner systems.

The engineer must consider the manufacturing process when specifying a needle-punched, nonwoven geotextile. As the geotextile is made, there is the potential for needles to break off and become embedded in the fabric. The specifications must require quality control procedures to be conducted at the manufacturing plant that reduce the potential of undetected needles in the geotextile. While all of the major producers of geotextiles conduct a high level of quality control, new or foreign manufacturers may not be as rigorous.

During the deployment of a composite liner system at the Yolo County Central Landfill near Davis, California, a large number of broken needles were found in the filter geotextile. Over the course of the project, testing was conducted to determine the effect of the needles on the integrity of the system. The evaluation included large scale hydrostatic puncture testing based on GRI Test Method GM3 and leakage rate calculations from potential punctures in the geomembrane. From this information, procedures were developed to inspect the on-site rolls of geotextile and determine the acceptability of the fabric. Following the successful completion of the project, language was developed for the specifications to minimize the potential for this problem to manifest itself in the future.

BACKGROUND

The Yolo County Central Landfill was opened in 1975 and has accepted over three million tons of nonhazardous solid wastes, construction debris, and nonhazardous liquid wastes. The site is designed as a Class III landfill in accordance with the California Code of Regulations, Title 27. Since opening, approximately 56.7 hectares (140 acres) of the 291 hectare (720 acre) site have been filled.

Landfilling activities at the Yolo County site presently involve the development of landfill cells using the area fill method. A composite liner system was designed by the County of Yolo for the Module B waste management unit (part of a 34.8 hectare [86 acre] expansion at the site). From bottom to top, the liner system was composed of the following components: 61cm (two feet) of clay with a hydraulic conductivity less than 1 x 10^{-7} cm/sec, a 1.5 mm high density polyethylene (HDPE) geomembrane, HDPE geonet, nonwoven, needle-punched geotextile, and 46 cm (1.5 feet) of protective cover soil. A detail of the liner system is shown in Figure 1.

Construction quality assurance (CQA) services were provided during construction of the liner system in accordance with the CQA Plan prepared by the County. The physical properties of the materials were tested in the field and laboratory to ensure conformance with the specifications. As the materials were placed, the contractor's work was observed and documented.

Since the liner system was being installed in late summer/early fall, high temperatures caused the HDPE geomembrane to wrinkle during the daylight hours. In order to avoid folding the liner and creating potential stress points, placement of the protective cover soil was conducted at night when cooler temperatures caused the liner to contract. Prior to placement of the protective cover soil over the geomembrane and geonet, a layer of 407 gm/m^2 (12 oz/yd^2) needle-punched, nonwoven filter/cushion geotextile was placed, overlapped, and sewn.

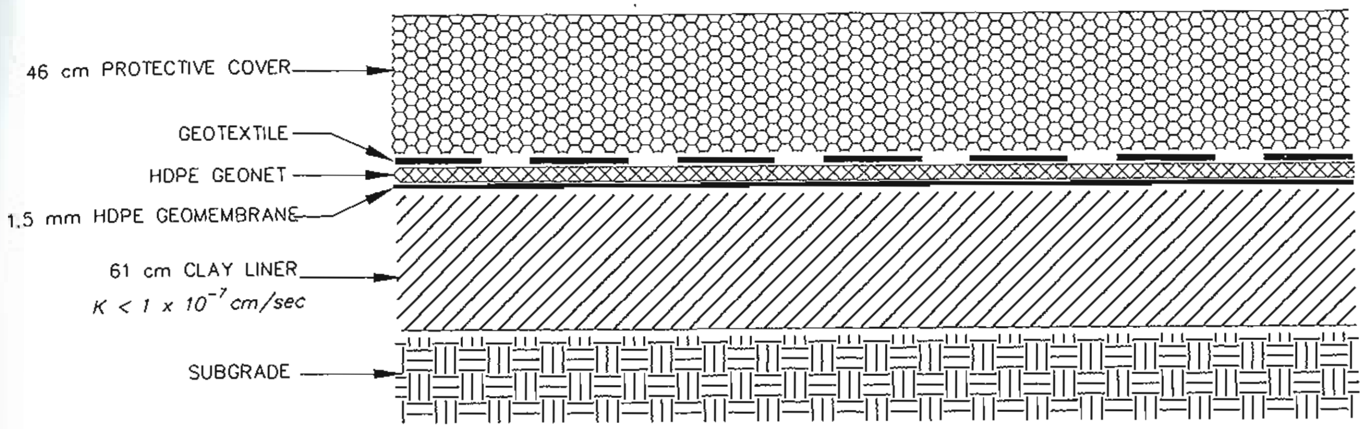

Figure 1. Detail of Liner System

PROBLEM

Since CQA personnel were monitoring the placement of the geotextile and protective soil materials at night, the identification of needles in the geotextile would be very difficult. Although they were not specifically looking for needles, CQA personnel monitoring the work being conducted in the daytime hours noticed broken needles in the geotextile at the edge of the protective cover soil. A more careful inspection of the immediate area resulted in finding broken needles and needle fragments in three additional areas.

A deficiency meeting was immediately held between the contractor, County, installer, and CQA firm. Two related problems were identified. First, approximately 3.2 hectares (8 acres) of the 8.1-hectare (20-acre) expansion area had already been covered with protective soil. Secondly, almost all of the remaining geotextile was already on-site with some of it deployed and ready to be covered with protective soil.

It was recognized that extensive evaluations would be necessary to determine the potential for damage to the geomembrane under the area already covered by protective soil. Of more immediate concern was what to do with the deployed but not covered geotextile and the rolls already on-site. As a result of the deficiency meeting, it was agreed that more rigorous inspection procedures would be implemented for the geotextile that had been previously deployed but not covered, and for geotextile yet to be deployed.

After the needles were identified, and in an attempt to determine the source of the needles, the CQA firm performed a plant visit to inspect the production facility and review the plant quality control program with respect to needles. The CQA Officer and County project manager attended the plant audit at the manufacturer's plant in Southern California.

During the audit, it was found that the production line used needling boards at two locations and that the needles from the plant matched those found in the field. Regarding quality control, the facility used a magnet over the geotextile to remove loose needles. The magnet was cleaned of needles every two days with about 200 needles typically recovered (100 needles per day). No inventory was taken to compare needles recovered with those lost from the boards. Furthermore, no metal detector was used in the production line to identify broken needles that bypass the magnet.

From this audit, it was concluded that the needles were most likely from the plant and that plant practices were insufficient to prevent needles from being incorporated into the geotextile in significant quantities.

INSPECTION OF EXPOSED GEOTEXTILE

Due to significant delays associated with obtaining new rolls of geotextile, procedures/criteria were quickly developed by the CQA firm to accept or reject the existing on-site materials. Different procedures were developed for rolls of geotextile that had not been deployed and rolls that had been deployed but not covered.

For the rolls of geotextile that had not been deployed, the inspection procedures were as follows:

1. Six contractor personnel wearing cotton gloves standing shoulder to shoulder were utilized for the inspection of each roll.

2. The personnel slowly unrolled the geotextile on a flat surface and visually and physically inspected the roll over its entire surface. Any needles found were marked and removed.

3. Once the geotextile was unrolled, the six personnel knelt down and inspected the other side of the roll.

4. After both sides of the geotextile were inspected, the roll was opened to expose the inner sides of the geotextile [each roll consisted of two rolls of geotextile factory seamed together, folded over, and re-rolled]. These two sides were also inspected.

5. An approved metal detector was employed during the inspection process. The Contractor proposed the type of detector and the procedure to be used, which was approved by the Engineer.

6. Any geotextile roll with four or more needles found was rejected and not used on the project. Rolls with three or less needles were used after the needles had been removed.

7. The CQA firm continuously monitored the inspection of the geotextile. A log was kept on each roll documenting the roll number, amount of needles found, and acceptance/rejection of the roll. No rolls were used on the project unless the CQA Monitor released them.

The geotextile that had already been deployed, but not covered with protective soil material was inspected as described below:

1. To enable adequate inspection, the sewn seam for each double roll of geotextile was cut and the thread removed. Six Contractor personnel inspected each half of the double roll by kneeling and visually and physically inspecting the geotextile.

2. After one side of one panel of the double roll had been approved, the material was folded over and the other side inspected.

3. After folding the material back, the geonet was inspected by kneeling and visually observing the geonet for the presence of needles. After the geonet was inspected and determined to be free of needles, the inspected geotextile was folded back on top of the geonet.

4. The opposite side of the double roll was then inspected. The geonet was also inspected as described above in No. 3.

5. A metal detector was used on the geotextile in addition to the manual inspection using the approved method.

6. If four or more needles were found, the roll was rejected and removed from the project. If three or less needles were found, they were marked and removed and the geotextile utilized for the project.

7. The CQA firm provided continuous monitoring of the inspection and kept a log of each roll. The rolls were not used unless kept by the CQA Monitor.

For rolls of geotextile that were already deployed, if only one side of the double roll was found to have excessive needles, it was removed and the other side utilized. For new rolls of geotextile, the entire double roll was rejected if four or more needles were found.

The above inspection procedures were performed on 111 panels (individual rolls of geotextile) and needles were identified in 74 of the 111 panels (67%). All identified needles were removed, and panels with more than four needles were rejected and removed. The total number of needles found averaged 59 needles per 0.4 hectare (1 acre). The attitude of the needles was randomly oriented and ranged from horizontal and sub-horizontal to vertical and sub-vertical.

Based on the rigorous inspection procedures developed for identifying and removing needles in the geotextile, rolls were later accepted for use at the site that contained more than four needles. This procedure was only allowed after the contractor demonstrated that all the needles could be removed with the inspection process.

In addition to collecting and removing the needles, Vector performed a size distribution analysis on 353 broken needles and needle fragments found. The results of this analysis are shown in Table 1.

Table 1. Needle Size Distribution

Size Range, cm (inch)	Occurrence, %
1.6 – 1.9 (5/8 – 3/4)	17
1.3 – 1.6 (1/2 - 5/8)	24
.95 – 1.3 (3/8 – 1/2)	17
.64 - .95 (1/4 – 3/8)	31
.32 - .64 (1/8 – 1/4)	10
< .32 (<1/8)	<1

Attempts to correlate panel location with needle occurrence were not successful. The needles seemed to occur randomly.

DISPOSITION OF COVERED GEOTEXTILE

Because of the pervasive frequency of needles throughout the exposed geotextile, the CQA firm concluded that the 3.2 hectares (8 acres) of covered geotextile also contained needles. It was assumed that the needles were at the same frequency as identified by the modified quality control procedures, or 59 needles per 0.4 hectare (1 acre).

Because the needles underlying the 3.2-hectare (8-acre) covered area in the western portion of the module could not be easily located and removed, the CQA firm was asked by the County to perform laboratory puncture testing and to qualitatively estimate the leakage threat posed by the needles. Laboratory puncture tests were performed at the CQA firm's geosynthetics laboratory. In order to obtain collaboration with the results, an additional independent geosynthetics laboratory conducted concurrent testing. The testing was performed in general conformance with GRI Test Method GM3.

The GRI Test Method GM3 places a geomembrane test specimen on the proposed installation materials within a high-pressure test vessel. Once the membrane and other materials are placed within the vessel, hydrostatic pressure is applied to an intended value, typically, to a pressure that simulates the anticipated field conditions. Pressures in the field are induced in two modes; one mode is during construction by foot and equipment traffic and the second is during the operational life applied by the vertical loading on the liner from refuse and soil. Based on these anticipated field conditions, an ultimate pressure of 689.5 kilo Pascals (100 pounds per square inch) was used in the performance of the test.

The test apparatus consists of a two-piece pressure vessel. The inlet pressure is applied to the upper half connected to a regulated nitrogen tank and the bottom of the tank has a pressure relief outlet valve. Steel flanges that are welded to each section fasten the two halves to each other.

The lower unit of the pressure vessel was filled partially with free-draining pea gravel and the remaining portion was filled with the soil proposed for use as an operations layer at the site. The native protective soil consists of mostly sandy and silty clays with some gravel material. A layer of geotextile was placed between the operations material and the pea gravel to prevent cross contamination.

Once the soil was in-place, representative samples of the geotextile and the geonet were cut to fit the inside diameter of the pressure vessel. They were then taped together along the edges so that they would not move around during test assembly. Eleven broken needles, which were retrieved from geotextile materials at the site, were placed within the central portion of the test geotextile sample. Each needle location was noted with a white circle marked on the geotextile. These needles were oriented with their points essentially perpendicular to the HDPE liner which would be placed on top of these materials during the test. The geonet and geotextile were placed against the compacted operations material in a "floating" position (i.e. they were not fixed in-place by the flange of the vessel).

The geomembrane was then cut and holes drilled to fit the general configuration of the outside flanges of the pressure vessel. Neoprene rubber gaskets were placed along the flanges and the geomembrane was placed against the underlying materials. Once the materials were set, the upper section of the vessel was placed and bolted to the lower half. The lower (outlet) valve was kept open at all times during the test so that no buildup of pressure could occur below the test sample.

The upper section was then filled with water through the top portal valve. Once filled, the system was gradually pressurized at a prescribed rate of 70 kilo Pascals (10 psi) per minute to an initial target value of 414 kilo Pascals (60 psi). This pressure was held constant for a dwell time of approximately 48 hours. The test pressure was then increased at the rate indicated to a final value of 689.5 kilo Pascals (100 psi), at which time the test was completed. Once the test was started, the pressure was monitored periodically to ensure that the proper pressure was maintained. At the completion of the test, the condition of the geomembrane was noted.

As mentioned previously, each test was performed using two samples of the geotextile. In the first test, the geomembrane had been penetrated and partially damaged by seven of the eleven needles placed in the geotextile. Two of these needles remained embedded in the liner and one of the needles had completely perforated the geomembrane. Similar conditions were noted on the second specimen with nine needles damaging the geomembrane and no needles embedded in the liner. However, four needles had perforated the geomembrane in the second sample. The independent testing firm's results were similar with five needles perforating the geomembrane in one sample and none in the other.

The results of the puncture testing demonstrated that the potential existed for broken needles present within the geotextile materials to penetrate and damage the liner materials. In order to simulate a worst-case orientation of the needles, they were placed vertically in the geotextile perpendicular to the HDPE liner. It should be noted that only a very small percentage of vertically oriented needles were detected at the site in the existing geotextile.

Following the above testing that demonstrated the potential for liner puncture, the County, CQA firm, and contractor developed a new testing program in conjunction with another independent consulting firm. The purpose of the new program was to more realistically assess the potential for leakage by mimicking the actual field conditions as closely as possible and increasing the testing database.

The new testing program included the following modifications:

1. **The number of tests performed was increased to include more needle fragment orientations.** The new puncture tests were performed with needle fragments oriented at 30, 45, 60, and 90 degrees from the horizontal. It was generally agreed that needles oriented less than 30 degrees from the horizontal would not pose a serious puncture risk. Tests were also conducted with bent needle fragments placed both vertically and horizontally with the points allowed to settle in place.

2. **The number of tests performed was increased to include two loading patterns.** Two loading mechanisms were identified which could cause punctures in the geomembrane. The first was the loading from a scraper running over the protective layer fully loaded. This was modeled by quickly loading the sample to 414 kilo Pascal (60 psi), unloading it, reloading it, and unloading it again. Each cycle took approximately three minutes. The second loading mechanism modeled the forces due to the final build-out of the landfill (up to 61 meters [200 feet]). The waste load for full build-out was 689.5 kilo Pascals (100 psi). Each loading type was performed on each needle fragment orientation and type.

3. **The protective soil layer was placed at 90 percent of the ASTM D-1557 maximum dry density within two percent of the optimum moisture.** Although there were no compaction requirements for the protective soil layer, this density was reasonable following scraper traffic and refuse loading.

4. **Needle fragment lengths met the distribution of fragments noted in Table 1.** This distribution was not available during the initial round of testing.

5. **Half of the fragments were placed with their points toward the geomembrane and half were placed with their points away from the geomembrane.** Due to the factory seaming of two rolls of geotextile together, there was no way to determine the direction of the needle fragments. Therefore, it was agreed that half of the fragments could be assumed to be in each direction.

6. **More needle fragments were used for each test.** To improve the statistical significance of the testing, more needle fragments than utilized in the first round of testing were used in each of the tests.

Based on the above criteria, a total of ten puncture tests were conducted using a total of 192 needle fragments. None of the tests with straight needle fragments showed any punctures or partial penetrations of the geomembrane. One of the tests using bent needles under a simulated scraper loading showed a penetration of the liner.

Based on the observed puncture, a leakage rate determination was conducted. A formula for calculating leakage rates through composite liners from a puncture in the geomembrane was developed by Giroud (1989).

That formula was:

$$Q = 0.21\, h_w^{0.9} a^{0.1} k_s^{0.74}$$

where: Q = the leakage rate in cubic meters per day
h_w = the head on the liner in meters
a = the area of the hole in square meters
k_s = the hydraulic conductivity of the underlying clay in meters/sec

For this application, a leachate head of 0.003 m (per Giroud and Bonaparte, 1989) for geocomposite liners with geonet drainage layers was used. This assumes that the leachate collection and removal system was designed, constructed, and will be operated to minimize leachate head buildup. The diameter of the hole from the puncture testing was measured and the area was calculated to be 1.6×10^{-7} square meters. The hydraulic conductivity of the underlying compacted clay layer was determined to be 1×10^{-9} m/sec. Using these values in the above-noted formula resulted in a calculated leakage rate of 0.0045 liters (0.0012 gallons) per day per puncture.

Of the needle fragments found in the area of the landfill which had not been covered by the protective soil layer, 28 percent were bent. The additional testing indicated that 5 percent of the bent fragments could cause punctures of the geomembrane. Using these percentages on the

59-fragment/0.4 hectare (1-acre) value results in 0.8 punctures per 0.4 hectares (1-acre) or 6.5 punctures for the 3.2-hectare (8-acre) area.

Using this calculated potential puncture rate of 0.8 punctures per 0.4 hectares (1 acre) and the leakage rate of 0.0045 liters (0.0012 gallons) per day per puncture, an area leakage rate of 0.029 liters (0.008 gallons) per day was calculated. This translates to less than 11 liters (2.8 gallons) per year from the entire 3.2-hectare (8-acre) area.

Included in the leakage formula used is an inherent assumption that a puncture is a hole in the geomembrane and it will likely remain as such. If a needle fragment causes a puncture, the fragment will remain in the hole acting as a barrier to liquid until it is removed or rusts away. It could be removed by degradation caused by the leachate, but some metal fragments would remain. Factors such as tensile stresses induced by settlement of the foundation soils could elongate holes. However, soils, microorganisms and other suspended material within the leachate would tend to settle in low spots on the geomembrane and plug small holes. Under the pressure of increased loading and elongation from increased temperature in the presence of leachate, the HDPE geomembrane could expand laterally a small amount and act to either seal or elongate a hole.

CONCLUSIONS

Based on the extensive puncture testing conducted on samples of the geotextile containing needle fragments, it was determined that the potential exists for needles present in a geotextile to puncture an underlying geomembrane. While the leakage rate through the punctures will be minimal, it does represent an increase over and above the standard leakage rate from a 1-cm diameter hole that would be expected from a well-constructed composite liner system (U.S. EPA 1987, 1992). High groundwater levels (within 1.5 meters [5 feet] of the ground surface) at the Yolo County site also required any leakage to be seriously considered.

After evaluating the amount of potential leachate that could be generated along with other site specific factors at the landfill, it was determined that the composite liner system in-place would adequately protect the waters of the State. This information was presented to the regulatory agencies and the facility was permitted to accept refuse.

For subsequent phases of construction at the Yolo County Central Landfill, the specifications were amended to specifically address the potential for needles in the geotextile. Included in the amended specifications was the following: "Prior to delivery, submit to the Engineer and CQA Monitor a letter of certification from the geotextile supplier stating that the geotextile products are in conformance with the requirements of these Specifications. The manufacturer shall provide documentation stating that the plant quality control includes magnets and continuous metal detectors to detect manufacturing needle fragments, and shall certify that the geotextile provided is "needle-free". Also included in the specifications was a statement that the geotextile shall be free of foreign objects or debris, including manufacturing needle fragments.

It should be noted that all major manufacturers of geotextile in the United States currently follow rigorous quality control procedures that include both magnets and metal detectors. However, by using the above specification language and conducting a plant audit of manufacturers, the engineer can minimize the potential for needles in the geotextile component of liner systems.

REFERENCES

Giroud J.P., and Bonaparte, R. (1989) "Leakage Through Liners Constructed with Geomembranes – Part I. Geomembrane Liners." Geotextiles and Geomembranes, Vol. 8, No. 1, pp. 27-67.

U.S. EPA (1987) Background Document on Proposed Leak Detection Rule, IPA/530-SW-87-015, Washington, DC.

U.S. EPA (1992) Action Leakage Rates for Leak Detection Systems Supplemental Background Document for the Final Double Liners and Leak Detection Systems Rule for Hazardous Waste Landfills, Waste Piles, and Surface Impoundments." EPA/530-R-92-004, Washington, DC.