LESSONS LEARNED FROM 10 YEARS OF LEAK DETECTION SURVEYS ON GEOMEMBRANES

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SUMMARY

Statistics obtained from geoelectric leak detection surveys performed on more than 89 projects totalling 2 652 000 m^2 are presented. Although many papers have been previously published on this topic, few authors have gone as far as to identify leak densities on geomembranes (exposed and covered) with respect to their thicknesses, the application or absence of a Construction Quality Assurance (CQA) program and water puddle leak detection survey on exposed geomembrane prior to the placement of a covering material. Results obtained within this investigation show that the average leak density on exposed geomembranes (many types and thicknesses) that were installed under a rigorous CQA program is approximately 4 leaks per hectare. Conversely, the statistics show a sharp climb, to 22 leaks per hectare, in the absence of such a CQA program. The situation was found to be similar with covered geomembranes: a negligible leak density (0.5 leaks/ha) found on geomembranes installed under a strict CQA program and a prior water puddle leak detection survey on the exposed geomembrane, climbing sharply to a density of 16 leaks/ha in the absence of both a CQA program and the water puddle leak detection survey.

1. INTRODUCTION

Leak detection surveys performed on exposed geomembranes (totalling 2 291 000 m^2) and covered geomembranes (totalling 361 000 m^2) during a 10 year period, applied to 89 projects located in 8 different countries have been analyzed in order to complement recently published data and to stress the importance of the implementation of rigorous Construction Quality Assurance (CQA) programs during geomembrane installation. The data collected was used to calculate the number of leaks per hectare (leak density) for each project, and to register the types and size of located leaks. The surveyed sites were lined with HDPE, PVC, or bituminous geomembranes.

Two different leak detection techniques used to verify the integrity of a geomembrane are presented: the water puddle technique as used on exposed geomembranes either during or after their installation and the dipole technique as applied on geomembranes covered with a soil layer.

Statistics indicating a global decrease in the number of leaks found on sites where a rigorous construction quality assurance program is implemented are then discussed. In the context of this article, a rigorous CQA program is defined as a constant surveillance by an expert who possesses recognized expertise in geomembrane installation during all of the liner installation phases, including subgrade preparation, liner installation, seaming procedures and covering of the geomembrane.

2. GEOELECTRIC LEAK DETECTION TECHNIQUES

Geoelectric leak detection techniques used on geomembranes have been described in many publications, such as Peggs (1989, 1990, 1993), Darilek *et al.* (1988, 1989), Laine *et al.* (1989, 1991, 1993) and Rollin *et al.* (1999, 2002, 2004), and in standards such as ASTM D6747 (Standard Guide for Selection of Techniques for Electrical Detection of Potential Leak Paths in Geomembranes), ASTM D7002 (Standard Practice for Leak Location on Exposed Geomembrane Using the Water Puddle System) and ASTM D7007 (Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earth Materials).

The water puddle method consists in the creation of a potential difference between a soil under an exposed geomembrane and a puddle of water projected from a diffuser onto the surface. Most geomembranes are highly resistant electrical insulators and inhibit electrical currents. As soon as water percolates through a perforation and reaches the supporting soil, a 'bridge' is created between these two potentials which generates an electrical current. A detector signals the presence of an infiltration to the operator (via acoustical and visual signals). This technique permits the detection of leaks with dimensions of 1 mm^2 or greater (ASTM D7002).

On-site preparation is minimal and generally permits the survey to proceed during the geomembrane installation. The prospecting rate is approximately 5000 m^2/day/operator, depending on site conditions. To achieve this survey rate, a continuous water supply of approximately 4 m^3/day/operator is necessary. This water supply may be provided from a tanker or a direct connection to a municipal network. If a water supply proves difficult, the use of a closed circuit with a low point is also possible. Figure 1 provides a general schema of the water puddle method.

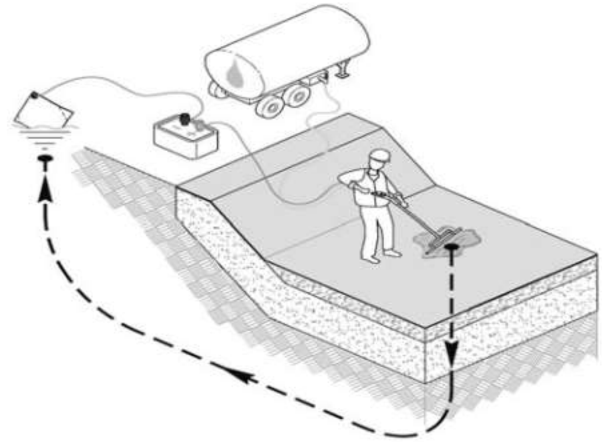


Figure 1. Water puddle technique on exposed geomembranes.

In the dipole leak detection technique, an electrical potential is applied between the covering material above the geomembrane and the soil below it. Since most synthetic geomembranes are effective electrical insulators, the presence of a leak creates a localized passage of current, which perturbs the potential field in a characteristic way. Leaks are located by recording potential readings with the dipole at predetermined grid densities.

Under moderate climatic conditions, on-site preparation is minimal. Spraying water on the covering soil surface might be necessary to insure good contact with the dipole under very dry conditions. The detection limit is variable but generally allows detection of holes with dimensions of 6 mm^2 or greater (ASTM D7007). Figure 2 provides a general schema of the dipole method.

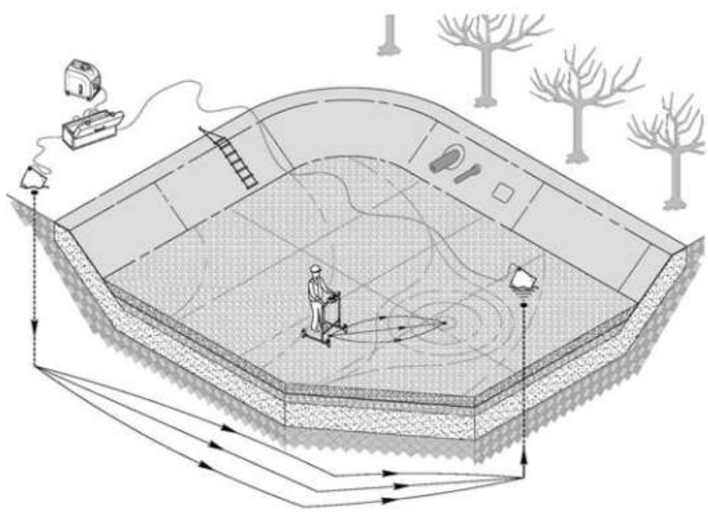


Figure 2. Dipole technique on covered geomembranes.

3. LEAK DENSITIES - DIFFERENT TYPES AND THICKNESSES OF GEOMEMBRANES

The results obtained from 57 geoelectric leak detection surveys performed on exposed geomembranes (HDPE, PVC and bituminous) of different thicknesses are presented in Figure 3. The leak densities used in this investigation were calculated using data collected from the leak detection surveys.

The majority (80%) of the projects where the liner installation was performed using a rigorous CQA program had very low leak densities, ranging from 0 to 7 leaks per hectare, with an average of 4 leaks per hectare. The remaining 20% of projects, which included a CQA program, had leak densities greater than 7. On the other hand, an average leak density of 22 leaks per hectare was calculated for projects without a rigorous CQA program.

An analysis of eight (8) projects performed using a rigorous CQA program that had leak densities greater than 7 leaks per hectare indicated the following:

- In one project, the geomembrane installed in the proximity of a rock wall was not properly protected from falling rocks puncturing the geomembrane;
- In another project, seaming problems were encountered during the installation caused by the inexperience of the installer;
- In a third project, extensive extrusion welding caused half of the leaks detected;

- In the remaining five projects, the lined areas were very small (between 600 and 5310 m^2) which rendered the leak density analyses biased.

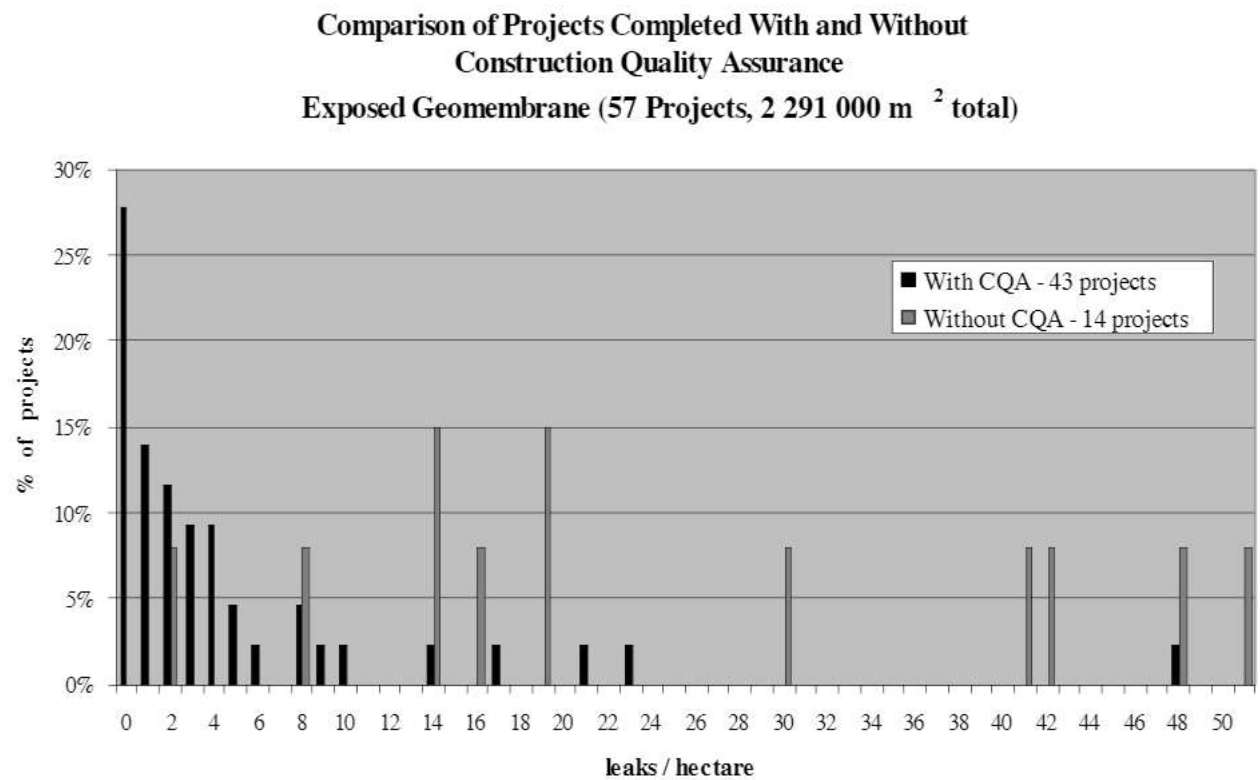


Figure 3. Leak Densities – With and Without a Rigorous CQA Program (Exposed Geomembranes).

For leak detection surveys performed on covered geomembranes, where both a rigorous CQA program and a water puddle leak detection survey on exposed geomembrane during installation were implemented (corresponding to approximately 80% of the projects), the calculated leak density was found to be almost negligible, approximately 0.5 leaks per hectare. Conversely, an average leak density of 16 leaks per hectare was found for projects that did not implement a strict CQA program.

4. LEAK DENSITIES - HDPE GEOMEMBRANES

The data obtained for different HDPE geomembrane thicknesses was gathered to determine the influence on the quantity of perforations during installation. The survey results have been grouped as exposed and covered geomembranes. Columns 1 and 2 of Table 1 present the results of the leak densities for exposed geomembranes with and without CQA implemented during installation. The results obtained for covered geomembranes are presented in columns 3 and 4. The surveys on projects with deficiencies at the design level, and projects with a total surveyed area of less than 10 000 m^2, were discarded in order to permit an objective comparison of the influence of CQA programs and leak detection surveys.

Table 1 - Leak Density Comparison (HDPE Geomembranes).

Geomembrane Thickness	***Exposed HDPE Geomembranes (Water Puddle)***		***Covered HDPE Geomembranes (Dipole)***	
	Column 1	Column 2	Column 3	Column 4
	With CQA	Without CQA	With CQA and geoelectrical leak survey (water puddle) before covering	Without CQA and no geoelectrical leak survey (water puddle) before covering
	Number of leaks per hectare (prospected area m^2)			
2.0 mm	**3.2** (362 460)	N/A (0)	**0.2** (170 190)	**15.6** (50 600)
1.5 mm	**5.1** (66 880)	N/A (2 760)	N/A (0).	**24.7** (10 500)
1.0 mm	**20.5** (17 070)	**31.5** (313 770)	N/A (1110)	N/A (0)

N/A: Data nonexistent or insufficient to enable a good representation.

As intuitively expected, leak density was found to decrease as the thicknesses of the HDPE geomembranes increased. However, it was not found to be inversely proportional to the thickness of membranes installed where a rigorous CQA program was implemented: leak densities of 20.5, 5.1, and 3.2 leaks per hectare, respectively for 1 mm, 1.5 mm, and 2 mm thick exposed geomembrane were found.

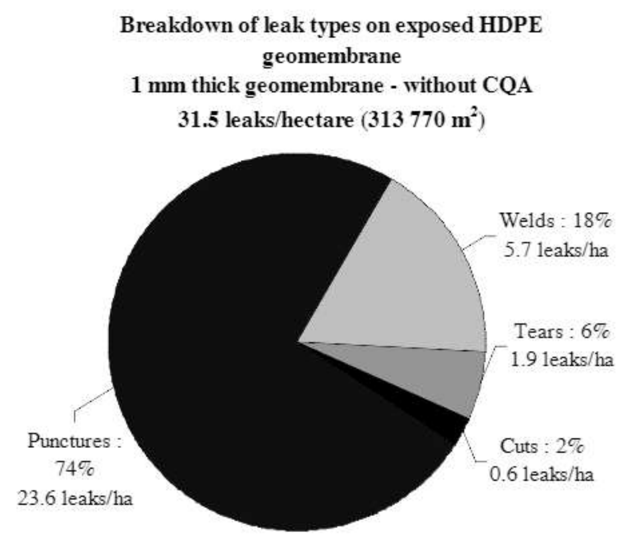
As shown in Table 1, the leak densities obtained from projects without a rigorous CQA program correspond well with the data presented by Rollin *et al.* (EUROGEO 2004), Nosko *et al.* (2000), and Phaneuf *et al.* (2001). More important is the fact that the calculated leak densities for applications where a rigorous CQA program was implemented are greatly reduced and correspond better with the densities forecasted by Giroud (1989).

Another essential observation arises from efforts to determine the number of perforations resulting from the installation of a covering material on top of a geomembrane. A comparison of the data for exposed and covered 2 mm thick HDPE geomembranes in projects where a CQA program was implemented (columns 1 and 3 in Table 1), indicating respective densities of 3.2 and 0.2 leaks/ha, leads to the conclusion that only 6% of the perforations were caused during the covering material installation. In a 1996 survey reported by Nosko *et al.,* and one in 2001 by Phaneuf *et al.*, the results obtained in landfills indicated that 73% of damage occurs when the soil layers are placed on top of the geomembranes, 24% occurs during geomembrane installation, and 2% occurs during the post construction phase. They concluded that, contrary to the general perception, most damage detected in landfills occurs during covering layer installation and is not caused by improper seaming. This conclusion is probably valid only in cases where no rigorous CQA program has been implemented.

5. LEAK TYPES - HDPE GEOMEMBRANES

An analysis was performed to determine the breakdown of the four types of perforations generally found on geomembranes and identified as faulty welds, tears, cuts, and punctures. Perforations can be caused during the welding process and include separation due to poor double fusion welds, perforations during the fusion process, insufficient water tightness or perforations as a result of faulty extrusion welds. Tears are generally caused by difficulties in handling the geomembranes during installation or by heavy equipment traffic used during the covering phase. The installer is most likely to be responsible for damage due to cuts. Finally, punctures arise from contact with static objects (such as sharp edged stones and gravel) left on or under the geomembranes.

Figure 4 presents a breakdown of the different causes of perforations. The first graph considers the data obtained from exposed 2 mm HDPE geomembranes installed using a rigorous CQA program, and the second presents the results from exposed 1 mm HDPE geomembranes in the absence of a CQA program. It must be noted that this comparison deals with 2 variables due to the complete lack of data concerning 2 mm geomembranes installed without a rigorous CQA program.



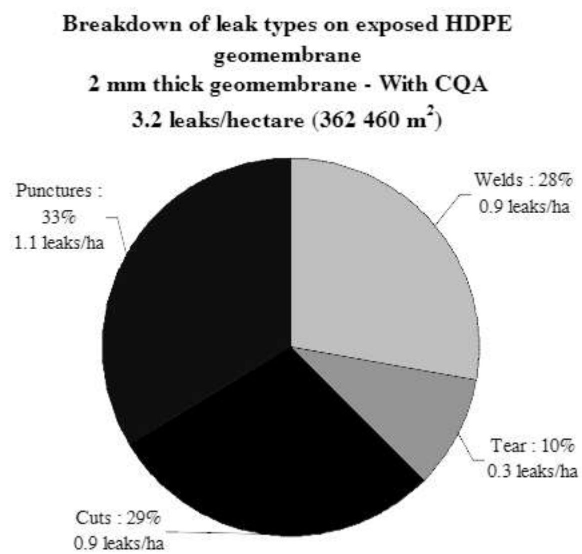


Figure 4. Breakdown of Leak Types (Exposed HDPE Geomembranes).

The analysis of the leak types, as presented in Tables 1 and 2, permits the measurement of the impact of the thickness and of CQA implementation on the leak densities.

A comparison of Tables 1 and 2 permits the following conclusions:

- Confirming what has been previously published on this topic, approximately 30% of leaks are found at seam edges, and 70% are found on the panels;
- There is no correlation between the geomembrane thickness and the implementation of a CQA in regard to the number of knife cuts;
- The number of tears found is six (6) times greater for the 1 mm geomembrane without a CQA program than with implementation of a CQA program (1.9 vs. 0.3 leaks/ha);
- The number of faulty seams is six (6) times greater for the 1 mm geomembrane without a CQA program than with implementation of a CQA program (5.7 vs. 0.9 leaks/ha);

- The number of punctures is twenty one (21) times greater for the 1 mm geomembrane without a CQA program than with implementation of a CQA program (23.6 vs. 1.1 leaks/ha).

6. LEAK DIMENSIONS - HDPE GEOMEMBRANES

Even though the leak densities on 2mm thick HDPE covered geomembranes are very low after the application of a rigorous CQA program (0.2 leaks/ha), it is important to mention that the vast majority of these perforations are caused by the heavy equipment traffic used during the installation of the covering materials. Consequently, the sizes of these perforations were found to be relatively large. This is corroborated by Nosko and Touze Foltz (2000) that characterised the dimensions of the perforations as a function of their type. Table 2 presents their results for covered and exposed geomembranes, while not taking into account the thickness or the presence or absence of a rigorous CQA program. It is interesting to note that the perforations caused by heavy machinery represent 75% of the tears greater than 10 cm^2.

Table 2. Perforation Sizes and Types (Nosko and Touze Foltz, 2000).

Diam. Size (cm^2)	**Stones (%)**		**Heavy equipment (%)**		**Seams (%)**		**Cuts (%)**		**Installer 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	-	-	-	-	6701
Amount	2985		654		265		59		231		4194
Total	71.17%		15.59%		6.32%		1.41%		5.51%		

Figure 5 shows a typical geomembrane perforation originating from heavy equipment traffic on the covering material located at the cell bottom.

Figure 5. A one meter tear discovered using the dipole method, caused by heavy equipment during covering material placement.

7. CONCLUSION

The water puddle and dipole techniques used in geoelectric leak detection surveys are standardized methods (ASTM) that enable a control of the global integrity of the geomembranes during the installation and covering phases. The vast majority of leaks discovered after the geomembrane installation (exposed geomembranes) are found in the panels (up to 70 %), not at the seams. It is therefore mandatory to check the total lined area to ensure the geomembrane integrity and not only to implement destructive and non-destructive seams testing.

The relationship between the leak density and the presence or absence of a rigorous CQA program and geomembrane thickness has been found to be crucial. It was found that most perforations are caused during geomembrane installation and not during its covering phase whenever a rigorous CQA program is implemented. However, larger tears and holes are usually encountered during the geomembrane covering phase.

For landfills, a rigorous CQA program combined with leak detection surveys on exposed and covered geomembranes is recommended. Even though designers use high factors of security to reduce the possibility of perforations in many projects, leak detection surveys are an alternative that significantly reduce these factors, resulting in a reduction of the thickness of the covering material layers, the protective geotextiles and the geomembranes themselves. In certain cases substantial economic savings would result. A leak detection survey is a useful tool in assuring the integrity of a containment project using geomembranes.

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