Proceedings of Geosynthetics Mining Solutions, 2014
September 8–11, 2014, Vancouver, Canada
Published by InfoMine, © 2014 InfoMine, ISBN: 978-0-9917905-5-5

# A Case Study on the Installation of LLDPE Geomembranes in Cold Weather

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## Abstract

For many reasons, such as ice bridges and operation-down periods, construction on mining sites sometimes needs to happen during winter. Therefore, materials like geomembranes sometimes need to be installed during some of the coldest and harshest weather conditions on earth. However, installing materials such as geomembranes in cold weather presents installation challenges that can compromise the integrity of the liner. Advancements in installation and material technologies have benefited this practice tremendously. One of these innovations is the use of linear low-density polyethylene (LLDPE) geomembranes for these applications—one of its well-known benefits is the reduction of stress crack probability.

This paper looks at a cold-weather installation of geomembranes for a mining project in Quebec, Canada. The installation of this geomembrane was performed at temperatures as low as −39°C. This paper discusses the challenges the installation crew faced during this period, as well as how they were overcome. It also compares the installation parameters, such as productivity and special measures, from this phase of the project with the installation parameters of other phases that were done with different materials and/or during warmer periods in the year.

Finally, the intent of this case study is to identify good cold-weather installation practices, as well as optimal designs that will allow for proper winter installation of geomembranes for mining projects. Based on these findings and conclusions, this paper makes recommendations on good practices for cold-weather installation and design of polyethylene geomembranes.

## Introduction

Human nature being what it is, we are always trying to push the limits of technology to find natural resources and maximize the extraction of them. As such, we are now working in areas of the world where we never thought we would find any valuable resources. Thus we need to engineer materials, technologies, and processes to reach and extract these resources.

In the mining industry we extract valuable minerals in some of the harshest deserts, some of the coldest areas, and even in the middle of lakes and seas. Technologies and materials have been improved to maximize the efficiency of the extraction processes. Geomembranes do not escape this phenomenon, and advancements in resin, processes, and finishes have allowed polyethylene geomembranes to be able to perform in these harsh environments.

In 1997, the Geosynthetic Research Institute (GRI) published the first version of the GM13, which set the standard that is still used today for many critical applications of polyethylene (PE) geomembranes. In 2000, the GRI published the original version of the GM17, which set the standard for the linear low-density polyethylene (LLDPE) geomembrane. However, the momentum that high-density polyethylene (HDPE) had gained, as well as its better mechanical properties and chemical resistance, made it the material of choice for most designers of geomembrane applications in the mining industry.

Numbers have shown that installation of PE geomembranes during winter has increased on average by 10 percent annually since 2009 (Solmax sales data, 2009−2013). Many issues arose from installing in such conditions, and LLDPE quickly became the material of choice for cold-weather installation. In fact, while overall PE was increasing at a rate of 10 percent annually, for LLDPE the average annual increase was about 30 percent (Solmax sales data, 2009−2013). Figure 1 shows that LLDPE winter installations have increased from 20 percent of all Solmax's PE geomembranes installed in winter 2009, to close to 42 percent in 2013 (Solmax sales data, 2009−2013).

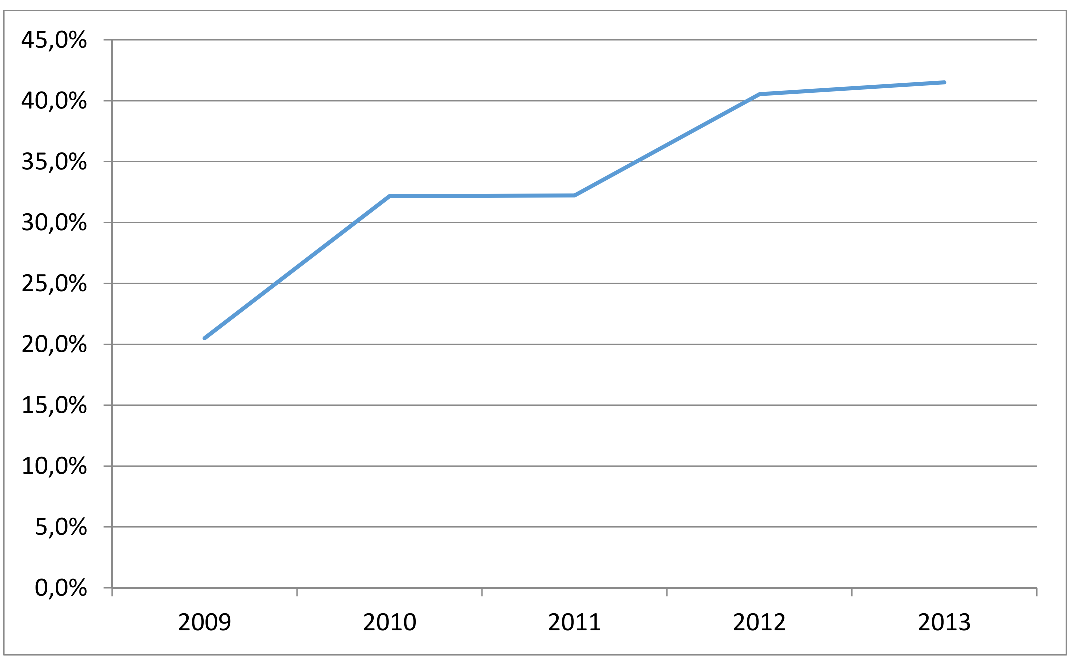


**Figure 1: % of LLDPE/PE Winter Installations**

This paper looks at the issues arising from installing HDPE in winter conditions and shows that LLDPE has solved most of these issues. It also analyzes and compares two winter installations that were performed by the same crews using the same equipment. However, one project used HDPE while the other used LLDPE. It also compares the on-site quality control (QC) data for each project to determine which installation was the most efficient. Finally, this paper will validate, based on the data collected, the theory that installing LLDPE in cold-weather conditions is more efficient than installing HDPE.

## LLDPE for Winter Installations

### Issues with HDPE in Winter Installations

While HDPE has been installed in cold conditions for many years, the requirements for the installers are many. Therefore, unless the installers are highly experienced with this type of installation, many issues can arise during this process which frustrate the engineers and designers and discourage the installers. The main issue is due to the fact that HDPE has a higher melting point than LLDPE, as well as a high heat-transfer demand. This requires the welders to work at a slower pace and due to the cold weather, might lead to more failures of destructive testing. Inexperienced installers would usually try to weld at the same rate as for their warm weather installations, but would quickly have issues with calibration testing as well as destructive testing.

A second issue with cold-weather installation of HDPE came when the installers tried to repair a defective fusion weld. Typically, installers will use an extrusion weld to repair a fusion weld that did not pass the destructive testing. However, if this extrusion weld is performed to close to the original weld (less than 1″ away), the many temperature variances can provoke a thermic shock and lead to stress cracking of the geomembrane. Due to its high crystallinity, HDPE is susceptible to stress crack.

The third issue—and probably the main one with cold-weather installation of HDPE geomembranes—does not necessarily occur during the installation process but can arise during the liner’s service life: stress cracking. As explained above, due to the high crystallinity of HDPE, which gives these types of liners the high mechanical strength and chemical resistance; they are more susceptible to stress crack. While the example above (the second issue) was a good example of stress cracking during installation, this phenomenon can occur at any time during the service life. HDPE is particularly susceptible to environmental stress crack (ESC) in cold-weather applications of geomembranes. Unfortunately, such events with HDPE geomembranes have led designers to search for other alternatives when the liner is to be used in these harsh conditions.

## Why LLDPE is Ideal for Cold Weather Installations

LLDPE differs from its HDPE counterpart in many ways, e.g., elongation at break, tear resistance, and puncture resistance—but it makes up for this with its unequaled deformability from its low modulus (Geosynthetic Research Institute GRI-GM17, 2012, and GRI-GM13, 2012). LLDPE contains less crystalline molecular phase (≈ 10 percent) than HDPE (≈ 50 percent). This leads to its density and melting point being lower, while its elasticity is enhanced (Islam et al., 2011), making it a much more ductile material highlighted by superior multi-axial deformation of 90 percent and above (American Society for Testing and Materials D 5617, 2010). The increased flexibility of LLDPE geomembranes enables easier handling and fitting around acute rigid appurtenances as well as allowing shop pre-fabrication and accordion folding on thinner gauges without permanent damage to the material.

LLDPE geomembranes may also be easily assembled to HDPE geomembranes using industry-standard welding protocols (IAGI, 2007). Under those circumstances LLDPE's mechanical properties should govern acceptable weld-testing-passing values, in similar fashion to welding two different thicknesses of the same polymer, where the thinner one's mechanical properties command (Geosynthetic Research Institute, 2012).

Also, because of their lower melting point and heat-transfer demand, site assemblies of LLDPE geomembranes are accelerated by having their welding equipment speed increased. For all the reasons mentioned above, LLDPE is often considered to be a foolproof material from a construction point of view, due to its wider window of welding parameters. This is especially beneficial in cold-weather seaming conditions.

For the designers, LLDPE also offers a major advantage over its HDPE counterparts as LLDPE does not have any risk of stress cracking. Thermal shock occurs when a thermal gradient causes different parts of an object to expand by different amounts. This differential expansion can be understood in terms of stress. At some point, this stress can exceed the strength of the material, causing a minute initial crack to form. If nothing stops this crack from propagating through the material, it will cause the object's structure to fail. Thermal shock is most likely to occur when welding polyethylene geomembranes in cold temperatures. As the cold geomembrane is exposed to rapid heat transfer, its crystalline phase percentage may actually increase from molecular rearrangement, hence its fragility. This thermal shock can lead to stress crack within the geomembrane.

Due to its high amorphous phase percentage LLDPE has absolutely no potential to stress crack even under the worst installation conditions and cold environments, as evidenced by the industry-standard GRI-GM17 which does not even require testing to that effect. As mentioned above, since LLDPE has a lower density and melting point than HDPE, LLDPE geomembranes also require less heat transfer for their welded assembly. This equates to more expedient assemblies at low ambient temperatures without stress-cracking concerns.

## Case Study of HDPE vs. LLDPE Cold-Weather Installations

Solmax partnered up with one of its installers, Texel Geosol, and collected data from two cold-weather installations. Both installations were performed with the same crews and the same equipment in roughly the same area. The materials used on both installations were the same thickness, with the same finish, and produced in the same plant. The only difference between the two installations was that one used HDPE and the other LLDPE. Therefore, the data collected allows us to compare the difference in installation efficiency between LLDPE and HDPE geomembranes. The data that is compared in this study are the calibration test results for both installations, as well as the destructive test results. From these, the efficiency of the two installations will be identifiable and compared.

### HDPE Cold-Weather Installation

This project was the installation of a liner for a tailing dam in northern Quebec, Canada. The installation took three months and was performed during the fall. Table 1 shows the temperature data during the installation.

**Table 1: Temperature Data during HDPE Cold Weather Installation**

| Temperature Parameter | Values |
|---|---|
| Average Installation temperature | 1°C |
| Maximum installation temperature | 18°C |
| Minimum installation temperature | −12°C |
| Temperature samples taken | 256 |

The four machines used for fusion welding during this installation were built by the installers. All of the machines were used to weld at a temperature of 750°C and used the same pressure. The only parameter that changed during the fusion welding of the liners was speed. Therefore, the machine speeds as a function of the ambient air temperatures based on the calibration testing can be charted. The results are shown in Table 2.

The speeds expressed in the table are in POT and do not represent the actual speed in m/min or ft/min. While 100 POT represents about 1 ft/min (0.3048 m/min), 0 POT does not represent 0 ft/min. Therefore, the values are to be used as relative values, as the actual values are proprietary information of the installer.

Figure 2 shows the statistics from the data collected on site from the calibration testing of these machines. As the data shows, there is a clear difference in welding speed when the ambient temperature is above the freezing point and when it is below it. The average speed when welding above 0°C (32°F) was 653 with a maximum speed of 992 (note: maximum machine speed is 1,000), while the average speed when welding below that temperature (0°C/32°F) was 375 with a maximum of 630. A difference in average speeds of 278, and of 362 for maximum speeds.

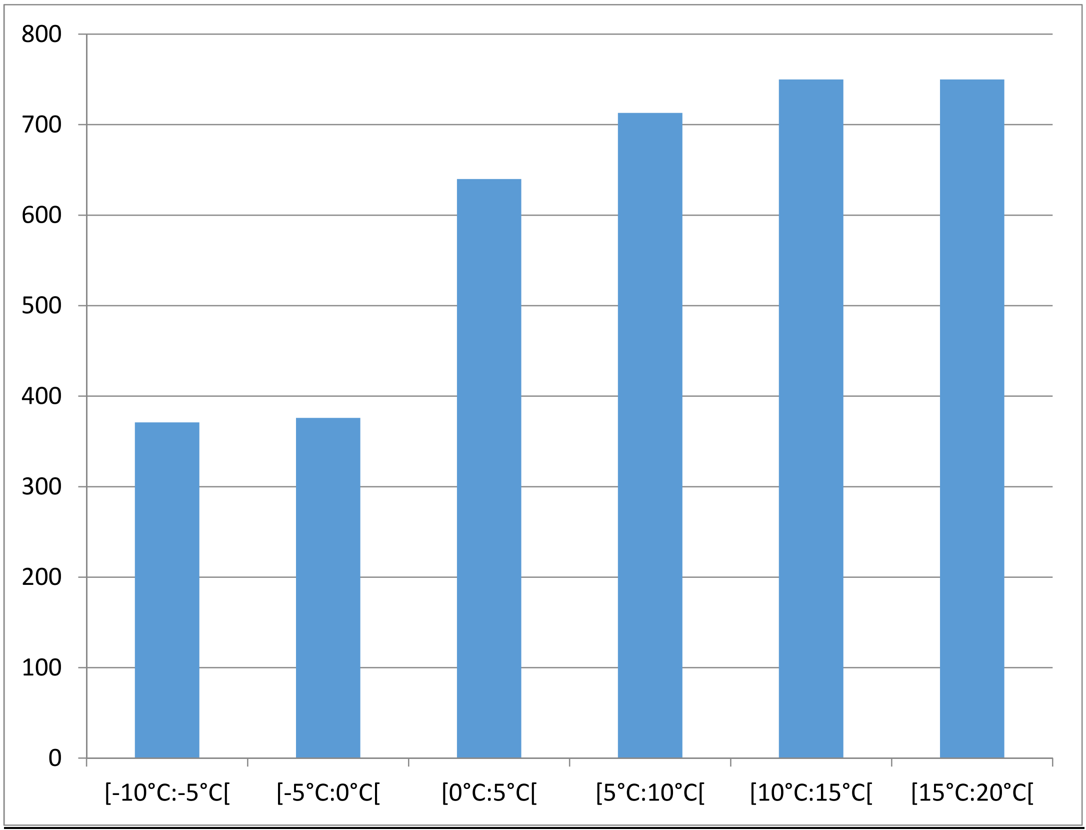


**Figure 2: HDPE Cold Weather Installations—**
**Average Maximum Machine Speeds/Ambient Temperatures**

**Table 2: Welding Speed Data during HDPE Cold Weather Installation**

| Speed Parameter | Values |
|---|---|
| Average Speed | 530 |
| Maximum Speed | 992 |
| Average Speed (Temp >=0°C) | 653 |
| Maximum Speed (Temp >=0°C) | 992 |
| Average Speed (Temp <0°C) | 375 |
| Maximum Speed (Temp <0°C) | 630 |

The destructive testing, i.e., peel resistance and shear resistance, was also studied for this project. Table 3 shows the percentage of passing samples taken from the HDPE project.

**Table 3: HDPE Destructive Testing—Passing Percentage**

| Test | Passing Percentage |
|---|---|
| Peel Resistance | 94.8 |
| Shear Resistance | 91.5 |
| Peel Resistance below 0°C | 94.3 |
| Shear Resistance below 0°C | 90.0 |

The HDPE destructive-testing analysis shows that the percentage of passing test was slightly lower when ambient temperature was below the freezing point, but was not significant enough to conclude that cold-temperature welding affects the mechanical properties of the weld on HDPE liners.

### LLDPE cold-weather installation

This project was also a tailing dam project in Northern Quebec. The installation was performed in two phases. The first took a little over one month and was performed during winter, while the second took one month and was during the summer time. The ambient temperature data collected is shown in Table 4.

**Table 4: Temperature Data during LLDPE Cold Weather Installation**

| Temperature Parameter | Values |
|---|---|
| Average Installation Temperature | −9°C |
| Maximum installation temperature | 28°C |
| Minimum installation temperature | −37°C |
| Temperature samples taken | 425 |

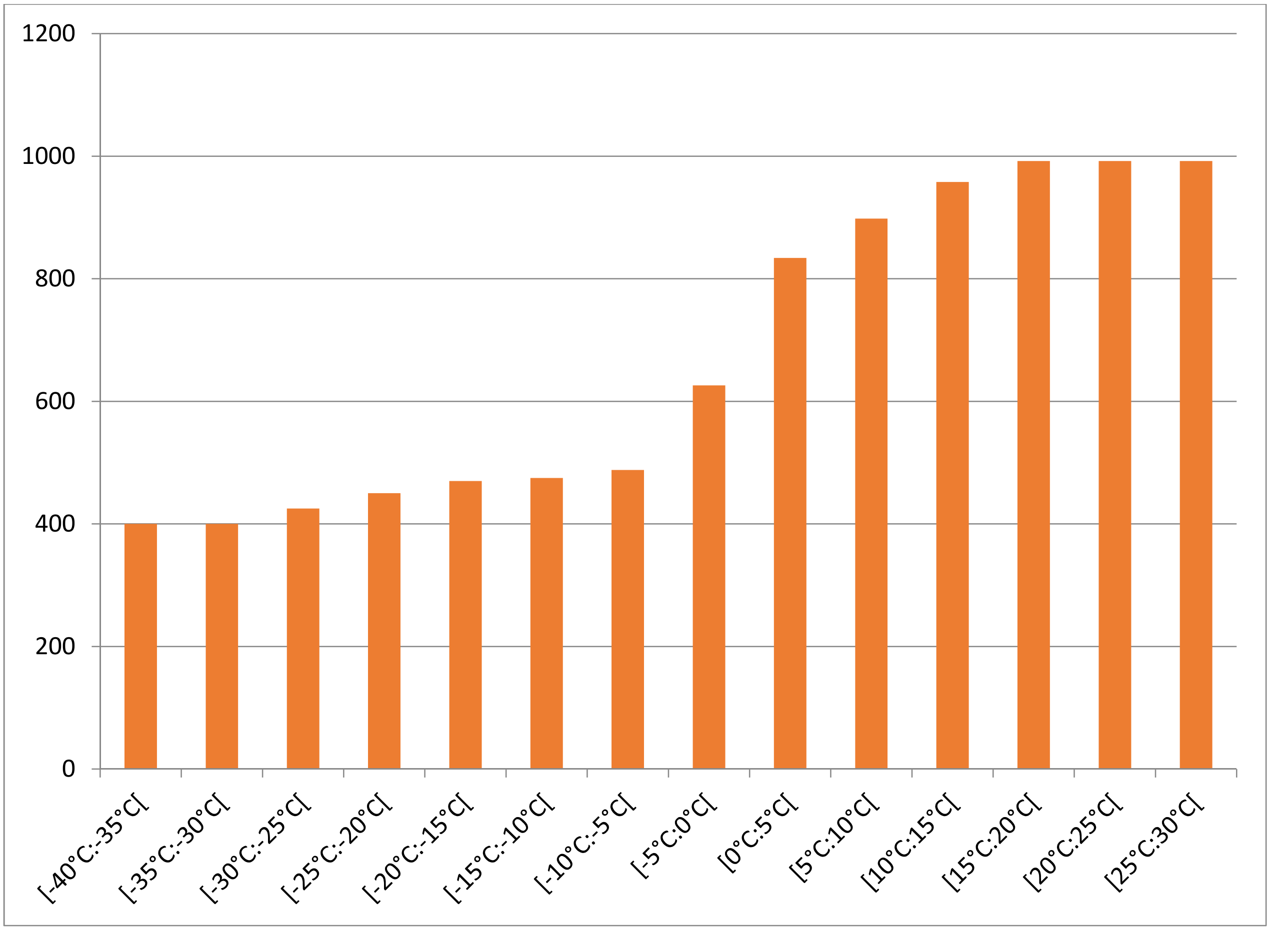


**Figure 3: LLDPE Cold Weather Installations—
Average Maximum Machine Speeds/Ambient Temperatures**

The same four machines that were used on the HDPE project were used in both phases of this project. They were all set at 750°C and with the same pressure; therefore once again, the only parameter that changed was the speed of the machines. Figure 3 shows the average machine speeds for different temperature ranges.

Phase 1 of the LLDPE project was performed at much lower ambient temperatures than the HDPE project. However, based on the above table, even when ambient temperatures reached −37°C (−35°F), the maximum machine speed used was higher than for HDPE. Table 5 shows the same data analysis for LLDPE that was performed for HDPE.

**Table 5: Welding Speed Data during LLDPE Cold Weather Installation**

| Speed Parameter | Values |
|---|---|
| Average Speed | 664 |
| Maximum Speed | 992 |
| Average Speed (Temp >=0°C) | 835 |
| Maximum Speed (Temp >=0°C) | 992 |
| Average Speed (Temp <0°C) | 454 |
| Maximum Speed (Temp <0°C) | 626 |

As stated above, 100 POT for these machines represent about 1 ft/min. Therefore, as we are analyzing the cold-weather data, when temperatures were below the freezing point, the average speed for LLDPE was 79 POT (0.79 ft/min or 0.24 m/min) higher than for HDPE. To push the analysis even further, the 454 POT average for LLDPE takes into account installations for very cold weather, which wasn't the case for HDPE. If the data analyzed is limited to the same temperature ranges for LLDPE and HDPE, the average maximum welding speed for LLDPE was 557 POT, which represents a difference of 182 POT (1.82 ft/min or 0.55 m/min) with HDPE.

What does this represent? If welders weld at an average speed of 10 ft/min in cold weather for HDPE, they would weld 18 percent faster with LLDPE.

The data that was studied for the destructive testing of LLDPE was only for the cold-weather phase. Table 6 shows the results of this analysis.

**Table 6: LLDPE Destructive Testing – Passing %**

| Test | Passing % |
|---|---|
| Peel Resistance below 0°C | 96.5 |
| Shear Resistance below 0°C | 95.3 |

It is important to reiterate that the installation for the LLDPE project was performed at much lower temperatures than the HDPE project. Yet, both peel-resistance testing and shear-resistance testing showed better results than for the HDPE project. In fact, they were even better than the overall HDPE values.

Therefore, while both installations were performed by the same crews and the same equipment, the LLDPE installation, while being at much lower temperatures, was performed at a higher pace and was more efficient.

## Conclusion

The main advantage of using LLDPE in cold-weather applications is its resistance to stress cracking. This has been a known fact for some time, as proven by the fact that ESCR (Environmental Stress Crack Resistance) is not even tested in the GM-17 standard, and by the fact that there are no registered stress-crack issues with LLDPE geomembranes (Solmax internal data). Analysis of Solmax's internal data has shown that while LLDPE represented 20 percent of the PE geomembrane volume installed five years ago, it is close to 43 percent today. As winter-time installations are more frequent due to project constraints, LLDPE is more and more the solution of choice by installers.

Data analysis of two cold-weather installations, one of HDPE geomembranes and the other LLDPE, showed that LLDPE also represents advantages on the installation efficiency of the liners. While the installation of LLDPE took place at colder temperatures, it was performed at a higher productivity level and with better efficiency. Table 7 below shows the summary of the results.

**Table 7: Results Summary**

| Parameter | HDPE | LLDPE |
|---|---|---|
| Average Installation Temperature | 1°C | −9°C |
| Maximum installation temperature | 18°C | 28°C |
| Minimum installation temperature | −12°C | −37°C |
| Average Speed (Temp <0°C) | 375 | 454 |
| Maximum Speed (Temp <0°C) | 630 | 626 |
| Peel Resistance below 0°C (%) | 94.3 | 96.5 |
| Shear Resistance below 0°C (%) | 90.0 | 95.3 |

Even though this information does prove that installation with LLDPE in cold weather is more efficient than with HDPE, more data should be collected and analyzed to prove this without a doubt. Certain parameters were not taken into account in this study, such as job-site restrictions, available human resources on the job site, project specifications and other climatic factors such as humidity. All these parameters could impact the values collected, especially the welding-machine speed. For example, a project's specification could specify that below a certain temperature, welding-machine speed should not exceed a certain value. This could influence the data. This being said, the data collected was for work performed by the same teams, with the same equipment, and in a similar environment. In any case, if only for its stress-crack resistance, LLDPE should always be the material of choice of designers planning on installing or having a liner perform under cold-weather conditions, as this will lead to a more effective installation and a longer service life.

## Acknowledgements

Solmax would like to thank Texel Geosol for their participation in this study. The access to the jobsites as well as the data was essential to write this case study.

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