LESSONS LEARNED FROM A GEOMEMBRANE LINER FAILURE IN A COLD ENVIRONMENT

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ABSTRACT

Several sets of steps were constructed on the 2H:1V side slopes of a 20 m deep irrigation pond in a cold environment. The pond, lined with a single HDPE geomembrane, filled with water during the winter and was emptied in the summer. Early in the summer the pond was found to be leaking. Steps were torn off the strip on which they were attached. The strip had been tack-welded to the liner. Several tack welds were torn off causing leaks in the liner. Damage was caused by ice attaching to the steps and ice and snow masses sliding down the side slopes.

INTRODUCTION

In the northwest USA where freezing winter conditions occur an irrigation pond 20 m deep with 2H:1V side slopes was constructed with a single high density polyethylene (HDPE) liner in the late fall and winter. Every 33 m along the slopes a 1 m wide strip of structured HDPE with short lengths of inverted concrete embedment strips (acting as steps) welded to it was tack welded to the primary liner (see Figure 1). After the next winter the pond liner was found to be leaking. Most of these leaks were associated with holes at the ladder strip tack welds.

Figure 1 shows a series of steps and the extent of their tearing from the support strip. This damage was primarily below the upper water line, but there was also some damage on the steps above the water line. Fortunately, this step damage did not result in liner leakage but it did demonstrate that there were significant forces acting on the steps to cause the tearing. The probable cause of the forces was attached ice. The downward forces, above the water line, were applied by sliding snow and ice, as evidenced by twisting of the ends of the steps closest to each corner. The ends of the same steps further away from the corners were much less damaged.

Figure 1. Damage to steps and strip
Figure 2. Typical turned-up tack weld
Figure 2 shows that the tack weld beads along the edge of the strip supporting the steps have also been lifted at their upper ends and bent back downslope. That they are still rigidly oriented at 90° to the slope indicates that they have been forced into that orientation for some time – the initial induced bending stresses have relaxed. Clearly, once a feature is made more prominent on the surface more ice and snow will be retained by it on the surface, and the more susceptible it will become to damage by sliding snow and ice.

In many cases the extrusion beads were further peeled back by the ice and snow resulting in tearing of the liner and consequent significant leakage pathways. Figure 3 shows a “small” leak (left) and more extensive leakage right along a significant portion of the complete length of the bead. At those locations where the liner had not been torn, the weld was, fortunately, not 100% effective. It was still possible to see the grinding marks made on top of the liner in preparation for extrusion welding. Clearly, the weld bead had not melted the surface layer of the geomembrane but had simply conformed to the profile of the grinding gouges and made a mechanical “grabbing” bond to the sheet. Therefore, the bond was easy to separate under a moderate peeling force, without damage to the liner. Yet it may still have adequate shear strength to prevent the steps from sliding as a person walks up or down them. This is the preferred mode of “failure”.

![Figure 3. Small leak at turned-up bead (left) and long leak under bead (right)](image)

**DISCUSSION**

Many of the breaks between steps and strips, and tack weld beads and liner, were examined closely for evidence of stress cracking (SC). However, all the fracture faces examined showed the yield thinning and the fibrils associated with ductile tears, indicating that the weld or sheet has simply been overloaded by a stress exceeding the break strength of the weld or sheet.

That a newly installed single liner leaks is not at all unusual – it should be expected. This was recognized by the maximum allowable leakage rate (ALR) in the project specifications – 3 mm water level loss per day. However, this is an unusually high ALR. For comparison, waste water treatment plant lagoons area are typically required to have an ALR of 5000 liters per hectare day (lphd) or 3 mm per week.
An electrical leak location survey of the pond liner was also performed. In addition to the obvious leaks at the steps and adjacent strip tack welds the survey found 21 small holes on the floor and elsewhere on the slopes. These were typically small stone punctures and knife cuts, usual features of any liner installation. At a total liner area of about 8 ha this is an average of 2.6 leaks/ha which is approximately the international statistical average for large area liners as reported by Rollin (1999). Therefore the installed liner was of good average quality, which was quite surprising considering the steepness of the slopes and the cold weather and snow during liner installation.

One of the well-established principles of designing a geomembrane liner, particularly an HDPE geomembrane, is that the liner should function solely as a barrier and not as a load bearing member of the system. Thus, minimizing stress on the liner is a design priority. In large deep ponds in cold environments, where ice might form, it is most important to consider stresses generated by ice attaching to protrusions in the liner, ice floes impacting and abrading the liner in wind and waves, and snow/ice combinations sliding down the liner. It is also important to consider that freezing water trapped in narrow channels and crevices will exert a separating force between the two surfaces since the volume of ice is larger than the volume of the water from which it is formed. Thus, freezing water could lift the edges of steps, the ends and edges of weld beads, and the edges of the ladder strips, off the liner and make them more susceptible to impact and damage from sliding snow and ice. In other words the freezing water effectively performs a peel test between the liner and the components attached to it. This will occur when ice forms between the ladder strip and the liner under the center of the weld bead, at the edge of the top sheet.

The pond starts filling in September and continues to fill through May to reach a maximum depth in June when it begins to empty as irrigation commences. Ice will initially form on the surface of the water in November/December. The ice will attach to the steps and form behind and around the ladder strips. As the pond continues filling the ice, floating on the water, will be forced to rise thereby lifting the steps and other objects to which it is attached. Although the general force lifting a 300 mm (12 in.) thick layer of ice is only 3000 Pa (62.5 psf), this force is transferred to the liner through only a few contact points – the strip tack welds. The surface area of the water was approximately 5 ha, so the force necessary to lift 300 mm of ice is 155 MN (35 Mlb). These forces are transferred to the liner primarily through about six tack welds attaching approximately 40 step strips to the liner at the ice layer. If each tack weld was 300 mm long by 15 mm wide (the half of the bead on the liner) the stress on the weld bond would be approximately 67 MPa (9700 psi), much higher than the typical HDPE geomembrane break strength of 27 MPa (3800 psi). Therefore, it is not surprising the liner at the tack welds failed.

In the meantime the observed snow and ice cornices built up on the crests of the slopes and on the above-water steps can break lose and slide down the liner, further damaging features in their path. In the springtime, as the ice melts, the water level will still be rising, thus contributing to break-up of the ice into small ice-floes. In the wind and waves these will impact and abrade the liner and the steps. Ice floes still attached to the steps and around the ladder strips will cyclically stress the welds.
Clearly much of the liner/ladder damage had initiated at, and propagated down from the upper ends of the tack welds. An alternative method of reducing, but still not eliminating damage to the liner would have been to remove all of these upper ends by continuously welding the ladder strip to the liner.

It is also a feature of the average extrusion weld that bead ends and edges are not 100% bonded to the liner. As with most manual kinetic processes, it is extremely difficult, if not impossible, to start with 100% efficiency. The initial weld placed on the liner has a center and an edge. The center is hotter than the edge. Therefore the edge does not bond to the sheet as effectively as the center. The same occurs at the end of the bead, although sometimes removal of the extruder is a little delayed to assure bonding of the main bead. Thus, there remains a mound at the end of the bead. This can be hit by sliding ice and/or grabbed by ice on the water. Alternatively, the end of the bead can be smeared out along the liner with a sweeping, tilting-back action on the extruder to eliminate the end mound. In this case the swept bead would likely not be well-bonded to the liner. However, even if the weld had been perfectly made and the beads were 100% bonded right to their edges a lifting and peeling action would still occur at the center of the bead between the ladder strip and the liner, just where the leak was shown in Figure 3 (right).

Along the length of the weld the typical squeeze-out at the edge of the extruded bead is also often not 100% bonded to the sheet, and there are frequent notch geometries between the squeeze-out and the sheet. When water penetrates these notches and lesser-bonded areas and freezes, it will lift these features and tend to separate the bead from the sheet. As seen, these higher geometrical profiles become even more susceptible to damage by ice, both on the water and sliding down the slopes.

**SUMMARY**

- The presence of the steps seriously compromised the performance and integrity of the lining system.
- The ductile damage to the liner at the steps is the result of simple overload tearing.
- The high stresses causing the damage have been induced by ice and snow loading. Ice on the surface of the water as the water level changed probably caused most of the initial distortion of the steps and adjacent welds, and sliding ice/snow on the slope caused some subsequent tearing.
- When welding steps/strips to liner use a weld that will separate from the liner when peeling without causing damage to the liner.

**REFERENCES**