

Impacts of construction practices and reservoir filling on geomembrane uplift

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Keywords: geomembrane, uplift, case history, construction, filling procedures

ABSTRACT: This paper addresses a case history, illustrating a common phenomenon experienced during the first filling of liquids reservoirs lined with an exposed geomembrane. During the first filling of the considered reservoir, uplift of the geomembrane occurred. The analysis of the phenomenon shows that the uplifting was caused by air entrapped beneath the geomembrane. This paper discusses the causes of geomembrane uplifting and presents the method that was used to mitigate the problem. The paper shows that the designer's job is not finished upon completion of design, or even after all construction activities are complete. Provisions for the first filling of liquid reservoirs lined with exposed geomembranes are essential.

1 INTRODUCTION

Uplift by gas of exposed geomembrane pond liners has been discussed in several publications (e.g. Giroud 1982, 1983; Giroud and Goldstein 1982) and the importance of gas venting and under-liner drainage is emphasized in these publications. As indicated by Giroud (1983), the gas that uplifts a geomembrane pond liner can have a variety of origins: (1) gas due to decomposition of organic matter contained in the soil underlying the geomembrane; (2) gas due to soil contamination prior to the installation of the geomembrane; (3) gas emanating from biodegradable products contained in the impounded liquid and leaking through geomembrane defects; (4) gas resulting from chemical attack of the soil underlying the geomembrane by liquid leaking through geomembrane defects; (5) air contained in the pore space of the soil underlying the geomembrane and pushed upward by a rising groundwater table; (6) air entrapped beneath the geomembrane during installation and floating on top of liquid accumulated under the geomembrane (such as a rising groundwater table or liquid leaking through the geomembrane); and (7) air entrapped beneath the geomembrane during installation and uplifting the geomembrane during first filling of the pond. This paper addresses essentially the last of the seven listed cases.

The situation whereby air is entrapped beneath the geomembrane during installation, resulting in uplift of the geomembrane as the pond is being filled, is known to geosynthetics installers and experienced

designers. However, it is frequently new to owners and operators of these facilities. This may result in considerable concern regarding the liner system that is generally unfounded.

This paper discusses a sewage lagoon case history in which the newly installed geomembrane liner was uplifted at several locations by entrapped air, during the first filling of the reservoir. The paper presents an analysis of the phenomenon and describes the method that was used to mitigate the problem prior to completion of filling. The case history presented herein is remarkable because geomembrane uplifting occurred even though there was, beneath the geomembrane, a drainage layer connected with air vents located near the crest of the lagoon side slopes. It is important to learn a lesson from this case history, because it is generally believed that a drainage layer and air vents prevent geomembrane uplifting by entrapped air.

2 LAGOON DESIGN AND CONSTRUCTION

The lagoon had a length (in the east-west direction) of 196 m and a width of 126 m. The bottom dimensions were 178 m by 105 m, with the north end higher than the south end by approximately 0.8 m. The lagoon base grade was approximately 0.75% in the north-south direction; the side slopes were 2H:1V (26.6°) on the west side and 3H:1V (18.3°) on the three other sides. The depth of the lagoon was 3.25 m at the north end and 4.05 m at the south end.

A 0.15 m thick sand layer was constructed on the natural ground and extended all the way up the side slopes. The sand characteristics were: $d_{85} = 2$ mm and $d_5 > 0.075$ mm.

A geocomposite drain was incorporated below the geomembrane to ameliorate the drainage beyond that provided by the sand layer. The drainage geocomposite consisted of a high density polyethylene (HDPE) geonet with nonwoven geotextiles bonded to both sides. This drainage geocomposite extended over the entire lagoon area, including the side slopes.

A 1.5 mm thick smooth HDPE geomembrane was placed on top of the geocomposite. Passive air vents were included in the geomembrane. These air vents consisted of a 50 mm diameter hole in the geomembrane, with an extruded HDPE cap on top of the hole to prevent rainwater and runoff water from entering the hole. These air vents were located 0.3 m down the slope from the crest of the side slopes. The distance between air vents was 7.6 m. Thus, a total of 80 air vents were used. These vents were intended, in particular, to allow the relief of air pressure accumulating beneath the liner due to groundwater fluctuations resulting from the tide in the nearby ocean and rainfall in adjacent wetlands. It should be noted that, in accordance with the state of practice (a state of practice not supported by any analysis), vents are generally provided at 15.2 m intervals. In this case, intervals of 7.6 m were selected for the sake of conservatism.

The liner system was constructed in the summer of 2004. Construction of the liner system was relatively uneventful, with full time construction quality assurance provided through all phases of geomembrane installation. However, no electric leak detection was performed.

The installed geomembrane exhibited wrinkles (Figure 1). However, the height of these wrinkles (approximately 0.15 m) was considered normal for an HDPE geomembrane.



Figure 1. Wrinkles in the HDPE geomembrane at the end of installation.

3 GEOMEMBRANE UPLIFT UPON FILLING

3.1 Observations during initial filling

Shortly after completion and certification of the liner system, the owner began filling the lagoon with water from the wastewater treatment plant. When the depth of water reached approximately 0.2 m at the lagoon north end (and approximately 1 m at the south end), it was noted, at 15 to 20 locations, in the north half of the lagoon, areas of the geomembrane were emerging slightly above the water level. These “bubbles” are shown on Figure 2. With continuous filling, and after several days, there was no diminution of the geomembrane-emerging areas. Observers concluded that these geomembrane areas were “floating” on water. In fact, the geomembrane was not really floating, as discussed hereafter.



Figure 2. Emerging areas of geomembrane upon initial filling of the lagoon.

It should be noted that the water contained sludge particles in suspension. Typically, these particles settle very slowly, and it takes weeks before sludge starts settling on the liner. Therefore, when the bubbles were observed, there was a negligible amount of sludge deposited on the geomembrane.

3.2 Discussion of bubble formation

Whether a geomembrane exhibits large wrinkles or not, air is always present under the geomembrane at the end of geomembrane installation. If there is a continuous drainage path toward vents, the air present under the geomembrane will flow toward the vents if the air pressure under the geomembrane, at the bottom of the reservoir, is greater than the pressure due to a column of air having a height equal to the difference in elevation between the air vents and the bottom of the reservoir. In the considered lagoon, the difference in elevation between the air vents and the bottom of the reservoir is of the order of 4 m. The density of water being 775 times the density of air, a 4 m column of air generates the same pressure as 5 mm of water (i.e. 50 Pa). Therefore, a very small pressure applied to the air present under the geomembrane would be

sufficient to force this air to flow toward the vents. This pressure can be generated partly by the weight of the geomembrane and partly by the weight of sludge and water above the geomembrane. However, the pressure generated by these weights is more than counterbalanced by the structural strength of some of the geomembrane wrinkles. A number of wrinkles are sufficiently strong to resist loading and they do not flatten out. The air entrapped beneath those of the wrinkles that do not flatten out is not subjected to any pressure by the overlying materials and, as a result, does not flow toward the vents.

Filling of the lagoon started on the south side (i.e. the lowest side). As water submerged the wrinkles in the south half of the lagoon, the cooling effect of the water caused thermal contraction of the geomembrane and reduced all wrinkles. As a result, some air was expelled toward the drainage geocomposite. Also, the water applied pressure on the wrinkles. Some wrinkles flattened out, others did not. The air expelled from the wrinkles that flattened out was subjected to significant pressure, and traveled in the geocomposite toward the vents. It is possible that the lower part of the drainage system was filled with water (i.e. water from the fluctuating groundwater table or water entrapped in the drainage system during construction). Therefore, air may have been prevented from flowing southward. Also, it was easier for the air to flow toward the north for two reasons: (1) the length of the lagoon bottom is shorter in the north-south direction than in the east-west direction; and (2) water depth, hence normal stress on the geomembrane and the drainage layer, was less in the north part than in the south part of the lagoon. On its way toward the north end of the lagoon, the flowing air was trapped into certain wrinkles where the air pressure was still low in spite of the rising water level in the lagoon. As a result, air accumulated in some wrinkles located in the north half of the lagoon. At those locations, the geomembrane buoyed by the underlying air pockets was uplifted as the water level was rising in the lagoon. Thus, the bubble formation started.

Based on Figure 1 and the size of the lagoon bottom (178 m × 105 m), one may consider that there were of the order of 500 wrinkles distributed throughout the lagoon bottom. These wrinkles had the following typical dimensions: 3 to 10 m long, 0.15 m high and 0.3 m wide. As a result, it can be estimated that a volume of air between 50 and 100 m³ was entrapped in the wrinkles. During the first filling, a fraction of this air was pushed toward the vents by the water pressure, and a fraction accumulated in wrinkles located in the north half of the lagoon to form 15 to 20 bubbles of approximately 3 m³ each.

3.3 *Comments on ballasting*

Based on the above discussion, it is clear that water ballasting is incapable of overcoming the inherent

stiffness of many wrinkles. In contrast, ballasting with solids appears to be more effective than ballasting with liquid since geomembranes covered with a layer of soil have not been reported to be uplifted during reservoir filling, to the best of the authors' knowledge. One possible reason is that the pressure applied by construction equipment placing the soil layer forcefully flattens the geomembrane wrinkles, thereby forcing the entrapped air to flow toward the vents.

3.4 *Comments on geomembrane properties*

HDPE geomembranes are prone to the uplift phenomenon described in this paper because they exhibit large wrinkles due to their high stiffness and thermal expansion coefficient, the two main parameters of wrinkle development according to Giroud and Morel (1992). Also, their stiffness makes HDPE geomembranes resistant to re-conformation to a flat substrate. However, it should be noted that PVC geomembranes also are uplifted during first filling by air entrapped during construction, even though they do not exhibit large wrinkles due to their flexibility. This indicates that a significant volume of air can be entrapped beneath PVC geomembranes. Due to their flexibility, PVC geomembranes can deform to form dome-shaped bubbles, whereas HDPE geomembranes, which are stiff, tend to form relatively flat bubbles (Figure 2).

It should be noted that that the density of the geomembrane does not play a significant role. It is sometimes assumed that HDPE geomembranes are prone to uplifting because their density (940 kg/m³) is less than that of water (1000 kg/m³). This consideration is not relevant because the geomembrane is not actually floating on water, as explained in Section 3.2. PVC geomembranes have a density (1200 kg/m³) significantly higher than that of water and they are uplifted by entrapped air.

4 MITIGATION OF THE PHENOMENON

4.1 *Presentation of the method*

Removal of the entrapped air is necessary for relief of the problem. A simple solution was adopted to mitigate the phenomenon. In December 2004, a team of up to five owner and contractor personnel equipped with hip waders walked on the geomembrane, pushing the bubbles ahead of them. As they walked, they felt under their feet some wrinkles, which they pushed toward bubbles, thereby feeding the bubbles with air from the wrinkles. Then, they walked the bubbles to the toe of the nearest side slope, generally the north side slope. Then, the air naturally flowed in the geocomposite up to the vents. The geomembrane, thus relieved of the upward forces caused by the entrapped air, was submerged and held below the water level. This was easily accomplished and only a

few isolated areas had to be “re-walked” to rectify the situation. Some also worked from boats, using oars or paddles to push the geomembrane down. The operation lasted two days and was followed by one day of inspection by boat.

Figure 3 shows the lagoon shortly after the removal of the bubbles, and as it operates to this time, over a year later. This is a simple solution to a simple problem, but one which appeared severe and seemingly catastrophic to the owner at the time.



Figure 3. Removal of the “bubbles” has completed the installation and start-up process for the lagoon.

4.2 Discussion

The methodology of “walking-out” the wrinkles and bubbles works with or without the presence of a drainage layer beneath the geomembrane. If there is no drainage layer, it is necessary to walk the bubbles all the way to a side slope, above the water level. In fact, this is the case even if there is a drainage layer, because the walking does not apply on the entrapped air a uniform pressure that would force all of the entrapped air to flow toward the vents. It is, therefore, necessary to laterally displace the wrinkles toward the vents. Once relieved of its supporting volume of air, the liner can conform to the subgrade, confined under even the low normal loading of the water contained within the lagoon.

An important consideration is the efficacy of construction quality assurance. On this project, the construction quality assurance representative had demobilized after the geomembrane had been installed. Yet it is essential to ensure that the system will properly function during the start-up phase. Therefore, measures should be incorporated into the project specification to address potential problems during filling of the reservoir as a part of the contractor’s responsibilities, and a construction quality assurance representative should be present during the first filling.

5 CONCLUSIONS

The following conclusions can be drawn from this case history:

- A considerable amount of air can be entrapped in geomembrane wrinkles during installation.
- When ballasted by soil cover, the wrinkles are flattened out due to the pressure applied by construction equipment and air is expelled into the ground or the underlying drainage layer.
- If the geomembrane is not ballasted by soil cover, liquid pressure during the first filling of the reservoir may flatten some of the wrinkles by applying pressure on the wrinkles or by thermal contraction due to the low temperature of the liquid. As a result, some air is expelled and may accumulate under the geomembrane in high areas of the reservoir bottom. This results in uplifted areas of the geomembrane (“bubbles”), buoyed by the underlying air pockets.
- A simple solution to the problem consists in using a team of workers “walking out” wrinkles and bubbles, thereby displacing the air contained in wrinkles and bubbles toward the vents.
- The vents provided in the geomembrane and the drainage layer located beneath the geomembrane and connected to the vents are necessary, but not sufficient, to ensure air removal during the first filling of the reservoir.

This case history illustrates the importance of construction quality assurance during the first filling of reservoirs lined with exposed geomembranes. Most owners and operators of facilities are not familiar with the behavior of systems incorporating geosynthetics. Similarly, once the geosynthetics installer has departed, the general contractor is usually not familiar with these systems. It is the responsibility of the engineer or his construction quality assurance representative to ensure that appropriate assistance is provided.

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