A Case Study of Wrinkles in a Textured HDPE Geomembrane on a Slope

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ABSTRACT

Wrinkles in a 1.5-mm-thick, textured, high-density polyethylene geomembrane on a 65-m-long slope inclined at 3 horizontal to 1 vertical were captured with aerial digital photography and quantified with digital image analysis. For the particular date and time of day reported there were 2286 wrinkles with a height greater than 3 cm in a 65 m by 120 m area. Most of these wrinkles had widths between 0.1-0.3 m and lengths less than 7 m. However, there were a few very long wrinkle features that essentially extended the full length of the 65-m-long slope. The percentage of the area occupied by the wrinkles increased with the distance from the top of the slope, reaching a maximum of 26% of the total area.

1. INTRODUCTION

If there are no holes in a geomembrane, then there is no flow under a hydraulic gradient. Leakage through a hole in a geomembrane depends on: the hydraulic gradient, the size and number of holes in the geomembrane, the transmissivity at the boundary between the geomembrane and the underlying material, and the thickness and the hydraulic conductivity of the underlying material (Rowe et al. 2004). Wrinkles can form in a geomembrane during installation, which creates an airspace between the geomembrane and the underlying material (Figure 1). If there is a hole in the geomembrane at or near a wrinkle, this airspace provides a pathway for fluid flow and the leakage now also depends on the length and width of the wrinkle (Rowe 2005). There can be significant hydraulic interconnectivity between adjacent wrinkles (Take et al. 2007). The objective of this paper is to quantify the number, geometry and distribution of wrinkles that develop in a textured geomembrane on a slope with the intent of expanding the available data-base of wrinkles that can occur in the field.

2. SITE DETAILS

The particular site investigated is a cover system for a waste sand and gravel pile located at 46°10’N 60°06’W. A 1.5-mm-thick high-density polyethylene textured geomembrane was installed on top of 150-mm-thick layer of sand. The wrinkles were quantified on a portion of the west slope. The slope was inclined at 3 horizontal to 1 vertical (Figure 2). The distance from crest to toe of slope was about 65 m. The wrinkles reported in this paper were quantified between 13:14 and 13:27 on July 18, 2006, although additional data has been gathered to describe how wrinkles change over time. The air temperature was 28°C, the average wind speed was 19 km/h, and there were no clouds.
3. LOW ALTITUDE AERIAL PHOTOGRAPHY AND DIGITAL IMAGE PROCESSING

A low altitude aerial photogrammetry system was used to capture images of the geomembrane for quantification. The specific details have been reported by Chappel et al. (2007), and only a brief overview is given here. The system consists of a Digital Single Lens Reflex (DSLR) camera mounted on the underside of a 6.4-m-long helium-filled blimp, shown in Figure 3, to capture near-vertical air photos. The blimp is tethered to a 15-kg-anchor, which is carried over the geomembrane by one person. A second person has remote control of the camera's shutter release, and consequently determines when the photos are taken. Many photos are taken to ensure complete coverage of the site. Each photo covers an area of approximately 19 m by 28 m, with a 50 mm lens at an elevation of 60 m. Under ideal weather conditions (sunny and no wind), this results in an image scale of 1 pixel to 5 mm. Before the camera is flown over the site, a grid of Ground Control Points (GCPs) is painted on the geomembrane every 5 m along each seam of the geomembrane. These GCPs are surveyed, and labeled with an alphanumeric grid coordinate which is required for digital image manipulation.

The subsequent digital image processing transforms the images, stitches the transformed images together to form a master image of the geomembrane, and then quantifies the wrinkles for their length, width and degree of interconnectivity. The details of this process are reported in Take et al. (2007). Although the raw images are near-vertical, the actual location of the camera in space relative to the plane of the geomembrane surface is unknown, which distorts the scale across an image. The first step in digital processing is to correlate the image pixel coordinates to real world coordinates using the known locations of the GCPs. Then the image is geometrically corrected through image transformation to create a constant scale factor of 1 pixel to 0.01 m. A constant scale factor is a convenient method of accurately measuring distance in an image. The GCPs are used to create a single master image of the geomembrane site by stitching together the individual images. The wrinkles on the master images are manually selected, and then the length, width and area are digitally computed for individual wrinkles. The total length of hydraulically connected wrinkles can also be measured.

![Figure 3. Helium blimp used as a stable platform for low altitude aerial photography (modified from Take et al. 2007).](image)
4. RESULTS

The network of wrinkles occurring on the exposed geomembrane slope between 13:14 and 13:27 on July 18, 2006 are captured in the master image of Figure 4. This image is comprised of twelve air photos which have been transformed into a common coordinate system. The edges of the individual images can be seen by slight differences in contrast at the overlapping images. The wrinkles appear as dark, linear features. The coordinate system chosen for this image is in the plane of the slope (i.e. along the 3H:1V slope), covering a region 120-m-long in the horizontal direction h (i.e., across the slope) and 75 m perpendicular to the toe of the slope s (65 m up the slope and up to 10 m beyond the crest). The top of the image is near the crest of the slope (s=64-66 m), where the geomembrane is seamed to the top cover of the waste pile. The toe of the slope is at the bottom of the image (s=1-2 m), where there is a ditch and sandbags to temporarily prevent wind uplift. The right edge is the northwest corner of the waste cover. The geomembrane at the left edge of the study area continues for a further distance of approximately 80 m. In total, the study area of the master image consists of 18 geomembrane panel sections installed with the roll, or machine direction (MD), running roughly up and down slope (Figure 4). The geomembrane panels were installed from left to right across the image. Near the right side of the image, a triangular shaped section of geomembrane has been added to better align the geomembrane panels towards the dip of the slope prior to reaching the corner of the installation at the right hand side of the image.

Figure 4. Master aerial image taken on July 18, 2006 between 13:14-13:27.

The master image shows that wrinkles form both perpendicular and parallel to the length of a geomembrane panel. To give an indication of the very high resolution of the base image (1 pixel = 1 cm), a section of the master image in Figure 4 is shown in full resolution in Figure 5. At this scale, wrinkles are of 10-40 pixels in width, thus providing sufficient resolution to precisely measure the width of individual wrinkles. This image indicates that, with this geomembrane product, the wrinkles in the machine direction have an abrupt peak, whereas the wrinkles in the cross-roll direction have the more rounded shape as shown in Figure 1. The operator of the blimp is also visible in this image for a sense of scale.
Following the methodology of Take et al. (2007), the wrinkles in the master image have been subdivided into major and minor wrinkles, with an arbitrary threshold of 3 cm in height as the dividing line between the two. The height of any given wrinkle can be inferred from the contrast and shadows of an individual wrinkle relative to its surroundings. To aid in this process, the height of wrinkles in several panels of geomembrane were hand measured to calibrate the manual selection of major wrinkles. The pixels identified as comprising major wrinkles are presented in Figure 6.

The network of major wrinkles presented in Figure 6 contains 2286 major wrinkles, with an aggregate length of 6300 m. The distribution of major wrinkles presented in Figure 6 shows a trend of increasing wrinkles density towards the toe of the slope. This trend has been quantified in Figure 7, in which the percent aerial coverage of wrinkles is calculated every five meters down the slope for the full 120 m wide study area. Once below the crest of the slope (s=64-66 m), wrinkles were found to quickly increase in number to approximately 15% of the study area at this elevation. The proportion of the area occupied by wrinkles then increased until comprising a maximum of approximately 26% of the area surveyed.

Statistical analysis of the wrinkle network indicates that the mean width of wrinkles at this site is 0.21 m (averaged along the entire length of each wrinkle) with a standard deviation of 0.06 m. A histogram of wrinkle width is presented in Figure 8. This data indicates that 92% of wrinkles in the master image have a width of between 0.1 and 0.3 m. The observed length of individual geomembrane wrinkles is presented in Figure 9. In this histogram, the width of each bar represents one half panel width of installed geomembrane (i.e. 3.35 m). This data indicates that 94%, or 2155 individual wrinkles, are of a length less than a full panel width of geomembrane. The remainder of are very long roll-direction wrinkles and the mid-slope lateral wrinkles. The longest individual geomembrane wrinkle was found to be 67 m long; this is the maximum distance in the roll direction from the crest of the slope to the anchor trench at the toe of the slope. In other words, the maximum length of geomembrane wrinkles observed at this site has been found to correspond to the size of the installation in the roll-direction.
Figure 6. Network of major wrinkles.

Figure 7. Distribution of wrinkles along slope.
Figure 8. Histogram of wrinkle width.

Figure 9. Histogram of wrinkle length.
5. CONCLUSIONS

The wrinkles in a 1.5-mm-thick, textured, high-density polyethylene geomembrane occurring on a 65-m-long slope inclined at 3 horizontal to 1 vertical were captured with aerial digital photography and quantified with digital image analysis. For the particular date and time of day reported (July 18, 2006 between 13:14 and 13:27) there were 2286 wrinkles with a height greater than 3 cm. Most of these wrinkles had widths between 0.1-0.3 m and lengths less than the panel width (6.7 m). However, there were a few very long wrinkle features that essentially extended the full length of the slope (65 m). The percentage of the area occupied by the wrinkles increased with distance from the top of the slope, reaching a maximum of 26% of the total area. The actual number of wrinkles that could influence the quantity of leakage through any holes in the geomembrane liner will depend on the wrinkles present at the time of placing the protection system and overlying cover soil as well as the method of cover soil placement. Work is on-going to quantify the wrinkles that occur at different sites and how the wrinkles change during the day, day-to-day and season-to-season.

ACKNOWLEDGEMENTS

This work is funded by the Natural Sciences and Engineering Research Council of Canada through a Strategic Project Grant and is being done in partnership with the Ontario Ministry of the Environment, Terrafix Geosynthetics Inc., Solmax International Inc., AMEC Earth and Environmental, Gartner Lee, Golder Associates, CTT Group, and Dr. Grace Hsuan from Drexel University. The efforts of Mr. David Bleiker from AMEC Earth and Environmental to arrange access to this site are appreciated. Mr. Jeff Kemp assisted with gathering the aerial photographs.

REFERENCES


