

Development of a low altitude aerial photogrammetry technique to quantify geomembrane wrinkles

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Abstract

ABSTRACT: A low altitude air photo system has been developed to quantify the geometry of geomembrane (GM) wrinkles at a large scale. Wrinkles which are caused mostly by solar heating and expansion are of particular interest for high-density polyethylene (HDPE) geomembranes. It is important to improve wrinkle quantification because wrinkles may lead to greater leakage through the geomembrane if a hole is at or near a wrinkle. Wrinkles also result in greater local tensile strains in the geomembrane.

A low altitude aerial photogrammetry technique to quantify geomembrane wrinkles is presented. The system consists of a Digital Single Lens Reflex (DSLR) camera, with remote infrared shutter control mounted on a tethered helium blimp. This system allows the operator to obtain clear, accurate near-vertical air photos.

The wrinkle geometry is analyzed from the low altitude air photos using the digital image processing capabilities and custom functions in Matlab. This allows the user to geometrically correct images; stitch images of parts of a site together into a single image; and select and quantify wrinkle geometry from the image of the site. Preliminary results on the length, connectivity and frequency of wrinkles are presented.

Introduction

Calculations commonly used to estimate leakage through composite liners typically assume that there is intimate contact between the geomembrane and the compacted clay liner or the geosynthetic clay liner beneath it. This contact restricts the horizontal flow of leachate between the two barriers in a low transmissivity interface zone. Wrinkles (also referred to as waves) substantially increase the potential leakage though a hole in the geomembrane when it coincided with a wrinkle (Rowe, 2005). They also increase the tensile strains in the geomembrane when covered and buried beneath waste (Gudina and Brachman, 2006). The wrinkles in high-density-polyethylene (HDPE) geomembranes predominantly form due to material expansion by heating from the sun.

Rowe et al. (2004) reported the distribution of wrinkles on the base of one particular landfill cell during construction. These wrinkles were randomly distributed with no discernable patterns, thus making it challenging to quantify their length and spacing. Wrinkles developed at, and parallel to, the geomembrane seams as well at locations both perpendicular and inclined to the seams. The longest wrinkle was at least 17 m and may have extended the entire length of the cell (≈ 40 m). The shortest wrinkle was roughly 1 m long and the minimum spacing between wrinkles was about 0.5 m. The wrinkles inclined to the seams appeared to be connected to the long wrinkles at each seam. Such a distribution of wrinkles would provide an extensive preferential pathway for liquid migration beneath the geomembrane if there were any holes in the geomembrane at any point on the interconnected wrinkles.

Pelte et al. (1994) reported field observations of wrinkles for 1.5 mm thick black HDPE geomembrane overlying clay in a 30 m by 30 m cell in a landfill in France. They observed that major wrinkles occurred parallel to the length of the geomembrane roll at the location of seams, and also perpendicular to the seam direction. They reported large wrinkles between 0.05 to 0.1 m high and 0.2 to 0.3 m wide, and had a spacing of 4 to 5 m and appeared to extend across a significant width of the cell. They also noticed small wrinkles (less than 0.05 m high and 0.2 m wide) occurred perpendicular to the seams.

Touze-Foltz et al. (2001) quantified wrinkles in a 2 mm thick HDPE geomembrane over compacted clay using a photogrammetric technique. Wrinkle heights varied between 0.05 and 0.13 m, wrinkle widths between 0.1 and 0.8 m, spacing between wrinkles from 0.3 and 1.6 m, while the length of wrinkles was less than 4 m with most wrinkles 1-2 m long. The size of installation was only 7.5 m by 7.5 m, and consequently most likely limited the length of wrinkle that could form. However, the technique of Touze-Foltz et al. (2001) represents a very useful way of quantifying wrinkles at larger sites.

The objective of this paper is to present the details of the development of a low altitude air photogrammetry system to quantify the geometry of geomembrane (GM) wrinkles at a large scale. Details of the equipment used for obtaining the photos, the method of acquiring the photos, digital wrinkle analysis and the photo calibration are presented. Preliminary results from a large geomembrane installation are presented.

Low altitude aerial photography equipment

The system consists of a Digital Single Lens Reflex (DSLR) camera with remote infrared shutter control, attached to a tethered helium blimp (Figures 1 and 2). A Canon 5D DSLR camera is used for this application. It has a 13.3 megapixel complementary metal oxide semiconductor (CMOS) that measures 35.8 mm by 23.9 mm. The high density of pixels allows a greater resolution than cameras with a lower pixel count. The area of the CMOS is very close to the format of a film 35 mm SLR camera, which permits the use of the full focal length of a lens, unlike most DSLR cameras.

The blimp stability is a function of both the blimp size and wind speed. The blimp is 6.4 m long by 2.1 m diameter, which optimizes platform stability and ease of handling on the ground. The wind speed at ground level is greater and less predictable because there are

many localized currents due to uneven ground surface and differential heating. At an elevation of about 60 m, the wind speed is more constant. Thus a flying elevation of approximately 60 m is used in this study for the best possible stability. The blimp can lift 4.8 kg, and requires a 15 kg anchor. Since the blimp is streamlined and has tailfins, it will always orient itself into the wind. This prevents the blimp from becoming a large kite, and reduces the lifting or dragging the anchor in high winds; higher winds result in more side-to-side movements, as well as a decrease in altitude as the blimp blows downwind. Increased camera motion must be accommodated by a higher shutter speed although this reduces the resolution of the image.



Figure 1 Photograph showing blimp equipped with a digital camera used to obtain images of geomembrane wrinkles.

Low altitude aerial photogrammetry technique

This blimp and camera system allows the operator to take clear, accurate near-vertical air photos by optimizing the following variables: altitude of the camera, focal length of the lens, resolution of the image, field of view (or ground coverage), and number of images required to capture the site.

The altitude of the camera is controlled by the length of the blimp tether. The control over the altitude of the camera using this method should be considered nominal, as the

true height of the blimp, and therefore the camera, is ultimately controlled by the wind speed and direction. The wind direction affects the direction of the blimp, because the blimp will always point into the wind, and a greater wind speed will push the blimp downwind, and decrease the altitude. If the blimp moves in the air with gusts of wind, then the angle of the camera with respect to the ground will also change. The choice of nominal camera altitude is particularly important as the scale, S , of a captured photo is determined by the ratio of the focal length, f , of the camera lens to the altitude, A , of the camera. In the present study, the focal length of the camera is 0.050m and the nominal camera elevation is 60m, leading to a scale factor of 0.050/60, or 1:1200.

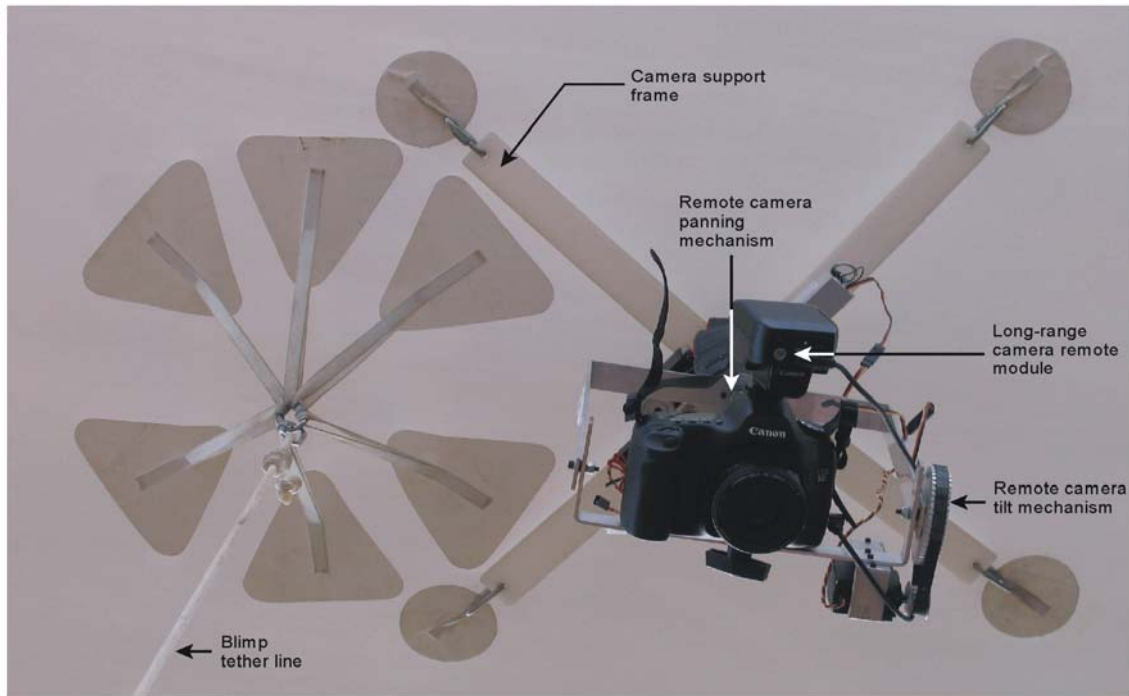


Figure 2 Photograph showing digital camera mounted to the underside of the blimp.

At a given blimp altitude, changing the focal length of the lens allows the user to change the object-space resolution and the ground coverage (i.e. field of view) of the photo. The object-space resolution describes the effective size in real-world units (i.e. mm) of a single pixel. This resolution can be calculated by considering a simple pin-hole camera model in which:

$$\text{ground coverage}(m) = \frac{\text{altitude}(m) \times \text{CMOS sensor width}(mm)}{\text{focallength}(mm)}$$

Thus, for the same camera orientation the object-space resolution of the images will be the ground coverage / number of pixels in the CMOS sensor. Whereas a shorter focal length will take wider angle photos and enable greater land coverage, this will be at the expense of the object-space resolution of the image and increased lens distortion. The resolution and image quality of the photo is very important, because the system must

have sufficient resolution to define wrinkles of a few centimetres in height at a camera elevation of 60 m. For image collection, a 50 mm lens is the optimal size to maximize land coverage per photo (19.1m x 28.6m) while still maintaining the precision needed to detect small wrinkles. The 50 mm lens at 60 m above the ground results in a theoretical resolution of 1 pixel = 5 mm on the ground. This can commonly be achieved in the field under good conditions. Photos for analysis are taken as close as possible to vertical. This minimises the image transformation errors when correcting the projection of the image.

During data collection, there is a theoretical minimum number of photos required to cover the entire field site. In practice, since the photo content and quality are initially unknown, with an unknown camera location, hundreds of photos must be taken to choose the best set of images required to produce a single image of the entire GM.

XY plane wrinkle geometry analysis

The black GM reflects enough light that the wrinkles are easily delineated by the contrast difference between the wrinkle reflecting the sunlight and the flat black of the non-reflecting flat portions. The wrinkles are linear white features on the black geomembrane (Figure 3).

The wrinkle geometry is determined by manipulating and analyzing the low altitude air photos with the image processing features and custom functions developed with Matlab. For this analysis, a single large image of the GM area is created from a selection of photos that cover the entire area to allow the analysis of the full area.

The wrinkles are subsequently located and quantified. The user digitally selects the wrinkles and the continuity of the linear features. The vectors created are located by a Matlab function which determines the geometric wrinkle properties of interest: length, connectivity and frequency, as well as the hydraulic connectivity.



Figure 3 Air photo of geomembrane installation. 1.5 mm smooth HDPE; Camera

elevation 65 m; Latitude 43°16' N; Air temperature 28°C; 1:20 pm Aug 18 2006

Calibration of images

Calibration is achieved by using the surveyed control points (CPs) as known points in the photos of the GM. This allows the photos to be geometrically corrected and stitched together to create one large image of the entire GM with a known scale. The scale chosen is one pixel represents 10 mm on the ground, which is a lower resolution than the original photo with one pixel representing 5 mm on the ground. This reduces the file size of the large image, and simplifies further measurements and quantification.

To develop an image of the entire GM area, a grid of labelled CPs every 10 m were drawn and labelled on the geomembrane. The spacing of 10 m ensures that there will always be many CPs in each picture. Each CP is marked on the GM by an “X” and is labelled with a grid coordinate. These ground control points are surveyed using a total station, and are visible in the photos. By connecting the grid locations of the CPs to the markings in the photos, the user can determine the orientation and scale of the objects in the photo in real world units. This also allows the user to further quantify the images.

Geometrically corrected images are created from the original photographs, using the known locations of the CPs. The individual images are then digitally stitched together to create one large image of the site, once again by utilizing the actual surveyed location of the CPs.

In a vertical air photo, there is geometric distortion due to three dimensional objects being projected on a two dimensional plane. This distortion results in a change in scale between the centre of the photo and the edges. In a geometrically corrected image, this distortion is eliminated by determining the three dimensional coordinates of objects of several points in each photo. This correction is completed by the user manually choosing the points on the digital photo and inputting relative coordinates into a custom Matlab function.

After photos have been geometrically corrected, the grid of CPs can be used to stitch all of the geometrically corrected images of the field site. This creates one large image with a scale of 1 pixel represents 1 cm.

Preliminary results

The air photo shown in Figure 3 was obtained during installation of a 1.5 mm thick, smooth HDPE geomembrane. The site was at a latitude 43°16' N and the image was captured at 4:09 pm on August 17, when the air temperature was 24°C. The camera was at an elevation of 60 m.

Wrinkles parallel, perpendicular and inclined to the geomembrane panels are visible in Figure 3. There were at least 76 wrinkle features identified over the 1172 m² area capture in this image. If extrapolated, this represents nearly 650 wrinkles per hectare. The

minimum wrinkle length was 0.5 m, maximum wrinkle length was 29 m. Sixty-eight percent of the wrinkles had lengths between 1-5 m, while 9% has lengths between 20-30 m. At many locations, it appears that adjacent wrinkles may be interconnected as they intersect and join each other and thus the length of hydraulically connected wrinkles is much greater than the maximum wrinkle length.

Summary

High resolution, digital images have been successfully used to capture wrinkle formation in geomembrane liners. Following photogrammetric principles, the altitude of the camera platform (in this case, a 6.4 m long blimp), the camera lens, the land coverage, and the resolution of the photos have been optimized to yield images of sufficient quality to define the spatial orientation of wrinkles over large areas. The wrinkles are analyzed using the image processing toolbox in Matlab, as well as custom functions. The photos are calibrated and connected together to create one large image of a GM installation. Work is currently ongoing to gather and analyse wrinkle image data from different field installations to better quantify the process of wrinkle formation in geomembrane liners.

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