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Innovative monitoring of dikes

Des observations innovantes de digues

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ABSTRACT: Like many other countries, Belgium has a high number of dikes, protecting the hinterland from flooding. The survey of all these dikes requires constant presence and attention from the dike managers. Furthermore, the identification of the damage type is not always possible at the onset of damage and often damage has already taken large proportions before any action can be undertaken. Therefore, alternative dike monitoring techniques could support the dike owners to faster recognize those areas which need extra attention. Two examples of such techniques are fiber optic measurements and satellite interferometry. The advantage of fiber optic measurements is that a rather large length can be monitored in detail. Fiber optic measurements, with glass fiber cables over 3km length along a river dike, were performed for a period of just over 1 year. The advantage of satellite interferometry is that it does not require the installation of any equipment and that deformations over large areas can be monitored. Satellite interferometry was carried out in the region of Antwerp, showing the possibilities of this technique to detect and monitor displacements over a large area. The results and challenges of both techniques are presented.

RÉSUMÉ: Comme beaucoup de pays, la Belgique compte un grand nombre de digues, protégant l'arrière-pays des inondations. L'inspection de toutes ces digues nécessite un constante présence et attention des gestionnaires des digue. En plus, l'identification du type de dégât n'est pas toujours possible lorsque le dommage apparait et souvent le dégât a déjà pris des grandes dimensions avant qu'on ait la possibilité de faire les remédiations. Pour cette raison on recherche des techniques d'observation alternatives qui pourraient assister les gestionnaires a identifier plus rapidements certains tronçons de digues qui exigent une attention particulière. Les mesures par fibres optiques et la télésurveillance par interférométrie radar sont deux exemples de nouvelles techniques. Les mesures par fibres optiques d'une part offrent l'avantage qu'on peut surveiller en détail de longues tracés. Cette technique de mesure a été utilisée le long d'une digue fluviale sur une longueur de 3km pendant plus d'une année. La télésurveillance par interférométrie radar d'autre part présente l'avantage qu'elle nécessite aucune installation d'équipement et permet de surveiller de grandes zones. Cette méthodologie a été appliquée dans la région d'Anvers, montrant ses possibilités à détecter et surveiller les déplacements dans des régions étendues. Dans cet article les résultats des deux projets pilotes mettent en évidence les possibilités et les défis de ces deux techniques.

Keywords: Dikes, monitoring, satellite interferometry, fiber optics, deformations

1 INTRODUCTION

As do many other countries, Belgium has over 1000km of dikes to protect the hinterland from flooding. The survey and maintenance of all these levees requires constant presence and attention from the dike managers. As a detailed inspection is not always possible, the timely identification of the damage is not always done and damage has often already taken large proportions before any action can be undertaken.

Traditional monitoring techniques like piezometers and inclinometers, measuring ground water levels and ground displacements, only give local information on the site where these instruments are installed. Even though these techniques are often indispensable to determine the extent and cause of the damage, it is impossible to equip the dikes along their full length with these instruments.

To assist the dike managers with their inspections, a search for solutions which can easily monitor large lengths of dikes is ongoing. Two examples of such innovative monitoring techniques, which can help to localize damage faster, are fiber optics and satellite interferometry. They were tested on a rather large scale in Belgium.

After localizing possible failure modes, local monitoring techniques can help to better understand the cause of the damage.

2 FIBER OPTIC MEASUREMENTS

2.1 Measurement technique

Fiber optical cables are already used for several years within the telecommunication industry to transport data. The glass fibers appear to be suited to detect strain and temperature changes as well, as the reflection and transmission of the transported light vary with strain and temperature. Several fiber optic techniques exist and a distinction can be made between distributed (continuous) and point-wise (discontinuous) measurements. For long distance measurements, a distributed technique, like Brillouin Optical Time Domain Analysis (BOTDA) appears to be advantageous. BOTDA is based on the Brillouin scattering, which uses the shift in frequency of the backscattered light to obtain information on strain changes (see Figure 1). Reflection is measured along the full length of the glass wire, practically this is every 5-20cm. The information on reflection in each point is averaged out over 0.5-1m. An accuracy of 10-30 µstrain can be obtained when using this technique. The disadvantages of BOTDA are that a loop is required to make the measurement and that the measurement is highly influenced by temperature changes. The Brillouin Optical Time Domain Reflectometry (BOTDR) requires only a single ended access to the source, but results in much lower accuracies. The temperature dependency implies that correction for temperature changes need to be taken into account.

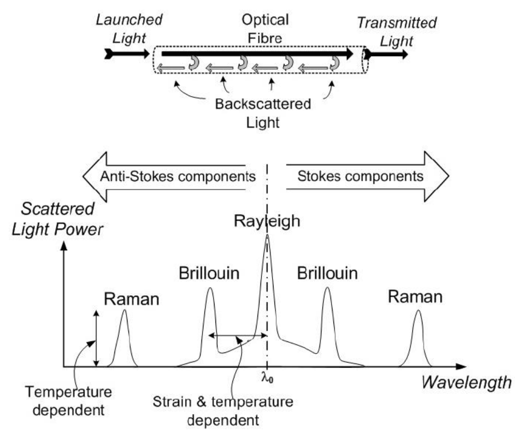

Figure 1. Different variations in backscattering light (Mohamad H., 2008)

2.2 Example of an on-site test

Along the right side of the river Scheldt, a new tow path was made over a distance of 3km (see Figure 2). Due to differences in available space and in geotechnical parameters along the length of the road, several solutions for the stability of the slope were designed. On the river side (at the top of the slope) a glass fiber was installed along the full length of this new road (see Figure 3). Two cables of 1.5km length were placed, with a central read-out position. A layer of sand was placed underneath to avoid damage to the cable.

Figure 2. Location of the new tow path and fiber glass cable

Figure 3. Pictures taken during and after installation

The intent was to place the cable as straight as possible, without any pretension on the cable. The result of the raw measurements is shown in Figure 4. It can clearly be seen that some peaks are present in the strain, indicating that a varying pretension is present in the fiber, due to installation of the fiber.

Figure 5 shows the results of the analyzed measurements for several days in relation to two different reference days. The top graph clearly shows a high amount of peaks and troughs, most often at the location of strain peaks in Figure 4. This shows that the pretension in the fiber is slowly disappearing, resulting in a decrease of the strain at the location of the stress point and an increase of the strain in the zone next to it. The bottom graph shows the results when using a reference date approximately 1 year after installation.

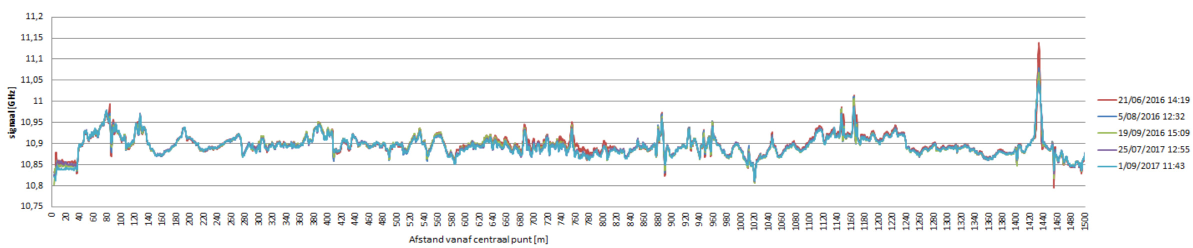

Figure 4. Raw measurement signal at different points in time

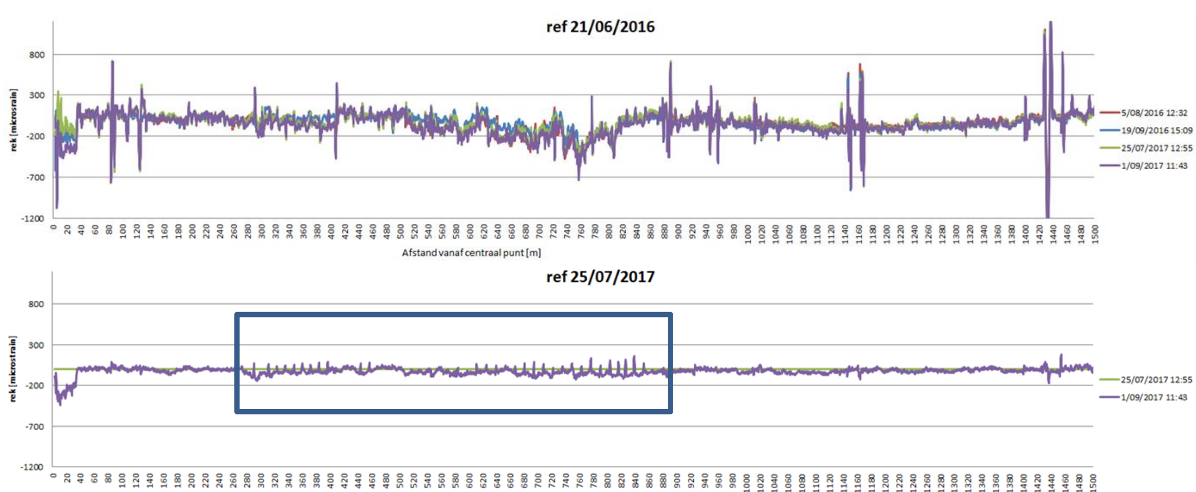

Figure 5. Results when taking into account different reference times

The largest peaks due to the pre-applied stress have disappeared. Some small peaks can be seen in the framed region. This is an area where a sheet pile was used to guarantee stability. The distance between the small peaks matches the distance between the concrete blocks on top of the sheet piles, which appear to move slightly away from each other.

3 SATELLITE INTERFEROMETRY

3.1 Measurement technique

Different types of satellites fly in fixed orbits around the Earth. InSAR (Interferometric Synthetic Aperture Radar) (Massonnet et al., 1998; Hanssen, 2001) is a satellite remote sensing technique used for the measurement of displacements of the Earth's surface. The measurement technique is based on the use of satellites which send out radio signals and which capture the reflected signal from the earth (giving RADAR images). When comparing different RADAR images acquired at different points of time of the same area, it is possible to derive the temporal evolution of displacements of objects well visible from the satellite during the period of analysis. Based on information of the time of flight of the signal and the changes of the phase of the signal, an analysis can be done of objects (seen as “radar targets”) on the Earth’s surface, resulting in information on the displacement of these objects. A semi-automatic analysis can be done for objects which are characterized by a signal which has a high stability over time.

The observed displacement is a displacement in the line of sight of the satellite. When coupling ascending and descending image results, it is possible to make a distinction between horizontal displacements (movement) and vertical displacements (settlements).

The advantages of the technique are that:

- there is no need to install instruments
- it is possible to analyze a large area
- it is possible to go back in time (using historically acquired satellite images)

The disadvantages of the technique are that:

- moving objects (cars, containers, vegetation) disturb the images, resulting in less obtained points
- the nearby presence of water is a problem.
- the analysis is quite advanced, as different aspects, e.g. atmospheric variation, need to be taken into account

3.2 Example of an on-site test

After performing some smaller scale tests, which demonstrated the possibilities of the technique, a larger scale pilot was set up to investigate the use of InSAR with very high resolution images (pixels of 3 m by 3 m, compared to 5 m by 20 m for the older satellites), in order to detect displacements while covering a large area. One of the goals was to see if in this case information of the displacement of areas which are located close to water (like dikes and embankments) can be obtained. An area around the city of Antwerp (Belgium) was chosen for the pilot. Figure 6 shows the area covered by the ascending and descending satellite images. The analysis was done in the overlapping area.

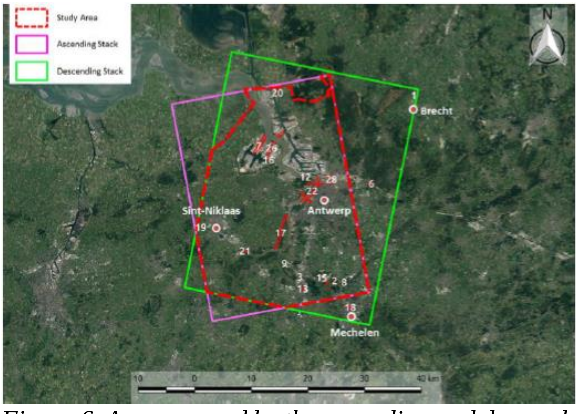

Figure 6. Area covered by the ascending and descending satellites

Images are gathered in both ascending and descending order, resulting in a frequency of 1 image/14 days for each viewing direction. Images were taken over a time span of 1 year. Figure 7 shows the result of the obtained deformation velocity (displacement/ year) for the study area. Red and yellow dots indicate movement away from the satellite (usually settlement), blue dots indicate movement towards the satellite (e.g. heave), green points are not showing any displacement over the observed period of 1 year.

For each point, the information of the displacement in the analyzed period can be obtained (see Figure 8).

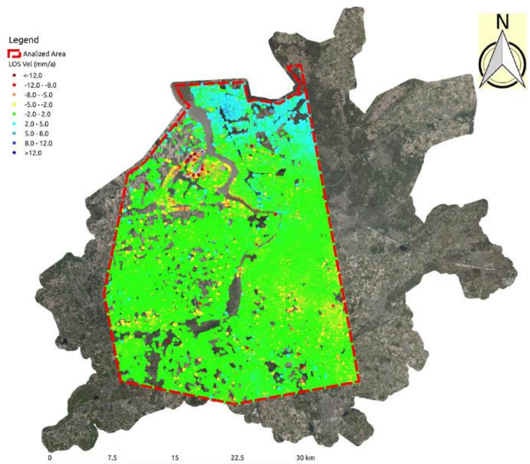

Figure 7. Result over the covered area

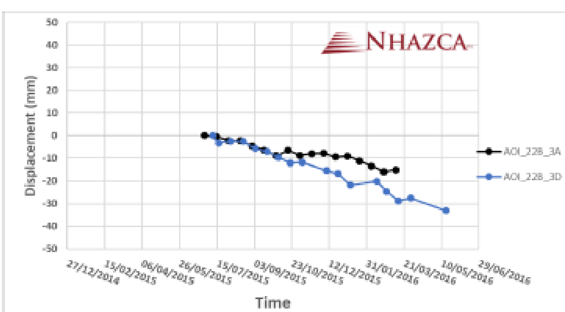

Figure 8. Information of displacement of 1 point

Figures 9 to 11 show some more detailed results of the analysis. In Figure 9, quite large movements can be seen at the right bank of the river Scheldt (above the river in the picture). This proved to be a recently heightened part of the dike, where the areas with the largest movement were known to be the areas with the softest soil. In Figure 10, an area of interest is shown, where no resulting deformation points are obtained. This is probably due to a bad reflection of the installed asphalt layer. Figure 11 shows another example of a local instability of settlement which was deduced based on the results of the analysis.

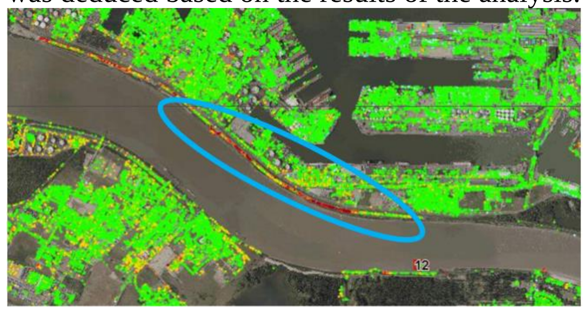

Figure 9. Quite large movements along a recently heightened part of a dike

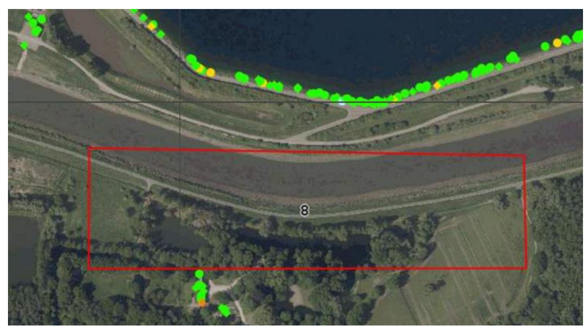

Figure 10. Large dike length without any retained measuring points

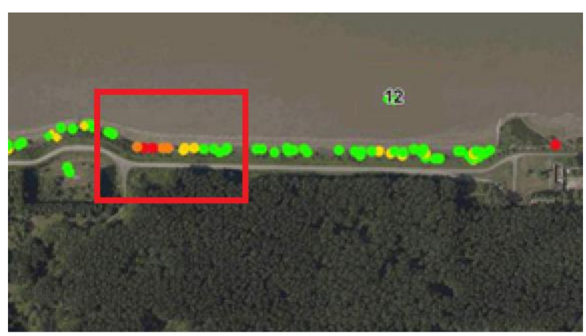

Figure 11. Local movement of a recently increased part of a dike.

A local scale analysis was performed to investigate whether a better result could be obtained for some areas with little to no results. The local scale analysis takes into account local atmospheric variations and manual selection of suited points. This approach results in more valid points and has the possibility to gather also information on the absolute height of the measured points. This implies that the information can be fitted on 3D images, and a better understanding of the actual moving objects can be obtained (see Figure 12).

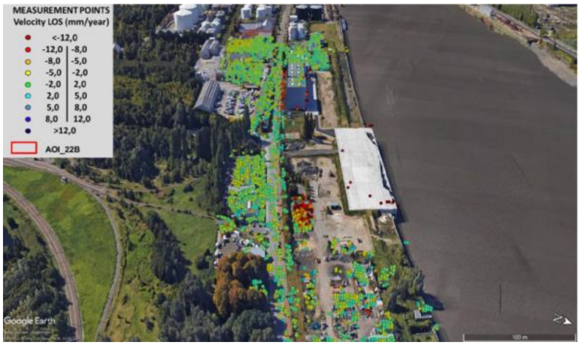

Figure 12. Example of a manual analysis result

The main advantage of this technique, apart from the ones described in section 3, is that a large area can be covered, indicating areas with potential problems. The main disadvantages are that:

- some points/areas are reflecting better than others, where it is not always clear what is the reason for this
- one cannot “choose” which points reflect. The reflecting objects are often metallic, which are highly influenced by thermal effects.
- Areas with moving objects (roads, industrial areas) require a manual analysis to choose the images which are useful for the analysis.

4 CONCLUSIONS

Two innovative monitoring techniques for dikes are discussed: the use of fiber optics to locate moving areas and the use of satellite images to determine displacements. Both techniques have their advantages and disadvantages, but it is clear that they can have a substantial added value when it comes to surveying larger areas and with that also longer stretches of dikes and embankments. A clear challenge is how to cope with the large amount of data which becomes available through this techniques.

5 ACKNOWLEDGEMENTS

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