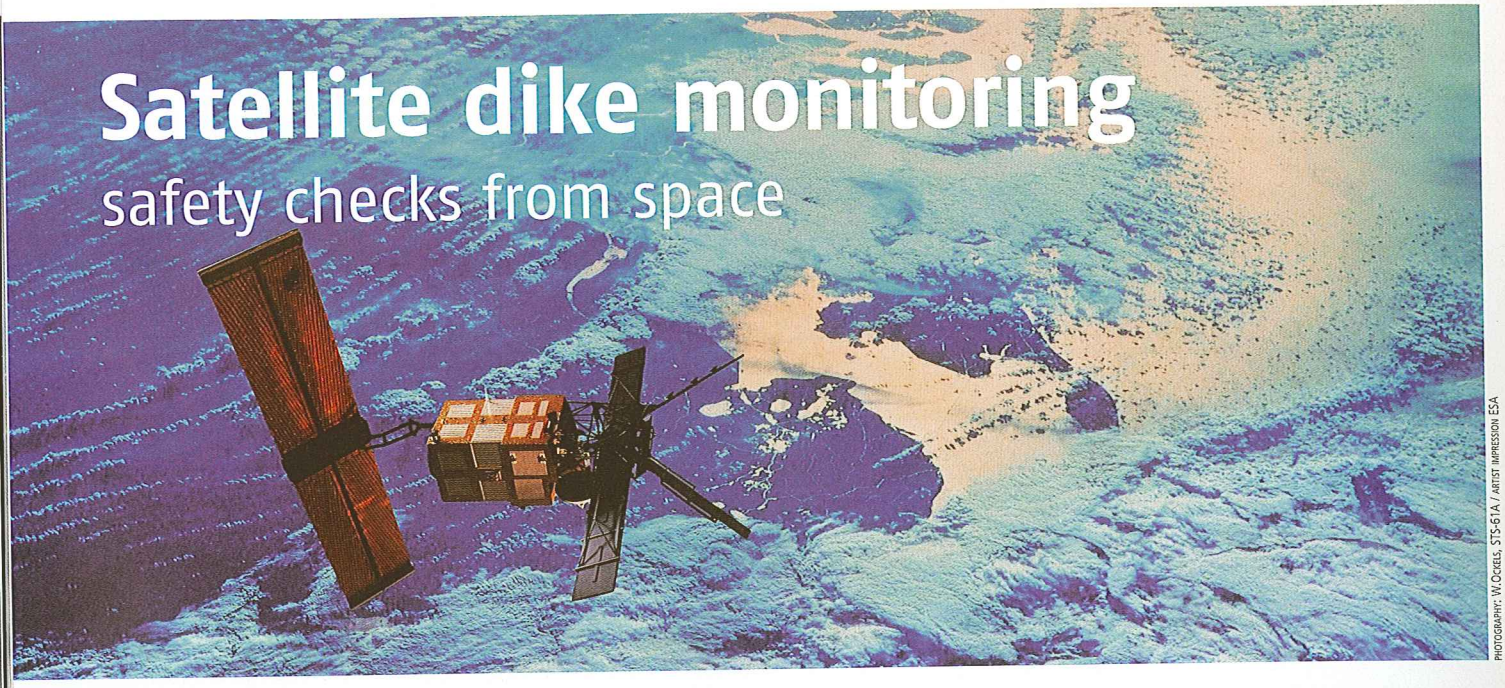
Satellite dike monitoring

safety checks from space



PHOTOGRAPHY: W. OCKELS, STS-61A / ARTIST IMPRESSION ESA

Monitoring the safety of water defense systems is crucial for life in the Netherlands. Conventional monitoring of dams and dikes is often limited to visual inspection, with additional in situ measurements if deemed necessary. A new student project suggests that advanced satellite radar technology can be used to obtain weekly updates on dike stability for a significant part of all dikes in the Netherlands. This may have a dramatic impact on safety assessment in the Netherlands. The technology is currently presented to the Dutch water management boards.

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Satellite radar interferometry utilizes electromagnetic signals to estimate the distance between the satellite and points on earth. Due to the repeat orbit of the satellite, every point on earth is imaged at least once per thirty five days. Given an archive of satellite images starting in 1992, it is now possible to identify points that show a constant radar scattering behavior over the entire period. Generally, such points are related to hard objects such as rocks, houses, or infrastructure. By measuring the changes in distance between the satellite and these points, we can estimate their stability, or deformation, with mm-level precision.

Interferometry

Over the years, the Delft Institute of Earth Observation and Space Systems (DEOS) has built up a considerable expertise with this technique, leading to in-depth analyses of earthquake regions, volcano eruptions, glacier movement, and land subsidence. In the studies aimed to observe land subsidence, e.g., due to the gas production in Groningen, it was recognized that reasonably good radar reflections were received from water defense structures such as dikes and dams. However, although these observations were clear, it was less understood what they physically represent and how they should be interpreted. A student team, the Poseidon project, was formed to investigate this problem in close collaboration with scientists at DEOS.

Data Volumes

One of the main challenges of the technique is to work with the huge data volumes. The satellite images contain millions of potential points, and hundreds of satellite images need to be jointly analyzed to obtain the required measurements. A computer cluster of 30 nodes is dedicated to this challenging task. As 99.9 percent of all measurements are not suitable for further analysis, the main problem is how to identify the required hard, coherent scattering objects. Obviously, due to the complex nature of any natural terrain, errors will be made, and dedicated filter algorithms were designed to identify false detections while avoiding erroneous omissions.

Phase measurements

Radar interferometry is based on measuring the phase component of electromagnetic waves, emitted from ESA satellites such as ERS-1/2 and Envisat. Radar wavelengths of 5.6cm result in phase measurements which easily achieve a precision of millimeters, for every pixel in the image. This ranging information can be isolated from other contributions by differencing consecutive images. This is possible only when the interaction between the radar waves and the ground (or objects on the ground) remains unchanged. Moreover, in order to detect deformation of objects over long time intervals, it is necessary that this condition holds for several years. This excludes by far most of the resolution cells in an image.

Nevertheless, the number of surviving points is often between 10 and 300 per square kilometer, which is generally more than with any conventional method.

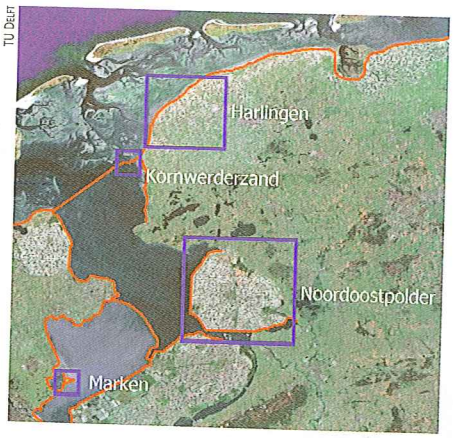

figure 1: Area of interest. The investigated dike segments are indicated in red. Boxes indicate regions of case studies.

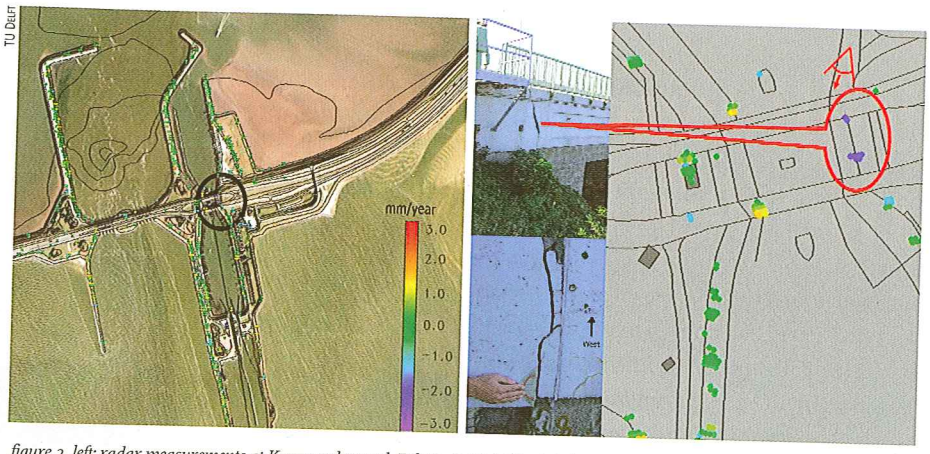

figure 2, left: radar measurements at Kornwerderzand. Relatively high (blue) deformation rates are found in the circle. right: structural damage of the bridge was found at the location of the deformation.

Dike monitoring

Modern dikes in the Netherlands consist of sand bodies with a thick outer layer of clay. Older and smaller dikes can consist entirely of peat. Together with the structural stability, the height changes of dikes are the most important parameters for hazard (breaching) assessment. Traditional leveling campaigns provide very accurate information, but they require representative benchmarks and are very laborious, and therefore too expensive for regular routine monitoring. Considering the 17,000km of dikes, this is not even considered a feasible option. For an overall status assessment of absolute height measurements, helicopter-based laser altimetry is currently a good option, yielding a precision of several centimeters.

Monitoring height changes, however, requires regular repeated monitoring, for which airborne surveys are too expensive, and the precision of the differencing measurements is close to the decimeter level. Consequently, the properties of cost effectiveness, nation-wide monitoring, high precision, and frequent temporal revisits are the main complementary aspects of satellite radar monitoring.

Results

The area analyzed is shown in fig. 1. Red lines indicate the dike segments for which useful radar information was observed. For most of these segments, no significant instability was detected. However, for four locations deformation was detected. These areas, indicated in the boxes, have been investigated in more detail. Figure 2 shows the radar data over the sluices of Kornwerderzand, superposed on airborne imagery. The anomalous blue points near the bridge, indicated in the circle, suggest deformation of more than 3mm/y. On site inspection revealed considerable structural damage to the bridge.

Another example is the Waddenzee dike near Harlingen. In this area, solution salt mining at great depths causes a land subsidence bowl at the surface. As the effective area of the bowl stretches out in the Waddenzee, the bowl-part of the dike also subsides.

Potential for routine monitoring

The results of the monitoring of water defense systems are intriguing. Perhaps most important-for practical purposes-are the extended segments of dikes which appear to be stable over the last 10 years. This implies that such segments have a constant height and that visual monitoring efforts could focus on other areas. Second, clear areas of non-stability could be identified. Many physical phenomena could result in non-stability, and therefore, the main message to the water management boards would be that these areas require extra attention. This way, the technique has an indicator function. The method can be applied more quantitative as well, though.

Conclusions

The POSEIDON project showed that it is possible to monitor dike parameters from space, with repeat measurements every two weeks, for a period of many years. The radar measurements relate to deformation of the dikes, and can reach precisions in the order of millimeters per year. Such measurements are not available everywhere, mostly depending on the type of protective cover on the dike. Nevertheless, about 90% of the Waddenzee and IJsselmeer dikes could be covered. Currently, discussions with water management boards are starting to tune this technique to the specific needs for water management and water defense system diagnostics.

Why the safety of the water defense systems is of paramount importance

The majority of the Dutch population is living on land reclaimed from the sea, and 70% of the gross national product is earned in these vulnerable areas. Therefore, the safety of the water defense systems is of paramount importance to maintain Dutch society. Failure can have catastrophic humanitarian and socio-economic consequences, as we have seen from the flooding in Zeeland (31/1/1953) when dikes breached at 400 locations and 1800 people died. In the 1990s, climate change and increased rainfall in central Europe led to flooding of the Rhine and Meuse rivers in the Netherlands. More recently, dike failures as in Wilnis (26/8/2003), Terbregge (1/9/2003), and Stein (27/1/2004) have shown that knowledge of failure mechanisms should be improved, and that the regular inspections of primary and secondary water barriers failed to detect hazardous areas. Following August 2005, when hurricane Katrina hit the southwestern coast of the USA and caused breaching of several dikes in New Orleans, causing the city to be inundated, a new sense of urgency was felt in the Netherlands to review its safety levels. The February 2007 IPCC report confirm a relative sea level rise prediction of 20-60cm up to 2100, leading to more discussion of the sustainability of Dutch society. Adequate and efficient monitoring tools for the safety of the water defense systems are considered of crucial importance.