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FIELD MEASUREMENTS OF VERY OBLIQUE WAVE RUN-UP AND OVERTOPPING WITH LASER SCANNERS

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Wave run-up and wave overtopping measurements in the field are scarce, since they are very difficult to perform. Wave run-up has been measured in the field using step gauges (e.g. Wenneker et al., 2016), stereo-photogrammetry (e.g. De Vries et al., 2011), ultrasonic altimeters (e.g. Matias et al., 2014) or video recordings (e.g. Vousdoukas et al., 2012). More recently, terrestrial laser scanners (LIDARs) have been used to measure the wave run-up in the field as well (e.g. Brodie et al., 2012; Vousdoukas et al., 2014). Wave overtopping measurements in the field are performed even less. Typically wave overtopping measurements in the field are performed using overtopping tanks (e.g. De Rouck et al., 2009). This is a robust method to measure wave overtopping, but at a fixed location and a fixed elevation.

An alternative flexible solution was developed in Oosterlo et al. (2019), using two terrestrial laser scanners. Oosterlo et al. (2019) validated the system with waves generated by the wave run-up simulator. These validation tests showed that the system can measure the run-up heights, depths and velocities of waves on a dike in field situations. From these measurements the virtual wave overtopping can be calculated at any height level as well. The paper will build on the system calibration and validation of Oosterlo et al. (2019).

An extensive field measurement project is being performed in the Eems-Dollard estuary in the north of the Netherlands for a period of 12 years. The measurements started in 2018, measuring wind, water levels, waves and wave run-up and overtopping. The estuary consists of deep channels and shallow tidal flats and is part of the Wadden Sea, a shallow shelf sea, see Figure 1. A particular aspect for this area is that the dike design conditions are characterized by very obliquely incident waves, up to 80° relative to the dike normal. As the reliability of the models as used for the Dutch dike safety assessment has not been sufficiently validated for such conditions, the aim of the measurements is twofold. First, to better understand the processes yielding nearshore wave conditions, ultimately leading to improved numerical prediction models. Second, to better understand the processes related to oblique wave run-up and overtopping, leading to improved prediction methods. In the project, the wave overtopping is measured with four wave overtopping tanks built into dikes at two locations. The laser scanner system of Oosterlo et al. (2019) has since been upgraded and has now been placed next to two of the overtopping tanks on the dike in the Eems-Dollard estuary to measure during actual severe winter storms, see Figure 2.

Figure 1 - The Eems-Dollard estuary in the Netherlands, area of interest of the field measurement project. Laser scanner system location indicated by white dot.

The goal of the paper is to further validate this innovative system for measuring wave run-up heights, depths and front velocities, and for determining the wave overtopping, (peak) wave period and angle of incidence during an actual severe winter storm with very oblique wave attack. To this end, the paper will describe the analysis of the data obtained during storm Ciara (10 – 12 February 2020). Furthermore, the laser scanner results will be validated with data from the overtopping tanks and video recordings. Finally, the data gathered during storm Ciara will be compared to the current knowledge on wave overtopping, to possibly gain new insights in the influence of very oblique wave attack on wave overtopping.

Figure 2 - Left: New laser scanner system next to the overtopping tanks on the dike in the Eems-Dollard estuary. Right: from the bottom to the top: Laser scanner 1, laser scanner 2, video camera.

The focus of the paper will lie on the measurements performed during storm Ciara. Storm Ciara was an extratropical cyclone that hit large parts of northern Europe starting on 7 February 2020. Measurements were performed from 10 to 12 February 2020. Ciara was the first actual storm that was measured with the laser scanner system, and immediately tested the system to the extreme. Ciara was a highly unique storm, with offshore directed wind at the measurement location and waves that turned somewhat on the shallow flats in front of the dike to become almost alongshore directed waves at the dike. Hence, Ciara caused highly complex conditions at the measurement location with very oblique wave attack with angles of incidence up to 75°. This posed large challenges for measuring e.g. the 3D front velocities and the overtopping volumes and discharges, also see Figure 3.

Figure 3 – Snapshot of a very oblique wave running up the slope during storm Ciara.

Despite the highly complex conditions during storm Ciara, the laser scanners performed well, regarding the measuring of the run-up heights of these very oblique waves. Figure 4 compares the largest run-up heights of one of the high tides of storm Ciara as measured by the laser scanners with the analyzed video recordings. In the Figure, HH and NBI are error metrics. HH is the HH-indicator as proposed by Hanna & Heinold (1985), NBI is the Normalized Bias Indicator. The analyses of the run-up depths, front velocities and wave overtopping are currently ongoing. The results will be validated with analyzed video recordings and data from the overtopping tanks. Furthermore, estimates of the (peak) wave period and angle of incidence will be derived from the laser data and will be compared to ADCP, step gauge and radar data. It is expected that the measurements of very obliquely incident waves during storm Ciara will lead to new insights in the influence of shallow water depths and very oblique wave attack on wave run-up and wave overtopping.

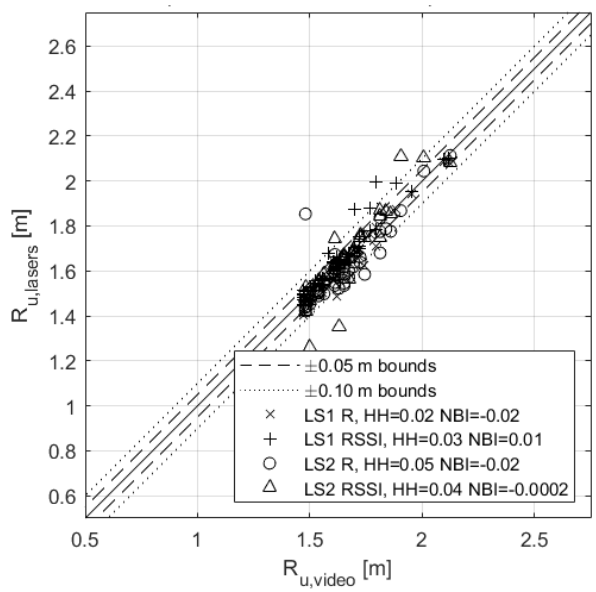

Figure 4 - Run-up data for one of the high tides of storm Ciara. The results of both laser scanners (LS1 and LS2) are shown, based on measured distance (R) and laser reflectance (RSSI). The laser results are compared with run-up heights from video recordings. The HH and NBI error metric values have been given as well.

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