

WAVE, WAVE RUN-UP AND OVERTOPPING MEASUREMENTS IN THE FIELD USING LASER SCANNERS

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This paper presents five years (2019 - 2024) of wave, wave run-up and overtopping measurements using two laser scanners (LIDARs) in the Eems-Dollard estuary in the north of the Netherlands (see Figure 1) during severe winter storms. The paper focuses mainly on the lessons learned: the improvements that have been made to the measurement system and analysis techniques during these five years and the interpretation and validation of the measured data. To this end, the paper describes the measured storms, the data analysis and results, which are validated with data from a radar, step gauge, ADCP, overtopping tanks in the dike, video recordings, numerical wave models and wave run-up and overtopping equations.



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

Wave run-up and overtopping are not measured often in the field, since these measurements are difficult to perform and extreme events are by definition rare. Step gauges are used commonly to measure wave run-up in the field (e.g. Wenneker et al., 2016). Stereo-photogrammetry (e.g. De Vries et al., 2011), video recordings (e.g. Vousdoukas et al., 2012) or ultrasonic altimeters (e.g. Matias et al., 2014) were used as well. More recently, terrestrial laser scanners have been used to measure the wave run-up in the field (e.g. Brodie et al., 2012). Overtopping tanks are used commonly to measure wave overtopping (e.g. De Rouck et al., 2009), but not often as they are very expensive. Recently, wave overtopping also has been measured using an array of capacitance-based sensors (Yelland et al., 2023).

Oosterlo et al. (2021a) developed an alternative flexible solution, using two laser scanners, see Figure 2. Oosterlo et al. (2021b) validated the system for wave run-up heights, depths, front velocities and wave overtopping during a severe winter storm with very oblique wave attack.



Figure 2 - Laser scanner system on the dike in the Eems-Dollard estuary. From the bottom to the top: laser scanner 1, laser scanner 2, infrared lamp, video camera.

The laser scanner system is located on the dike in the Eems-Dollard estuary, next to two wave overtopping tanks, see Figure 3. The estuary contains deep tidal channels and shallow flats and is part of the Wadden Sea, a shallow shelf sea (see Figure 1). An extensive field measurement campaign is performed in the estuary for a period of at least 12 years, see Van der Meer et al. (2019). In addition to the run-up and overtopping measurements, incident wave conditions are measured using a step gauge, radar, wave buoy and ADCP. The dike design conditions in this area consist of very obliquely incident wind waves, up to 80° relative to the dike normal. However, lower frequency energy at angles more perpendicular to the dike is present too, originating from the North Sea. The aim of the measurements is twofold. First, to understand the processes yielding nearshore wave conditions better, which should lead to improved numerical prediction models. Second, to understand the processes related to oblique wave run-up and overtopping better, which should

lead to improved prediction methods.

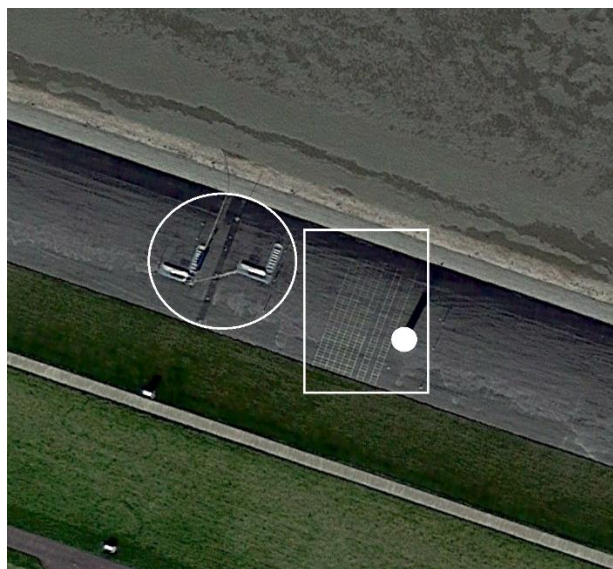


Figure 3 - Laser scanner system (dot) and laser scanner measurement grid (rectangle) next to the overtopping tanks (circle) on the dike in the Eems-Dollard estuary.

So far (2019-2023), three storms have been measured with the laser scanner system, since the required wind directions, wind velocities and water levels - which cause significant wave run-up and overtopping - are scarce. For these three storms, five storm peaks were determined (when overtopping was measured in the wave overtopping tanks), which were further analysed. The storm peaks are characterised by a westerly to north-westerly wind direction, with a water depth of at least 2 m at the toe of the dike and depth-limited significant wave heights of up to 1 m. These wind directions cause very oblique wave attack, with angles of incidence up to 80°.

Since the system was placed in 2019, several upgrades have been made to improve the system's performance further. E.g. video cameras were added to validate the measured data and the dike slope was painted to improve the laser reflection and data quality. Developments have been made to the data analysis procedures as well. The system measures distances and reflection intensities, from which wave run-up depths can be determined. From these run-up depths, also run-up heights, front velocities and virtual wave overtopping volumes (volume above a certain virtual crest level) can be determined. Recently, new analysis methods have been added, with which 1D and 2D wave spectra at the dike toe can be determined from the laser data. From these spectra, bulk wave parameters and angles of incidence can be determined. This could alleviate the need of other instruments to provide the incident wave conditions.

The laser scanner system generally performs well, despite the complex storm conditions with very oblique wave attack. The expectation is that further data analysis of the measured storms and measurements during future storms will lead to new insights in the influence of shallow water

depths and very oblique wave attack on wave run-up and wave overtopping.

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