Analysing wave-induced velocity fields around a saltmarsh cliff

An experimental study on the application of Particle Imaging Velocimetry in a complex hydrodynamic region

The Netherlands has large coastal zones in Friesland, Groningen and Zeeland containing saltmarshes. These coastal wetlands are daily inundated by saltwater tides. They play a crucial role during storms when water levels are higher than the saltmarsh. Wave energy is dissipated as they travel over the saltmarsh, mitigating their impact on coastal dikes. Despite this wave damping effect, Dutch coastal protection standards do not account for saltmarshes due to a lack of conclusive evidence regarding the stability and effectiveness of saltmarshes.

The vegetation of a saltmarsh has a reinforcing effect on the local soil. Moreover, sediment is effectively trapped between the canopy, making it typically more elevated. The bare mudflat in front lacks this vegetation and is more susceptible to erosion, resulting in a distinct cliff. Numerous studies have observed the erosion trends, including cliff erosion and lateral retreat of saltmarshes along the Dutch coast, under various wave conditions. However, a comprehensive understanding of the hydrodynamics governing cliff erosion during storm conditions remains unclear. Therefore, further research is required to explore the hydrodynamics driving cliff erosion under extreme storm conditions. This study specifically aims to identify wave-induced near-bed velocities at a cliff, as a proxy for erosion under extreme storm conditions.

In order to gain insight into the wave-induced velocities during storm conditions, experiments were conducted in a wave flume. A 1:10 scaled model of a typical coastal saltmarsh transect was designed featuring a foreshore, cliff, saltmarsh, and dike. Particle Imaging Velocimetry (PIV) is used to measure velocity fields in a non-intrusive way. PIV, an imaging technique for measuring flow velocities, utilizes the motion of seeding particles in the water column to calculate speed and direction. In this setup, a thin LED light sheet was used to illuminate the particles, resulting in 20 2D (vertical and horizontal) velocity fields per second. Experiments have been conducted with differing wave heights, water depths and wave periods.

Analysing the obtained velocity fields shows diverse patterns surrounding a 12 cm saltmarsh cliff, including stokes drift, return flow, a vortex in front of the cliff, and a vortex on top of the saltmarsh. This study confirms the influence of wave characteristics on the vortex in front of the cliff, as found in previous research. Increasing the wave height or period creates a larger and stronger vortex in front of the cliff, although this effect seems to be absent when waves directly break at the cliff.

The vortex in front of the cliff causes high near-bed velocities on the mudflat directed towards the dike, and upward velocities on the cliff face. The saltmarsh platform immediately after the cliff edge is susceptible to the return flow and the vortex on top of the platform. On the salt marsh platform further towards the dike, there are high near-bed velocities towards the sea wall. These occur as the wave crest passes over this region.

The water depth, wave height and wave period parameters have been varied to assess their influence on the maximal near-bed velocity in the four areas described above. The wave period is found to be the most influential parameter, because it has the highest influence on the size of the vortex in front of the cliff. A more general relationship for the maximal near-bed velocities has been derived for three of the four locations, the offshore Ursell number. The Ursell number is a parameter that describes the non-linearity of waves based on the water depth, wave height and wave length (which is dependent on the wave period). If further research substantiates this positive linear relation between the Ursell number and the maximal near-bed velocity, the maximal near-bed velocities can be estimated with only measurements of offshore wave conditions.

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