OBSERVATIONS AND MODELING OF CROSS-SHORE SEDIMENT TRANSPORT ON A LOW ENERGY, FETCH-LIMITED BEACH

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INTRODUCTION

Process-based profile models are used as a design tool for engineering sandy reinforcements to upgrade existing sea defenses in view of climate change and associated sea level rise (e.g. Perk et al. 2017), Hence there is a need for a reliable modeling tool, tried and tested on all beach types it is applied upon.

The beach profile of an entirely man-made nourished back-barrier beach along the Wadden Sea on Texel, the Netherlands was monitored from 2019-2022 (Van der Lugt et al., 2023). At this low-energy, fetch-limited site, the observed beach profile shows three persistent distinct characteristics: a nearly horizontal platform, a distinct beach step and a steep beach face of a steepness varying between 1:8 and 1:10 (Figure 1). The observed profiles also show swash bars persisting for the duration of one spring-neap cycle or until waves ran-up high enough to rework the sediment. They are a common characteristic of low-energy beaches (Nordstrom and Jackson, 2012), and evidence of a transport mode bringing sediment onshore. These characteristics reveal a marked difference in the balance of processes driving onshore and offshore transport between the low-energy profile and profiles at exposed sandy coasts.

The process-based profile model XBeach is however not capable of maintaining the near-horizontal platform of the observed low-energy beach profile under morphodynamics simulations. Episodes of storm conditions result in redistribution of sediment in the cross-shore with deposits under the water line, thereby flattening out the beach step and steepening the underwater platform. These deposits are not observed in the bathymetric data.

HYPOTHESIS

One cause of the mismatch between modelled and observed platform slope is the low-energy dominant sediment transport regime in which vortex ripples may play a role. The presence of vortex-ripples can be predicted by the mobility number:

$$\Psi = \frac{u_{bed,max}^2}{\Delta g D_{50}} \qquad (1)$$

with $u_{bed,max}$ the maximum near-bed orbital velocity, Δ relative sediment density, g gravitational acceleration and d_{50} the median grain size diameter. From observed hydrodynamics at this sheltered beach (van der Lugt et al. 2023), Ψ was generally found to be below 190 (Figure 1). Following the definition of O'Donoghue et al. (2006), this indicates that vortex ripples are present most of the time.

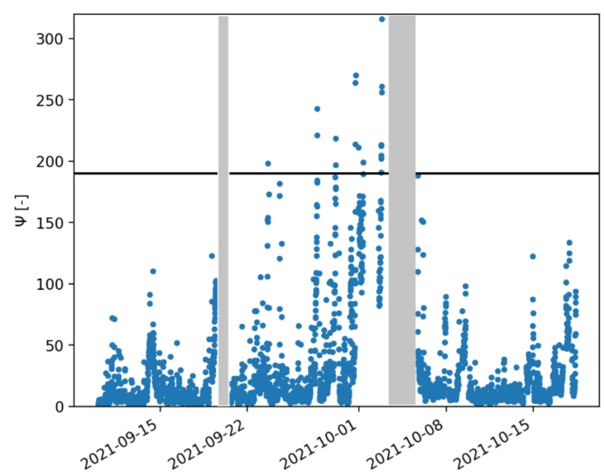

Figure 1 - Mobility number on the beach face during the SEDMEX campaign, Gray bars indicate days without data.

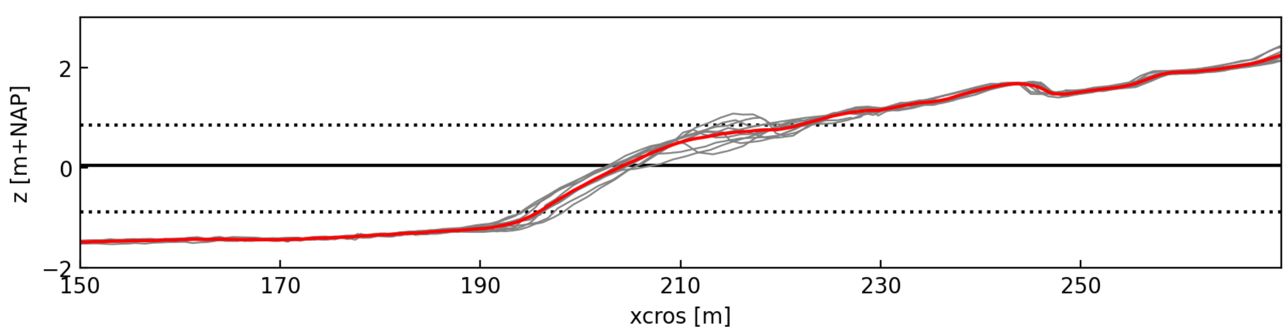

Figure 2 - Cross-shore profile of the Prins Hendrik zanddijk. All 11 surveyed transects between February 2022 and March 2023 in grey, the average profile in red. MWL (black solid line), MLW and MHW (black dotted lines) drawn for reference.

The current XBeach transport equations (Van Thiel et al. 2012) do not account for transport in this vortex-ripple regime (Ribberink 2008). In the vortex-ripple regime, the net transport direction is a balance between offshore directed vortex-shedded suspended sediment transport and shoreward bed load transport under non-linear waves. We hypothesize that the XBeach predicted net transport direction is off because vortex shedding is not included in the sediment transport equations.

METHOD

To validate our hypothesis on the cross-shore process balance existing on the studied low-energy beach, we gathered additional in-situ measurements of ripples and high resolution (dz=O(mm), dt=O(0.01s)) velocity and concentration profile data near the rippled bed from November 1-8 2023 during and in the aftermath of Storm Ciarán (November 2nd 2023).

The measurement frame, positioned at the mean low water line, consisted of 3 instruments. First, a prototype version of a UB-Lab-3C looking downward from 30cm above the rippled bed. This prototype developed by Ubertone is based on ACVP principles (Hurther et al. 2011) and was used in situ for the first time during Winter 2022 (Fritsch et al., 2022). This instrument was applied to resolve the vertical structure of the observed cross-shore velocity profile, and to see vortex shedding in the velocities and sediment concentrations above the ripples. To better grasp the spatial structure of the rippled bed we additionally installed a Marine Electronics Sand Ripple Profiling Sonar at 90 cm above the bed, scanning an arc of 90 degrees with angular resolution of 1.8 degrees and radial resolution of 0.9 degrees. To compare the observed near-bed velocity profile and ripples to wave conditions, the frame was finalized with a Nortek ADV measuring at 8 Hz at 45 cm above the bed.

Figure 3 – Frame on which the ripple scanner (central), UB-Lab (left, submerged) and ADV (right, submerged) are mounted to.

ANALYSIS

From the scans of the rippled bed in conjunction with the wave observations we aim to classify the ripple characteristics (wave length, height, 3-dimenionality) and their migration rate. The velocity and concentration data from the UB-Lab-3C is being used to estimate the transport direction as a function of height above the ripple and ripple phase. For this, a zero-crossing analysis is being performed on the free stream orbital velocity signal, after which we explore various methods to average the observations over similar waves at fixed phase of the ripple (e.g. ripple crest, ripple trough, leeside and stoss side). The recorded backscatter intensity is corrected for depth attenuation and converted to concentrations following Thorne and Hanes (2002). Using these observations, we aim to quantify the vertical structure in the observed cross-shore sediment transport above the rippled bed. These data are then used to compare to model predicted transport directions to investigate the relevance for a transport equation in the profile model XBeach that resolves the vortex-ripple regime.

These findings contribute to validation of applying state-of-the-art profile models tools (like XBeach) in the design process of beaches on low-energy, fetch-limited shores.

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REFERENCES

Fritsch, et al. (2023): Sediment dynamics under real waves. The Proceedings of the Coastal Sediments 2023.

Fromant, et al. (2019): Wave boundary layer hydrodynamics and sheet flow properties under large-scale plunging-type breaking waves. Journal of Geophysical Research: Oceans 124.

Hurther et al. (2011): A multi-frequency Acoustic Concentration and Velocity Profiler (ACVP) for boundary layer measurements of fine-scale flow and sediment transport processes, Coastal Engineering, vol 58

Nordstrom, Jackson (2012): Physical processes and landforms on beaches in short fetch environments in estuaries, small lakes and reservoirs: a review. Earth-Science Reviews, 111(1-2).

O'Donoghue et al. (2006): The dimensions of sand ripples in full-scale oscillatory flows. Coastal Engineering 53.12.

Perk et al. (2019): A rational method for the design of sand dike/dune systems at sheltered sites; Wadden Sea coast of Texel, The Netherlands. Journal of Marine Science and Engineering, 7(9), 324.

Ribberink et al. (2008): Sand motion induced by oscillatory flows: Sheet flow and vortex ripples. Journal of Turbulence 9: N20.

Thorne, Hanes, (2002): A review of acoustic measurement of small-scale sediment processes. Continental shelf research, 22(4).

Van der Lugt, Bosma et al. (2023): Measurements of morphodynamics of a sheltered beach along the Dutch Wadden Sea. Earth System Science Data Discussions 2023.