LINKING BERM ACCRETION TO ONSHORE BAR MIGRATION AND ASYMMETRIC WAVE PROPAGATION

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INTRODUCTION

Sandy beaches provide a multitude of services, including protection from flooding and provision of recreational space (tourism opportunities). However, sea level rise, reduced sand supply, and other global changes threaten those services. In this context, nature-based solutions and coastal restoration are becoming increasingly important to replace conventional engineering measures (Temmermann et al. 2013). While certain ecosystems dissipate wave energy, others reduce coastal erosion by stabilizing the seabed, for example (see Liquete et al. 2013 for a literature review of coastal ecosystem services).

Nevertheless, there are many difficulties for the practical implementation of coastal ecosystem restoration measures (Sánchez-Arcilla et al. 2022). In particular, technical barriers play an important role - i.e., limited understanding of how measures interact with the surrounding, physical environment. This applies especially to phases of beach recovery, following storm erosion. For example, it is very uncertain how sediment moves back onshore through the surf zone and how berms are formed in the swash zone. As a result, design of measures (e.g., sand nourishments) and coastal management (including restoration planning) are subject to large uncertainties. To reduce the uncertainties, the present contribution provides novel physical insights on the processes of beach recovery and berm accretion.

EXPERIMENTS

We conducted large-scale experiments in the CIEM wave flume at the Universitat Politècnica de Catalunya (UPC) in Barcelona. Sand with a D_{50} of 0.25 mm was placed into the 100 m long, 3 m wide, and 4.5 m deep flume. Subsequently, three different sequences (Table 1) of high energy storm (E1, E2) and low energy recovery (A1, A2, and A3; defined as such because of their dimensionless fall velocities Ω) waves were applied. The sequences started form a handmade slope of 1:15, followed by 30 minutes of random waves (B) to compact the handmade profile. After that, storm (red) and recovery (blue) waves were applied in succession. The change from storm to recovery waves (and vice versa) only occurred once the morphological evolution of the beach profile was negligibly low - ensuring that hydrodynamics and beach profile were in quasi-equilibrium.

Note that we applied bichromatic wave groups. This allowed us to reproduce and observe processes at different frequency bands - e.g., contrasting higher frequencies with infragravity frequencies (<0.2 Hz). Furthermore, we altered the succession of wave conditions. As a result, different initial conditions and their influence on beach recovery and berm accretion were investigated. At the same time, we used novel instrumentation. Across the surf zone, the Acoustic Concentration and Velocity Profiler (ACVP; Hurther et al. 2011) measured co-located vertical profiles (1.5 mm resolution, 50 Hz) of sediment concentration and fluid velocity in the lower 20 cm of the water column, including bedload sediment transport. In the swash zone, a conductivity-based concentration measurement system (CCM+; van der Zanden et al. 2015) provided detailed measurements of bed evolution, bed concentration, and sheet flow layer dynamics at sub-mm resolution. In addition, point-wise water surface elevation, sediment concentration, and velocity measurements were conducted throughout the surf and swash zones. A mechanical profiler measured the beach profile evolution. The experiments were conducted for uncommonly long duration (96.5 h of measurements over multiple months of the campaign).

Table 1 Wave sequences in the large-scale experiments. Storm waves shaded in red, recovery waves in blue.

Sequence	Test number	Wave condition	Duration [min]	Ω
1	16	B	30	2.21
	17-23	E1	240	3.34
	24-35	A1	600	1.44
	36-39	E2	120	2.54
	40-51	A1	600	1.44
2	52	B	30	2.21
	53-56	E2	120	2.54
	57-68	A1	600	1.44
	69-74	E1	240	3.34
	75-86	A1	600	1.44
3	87	B	30	2.21
	88-91	E1	240	3.34
	92-104	A2	780	1.05
	105-108	E2	120	2.54
	109-132	A3	1440	0.72

RESULTS

Previous work (Grossmann et al. 2022, 2023a,b) has explained the physical processes of bar migration in the surf zone, and their relation to storm erosion and beach recovery. Our detailed measurements showed the balance between suspended net offshore transport, related to wave breaking and undertow, and bedload net onshore transport, related to wave asymmetry. Depending on wave conditions, the balance either shifted to bar offshore migration (storm erosion) or bar onshore migration (recovery). Furthermore, the post-storm profile importantly influenced the subsequent bar onshore migration, causing bar dissipation or maintenance during onshore migration. In combination, the studies provided novel understanding on how sediment reaches from the outer to the inner surf zone. The present analysis takes this one step further, explaining how sediment is transported through the inner surf zone and into the swash zone. In this context, we explain how the initial, post-storm profile (starting recovery from E1 and E2 quasi-equilibrium profiles) and the energy of the recovery waves (A1, A2, and A3) influenced shoreline recovery and berm construction.

Different sequencing of wave conditions (Table 1) caused different types of berm construction, an example is shown in Figure 1. In certain tests, accretion of the shoreline and the berm were consistent with erosion in the inner surf zone. Other tests featured accretion in all three regions. This resulted from sediment availability and transport through the outer surf zone (and in the bar region). Here, the ACVP measurements explain at high detail how sediment reaches from one zone to the next, relating sediment transport to hydrodynamic forcing and key parameters (e.g., wave breaking). Furthermore, initial growth of the berm and growth of the back berm were characterized by distinct sediment transport processes in the swash zone. The water surface elevation, fluid velocity and suspended sediment concentration measurements show that, depending on the state of the beach, waves penetrated to different depths of the swash zone, causing suspension maxima at different positions. Notably, the shift of wave breaking from bars to shoreline brought more energy into the swash zone and triggered rapid berm accretion. Ongoing analysis of CCM+ measurements will provide additional insight into the resulting sediment transport processes in the sheet flow layer.

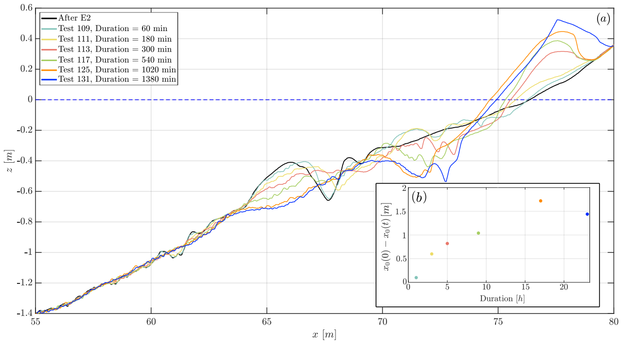

Figure 1 – Berm growth (a) at the end of sequence 3 (Table 1). Still water level (SWL; blue dashed line) versus beach profiles measured before each test (solid lines in various colors). Vertical axis showing distance to SWL and horizontal axis the distance to wave paddle. Shoreline accretion (b) with marker colors in accordance to (a).

CONCLUSIONS

We conducted large-scale experiments to fill important knowledge gaps on the physical processes behind shoreline and berm accretion during beach recovery. The use of novel instrumentation (ACVP, CCM+) in combination with complex experimental design and long experimental duration provided crucial, novel insights. The insights have important consequences in the growing topics of nature-based solutions and coastal restoration, as well as the traditional topics of morphological evolution and coastal management. Specifically, we add to the understanding and the modelling of cross-shore profile evolution, to the design of sand nourishments, and to long-term considerations of coastal management.

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