

MORPHOLOGICAL DIFFUSION EXPERIMENT: SEDIMENT SPREADING UNDER WAVE, CURRENT AND MIXED ENERGY FORCINGS

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Understanding the dispersal of sand from submerged mounds is key to evaluate coastal protection strategies. Most of the work on the evolution of submerged mounds, however has been based on currents only and neglecting the effects of waves. This contribution introduces the laboratory MORphological Diffusivity EXperiment (MODEX) aimed at examining morphological diffusivity under different forcing conditions: waves, currents and waves with currents. The experiment particularly addresses the linkages between small scale effects (e.g. bed slope, bedforms) on the larger scale adjustment of the sandy mounds. For this experiment the Hydralab+ scheme provided a unique opportunity to investigate morphological diffusivity while fostering collaborations between different institutes.

1. CONTEXT

Coastal protection is of prime importance for the upcoming century as the majority of the world population and economic value depends on beach and dune strength. Beach replenishments (also referred to as nourishments), where sand from offshore is disposed on or near the beach, are the principal mitigation measure in adaptive coastal maintenance during times of climate change for many locations. Recently, concentrated nourishments have been proposed as an innovative alternative to traditional smaller scale nourishments, using natural forces to spread the sand and feed the surrounding sand-starved coasts. A first pilot study of this type of replenishment scheme is the Sand Engine (Stive et al., 2013; de Schipper et al., 2016; see Figure 1).

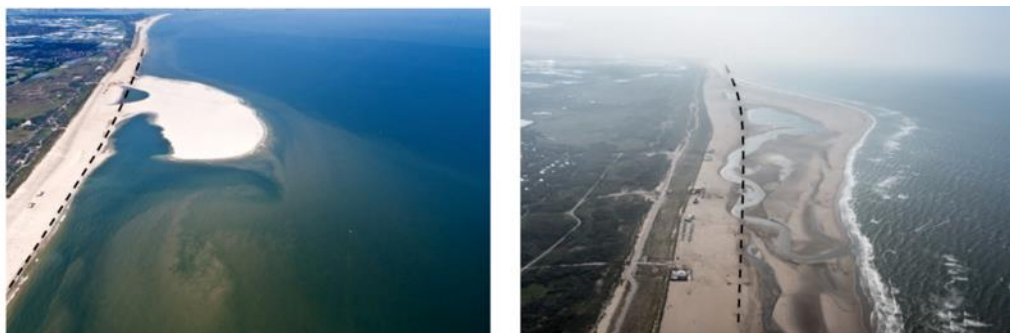


Figure 1 The evolution of a concentrated nourishment. Aerial photographs of the Sand Engine after completion in 2011 (left) and in 2015 (right). The location of the land/water interface prior to the project is given by the dashed lines. Photos adjusted from: Rijkswaterstaat/Joop van Houdt (left) and Jurriaan Brobbel (right)

To apply maintenance schemes, it is paramount to have knowledge and a good prediction skill of morphological diffusivity (i.e. the spreading characteristics) and its driving processes. However, an accurate prediction of this mechanism remains one of the great challenges in present day coastal engineering. For example, Arriaga et al. (2017) modelled the long-term evolution (30 year) of the Sand Engine and the simulated diffusivity was almost 3 times smaller than the prediction of the classical 1-line diffusion equation.

Moreover, though sand is sometimes placed on the beach for a nourishment, it has become more common to dispose sand in 3 to 8 m of water depth (Stive et al., 2013). The dispersal of sand

from submerged sandy bodies in the nearshore is driven by the interplay of processes such as converging and recirculating flows, changing roughness, bed slope effects and wave focusing/refraction. This morphological diffusivity is key to understanding sand bars in shallow seas, tidal inlets, estuaries, and the nearshore response to human interventions such as nourishments and dredging. Most of the work on the evolution of submerged mounds has been based on fluvial studies, focusing on flow without waves (e.g. de Vriend et al., 1987). In these cases, circular mounds tend to deform to crescentic (barchan) shapes. In contrast, observations of sandbars and berms in the nearshore subjected to waves show much more complex translation and deformation behavior (e.g. Rutten et al., 2018; Huisman et al., 2019).

This contribution introduces the laboratory MORphological Diffusivity Experiment (MODEX). This Hydralab experiment was focused on morphological diffusivity under different forcing types. MODEX is a collaboration between Delft University of Technology, Utrecht University, Oregon State University, CNRS, Université de Bordeaux, Universitat Politècnica de Catalunya and the University of Hull. The proposed experiment and concurrent numerical model development are meant to improve the prediction of concentrated nourishments in the near future and coastal response to human interventions in general.

2. EXPERIMENT

A detailed description of the experiment and instrumentation is given in de Schipper et al. (2019), while details on setting up the experiment are given below.

MODEX was executed at the Total Environment Simulator (TES) in Hull, United Kingdom for a total of 7 weeks in spring 2018. The TES is a facility that can run both waves and currents. The size of the flume, 6 by 12 meters, making it an ideal lab facility to execute the project goals. It is large enough such that flow easily diverges around the mound, yet small enough such that the sandy bed can be flattened and reconstructed in a single day.

For the experiment, the TES is filled with a layer of 0.1 m of sand with a D50 of 215 μm (Figure 2, middle). After two weeks preparation of the experiments, 9 different forcings were tested. In between each of these 9 tests the flume bed was flattened and a Gaussian mound was constructed using a mold.



Figure 2 Total Environment Simulator Laboratory setup in Hull, United Kingdom. Photos of the flume prior (left) to the experiment, after filling with sand (middle) and after a test (T4) was run (right). Blue panels on the back wall are the HR Wallingford wave paddles.

Experiments with combined flow and waves require a particular downstream beach-like structure. At this downstream end waves need to dissipate to prevent reflection, while flow needs to be diverted to the recirculation system below the flume. A permeable beach was therefore constructed with slopes of $\sim 1:5$. The beach panels are based on plywood with an artificial grass layer on top. Water flows into the recirculation system through 1) overtopping of the beach plane, 2) flow through the holes in the beach, and 3) a gap between the beach and the bed below the wave through level (Figure 3, left)



Figure 3 Beach like structure on the downstream side of the flume (left) and the mound prior to a test (right)

Nine different forcing conditions were tested on identical mounds (Figure 3, right). Test conditions are designed to span different energy levels, while exploring the waves, currents and combined forcings. The combined forcing tests (T7, T8 and T9) are particularly designed to have similar combined shear stress estimates with different ratios of wave to current forcing (Table 1).

Table 1. Forcing conditions used during different tests of the experiment. Θ refers to the expected non-dimensional shear stress (Shields parameter) for waves Θ_w or currents Θ_c used to create a dominance of either of the two. Currents follow from the imposed flow rate divided by the wet cross-section (6 by 0.4 m). Values are the imposed values, observed values near the centre of the mound given in bold.

Tests date	Wave forcing	Flow rate	Total time (intervals)
T1 Waves only (low) 16 & 17 May (day of year 136 & 137)	T=1s, H=0.11 m (0.10 m)	-	150 min (10 x 15)
T2 Waves only (medium) 21 & 22 May (141 & 142)	T=1.2s, H=0.14 m (0.12 m)	-	90 min (9 x 10)
T3 Waves only (high) 24 & 25 May (144 & 145)	T=1.3s, H=0.16 m (0.12 m)	-	60 min (9 x 6.66)
T4 Current only (large) 30 May (150)	-	900 l/s, 0.38m/s	35 min (10 + 5 x 5)
T5 Current only (medium) 1 June (152)	-	700 l/s, 0.29m/s	40 min (8 x 5)
T6 Wave+Currents (low energy) 5 June (156)	T=0.85s, H=0.07 m (0.055m)	400 l/s, 0.17m/s	125 min (5+5+10+15+30+30+30)
T7 Wave+Currents ($\Theta_w \approx \Theta_c$) 7 June (158)	T=1.2s, H=0.14 m (0.10 m)	500l/s, 0.21m/s	45 min (9 x 5)
T8 Wave+Currents ($\Theta_w < \Theta_c$) 11 June (162)	T=1.0s, H=0.11 m	580 l/s, 0.24m/s	47 min (2 + 9 x 5)
T9 Wave+Currents ($\Theta_w > \Theta_c$) 13 June (164)	T=1.3s, H=0.16 m	420 l/s, 0.18m/s	45 min (9 x 5)

During the experiment waves were in the non-breaking regime. Visually, wave shape altered as waves passed over the mound (Figure 4), which is to be explored further using the data.



Figure 4 Sideview of waves passing over the mound during testing (May 10) The mound is positioned below the vertical aluminum bar.

The morphological evolution showed a clear diffusion of the mound, while also showing the creation of bedforms (Figure 5). Observed diffusion and bedform type (symmetrical, linguoid) varied substantially between the different forcings tested.



Figure 5 Photo of the bed level after test T2. Paddles of the wavemaker (blue) are visible on the right.

For the analyses, the morphological evolution of the bed was recorded using terrestrial laser scanning, ripple scan sonar and altimeters (Schipper et al., 2019). The combination of the three techniques enables a detailed view of the bed changes during the test with high temporal and spatial resolution. Hydrodynamics are mapped using ADVs, Vectrino's and wave gauges.

First results of the experiment analyses will be discussed at the conference and in future publications.

3. CONCLUDING REMARKS

MODEX (MORphological Diffusivity EXperiment) was conducted in May/June 2018 with the aim to establish a link between the imposed hydrodynamic forcing and observed morphodynamic response of a sandy mound in shallow water. The experiment successfully brought together a group of (European) scientists from different institutes and background. It included a large group of young academics on site which were provided a unique opportunity to learn.

The data is made available on a repository to facilitate a wide use and interested parties are encouraged to contact the MODEX scientist for further details.

In the coming decades, many coastal locations will have to evaluate their coastal protection strategy in light of the projected climate change. With the data of the experiment and the analyses, we aim to support this decision making by providing a better understanding of the effect of anthropogenic interventions in the coastal zone.

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