A NATURAL MODE OF NOURISHMENT

INVESTIGATING DYNAMICS OF SHOREWARD PROPAGATING ACCRETIONARY WAVES

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In the Netherlands, the position of the coastline is maintained primarily by dumping sand at the coast that has been extracted from the seafloor at large water depths, this procedure is also referred to as shore nourishment. This coastal maintenance policy was adopted in 1990 and since then many nourishments have been applied at various locations in the Netherlands. Originally, nourishments were applied directly on the beach or foredune, but nowadays they are also applied on the shoreface, at a few meter water depth. Currently, a total yearly volume of 12 Mm^3 is artificially added by nourishment (De Ronde, 2008).

Interestingly, also a natural mode of shore nourishments was observed recently, albeit at a smaller scale than the currently applied shoreface nourishments. This phenomenon, named 'Shoreward Propagating Accretionary Wave' (SPAW), was described for the first time by Wijnberg and Holman (2007). It had never been recognized before in observations, nor appeared from theoretical studies. Therefore identifying the governing processes could potentially improve current knowledge about nearshore morphodynamics, and possibly prove relevant for the design of shoreface nourishments. This was the challenge I faced when I started my Master Thesis project at Deltares in Delft under supervision of Jan Ribberink and Kathelijne Wijnberg (University of Twente), and Dirk-Jan Walstra and Jebbe van der Werf (Deltares).

STUDY OBJECTIVE

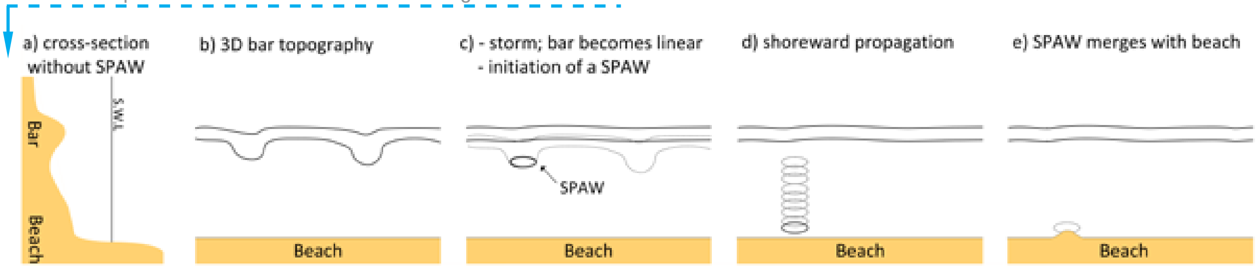
The objective of my study was to identify which nearshore processes control the shoreward propagation of a SPAW phenomenon after it has been initiated. Besides that, we investigated the influence of water depth, SPAW size and location, and nearshore bar topography of the feature on SPAW dynamics.

SHOREWARD PROPAGATING ACCRETIONARY WAVE (SPAW)

In order to fulfil the objective, it is important to define what is meant by a Shoreward Propagating Accretionary Wave (SPAW). It is a small bar shaped feature consisting of sand, which separates from the landward side of a nearshore sand bar during storm conditions. Subsequently, it propagates onshore, and eventually merges with the beach.

Wijnberg and Holman (2007) observed that a three-dimensional bar pattern with onshore protruding features favoured the initiation of SPAWs. The three-dimensionality will rapidly become linear when wave conditions become more energetic (i.e. storm events, figure 1c). In case the onshore protruding part is separated from the main bar a SPAW is formed. After initiation, observed SPAWs propagate from the nearshore bar to the shore and eventually merge with the beach (figure 1 d and e).

FIG.1 Conceptual sketch of SPAW initiation and migration



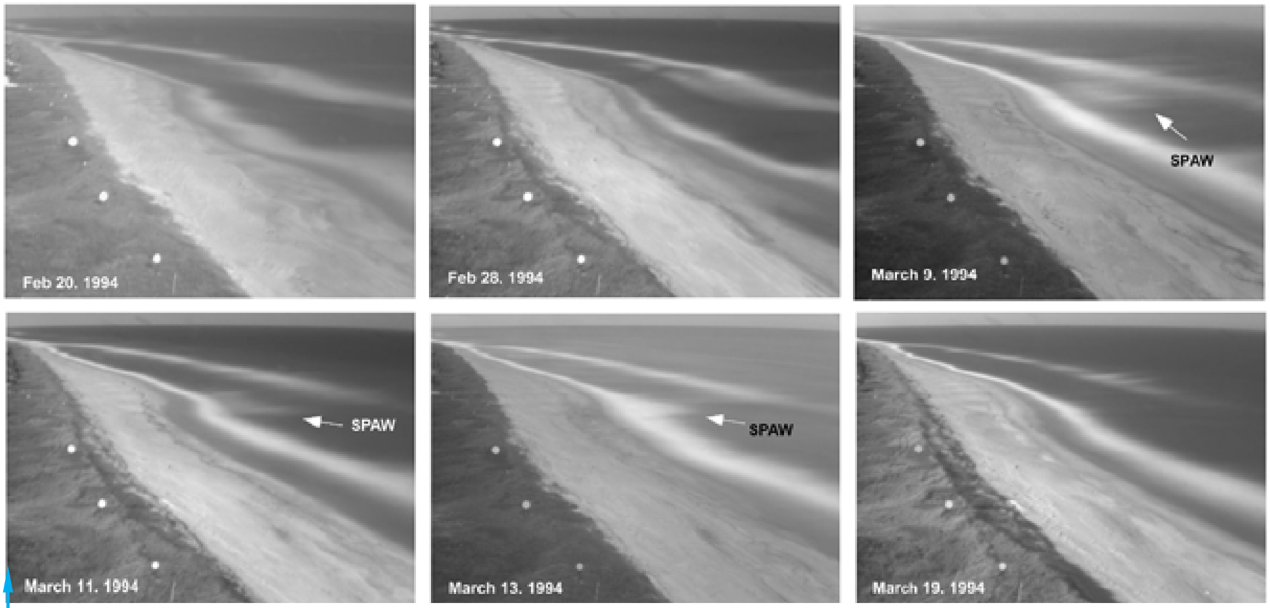


FIG. 2 Sequence of time-exposure images near Duck (USA), white areas represent wave breaking. Peaks in cross shore intensity indicate the presence of a sand bar or SPAW (Wijnberg and Holman, 2007).

SPAW observations

SPAW observations were done based on video time-exposure imagery (i.e. Argus images) taken over about a 10 minute time span. The technique is based on the fact that waves break when entering a shallower part. White areas in Argus images represent wave breaking, and peaks in cross shore intensity indicate the presence of a sand bar (Lippman and Holman, 1990). Since a SPAW is actually a submerged volume of sand it can be observed as an isolated, patch of foam in between the nearshore bar and the shoreline. Figure 2 shows an observation of a SPAW event in Argus images, clearly showing the initiation and migration of a SPAW. For example the merging with the beach is shown in the protrusion on March 13, 1994.

No field measurements of the flow-field and sediment transports during a SPAW event are available, because it is hard to measure a SPAW due to its irregular and unpredictable occurrence. A SPAW was captured in a bathymetric survey by accident at Duck beach (North Carolina, USA) only once.

SPAW dimensions

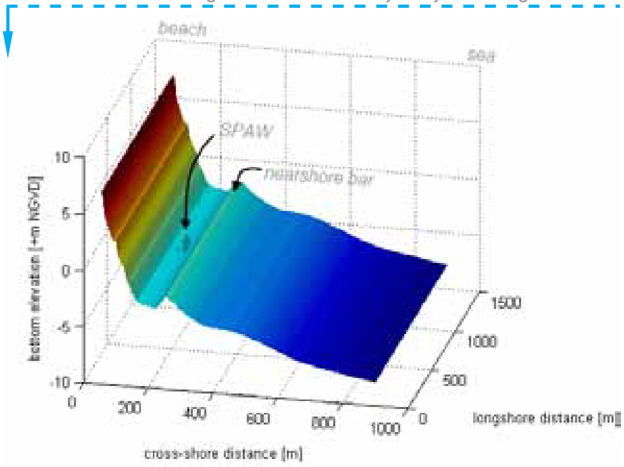
SPAWs represent a locally significant onshore sediment flux, which makes it an interesting feature for nourishment practices. Wijnberg and Holman observed SPAWs at beaches in the US and Australia, but SPAWs were also observed at Le Truc Vert (France, Almar et al., 2010) and near Egmond aan Zee (The Netherlands).

This study focused on the Duck study site, since most SPAW observations (19 in total) were done here. Besides that, this site has been extensively studied before and many hydrodynamic data are available. SPAWs observed at Duck have an average length of 126 +/- 60 m and a width of 30 +/- 10 m, which indicates the scale of the feature. The onshore migration rates at Duck are on average 3.1 m/day with a standard deviation of 0.8 m/day. The dimensions, in alongshore and cross-shore direction, are much smaller than the current artificial nourishments as applied at the Dutch coast, which are roughly 10 times longer and wider.

METHODOLOGY

We investigated SPAW dynamics by studying wave-driven flow fields and related initial sediment transport patterns using a state-of-the-art numerical model for nearshore processes (Delft3D). We started with formulating two hypothesis for the wave-driven flow field and sediment transport patterns based on a study of relevant nearshore processes in literature. Firstly it was hypothesized that a horizontal circulation cell would develop in the wave-driven flow field. This is generated by local shoaling/deshoaling and wave-breaking over the SPAW inducing longshore and cross-shore gradients in radiation stress. Secondly, it was hypothesized that the sediment transport over

FIG. 3 Schematic alongshore uniform bathymetry including a SPAW



the SPAW would be directed onshore due to non-linear wave transformation over the SPAW feature. Due to the decreasing water depth over the SPAW, waves will deform from a symmetric sinusoidal shape to a landward skewed and assymetric shape with a long flat trough and narrow peaked crest.

To test the hypotheses, a schematized 3-dimensional Delft3D model was set up for Duck beach (North Carolina, USA). The model schematization was based on earlier schematizations made for this site. It was adjusted by refining the grid, in order to have a proper resolution around the SPAW. Model input, such as bathymetry (base case: SPAW length=130 m and SPAW width=25 m) (Figure 3) and typical wave conditions (base case: H_s=0.56 m and T_p=8.2 s), were based on a representative SPAW event at Duck. For a detailed description of the Delft3D model schematization consult Van der Weerd (2012). In the model output we focussed on spatial patterns in wave height, in water level set-up and set-down, in cross-shore and longshore velocities, and in the resulting sediment transport.

In addition to the base case, we assessed the influence on sediment transport patterns of varying water levels, SPAW size and location, and nearshore bar geometry. Due to computational time limitations only initial sedimentation and erosion patterns were analysed (for these cases).

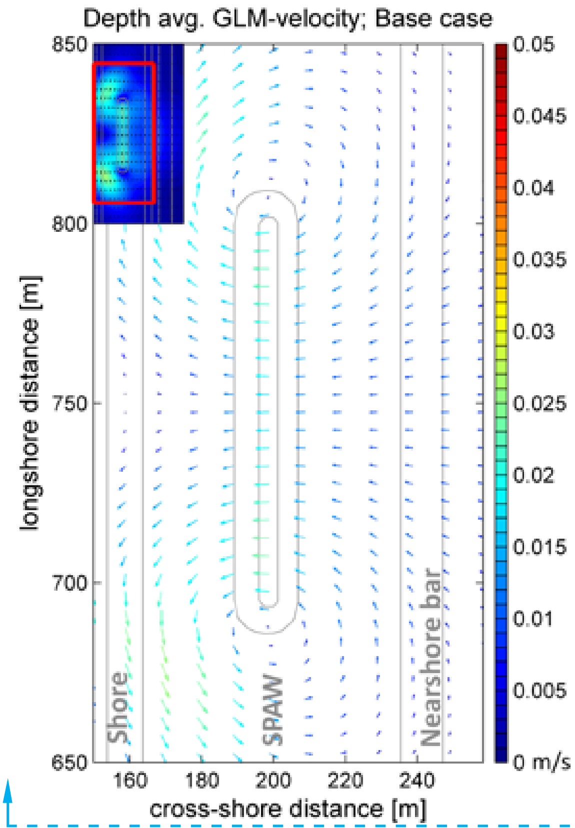


FIG. 4 Top view of depth-averaged Generalized Lagrangian Mean velocity pattern around the SPAW location. Vectors show directions and magnitude, contour lines show bottom contours.

WAVE-DRIVEN SPAW DYNAMICS

Results showed that wave height varies locally since waves break over the SPAW but do not yet break next to the SPAW. During wave breaking energy is locally dissipated and wave height is reduced. These variations in wave height induce cross-shore and longshore gradients in radiation stress, which generates local set-up (i.e. an increase in mean water level in onshore direction). Thus water level varies cross- and longshore around the SPAW, which cause longshore pressure gradients inducing currents. As a result, a horizontal circulation current develops around the SPAW tips, which is onshore directed over the SPAW crest and offshore directed around the feature (Figure 4). This is in line with the formulated hypothesis.

The modulated wave-driven flow field accross a SPAW was such that near-bed sand transport processes were dominant and onshore directed over the feature (Figure 5a). These processes consisted of (i) bed load transport due to waves and currents, and (ii) suspended load transport due to wave assymetry. The sediment transport contributions result in a shoreward displacement of the SPAW, namely erosion occurs seaward and sedimentation occurs just landward of it (Figure 5b). Results are consistent with the formulated hypothesis, with SPAW observations, and also with previous estimates of sediment fluxes (Wijnberg and Holman, 2007). The latter can be illustrated by comparing the roughly estimated sediment transport flux related to SPAW propagation based on observations (1 to 2 $m^3/m/day$) and the results of our analysis using a numerical model (1.3 $m^3/m/day$). The shoreward displacement pattern persisted for varying water levels, SPAW size and location, and nearshore bar geometry. Observations for these cases are briefly described below.

Water levels

To investigate the effect of tides on SPAW dynamics, we used different water levels to represent low and high tides. Water levels influenced the wave-driven flow field. For a lower water level the circulation was stronger because more waves break over the SPAW. Nevertheless, no extreme differences in sediment transport could be seen between the low water and the base case. This is due to the fact that sediment transport is a result of many processes counteracting each other, and also because near-bed sediment transport is dominant.

SPAW location

The effect of SPAW location was investigated to see whether the feature is expected to show similar behaviour regardless its cross-shore locations (between bar and shore). The location mainly influenced the wave-driven flow field; for SPAWs located closer to the bar a stronger horizontal circulation cell developed over the full length of the SPAW crest. Consequently, sediment transports were higher over the full length of the SPAW crest for this case, whereas for a feature located closer to shore sediment transport was concentrated at the tips.

SPAW dimension

In nature, SPAWs have varying dimensions. We ran a case with a wider and longer SPAW to test the effect of SPAW dimension on their dynamics. For a wider SPAW a stronger horizontal circulation current developed compared to the base case. For a longer SPAW, the horizontal current only developed around the tips, whereas for the centre of the longer SPAW no effects of the horizontal circulation currents were seen.

Nearshore bar bathymetry

Also we ran a case where the bathymetry of the nearshore bar was lowered seaward of the SPAW, since this was seen in the single existing bathymetric measurement of a SPAW. The change of local geometry of the nearshore bar, largely influenced the flow-field. The velocities were directed offshore through the location of the lowered bar. Nevertheless, sediment transport was still onshore directed over the SPAW. Another remarkable result was that the onshore directed sediment transports at the tips of the SPAW were directed slightly to the middle of the feature. This might be a contribution for the SPAW maintaining its shape during its propagation to the coast.

DISCUSSION AND CONCLUSIONS

The study provided insights in wave-driven dynamics of a recently discovered phenomenon, referred to as a 'Shoreward Propagating Accretionary Wave'. We showed that it is possible to model this small-scale bar shaped feature in Delft3D. We modelled a SPAW event for Duck Beach (USA), and results are therefore specifically applicable for this site. However they comply with a study on small-scale nourishment on Egmond aan Zee (Koster, 2006) and SPAW observations at other beaches. Which shapes confidence that results will be similar for other beaches, however it is worth to investigate this in more detail.

In conclusion, the numerical simulation shows that initial sedimentation and erosion patterns around a SPAW indicate it will propagate onshore. This is consistent with observations at Argus images. The result persisted for varying water levels, SPAW size and location, and nearshore bar geometry. It can be explained by the influence a SPAW has on the wave breaking pattern; waves deform and eventually break locally over the feature. This ultimately results in a different flow-field around it; a horizontal circulation cell develops around the SPAW tips. Besides that, near-bed sediment transport is influenced by the deformation of waves over a SPAW, and is shown to be onshore

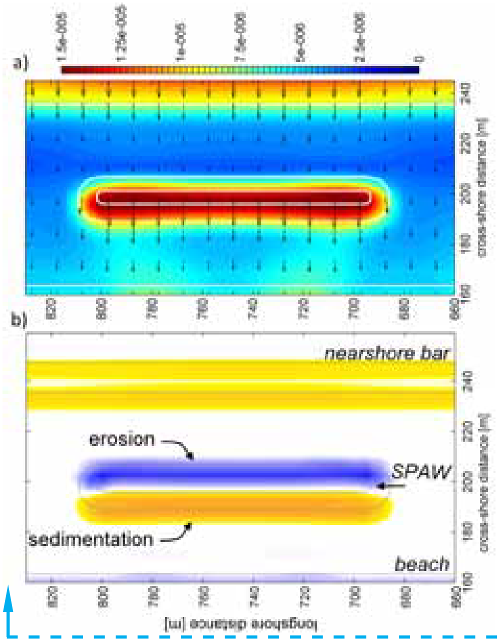


FIG. 5 Base case results. (a) Top view of total load transport across SPAW ($m^3/m/s$), (b) Top view of resulting initial sedimentation-erosion pattern across SPAW.

directed over the SPAW crest. The latter was observed to be the driving force for increased onshore sediment transport over the feature, and thus the SPAW's onshore propagation.

For nourishment strategies specifically, this study contributes to the idea that small scale nourishments can be an interesting alternative way of nourishing the shoreface.

Future research can be done to investigate what the cost-efficiency will be for small-scale nourishments at different locations and with different shapes in the nearshore. ■

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