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Initial spreading of a mega feeder nourishment: Observations of the Sand Engine pilot project

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ABSTRACT

Sand nourishments are a widely applied technique to increase beach width for recreation or coastal safety. As the size of these nourishments increases, new questions arise on the adaptation of the coastal system after such large unnatural shapes have been implemented. This paper presents the initial morphological evolution after implementation of a mega-nourishment project at the Dutch coast intended to feed the surrounding beaches. In total 21.5 million m^3 dredged material was used for two shoreface nourishments and a large sandy peninsula. The Sand Engine peninsula, a highly concentrated nourishment of 17 million m^3 of sand in the shape of a sandy hook and protruding 1 km from shore, was measured intensively on a monthly scale in the first 18 months after completion. We examine the rapid bathymetric evolution with concurrent offshore wave forcing to investigate the feeding behaviour of the nourishment to the adjacent coast. Our observations show a large shoreline retreat of O (150 m) along the outer perimeter of the peninsula, with locally up to 300 m retreat. The majority (72%) of the volumetric losses in sediment on the peninsula (1.8 million m^3) were compensated by accretion on adjacent coastal sections and dunes, confirming the feeding property of the mega nourishment. Further analyses show that the morphological changes were most pronounced in the first 6 months while the planform curvature reduced and the surf zone slope flattened to pre-nourishment values. In the following 12 months the changes were more moderate. Overall, the feeding property was strongly correlated to incident wave forcing, such that months with high incoming waves resulted in more alongshore spreading. Months with small wave heights resulted in minimal change in sediment distribution alongshore and mostly cross-shore movement of sediment.

1. Introduction

Sand nourishments are nowadays widely applied to enhance coastal safety and to increase beach width (e.g. Burcharth et al., 2015; Castelle et al., 2009; Dean, 2002; Kuang et al., 2011; Luo et al., 2015; Ojeda et al., 2008; Roberts and Wang, 2012; Yates et al., 2009). With the increasing pressure on the coastal zone in terms of population and the (projected) relative sea level rise, the number of nourishment projects and the total volume has increased greatly, e.g. for the US East Coast alone Valverde et al. (1999) report an increase in annual nourishment volume over all projects combined from ~1 10^6 m^3/year in the 1920s to ~12 10^6 m^3/year in the 1990s. The first nourishment projects, executed roughly before the 1970s, targeted specific local weak spots along the coast (Hanson et al., 2002; Valverde et al., 1999). The added sand was mostly placed on dunes or beaches and the success rate of the nourishment was predominantly quantified by the proportion of material remaining in the project area over time (e.g. Elko and Wang, 2007; Leonard et al., 1990). The cross-shore size of these nourishments, i.e. the nourished volumes per meter alongshore, was typically small (order of 100 m^3 per m) if these were used for beach maintenance. Following up on these initial beach and dune nourishments, shoreface nourishments have been carried out in the last quarter of the 1900s as an economical alternative for some locations (Grunnet and Ruessink, 2005; Mulder et al., 1994; Niemeyer et al., 1996). The cross-shore size of these nourishments is typically larger, i.e. in the order of 400–600 m^3/m (e.g. Ojeda et al., 2008; van Duin et al., 2004). The positive effect of a shoreface nourishment on the beach and dunes can be subdivided into two hypothesized effects: the wave attenuation

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function and the (cross-shore) feeder function (Mulder et al., 1994). The wave attenuation function is formed as waves break on the nourishment during storm conditions, thus reducing the wave energy and longshore wave driven currents higher up the profile. The second, feeder effect is caused as a gradual landward movement of sand is stimulated, thus causing a seaward movement of the coastline. Although in practice it can be difficult to delineate between both effects, measurements (Hoekstra et al., 1996) and modelling (van Duin et al., 2004) of experimental nourishments suggest that both effects are present.

At present, sandy mitigation strategies using frequent (every 3 to 10 years) beach and shoreface nourishments are carried out as the solution for several populated sandy coasts with a structural coastal recession (Cooke et al., 2012; Hamm et al., 2002). For locations with a large annual sand deficit however large quantities of sand need to be supplied or frequent re-nourishments are needed. It is questionable whether such frequent re-nourishing has not a detrimental effect on the fauna of the nourished site (e.g. Janssen et al., 2008; Peterson and Bishop, 2005; Speybroeck et al., 2006). Such potential negative effects and the upscaling to a more regional approach have given the incentive to look for better methods. In this light, the concept of nourishing with the intention to feed adjacent coasts by means of alongshore diffusion in the form of concentrated (mega) nourishments have been proposed as an alternative (Stive et al., 2013). In this approach a large volume of sand is placed at a single location with the intention to feed a larger alongshore stretch of coast over time. Under the combined natural forces of wind, waves and tides the sediment is expected to be redistributed in along and cross-shore directions, hence enhancing the safety of a longer stretch of coast. In the Netherlands, a concentrated mega-scale nourishment called the Sand Engine was implemented in 2011 as a large sandy hook with the size of approximately 17 million m^3 placed in an area of 2.5 km in the alongshore direction and 1 km in the cross-shore. In contrast to previous nourishments with cross-shore sizes of 400–2000 m^3 per meter alongshore and small transitions with the surrounding coastlines, the Sand Engine peninsula design project has a highly concentrated nourishment volume (up to 10.000 m^3/m) and sharp coastline angles with the intention to redistribute rapidly by means of alongshore diffusion of sand. An evaluation of such a feeder nourishment project cannot solely done in terms of the amount of sand that remains within the project area (as done with more traditional nourishments; e.g. Dean and Yoo, 1992; Elko and Wang, 2007; Verhagen, 1996), but requires a broader view on the coastal section, including the rate of spreading and the magnitude of the accumulation of sediment on adjacent coastal sections.

The objective of the current paper is to present the morphological evolution of the Sand Engine in the first 18 months after construction. Special attention is on the feeding character of the nourishment, assessing spatial and temporal redistribution of sediment. Although it is known that this response in the first period after completion is vital for the total evolution of the project, it is often poorly recorded due the lack of frequent monitoring data (Elko and Wang, 2007). We performed a high resolution monitoring study with frequent surveys to capture this behaviour in the first period after completion. In this paper we discuss the feeding of the mega nourishment pilot by focusing on the planform adjustment of the nourished peninsula (Section 4.2), cross-shore profile and volume changes at the Sand Engine and along adjacent coasts (Section 4.2), quantifying the proportion of eroded sand on the peninsula with respect to the accretion on adjacent sections (Section 4.3) and relating the feeding behaviour on a monthly timescale to the incoming wave power and the shape of the peninsula (Section 4.4).

2. The Sand Engine project

2.1. Coastal setting

The Sand Engine nourishment was executed along the 'Westland' coastal cell, a 17 km stretch of coast between the harbour entrances of Scheveningen and Rotterdam (Fig. 1). This southern part of the Dutch coast is subject to structural erosion, the coastline migrated landward by about 1 km in the period 1600–1990. After a retreat of *O* (300 m) in the 18th century, construction of rubble mound groynes was initiated (van Rijn, 1997). Yet, as this coastal stretch remained erosive despite the

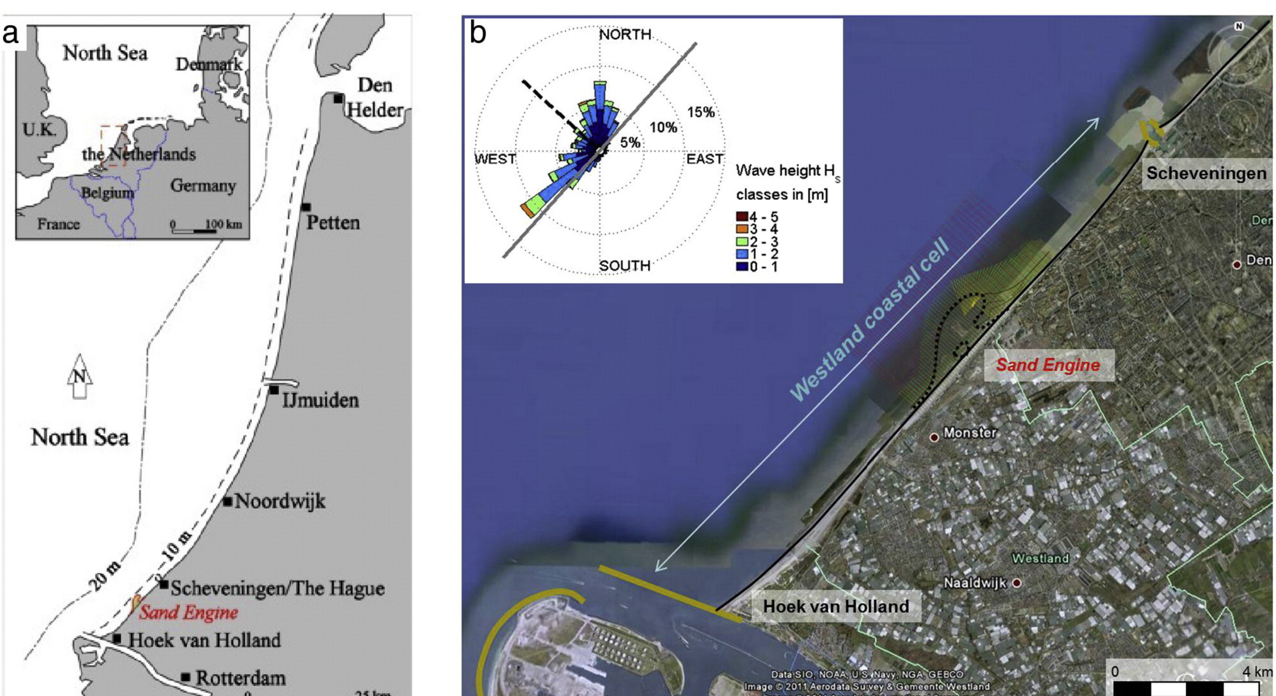

Fig. 1. a) Location of the Sand Engine on the North Sea coast. b) The 17 km Westland coastal cell in between the harbour entrances (represented by the yellow lines) of Scheveningen and Hoek van Holland. The insert shows the wave rose based on four years of data at Europlatform. Image data: Google, Aerodata. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)