A HOLISTIC APPROACH TO COASTAL PROTECTION FOR THE PRINS HENDRIK POLDER

BY JAN FORDEYN, EMILE LEMEY & LUITZE PERK

The Prins Hendrikzanddijk project on the Dutch island Texel is an integral project where flood defence is combined with nature development, public services and recreational appeal. Seaward of the existing dike, a dune is landscaped to act as primary coastal protection. The existing dike thereby loses its main function but remains in place as a scenic element.

Instead of using a classical engineering design approach, the inclusion and enhancement of public, recreational and ecosystem services were the focal point of the design.

A unique and dynamic nature reserve with dunes, salt marsh and beach in front of the current dike was designed, with the goal of upgrading some 200 hectares of the Wadden Sea coastal area (UNESCO World Heritage Site). Central to the design are the interactions between ecology and sediment dynamics. In traditional hydraulic engineering, there is a trade-off between safety and ecological value, and between sediment stability and dynamics. Coarse sand resists erosion better, but provides a less suitable habitat for benthos, which makes the area less attractive to wading birds.

Therefore, the target species and habitats were analysed, and sediment characteristics chosen accordingly. A specific strategy of including fine sands to stimulate benthos growth was applied. Other strategies for habitat creation included salt marsh recuperation and seashell patches. The design further dealt with the trade-off between recreational opportunities and the natural habitat disturbance, and between the dynamics of soft coastal protection and the lifetime of public functions. Project specific key performance indicators are assigned and monitored during construction and a five-year maintenance period.

This paper presents a nature-based solution for enhancing a coastal defence system while maximizing the ecological value of the area. A soft design is laid out, where safety, nature, recreation, agriculture and public services come together.

Introduction

Need for action

Primary water defences (dikes, dunes, storm surge barriers, etc.) absorb the forces of the sea and can protect urbanized coastal areas against floods. In the Netherlands, these structures must satisfy the safety standards defined in the Waterwet (the flood defence act). The design conditions of these standards are periodically adapted to recent knowledge and insights (Loucks & Van Beek, 2005).

The Dutch administrators for water defence structures check the strength of the primary water defences against the safety standards every 6 years. When certain sections are no longer compliant with the standards, corrective measures are implemented. During the review process in 2007, more than 70% of the 24-kilometre-long Wadden Sea dike on Texel Island failed to meet the standards. 14 km of the dike had been upgraded without altering the visual aspect of the dike. Width and height increased, and a new asphalt and stone cover was applied on the seaward slope. The subject of this paper is the refurbishment of section 9, the 3.2-kilometre-long dike, that protects the Prins Hendrikpolder, which harbours agricultural land, houses and nature reserves.

Hard versus soft coastal protection strategies

(Sub-) littoral sandy sediments, sandy beaches, and sand dunes offer natural coastal protection. Despite their importance, these sandy ‘soft’ defences have been lost in many European coasts due to the proliferation of coastal development and associated hard engineering. They also face further losses due to rise in sea-level, subsidence, storm surge events, and coastal land claim due to urban development (Hanley et al. 2014).

In order to protect the coastal erosion, hard coastal protection structures are often used. They consist of rigid or semi-rigid structures constructed along or in front of the coastline to resist deformation from wave or current action, either at the dune foot, intertidal beach or seabed. Hard coastal protection structures fall into the categories of sea dikes, seawalls, revetments, groynes and offshore breakwaters (IADC, 2017).

Although these hard-coastal protection structures are effective in stabilising the coastline, they offer a one-sided solution focussing only on protecting the land behind it from water action, while largely ignoring the characteristics of the water system (Van Slobbe et al. 2013). They have an immediate impact on local biodiversity and alter local hydrodynamic regimes, which in turn affects sediment supply, deposition and grain size. These alterations have an impact on both the soft-bottom sublittoral ecosystems and the beaches (Hanley et al. 2014). Existing dike revetments are classic examples of hard coastal protection.

Soft coastal protection strategies replicate the natural defence systems with locally available natural material to secure and restore the coastal dynamics and their flexible nature (IADC, 2017). They are based on careful observation and replication of these natural defence systems (Fordeyn et al, 2012). Restoring or reintroducing soft coastal defences was an opportunity to use a nature-based solution to upgrade the coastal protection capacity of Texel island.

Materials & methods

Project Location

The primary protection of Texel’s Eastern coast has a total length of circa 24 kilometres and consists of ten sections. Section 9 is the Prins Hendrikdijk with a total length of 3.2 kilometres between the ports of Oudeschild and NIOZ. The Prins Hendrikdijk protects the Prins Hendrikpolder, which consists of agricultural land, farmhouses, and two nature reserves, Ceres and Molenkolk. Two water pumping stations discharge into the project area (Gemaal Prins Hendrik and Gemaal De Schans). These stations pump brackish water into the project area, mimicking biogeochemistry processes of an estuary system. Halfway along the dike, near the Prins Hendrik pumping station, several public services cross the project area: two water supply pipes, two high-voltage- and two data cables. In the south, the project area is bordered by the NIOZ (Royal Dutch Institu----te for Sea Research) port breakwater.

Characteristics of the environment

Since the Middle Ages, dikes have been erected and reinforced to protect arable land from the forces of the sea. They are mostly hard structures made up of sand and clay with an asphalt, concrete and grass cover. These dikes are in contrast with the dynamic, soft transitions that naturally occur in the Wadden Sea and with the focus of the NATURA 2000-management plan Wadden Sea 2016-2022. The core assignment of the project was to maintain or restore the spatial cohesion of deep water, gullies, creeks, shallow water, salt marshes, tidal flats, beaches and dunes, and the related sedimentation and erosion processes, as well as the related biological communities.
Situated east of Texel island, the Texelstroom is one of the important tidal channels connecting the Wadden Sea with the North Sea. In between the Prins Hendrikdijk and the channel lies a shallow plateau between MSL+0 and MSL-2 meter of circa 400 meter wide. The largest waves hitting the project site originate from the North Sea, propagate through the Schulpengat and Marsdiep narrows and refract toward the coast. The site is therefore relatively sheltered with a 4,000-year return period design wave height of maximum Hs = 2.7m at MSL-5m (Van Vledder, 2016).

The project area mainly consists of NATURA 2000 habitat type H1110A (permanently submerged sandbanks). This habitat type refers to shallow, relatively flat areas and gullies, where the tidal influence is more important than the wave influence from the sea. Because of the low hydrodynamic action, the sea bottom sediments are mostly muddy to fine sands. A much smaller part of the project area is

Jan Fordeyn studied at the University of Ghent and graduated as a naval architect in 1994. Since 2007, he helps develop projects around the world that fall outside the classic canon of marine construction and whose result relies on the symbiosis of different disciplines. As such he maintains close relations with experts, consultants, universities and manages several innovation projects.

Emile Lemey works as Project Development Engineer at Jan de Nul Group. His background is in Bioengineering and Marine conservation. At Jan De Nul he has focused on nature-based solutions projects in which ecological considerations are an essential part of the design phase. He worked as Environmental Engineer on the Coastbusters project during the realisation phase.

Luitze Perk is director Coast&Sea at WaterProof BV. Luitze is hydraulic engineer working with hydrodynamic and morpho-dynamic numerical models for studies in coastal areas and estuaries in different places in the world. He has contributed to different port and coastal development projects in which he quantified the effects of inter-ventions on currents, waves, salinity and morphologic or sedimentation/ erosion effects.

composed of the important NATURA 2000 habitat type H1140A (tidal flats). This habitat type is relatively sheltered and protected from wave action. Close to the sea channel, the sediment is mostly sandy and shelly, while the sediment is very muddy at the upper end of the tidal range and close to the shoreline. The characteristics of the project area - the shallow seabed, the sheltered location and the absence of tidal flats - made it an ideal location to apply a soft coastal protection strategy.

Results

Acknowledging the potential of the site, the project owner, Hoogheemraadschap Hollands Noorderkwartier, issued a tender for the design and construction of a soft coastal defence solution in December 2016. The project was awarded to the Jan De Nul team (JDN) in September 2017. Notably the synergy of competences of both inside and outside the dredging world was vital for fitting together all the pieces of the puzzle: hydrodynamics and morphology (Waterproof and LVR sediment), marine construction (RPS), landscaping (Feddes & Olthoff), ecology (Altenburg & Wymenga), geotechnics (Wiertsema & Partners), hydrology (Artesia) and visual appeal (John Körmeling). The JDN-design is a unique and dynamic nature-based solution creating a reserve with dunes, salt marshes and beach in front of the current dike, adding some 200 hectares to the valuable Wadden Sea area that will protect the Prins Hendrik polder and provide a high quality ready-made environment for target habitat types and endangered species.

Prins Hendrikzanddijk reference design

The JDN-design did not start from scratch. Together with a list of 74 requirements, the tenderers were provided with a reference design devised by HHNK's advisor Witteveen+Bos. The reference design features a rectilinear dune that functions as the new primary defence, a nature zone with beaches and a sand spit creating a low dynamic zone north of the Prins Hendrik pumping station. On the seaward slopes a buffer layer of coarse sand is included to minimise the erosion caused by yearly average conditions. In order to minimize aeolian transport, the 20-ha surface of the safety dune is to be covered with marram grass.

Optimized design

The price correction system in the tender procedure allowed for a fictive reduction of the tender price up to 30% for initiatives that would increase the quality of the offer. Therefore, numerous changes to the reference design were considered, evaluated and implemented to maximize the added value for safety, ecology, recreation and public functions.

In the small playing field that is the project area, any change that adds value to a certain aspect has an immediate effect on other aspects. Therefore, a holistic approach to the design optimisation was chosen that was also central to the Vlaamse Baaien design (THV Vlaamse Baaien, 2009). Optimisations were dimen-sioned and evaluated based on their merit for the totality of the project objectives.

Layout and location of elements

The sand spit was shifted offshore in order to accommodate the relocated pumping station outflow and increase the size of the ecologically important sheltered zone. By shifting the outflow construction southwards, the length of the tidal stream within the sheltered area was increased, thereby increasing the size of the rare habitat where sea and fresh water meet. Two bulges were introduced in the sheltered area to guide

Figure 1. Visualization of the low dynamic zone behind the sand spit (Feddes & Olthoff)

the outflow and tidal stream into a narrow gully while simultaneously creating gently sloped salty pioneer vegetation (habitat H1310A).

Safety dune height

The crest of the safety dune was designed to the lowest allowable level for a number of reasons. First, the Wadden landscape differs from the high and steep North Sea dunes. Secondly, lower dunes do not present a visual barrier for walkers and cyclists on the dike who want to see the horizon. Furthermore, a lower crest height will induce less sand blown over the dike towards the polder. Building a low and wide dune is a robust solution for the future; if it is decided to provide increased safety in the future, the wide base of the dune could be easily heightened without further disruption to the Wadden Sea nature. However, because the two water supply pipes, data- and power cables will be buried under the Prins Hendrikzanddijk, the settlement of the surrounding soil due to the added surcharge of the safety dune, which reaches up to MSL +11 m, would cause additional stresses in pipelines and cables. To avoid this condition the design of the area of pipelines and cables was therefore adapted to the lowest allowable height from a safety perspective.

Natural character

In the optimised design the safety dune is overlain with an undulating layer that replicates the character of natural dunes. The height and size of the relief varies, creating a changing character along the length of the dune. Inspiration was drawn from the existing natural dunes at the Wadden Sea coasts of Texel and the other islands (so-called Nollen). It was found that they were different from the North Sea dunes on the islands that face dominant westerly winds, in terms of slopes, form, size, microrelief and vegetation.

Careful thought was given to variations in the transition from dune to dike. At two sections, the dune was moved seaward to create a dune valley between the safety dune and the existing dike. The first valley is located halfway along the dike near the Prins Hendrik pumping station. The increased distance between dike and dune will soften the change in surcharge and decrease tension on the waterline and cables. The second valley is located at the Ceres nature zone to enhance the visual appeal of the footpath that leads to the observation platform. Finer sand can be applied in these valleys because the wind will have little influence there. At two other locations, a connection was made between dike and dune just beneath the dike crest to accommodate the cycling path access.

The dune base and seaward slope of the safety dune was given natural contours. Along a part of the dune base, small embryonic dunes with fine sand, which can be colonized by vegetation, were added. These embryonic dunes will form the natural transition from dune to the mudflat and tidal flat. The dune will reach its maximum level near its southern and northern end in order to both increase the visual appeal to hikers and cyclists and to create a physical barrier between recreation on the dune and nature in the low dynamic zone.

Minimize Sand drift

Most state-of-the-art calculations for beach erosion in the Netherlands are developed and calibrated with the experience of North Sea beach maintenance, where wind and wave direction are close to perpendicular to the beach. Sites with a dominant offshore wind and oblique incident waves, like the Prins Hendrikzanddijk project area, are rare and therefore poorly accounted for in these formulas. Therefore, cross-shore and longshore transport was calculated with different available models such as X-Beach 1D, X-Beach 2D, Delft 3D and Longmor and supported by expert assessment.

The models predict a significant northward longshore transport along the sand spit that may in time create a sandbar across the mouth of the sheltered area. The beach at the northern edge of the project area was therefore reshaped to maximize the tidal in- and outflux of the sheltered area. The beach level was lowered to increase the area of valuable H1140 habitat and minimize drifting sands. Two measures were taken to minimize erosion and future maintenance during the lifetime of the primary defence: the Dutch shallow North Sea was combed to find the coarsest sand available and seaward slopes were adjusted to approach the natural slope for the encountered grainsize.

Minimize negative effects on groundwater

The presence of a sand body seaward of the existing dike has a beneficial long-term effect on the saline/freshwater balance in the polder due to the increased hydraulic resistance and lower seepage through the dike. In the construction phase however, temporary overpressure on the groundwater may cause instability of the dike and the nearby buildings. In the polder, the seepage of saline water may displace the fresh rainwater layer at the surface of the agricultural land, causing damage to growing crops. At Prins Hendrikzanddijk, an extensive real-time measurement system monitors changes in groundwater pressure and salinity in the dike and the polder. The surface water is captured at the seaward side of the dike by a horizontal drain installed close to the mean high-water level. At the landward side of the dike, seeping water is extracted from the first permeable layer by a series of vertical drainage wells. The depth and spacing of the wells vary along the length of the dike in accordance with the local geology. The final drainage design was based on trial tests done before the start of the project.

Safeguard operational Public Services

The water pumping station outflows were redesigned in order to ensure undisturbed drainage. The requirement of a lifelong operation of the pumping station is however at odds with the dynamic nature of the soft coastal protection and the natural aspect of the area. The outflow protection measures are made from natural materials (wood, rock) that provide a favourable habitat to marine life and allow for adjustments during their lifetime.

Conclusions

Seaward of the existing Prins Hendrikdijk coast on the Dutch island Texel, a dune was landscaped to protect the polder. The Prins Hendrikzandijk project integrates coastal protection with nature development, public services and recreational appeal. Instead of using a classical engineering design approach, the inclusion and enhancement of public, recreational and ecosystem services are made the focal point of the design. This example of a soft coastal protection strategy illustrates how many design initiatives that can be introduced to increase overall project value are often overlooked during project design. Key to this design was to steer free of the traditional engineering practice of splitting a complex project into a number of individual specific problems in different fields of competence, whose solutions are then brought together at the end. Instead, a holistic approach was chosen where every measure was evaluated in its own merit for safety, ecology, recreation and public functions and integrated into the whole solution during the design process. ■

References

Fordeyn, J. Malherbe, B. (2012). "Coastal Defense of Lowlands using Sand: Morpho-dynamic Concepts", Proceedings of the 8th International Conference on Coastal and Port Engineering in Developing Countries, Chennai, India, 932-943.

Hanley, M. E., et al. (2014). "Shifting sands? Coastal protection by sand banks, beaches and dunes." Coastal Engineering 87, 136-146.

Loucks, D.P., van Beek, E., Stedinger, J.R., Dijkman, J.P.M. and Villars, M.T. (2005). "Water Resources Systems Planning and Management. An Introduction to Methods, Models and Applications". UNESCO, Paris and Delft Hydraulics, The Netherlands.

THV Vlaamse Baaien (2009), Vlaamse Baaien, Veilig, Natuurlijk, Aantrekkelijk, Duurzaam, Ontwikkelend, Oostende, Belgium.

Van Slobbe, E., et al. (2013). "Building with Nature: in search of resilient storm surge protection strategies." Natural hazards 66.3, 1461-1480.

Van Vledder, G. (2016). "Hydraulische Golfrandvoorwaarden Prins Hendrikzanddijk Texel", *Project VC54*.