HYBRID DUNE STRUCTURES AROUND THE WORLD: A NEW OVERVIEW AND LESSONS LEARNED

Daan Poppema, Sierd de Vries, Ad Reniers and Alessandro Antonini, Delft University of Technology
D.W.Poppema@tudelft.nl, Sierd.deVries@tudelft.nl, A.J.H.M.Reniers@tudelft.nl, A.Antonini@tudelft.nl

INTRODUCTION

Shore protection strategies worldwide increasingly incorporate hybrid dunes, which combine sandy dunes with hard structures (Fig. 1). These hybrid dunes often intentionally combine classic erosion-resistant hard elements (rock, concrete elements, sea walls, etc) with sandy dunes. Hereby they aim to combine the best two worlds, as hard structures need less space and have less uncertainty in performance, while sandy dunes enable recreation and nature and can be more resilient under sea level rise. At times, hard elements such as buildings or outfall pipelines are introduced for other purposes, but unintentionally affect dune erosion during storms.

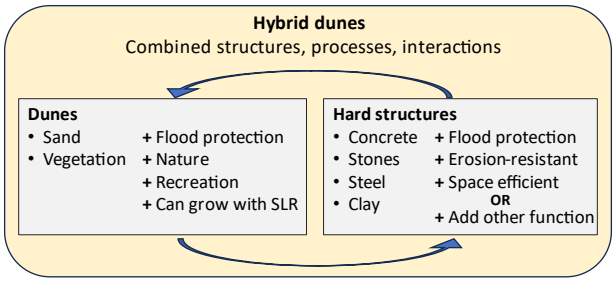

Figure 1 – Hybrid dunes combine sandy dunes and hard elements into a single interactive system

When combining hard and soft structures, their stability and hydraulic response are no longer only a function of the classical behaviour of either individual hard or soft parts under wave action, but also of the complex interactions between A) the local hydrodynamics and morphology at the hard structure; B) the dune condition; and C) the coastal profile at large. These complex interactions are poorly understood, but essential for the design of new hybrid dunes and for the safety assessment of existing defences.

To better understand and quantify these effects, we aim to conduct a unique hybrid dune field experiment, in which an artificial full-size hybrid dune is constructed at the high-water line and extensively monitored during storms. In this contribution, we present a first overview of hybrid dune cases around the world, in order to A) inform the design of the hybrid dune field experiment, and B) draw general engineering lessons on hybrid dune applications, opportunities and knowledge gaps.

METHODS

An inventory is made of international hybrid dune cases, where sandy dunes provide coastal protection together with, or affected by, hard structures. Hereby, we extend the notion of hybrid dunes as dunes with hard *defense structures* to coastal dunes affected by *any hard structures*, to take into account the possibly deleterious or beneficial effects of other hard elements. Cases in the inventory are categorized by the function of the hard structure, synergies or disadvantages of the hybrid nature, the type of hard elements (seawall, revetment, building, road, …), the location of the hard elements (behind/ underneath/in/on top of dune) and the order of development (built as hybrid dune, dune added later, hard structure added later, hard structure fortuitously present).

Characteristic or especially noteworthy typologies from the inventory will be studied, to A) derive knowledge gaps and lessons for the design and safety assessment of hybrid dunes; and B) inform the design of the field experiment.

RESULTS

A first inventory of hybrid dune cases has been collected (Fig. 2), with a preliminary selection of interesting cases.

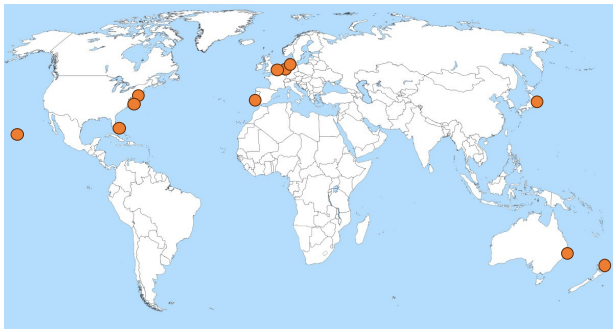

Figure 2 – A map of hybrid dune cases in the inventory

In Bay Head (New Jersey, US), a relic century old rock seawall was covered by sand dunes due to aeolian sediment transport following extensive nourishments. During hurricane Sandy, this seawall saved the hinterland from flooding (Fig. 3; Irish et al., 2013). The Gold Coast A-line seawall (Queensland, Australia) is similarly covered by dunes, but as part of the original design, ensuring a sandy coast and sufficiently wide beach for recreation, while the sea-wall offers protection during severe erosion events.

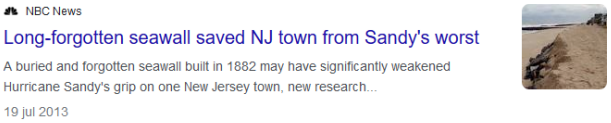

Figure 3 – A news article on the unexpected advantage of a hybrid dune with sea wall in Bay Head, US.

The Hondsbossche sea dike in the Netherlands (Fig. 4) is an example of a originally traditional dike with revetment, that is later converted into a hybrid dune. Because the dike did not meet safety standards anymore, sand nourishments were used to create a 300 m wide dune area in front of the old dike, with the combined aim of nature creation and flood safety improvement.

Figure 4 – Dunes created in front of the Hondsbossche sea dike (NL) to improve its safety level (HHNK, 2017)

In Katwijk (the Netherlands), a wide dune was constructed in front of an existing dike to improve the safety of the dike ('dike in dune concept'). Remarkably, under the new dune a large parking garage was constructed, optimizing the use of space near the boulevard while maintaining a visually attractive semi-natural landscape (Fig. 5).

Figure 5 – A parking garage under a dune in Katwijk, NL (DeltaExpertise, n.d.)

The rehabilitation of the Leirosa sand dune system (Coimbra, Portugal) employed a geotube dune core. After dune restoration with sand filling and vegetation replanting proved unable to withstand strong erosion events, five geotextile sand tubes were buried under the dune for extra erosion resistance, placed in formation from mean sea level to +8 m (Do Carmo et al., 2010).

All around the world, buildings such as houses, hotels and restaurants are present at the beach and in the dunes. In Hemsby, Norfolk (UK), severe dune erosion led to cliff formation and buildings collapsing (Fig. 6). Obviously houses are impacted by the dune erosion here, but inversely they also change hydrodynamics and sediment dynamics in their surroundings. In case of scour around houses, this may create weak spots in the dunes that upon failure affect a larger area.

Figure 6 – Buildings collapsed after coastal erosion in Hemsby, UK in 2013 (Gray & Crofts (2022).

DISCUSSION AND CONCLUSIONS

Some valuable lessons are drawn from this case overview. Hard structures for coastal defense are usually quite large and alongshore uniform. Consequently, they tend to affect (cross-shore) sediment transport over a larger area, while other structures (buildings, pipelines) usually have more local effects such as concentrated scour, with the potential to create localized weak spots in the dunes. Also, these other hard structures are often not built to the stringent standards of flood defenses, making them more likely to be moved, damaged or destroyed during storms, complicating the range of environmental impacts possible. In conclusion, safety assessments of hybrid dunes should not only take into account existing hard structures built for coastal protection, but also (negative effects of) any other hard structures.

Another observation is that for structures of the very same type, different histories still cause materially different characteristics. For example dunes that accrete *naturally* over time in front of a seawall versus *artificially* bulldozered dunes. At the aforementioned Bay Head seawall, the original dune accreted naturally over time, but when it was eroded by hurricane Sandy, a new dune was bulldozered to restore protection. However, even if the result eventually looks similar, artificial and natural dunes differ in sediment composition and vegetation. For instance, roots in natural dunes can extend downward for meters (from dune grass trapping sediment and slowly building op the dune), substantially improving erosion resistance (Gadgil, 2002). So to properly design or assess hybrid dunes, the dune history and resulting dune structure should be taken into account.

Overall, these results show that hybrid dunes can offer improved coastal safety, efficient use of space and synergy with other functions, leading to their widespread application. Nonetheless, the complex effects of combining hard and soft elements are poorly understood, and, in case of hard structures not built for coastal defense (buildings, roads), possibly negative.

At the conference, we will elaborate on the categorized *hybrid dune inventory*, and on *lessons learned* from it, for both the design or safety assessment of hybrid dunes, and for the design of the planned field experiment.

REFERENCES

DeltaExpertise (n.d.). HWBP Kunstwerk Katwijk. www.deltaexpertise.nl/wiki/index.php/HWBP_Kustwerk_Katwijk

Do Carmo, Reis & Freitas (2010): Journal of Coastal Research, 26(6), pp. 1068-1078.

HHNK (2017). De Hondsbossche, van dijk naar duin. www.youtube.com/watch?v=Hu200Q6hJko

Gadgil (2002). Marram grass (Ammophila arenaria) and coastal sand stability in New Zealand. New Zealand Journal of Forestry Science, 32(2), pp. 165-180.

Gray & Crofts (2022). The potential role of the geosciences in contributing to the UN's Sustainable Development Goals. Parks Stewardship Forum. 38(1).

Irish, Lynett, Weiss, Smallegan, & Cheng (2013). Buried relic seawall mitigates Hurricane Sandy's impacts. Coastal Engineering, 80, pp. 79-82.