

USING A SUBMERGED ARTIFICIAL REEF AS COASTAL PROTECTION IN A BI-DIRECTIONAL WAVE CLIMATE

Bjarke Eltard Larsen, Technical University of Denmark, bjelt@dtu.dk
 Kasper Kærgaard, Danish Hydraulic Institute (DHI), kak@dhigroup.com
 Erik Damgaard Christensen, Technical University of Denmark, edch@dtu.dk

INTRODUCTION

Sandy beaches are eroding all over the world. Methods to protect the beaches vary from soft methods, such as sand nourishments, and hard structures such as groins and detached breakwaters, which can be both emerged and submerged. Submerged breakwaters have been used at a variety of locations, but experiences relating to their performance are varying. Some locations have experienced accretion behind the breakwater as desired but in other locations the submerged breakwaters have contributed to erosion (Lamberti et al., 2005). Most research involving the effect of submerged breakwaters on the neighboring shorelines have involved waves coming perpendicular to the shoreline, which may cause accretion or erosion, or at an oblique dominant angle, where the shores will typically accrete behind the breakwater and upstream, but will erode downstream of the breakwater (Ranasinghe et al., 2010). Due to its location in the center of Denmark the eastern coast of the Island of Samsøe (Figure 1) historically have experienced a bi-directional wave climate as shown the wave rose in Figure 2.



Figure 1: Map showing Denmark as well as a zoom in on the Island of Samsøe and the eastern coast of the island. At the zoom-in on the east coast of Samsøe shoreline stretches which are stable/mildly accreting or experiencing erosion are marked with green and yellow arrows respectively.

Barrier reefs can enhance both coastal protection and biodiversity conservation. Using a numerical model, it will be investigated whether a submerged artificial reef exposed to the wave climate at Samsøe could be beneficial for protecting the area threatened by erosion (yellow arrows in Figure 1), while limiting erosion of the nearby shorelines by spreading the erosion of sand over a long stretch both north

and south of the reef.

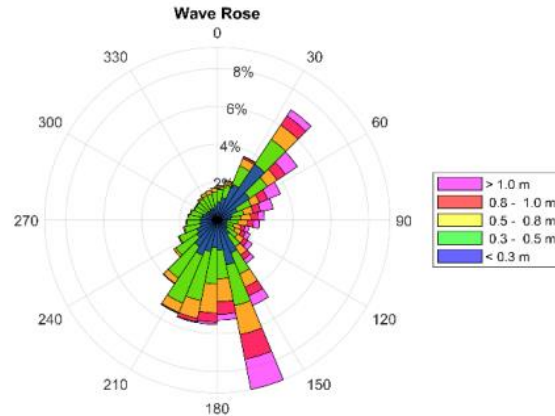


Figure 2: Wave rose from eastern coast of Denmark. Data comes from DHIs MOOD model covering a period from 2009 to 2018 at a water depth of 21 m.

MODEL DESCRIPTION AND SETUP

The model utilized for morphodynamic simulations is the so-called Shoreline Morphology module, which is a coupled model within MIKE 21 FM. In this model the waves are solved using a spectral wave model. Waves from the spectral wave model are passed to a non-linear shallow water model (NLSW) to model the depth-averaged currents. The combined wave statistics and currents are passed to pre-computed sediment transport tables, which then give the sediment transport rates. Finally, the longshore part of the sediment transport rates is integrated across certain shore-normal patches and the entire coastal profile is moved back or forward to satisfy the Exner equation, which describes the conservation of mass and relates gradients in sediment transport rates with changes in morphology. For more details of the model see Kristensen et al. (2013).

For the simulations the problem has been simplified assuming a constant cross-shore profile (the cross-shore profiles have been measured and are fairly constant), A constant shoreline normal with $\alpha = 102$ deg. is utilized. The reef is inserted with a crown length of $L_r = 100$ m as well as a crown width B of 4 m and side slopes of $S = 1 : 3$. The reef is positioned 200 m (two times the reef length) from the shoreline based on initial literature review. The water depth above the reef h_{rc} will be varied to investigate this parameters effect on the shorelines. The domain is quite long in the direction along the shoreline to accelerate the longshore currents from the boundaries towards the area of interest. The domain is discretized into 74,000 cells with gradual refinement towards the shoreline. The reef is discretized with 7 cells over the entire width and 12

cells over the length as can be seen in Figure 3 showing a zoom in of the mesh in the vicinity of the reef.

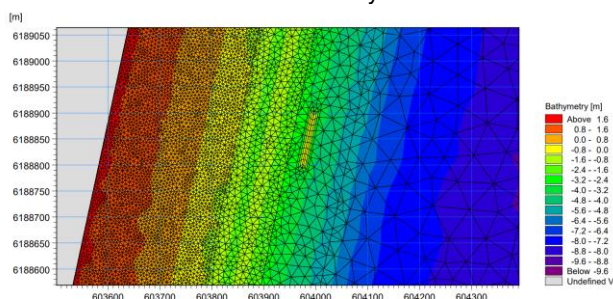


Figure 3: Mesh in the vicinity of the reef

The model is driven with the wave climate from Figure 2.

RESULTS AND DISCUSSION

Figure 4 shows a satellite image including the original shoreline as well as simulation results with varying h_{rc} . The effect of increasing h_{rc} is as expected, as the salient becomes smaller and the shoreline erosion in the neighboring stretches reduce. The reason for the reduced salient is that more waves propagate over the reef, and as result the longshore currents are not reduced on the lee side of the reef to the same degree.



Figure 4: Satellite image including the reef (yellow rectangle), original shoreline (blue) and predicted shorelines using different h_{rc} after 9 years.

Figure 5 shows the development in maximum shoreline gain and shoreline erosion for the four different values of h_{rc} . All four cases follow a very similar trend, but with the magnitude of both shoreline gain and erosion reducing with increasing h_{rc} . The case having $h_{rc} = 1$ m has resulted in 12 m shoreline gain behind reef and a maximum erosion of 4 m. In general, the erosion in the

neighboring beaches is, however, slightly smaller, around 2-3 m at its maximum.

The simulated effects shown in Figures 4 and 5 are

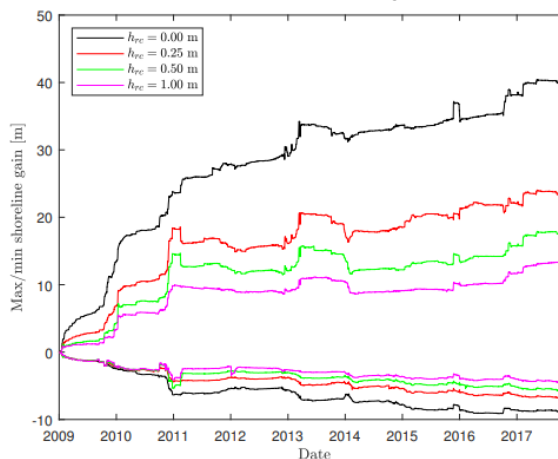


Figure 5: Maxi and min shoreline gain for different h_{rc}

relative to the existing trends shown in Figure 1, and therefore less accumulation and less erosion can be expected at Samsøe. Furthermore, the modelling has assumed an infinite amount of mobile sediment on the seabed, in reality parts of the shoreline north of the artificial reef has natural shallow stone reefs and thus cannot erode.

The trends shown above cannot be expected at all types of locations. If waves come perpendicular to the shoreline or primarily oblique at a certain angle, it will be demonstrated that lee-side erosion can be expected.

CONCLUSIONS

Using a state-of-the-art numerical model it has been demonstrated that, in a situation with a bi-directional wave climate, an artificial reef can stop existing erosion or create moderate accretion at certain stretches of the shoreline, with limited erosion and spreading the erosion over long distances at adjacent shorelines. The artificial reef can therefore in certain circumstances function as a nature-based solution to coastal protection while enhancing biodiversity.

ACKNOWLEDGMENTS

The authors acknowledge financial support from the Velux foundation and Vattenfall for the project: Construction of a barrier reef as a nature-based solution to coastal protection and biodiversity conservation (BARREEF).

REFERENCES

- Kristensen, Drønen, Deigaard, Fredsøe, J. (2013): Hybrid morphological modelling of shoreline response to a detached breakwater. *Coast. Eng.* 71, 13-27.
- Lamberti, Archetti, Kramer, Paphitis, Mosso, Di Risio (2005): European experience of low crested structures for coastal management. *Coast. Eng.* 52 (10-11), 841-866.
- Ranasinghe, Larson, Savioli (2010): Shoreline response to a single shore parallel submerged breakwater. *Coast. Eng.* 57, pp. 1006-1017.