MORPHOLOGICAL IMPACT OF COASTAL STRUCTURES IN THE ONE-LINE 'SHORELINES' MODEL

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INTRODUCTION

Many coasts around the world are under threat of erosion due to storms and slow but progressive retreat by sea level rise. Predictions of future climate change impacts and efficiency of coastal structures are essential to help coastal communities deal with this challenge. This holds especially for metropolitan coasts that are densely populated. Any evaluations of future climate impacts should therefore be made with models that can deal with the complex coastal structures that are present in the build-up metropolitan areas. The aim of this study is to describe the handling of coastal structures in the ShorelineS model.

SHORELINES MODEL

The 'ShorelineS' model is a 1D coastline model that computes (gradients in) wave-driven longshore transport along a 'grid' that is regenerated every timestep (figure 1). Barriers and elongated spit features can grow unconstrained in the model, as the numerical approach can handle high-angle wave instabilities. Segments of coastline can merge or split (figure 2). Multiple transport formulations (e.g. CERC, Kamphuis or Van Rijn, 2015) can be used. Equilibrium concepts are included for the cross-shore transport (e.g. barrier overwash, dune growth and erosion).

Table 1 - Comparison of ShorelineS to other models

		Regular 1D models	ShorelineS	Regular 2DH models
Processes	Beach transport (waves)	yes	Yes	yes, but slow
	Dune erosion/overwash	no	Yes	not or detailed[*1]
	Dune growth	no	Yes	experimental[*2]
	Spit & high-angle waves	no	yes	yes, takes long
	Climate change (decadal)	yes[*3]	yes[*3]	takes too long
	Estuarine / tidal transport	no	inlet only[*4]	yes
	Sediment	sand	sand	sand & mud
Measures	Nourishments	many simple	many complex	single/first years
	Revetments	yes	yes	yes
	Groynes	difficult[*5]	yes	yes
	Offshore breakwaters	difficult[*5]	yes	difficult[*6]
Efficiency	Ease of use (complexity)	difficult	easy	moderate / hard
	Time for model setup	weeks	~week	>month
	Computational efficiency	quick	quick	slow
	Adaptability of code	difficult	easy	difficult
	Detail of the results	low	moderate / high	high

[*1] : only for some field models (e.g. xbeach)
[*2] : experimental coupling in scientific models (e.g. Delft3D-Aeolis)
[*3] : for sandy coasts due to sea level rise or change in wave climate
[*4] : river function to keep tidal inlets open
[*5] : requires a model to compute the wave sheltering and diffraction
[*6] : not easy to model the beach behind the structure

With respect to other 1D models, the 'ShorelineS' model can deal with more complex coastal situations (e.g. offshore breakwaters, groynes, spits and climate drivers; Table 1) than existing models such asU NIBEST, Litpack and Genesis. Compared to 2DH models, the ShorelineS model has a substantial advantage in computational efficiency.

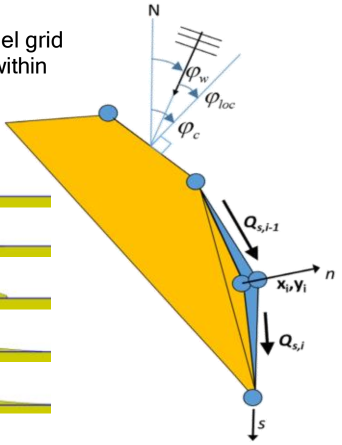

Figure 1 - Model grid schematization within ShorelineS

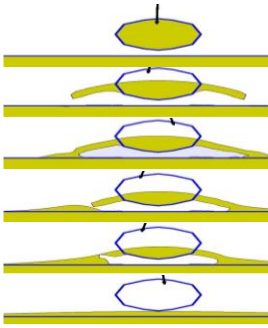

Figure 2 - Island merging with the coast

CONSIDERED COASTAL STRUCTURES

The following coastal structures are considered in the ShorelineS model, which are 1) cross-shore oriented breakwaters or groynes, 2) offshore breakwaters which are constructed coast-parallel in intermediate to shallow water depths, and 3) revetments that are placed at the waterline. Diffraction of waves is important both for the groynes as well as for the offshore breakwaters, while the revetments and groynes both bypass sediment to the other side. A diffraction example is shown for Sitges.

DIFFRACTION

Waves are shielded at groynes as well as at offshore breakwaters. The diffracted waves determine the coastline changes in the sheltered area. A reference dataset was made for the computed diffracted waves behind an offshore breakwater using Xbeach non-hydrostatic model runs with swell waves (see Figure 3).

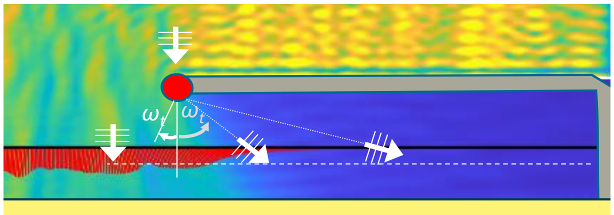

Figure 3 - Xbeach non-hydrostatic model (H_S=1m, 360°N)

Based on the simulations a parameterization could be made of the wave angle change ($\Delta\omega$) and wave height reduction (K_d) of the diffracted waves, which is determined by the rotation (ω_t) of the sheltered waves at the diffraction point, and on a spreading factor of the waves (*rotfac*). These diffraction formulations are used.

$$K_d = 1 - exp\left(-\left(\frac{0.5}{\omega_*}\right)^4\right), \omega_* = \frac{\omega + 90}{180}$$

$$\Delta\omega = \begin{cases} rotfac * (\omega - \omega_t), & \omega \geq \omega_t \\ 0 & , \omega < \omega_t \end{cases}$$

Also, other diffractions formulations (e.g. Dabees, 2000) use the wave rotation to compute impact on waves, but numerical models show that these often underestimate the diffracted wave angle-change and height for irregular waves (Elghandour, 2020). Offshore breakwater and groyne cases are shown in Figure 4 and 5.

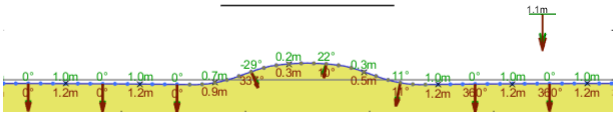

Figure 4 - Diffraction at an offshore breakwater

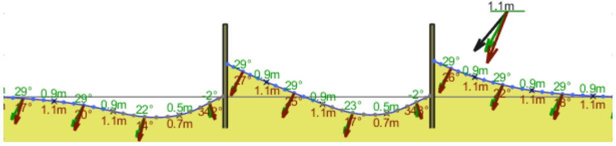

Figure 5 - Groyne scheme with diffraction and bypassing

BYPASSING OF GROYNES

Alongshore bypassing of sediment can be of importance for 'relatively short' groynes that do not extend beyond the depth-of-closure, as well as for revetments. The rate of bypass depends on the properties of the structure and the actual physical conditions (i.e. waves, tide and sediment). For the groynes, an approach is used which uses the ratio of the depth at the tip of the structure and the inner depth-of-closure (Hallermeier, 1981) to determine the degree of bypassing, which scales the transport. The depth at the tip of the structure is computed making use of a dean-profile with $h_d = A_p * L_g^{0.67}$ (Dean, 1977). Where h_d is the depth at the tip of the structure, Lg the groyne length and Ap the profile shape factor, which depends on the median grain size (D_{50}), with $Ap = (1.04 + 0.086 * \log(D_{50}))^2$. The bypassed transport is scaled up by an enhancement factor (Fc) that accounts for the contraction of the currents at the head of the groyne, which typically yields a 0% to 30% enhancement of the transport capacity. Because of this term the beach will not grow until the end of the groyne tip (Figure 6), which is a common problem with other 1D models. Bypassed sand is distributed over the shadow area, which is better than placement in the first cell.

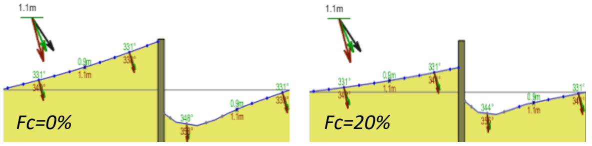

Figure 6 - Accretion for a contraction factor of 0% or 20%

REVETMENTS

Revetments should preserve the coastline behind the revetment, and at the same time allow bypass of sediment. This is achieved by limiting sediment bypass along the revetment to the rate of the updrift supply. In case sediment is present in front of the revetment, the transport can increase only to the extent that the available sediment allows.

SITGES EXAMPLE

An example run was made for Sitges to showcase the ability of the ShorelineS model to represent the local curvature of the beach as a result of the diffraction at the structures. Here it was found that a precise derivation of the nearshore wave conditions at the tip of the structures (in rather shallow water) was essential for obtaining a good results. Also, the temporal variation in wave conditions (mainly direction) is needed to obtain a good representation of the arches. While bypassing of the structures was less relevant for the local equilibrium beaches at Sitges.

Figure 7 - Bypassing at revetments

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