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Design of a Groyne Field to Counteract Beach Erosion at Wenduine, Belgium

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Abstract: The Belgian coastal town of Wenduine is situated at a change in coastline orientation and experiences beach erosion. A few kilometres to the northeast, the access channel to the Blankenberge marina experiences sedimentation due to littoral drift. On behalf of the Coastal Division of the Flemish Government, an integrated study on the mitigating measures for these morphodynamic issues at both Wenduine and Blankenberge is performed. This paper focuses on the design studies of the measures at Wenduine. A feasibility study is performed to investigate different solutions considering soft and hard measures. A conceptual design of the measures is carried out as a basis for a cost-benefit analysis. The solutions are also evaluated for morphodynamic effectiveness, currents and swimming safety, ecology and architectural aspects. The morphodynamic response and the hydrodynamic conditions are simulated using the numerical model XBeach and exported to a web application to visualize the effects of the different scenarios during stakeholder workshops. The construction of a rock groyne field in front of the dike of Wenduine is identified as the most effective and economic solution. During the design phase, the layout of the groyne field is optimized and this solution is further detailed.

Keywords: beach erosion, groyne field, rubble mound, morphodynamic shoreline evolution, XBeach

1 Introduction

The coastal town of Wenduine is situated in the central part of the Belgian coast. The coastline consists of a beach in front of a steep, smooth coastal dike. There are two distinct areas: a promenade parallel to the shoreline ending towards the southwest at a roundabout protruding into the sea (Fig. 1 left). Within the Master Plan for Coastal Safety of the Flemish Government (Flemish Government, 2011), this part of the coast was assessed as a weak link. In order to guarantee the coastal safety, flood reduction measures have been installed during the past years on the dike and roundabout. In combination with the beach in front of the dike, these measures guarantee a maximum overtopping discharge and hence the prescribed coastal safety level. An old groyne field is present on the beach, starting on the west side of Wenduine and extending beyond Blankenberge. With the beach level that is currently maintained, this groyne field has become inactive and is buried most of the time. As the town is situated at a change in coastline orientation (Fig. 1 left), it experiences recurring beach erosion. Due to this beach erosion, nourishments of the beach are frequently carried out to maintain the minimum beach level required for coastal safety.

About 3 km further to the east, sedimentation of the access channel reduces the accessibility to the marina of the coastal town of Blankenberge. The alongshore sediment transport runs net from west to east and moves sand from Wenduine into the channel, despite being separated from the adjacent beaches by two low jetties (Fig. 1 right).

On behalf of the Coastal Division of the Flemish Government, an integrated study on the mitigating measures for these morphodynamic issues at both Wenduine and Blankenberge is performed. This paper focuses on the studies of the measures at Wenduine, consisting of a feasibility and a design phase.

Fig. 1. Arial view of the Belgian coastline (left) and the coastal towns of Wenduine and Blankenberge (right).

A feasibility study is performed to investigate different solutions for the morphodynamic issues at Wenduine: extending the beach nourishment zone, performing foreshore nourishments or constructing one or multiple groynes at the beach. A conceptual design of the measures is carried out as a basis for a cost-benefit analysis. The solutions are also evaluated for morphodynamic effectiveness, currents and swimming safety, ecology and architectural aspects. The morphodynamic response and the hydrodynamic conditions are simulated using the numerical model XBeach and exported to a web application to visualize the effects of the different scenarios during stakeholder workshops. The construction of a groyne field in front of the dike of Wenduine is identified as the most effective and economic solution, and further detailed in the subsequent design stage.

During the design phase, the layout of the groyne field is optimized balancing the initial construction cost of the groynes and the morphodynamic effectiveness as well as taking into account the beach activities and swimmers safety. Variations in number of groynes, length and spacing are studied by means of a numerical high-resolution XBeach model. The cross sections of the groynes are designed in line with the existing rock groynes along the Belgian coastline. Furthermore, the effect on coastal flooding is quantified by means of a coastal safety assessment, considering the shoreline evolution at different time horizons.

2 Cost-benefit analysis of measures

During the feasibility study, different solutions for the beach erosion at Wenduine are investigated and compared to the reference scenario, a continuation of the present situation with recurring beach nourishments in front of Wenduine. Five solutions are defined and evaluated, consisting of soft as well as hard measures: foreshore nourishment in front of Wenduine, extension of the beach nourishment towards the area between Wenduine and Blankenberge, a single groyne east of Wenduine, two groynes situated west and east of Wenduine and a groyne field stretching from the west side to the east side of Wenduine. The measures are evaluated for morphodynamic effectiveness, cost, hydrodynamic effect and swimming safety, ecology and architectural aspects.

As a basis for a cost-benefit analysis, a conceptual design of the measures is drafted for which the investment and operational costs are quantified. The economic benefits are determined considering a reduction of the recurring beach nourishment works required to counteract any remaining beach erosion, compared to the reference scenario over a design life of 50 years. Based on the costs and benefits, the cost balance is set out for the different years over the design lifetime. This information is used to evaluate the different solutions based on initial investment cost, overall cost over the design lifetime and payback period.

The morphodynamic effectiveness of the measures is assessed by means of numerical simulations with a high resolution XBeach 2D model. The yearly morphodynamic evolution of the shoreline is determined. These results are used to evaluate the impact on the coastal safety and to quantify the required beach nourishment volumes to maintain the minimum beach level. The impact of the measures on the currents is examined by means of hydrodynamics-only simulations using the same XBeach model. The results are evaluated for swimming safety. The current flows are visualized dynamically in a web application (Fig. 2), in order to discuss the effects on swimming safety and other beach activities with the stakeholders such as authorities, lifeguards and marina users. This visualization also serves as a tool to make the stakeholders familiar with the new situation.

Fig. 2. Web-based dynamic visualization of XBeach hydrodynamic simulations.

2.1 Morphodynamics and shoreline evolution

The morphodynamic effectiveness of the measures is assessed by means of numerical simulations with a high resolution XBeach 2D model. The model domain is extended over a length of approximately 10 km along the coast. The yearly morphodynamic evolution of the shoreline is determined. A representative yearly wind, wave and tidal climate is considered using a morphological acceleration (morfac) approach.

The model is validated for the reference case by means of observed morphodynamic changes calculated from LIDAR and foreshore surveys with an interval of 1 year. The net volume changes along the coast as well as the net volume changes integrated over cross-shore profiles are compared for one morphological year. Both the model and the measurements display strong erosion in front of Wenduine, as the initial bathymetry includes a recent nourishment. In general the model predicts higher erosion volumes in this area compared to the measurements. The beach between Wenduine and Blankenberge generally shows sedimentation in both the observations and the model. The observations show more sedimentation, which can be explained by the fact that some of the sand dredged at the Blankenberge marina is deposited on the beach between Wenduine and Blankenberge.

Fig. 3 shows the net volume change integrated per cross-shore profile. The volume change is calculated landward of the -5.0 m TAW contour, which is considered to be the limit of the active beach profile in the survey data. Good agreement can be observed between both the magnitude and the spatial extent of the erosion in front of Wenduine (4000 m ≤ x ≤ 6000 m). West of Wenduine (x < 4000 m) and east of Wenduine (x > 6000 m), differences are visible between the model and the measurements, that are related to dredging and nourishment works during the reference period and are not included in the model.

In conclusion, the comparison of model versus observations shows good agreement, with the largest differences due to human interventions (dredging, nourishments) that are not included in the model.

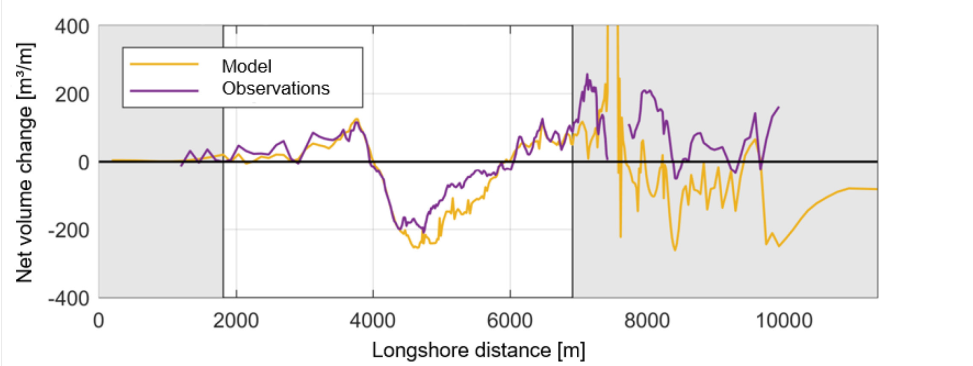

Fig. 3. Modelled and observed net volume changes integrated over cross-shore profiles along the coast.

The different erosion measures are simulated for their yearly morphodynamic evolution over a duration of 5 years. Within this timeframe two responses are observed. In scenarios in which erosion of the beach is reduced but not eliminated, a significant retreat of the beach is found requiring a new nourishment before the end of these 5 years in order to maintain the coastal safety level. The simulations allow the prediction of the number of nourishment repetitions and therefore cost price over the project lifetime. In scenarios in which the beach is stabilized, the model predicts that a new shoreline equilibrium is reached within these 5 years and only smaller variations are predicted beyond this horizon. A timeframe of 5 years is found sufficient to capture the trends in coastline evolution and evaluate the different erosion measures. Long-term sensitivity to yearly variability is not incorporated in this study.

For the case of a single groyne east of Wenduine, a reduction of the sediment losses from the nourished zone in front of Wenduine is observed. The updrift effect extends over the entire Wenduine area. However, there is still erosion at the western part of Wenduine, although a reduction is observed compared to the reference case. Downdrift of the groyne, erosion is observed due to blocking of the alongshore sediment transport, occurring especially on the upper beach.

When a second groyne is added west of Wenduine, the sediment is trapped updrift of the groyne, generating downdrift erosion in front of Wenduine instead of further reducing the sand losses from this nourished zone. As a result, this scenario is less effective at reducing erosion in front of Wenduine than the scenario with a single groyne.

By introducing a groyne field in front of Wenduine, sedimentation occurs over the entire area of Wenduine, as the alongshore transport is strongly reduced. Compared to the case with a single groyne, especially updrift of the westernmost groyne a large improvement is noticed. The downside is that the erosion downdrift of the groyne field in the area between Wenduine and Blankenberge further increases. Fig. 4 shows the sedimentation/erosion after 5 years for the reference scenario and for a groyne field.

The soft measures that are investigated have a limited effect on the beach erosion in Wenduine. The foreshore nourishment in front of Wenduine is intended to reduce the sand loss by sheltering the beach due to wave breaking on the foreshore, and by onshore sand transport from the foreshore towards the beach of Wenduine. The model shows however that after a few years, the foreshore nourishment is mostly found on the beach between Wenduine and Blankenberge. This could be attributed to the strong flood-dominant tidal current pushing the sand eastward rather than shoreward, the limited alongshore extent of the nourishment and the low level of the foreshore nourishment introducing wave breaking only during low water.

Placing a beach nourishment in between Wenduine and Blankenberge in order to reduce the shoreline orientation change at Wenduine and hence the long-term erosion, also affects the alongshore transport at Wenduine only limited as it results in only a slight reduction of the volume loss at Wenduine.

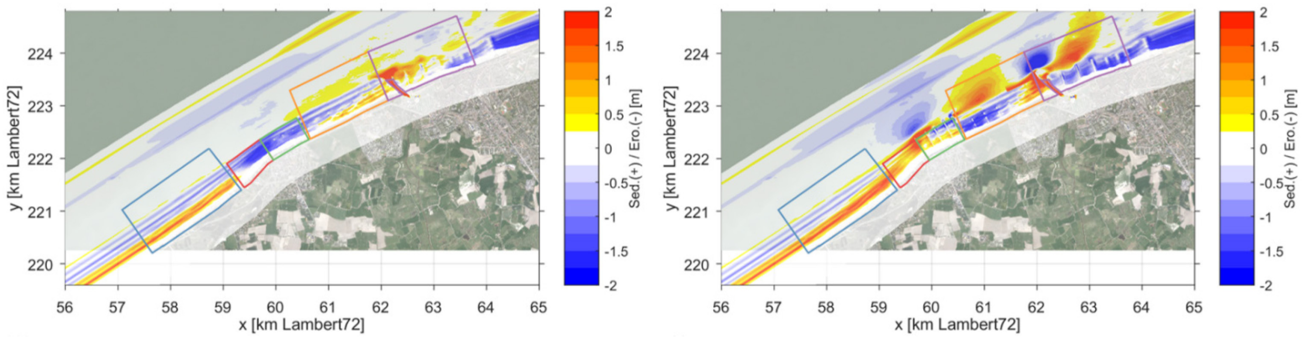

Fig. 4. 5 year sedimentation/erosion for the reference scenario (left) and a groyne field in front of Wenduine (right).

2.2 *Current patterns*

The XBeach model is also applied to investigate the effects on the hydrodynamics. Dedicated hydrodynamics-only simulations are performed including wave, wind and tide driven currents over a simulation period of 50 hours (roughly 4 tidal cycles). The model has already been extensively calibrated (Zimmermann et al., 2012) and is reused with minimal changes.

For the reference scenario (Fig. 5 left), the change in coastline orientation at Wenduine is not sufficiently sharp to generate flow separation or eddies. The existing groynes are mostly buried under the beach and have little impact on the flow: wave-driven currents remain shore-parallel and no stationary rips are formed.

A new groyne east of Wenduine impacts the flow, but the shore-parallel wave driven currents are still relatively strong at the location of the groyne since there is only one groyne to slow down the flow. During high water, when the groyne is mostly submerged, the wave-driven current bends slightly, but mostly flows over the groyne. During low water, when the groyne is mostly emerged, the current is bent around the groyne, forming a stationary rip current.

For a new groyne field in Wenduine (Fig. 5 right), the flow patterns are similar to existing (exposed) groyne fields along the Belgian coast. Around high water, wave-driven currents mostly flow over the groynes and are bent partially seaward. Around low water, wave-driven currents are bent stronger around the groynes and stationary rips are formed. These stationary rips interact with the tidal current further offshore and form circulation cells. The groynes also hinder the alongshore wave-driven current, generating lower current velocities than in the reference scenario.

Again for the soft measures, limited effects are observed. The foreshore nourishment in front of Wenduine forms a local shallow zone, causing slightly higher tidal flow velocities here. The changes in current velocity compared to the reference scenario are relatively small and no rip currents are generated. The beach nourishment placed between Wenduine and Blankenberge creates only a small change in the coastline orientation and places no new obstructions in the flow. As a result, there is little change in the flow field compared to the reference scenario.

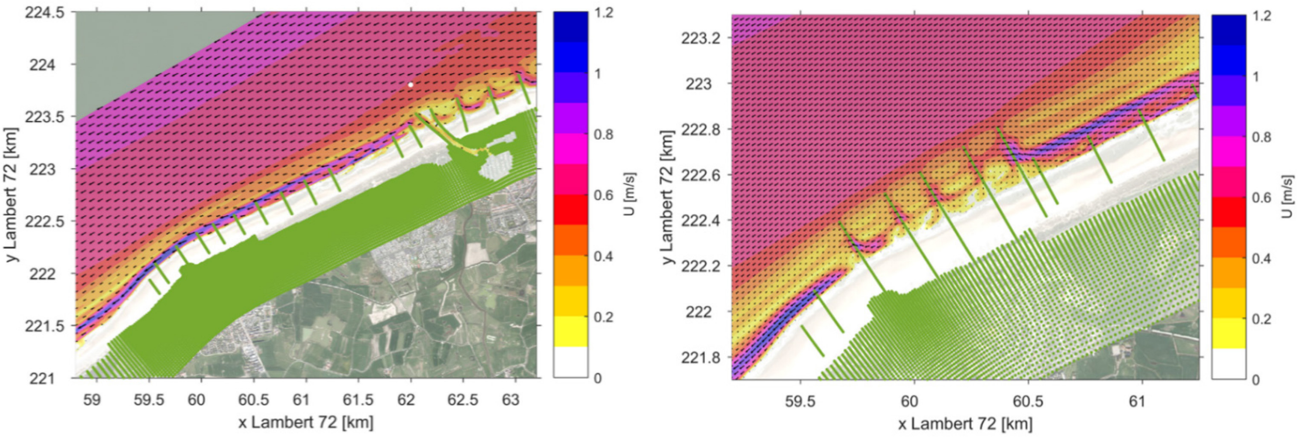

Fig. 5. Current pattern at peak ebb flow for the reference scenario (left) and a groyne field in front of Wenduine (right).

2.3 Preferred measure to mitigate Wenduine beach erosion

The preferred measure to mitigate the beach erosion in front of Wenduine is selected considering the cost-benefit analysis as well as the evaluation of the different measures for morphodynamic, hydrodynamic, ecological and architectural aspects. The implementation of a groyne field is selected as the preferred measure.

Together with the measure of a single groyne east of Wenduine, this measure is more cost-effective than the current nourishment strategy and the other measures. A groyne field has a longer payback period than a single groyne due to the higher initial construction cost of multiple groynes, but a lower overall lifetime cost.

The groyne field provides a significant reduction of the sand loss at Wenduine. Fig. 6 shows the shoreline evolution over 5 years for this scenario compared to the reference scenario. In the reference scenario, sand losses after the nourishment lead to shoreline recession in front of the seawall, reducing the safety level of the town of Wenduine against storm-induced flooding and raising the need for recurrent nourishments. In contrast, the shoreline in case a groyne field is installed remains stable and even shows a slight net growth in front of the seawall. A disadvantage of this scenario is the downdrift erosion on the beach between Wenduine and Blankenberge that may lead to dune erosion and loss of ecologically valuable dune habitat within several years. The model predicts that the erosion mainly affects the supratidal beach without reaching the dune toe under normal conditions and that the shoreline reaches a new equilibrium in this area after 4 to 5 years.

The groyne field introduces a reduction of the alongshore wave-driven current, but generates circulation cells in between the groynes with rip currents. The latter situation is not beneficial for swimming safety, but the current patterns are similar to existing groyne fields on the Belgian coast. Beach users and lifeguards are familiar with this situation and the impact of the new groyne field on currents is therefore still considered acceptable, based on stakeholder feedback.

The groyne field poses a visual compartmentalization of the beach. To reduce the impact, the height of the groynes needs to be limited and the groynes need to be easily crossable by beach users. Due to the change from soft to hard substrate, the groynes introduce a change in species composition in the bed. The groynes also form a barrier for migrating beach organisms, but increase the diversity of macro- and avifauna. With the stabilization of the beach, future recurring beach nourishments and their negative impact on the beach organisms are reduced.

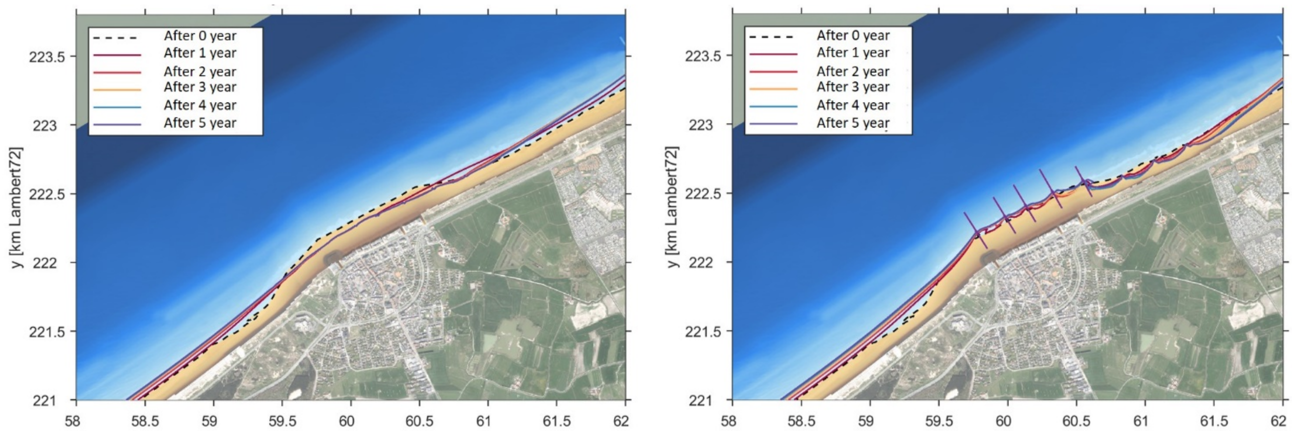

Fig. 6. Shoreline evolution over 5 years for the reference scenario (left) and a groyne field (right).

3 Design of preferred measure: groyne field

Following the feasibility study a groyne field is selected as the preferred measure for mitigation of the beach erosion at Wenduine. During the design phase, this measure is studied in more detail to optimize the layout of the groyne field, to design the beach and the groynes and to assess the coastal safety for this measure.

3.1 Layout of groyne field

The conceptual design of the groyne field during the feasibility phase consists of five groynes, corresponding to an increase and extension of the existing, mostly buried groynes in front of Wenduine. Morpho- and hydrodynamic simulations of multiple variants on the field layout are performed to determine an optimized layout. The number of groynes, the position and interdistance of the groynes and the length of the groynes is varied.

Initially, a retreat of the beach in between the eastern groynes is noticed after installation of the groynes due to a reduced sediment supply resulting from the presence of the western groynes (Fig. 6). After the first year, these sections start to experience a growth as bypassing of the eastern groynes is occurring.

The morphodynamic simulation of a field with four equidistant groynes shows that there is still a net growth of the beach in between the groynes after several years, though the volume growth is reduced by approximately 10% compared to five structures.

For all groyne distances included in the simulations, the formation of circulation cells for the current is observed. For smaller groyne spacings, the magnitude of the currents in the circulation cells slightly reduces but the safe swimming area outside the outward directed rip current also reduces. For swimming safety the larger groyne spacing of four groynes is found preferable based on stakeholder's feedback.

The groyne length is defined based on the influence on the alongshore sediment transport. Fig. 7 shows the alongshore transport over a cross-shore profile at the second groyne from the west for different groyne lengths. For the reference scenario representing the present situation, the transport mainly occurs in the surf zone. A groyne length extending beyond the surf zone significantly reduces the transport. Based on these results the optimal groyne length is determined as blocking most of the alongshore transport, and beyond which an additional increase of the length has limited influence.

The concern on the erosion introduced in the area between Wenduine and Blankenberge by the groyne field remains. This erosion is observed during the first years until sufficient bypassing of the groyne field is initiated. The model predicts that the shoreline reaches a new equilibrium in this area after 4 to 5 years. Applying a shorter length for the eastern groyne helps to reduce the initial beach erosion and the retreat of the equilibrium shoreline in this area, but does not avoid these effects.

Taking into account the numerical model results, as well as costs, construction aspects and designated beach user areas, a field consisting of four or five sloping groynes is found to be an effective and economic measure to stabilize the beach. The western groynes extend slightly beyond the surf zone or zone of increased alongshore sediment transport. A shorter length for the most eastern groyne introduces a gentler transition to the downdrift area.

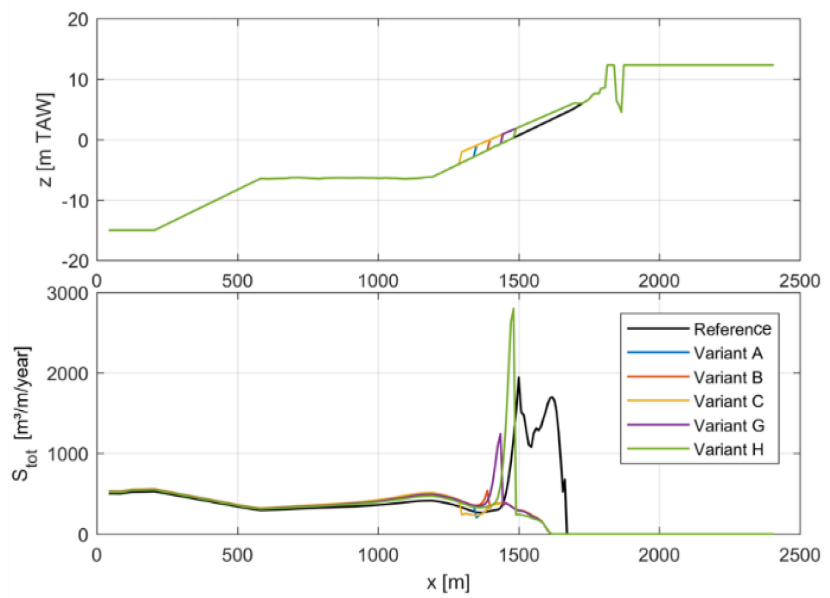

Fig. 7. Cross-shore profile (top) and yearly averaged alongshore transport along cross-shore profile at groyne 2 (from west) for different lengths.

3.2 Design of groynes

The groynes are designed for their primary functionality to retain the beach. In addition, secondary boundary conditions are considered in the design, such as accessibility of the beach, cross and along groyne transport by service vehicles, ecological opportunities within the different littoral sections. The groynes are divided into two areas along their lengths, approximately corresponding to the (supra)tidal beach (sections A and B) and the subtidal beach (sections C and D). In sections A and B, crossing by pedestrians and service vehicles needs to be accommodated, whereas in sections C and D only accessibility along the crest for service vehicles is requested.

The cross sections of the groynes are designed in line with the existing groynes along the Belgian coast to maintain a uniform landscape. Moreover the design takes into account the expertise gained from their monitoring and maintenance as well as the considerations of the ecological working group. The Belgian groynes are typically low-crested sloping structures consisting of regular rock or concrete blocks (Fig. 8). On the dry and tidal beach sections, a masonry with large, regular blocks is often used forming a trapezoidal section. The seaward sections consist of a wide cross section with two layers of regularly placed blocks. The crests of both sections can be equipped with a road for maintenance works. Many groynes have been constructed more than half a century ago, and during the following decades adjustments have been made. One typical adjustment is the extension of groynes by means of randomly placed blocks or rock.

The oldest structures have been built using blocks of basalt rock. To reduce the costs, concrete elements have been applied in more recent groynes. Pieces of basalt rock have been encapsulated in the concrete for ecological enhancement of these blocks. During the studies for Wenduine, an ecological working group has been consulted. In line with their recommendations, concrete blocks are selected to armour the groynes at Wenduine in sections A and B. Due to the porous surface area of the concrete, this material is creating a larger small-scale variation of dry and wet surface. In sections C and D, large quarried rock is selected.

The stability of the concrete armour blocks and rock is assessed by means of design formulae for low-crested structures with orderly or randomly placed elements, using the Rock Manual (CIRIA et al., 2007) and Van Rijn (2016) as reference works.

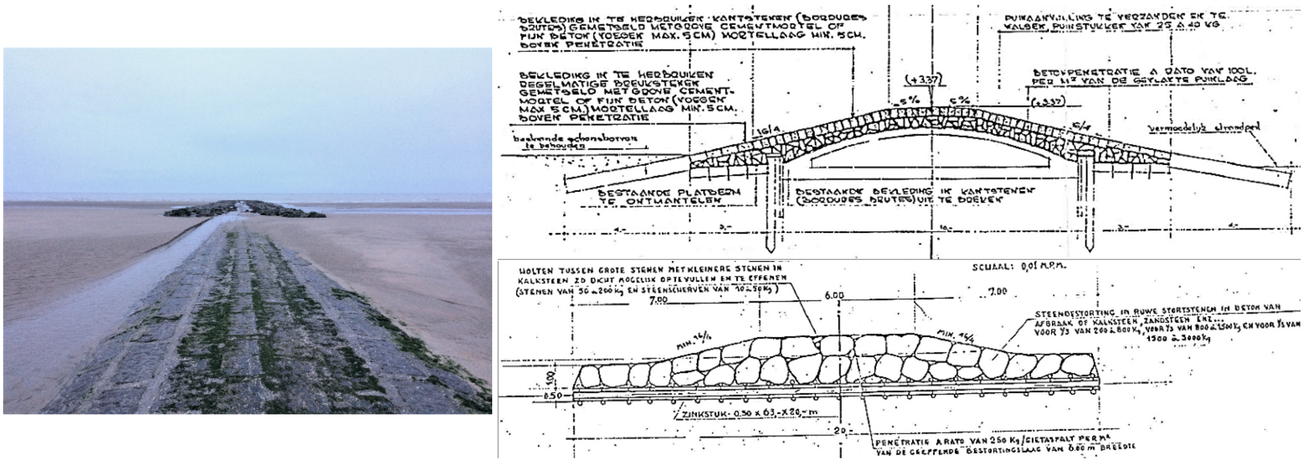

Fig. 8. Example of groynes along Belgian coast (left) and typical cross sections for the upper section (right top) and the lower section (right bottom).

3.3 *Coastal safety assessment*

The design of the groyne field is verified for compliance with the Master Plan for Coastal Safety (Flemish Government, 2011) by means of a coastal safety assessment. Storm conditions with a probability of occurrence of 1 in 1000 years are combined with the sea level rise over the project lifetime. The coastal safety is verified for the shoreline configuration observed at installation of the groyne field, after 1 year and after 5 years. Different time horizons are considered as for a number of sections initial erosion is observed followed by sedimentation until an equilibrium is reached.

The assessment is performed in line with the methodology outlined by the Flemish Government (Suzuki et al., 2016). Two different methodologies apply for the coastal sections within this study: “dikes” for the sections in front of Wenduine and “dunes without buildings” for the sections between Wenduine and Blankenberge.

For the dike sections, a model train of XBeach 2D, SWASH 2D and SWASH 1D is run. The outcome of the XBeach 2D simulations for the long-term shoreline evolution with the groyne field after 0, 1 and 5 years is used as input to the model train. First, the storm erosion of the beach profile is calculated in XBeach. Second, the waves are transformed from the offshore -5.0 m TAW contour to the toe of the dike using SWASH 2D. Third, SWASH 1D is calibrated to reproduced the same wave conditions at the toe, and finally, this calibrated model is used to calculate the overtopping discharge over the dike. The overtopping discharges at the sea defence line are verified for compliance with the prescribed criterion of < 1 l/s/m. For the dune sections, only the XBeach model is applied to determine the storm erosion profile. The eroded profile is verified for compliance with the criteria on remaining dune width and volume with respect to the sea defence line.

4 Summary

The selection process and design of the mitigation measures for erosion at the Belgian coastal town of Wenduine are discussed. Attenuated by a change in orientation of the coastline at this location, the beach in front of Wenduine experiences beach erosion and a recurrent beach nourishment scheme is currently being carried out to maintain the coastal safety level.

A feasibility study is performed to investigate different solutions considering soft measures such as extending the beach nourishment zone or performing foreshore nourishments, and hard measures such as constructing one or multiple groynes. Based on a conceptual design of the measures, they are evaluated for cost-benefit balance, morphodynamic effectiveness, currents and swimming safety, ecology and architectural aspects. The construction of a rock groyne field in front of the dike of Wenduine is identified as the most effective and economic solution.

The morphodynamic response and shoreline evolution over a period of 1 to 5 years are studied with a 2D XBeach model. The hydrodynamic conditions are also simulated using this model and exported to a web application to visualize the effects of the different scenarios during stakeholder workshops.

During the design phase, the layout of the groyne field is optimized. Variations in number of groynes, length and spacing are studied for morpho- and hydrodynamic response. Taking into account the numerical model results as well as costs, construction aspects and designated beach user areas, a field consisting of four to five sloping groynes is found to provide an effective stabilisation of the beach. The cross-shore profile of the alongshore sand transport is used to define the optimum length of the groynes. The western groynes extend slightly beyond the surf zone or zone of increased alongshore sediment transport. Introducing a shorter length for the most eastern groyne results in a gentler transition to the downdrift area and reduces the beach erosion in front of the dune area between Wenduine and Blankenberge.

The cross sections of the groynes are designed in line with the existing groynes along the Belgian coastline and taking into account the expertise gained from their monitoring and maintenance as well as the considerations of the ecological working group. A combination of regularly placed concrete blocks on the upper part of the beach and randomly placed quarried stone on the lower part of the beach is selected.

Finally, the design of the erosion mitigating measures is verified for compliance with the Belgian coastal safety requirements. A coastal safety assessment is carried out with a numerical model train using XBeach 2D, SWASH 2D and SWASH 1D, and considering the shoreline evolution at different time horizons as start bathymetry. The overtopping discharges for dike sections and the remaining dune width and volume for dune sections are verified against the prescribed criteria.

References

CIRIA, CUR, CETMEF, 2007. The Rock Manual: The use of rock in hydraulic engineering (2nd edition). C683, CIRIA; London.

Flemish Government, 2011. Masterplan Kustveiligheid (Master plan coastal safety).

Suzuki, T., De Roo, S., Altomare, C., Zhao, G., Kolokythas, G., Willems, M., Verwaest, T., Mostaert, F., 2016. Toetsing kustveiligheid 2015 - Methodologie: Toetsingsmethodologie voor dijken en duinen (Coastal Safety Assessment 2015 - Methodology: Assessment methodology for dikes and dunes). Versie 10.0. WL Rapporten, 14_014.

Van Rijn, L., 2016. Stability design of coastal structures (seadikes, revetments, breakwaters and groins).

Zimmermann, N., Trouw, K., Wang, L., Mathys, M., Delgado, R., Verwaest, T., 2012. Longshore transport and sedimentation in a navigation channel at Blankenberge (Belgium), in: Proceedings of 33nd International Conference on Coastal Engineering, Santander, Spain, ASCE, vol. 1 [Online]. DOI: 10.9753/icce.v33.sediment.111.