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CREST – CLIMATE RESILIENT COAST
RESEARCH HIGHLIGHTS WITH APPLICATIONS AT THE BELGIAN COAST

BY TINA MERTENS AND JAAK MONBALIU

On 24 September 2019, the IPCC presented the release of their new Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) in Monaco. Although purely by coincidence, the CREST team presented in their final conference on 26 September 2019 in Ostend, the highlights of 4 years of study on the physical system of the Belgian Coast http://crestproject.be/en/crest-final-conference

The Belgian coast is only 67 km long and is to a large extend a managed coast. It has mild sloping sandy beaches, varying from about 1/80 in the western part to nearly 1/20 in the eastern part. The coastal system is interrupted by the outlet of the Yzer estuary, a small river draining the low polder lands, by the access channel to the harbor of Blankenberge and by the break-waters of the harbors of Ostend and Zeebrugge. Also, many groins are present in the hope to keep sand in the section by reducing long shore-transport both by relatively strong tidal currents and by wave induced currents.

To protect the hinterland from flooding, either a dike or a dune system is present. Heavy storms in the past have eroded the dune foot and, in some sections, a hard dune foot protection has been constructed. Since the 1990's a protection policy of "soft if possible, hard if necessary" has been advocated and sand nourishment has been put forward as an effective measure against storm attacks. To ensure coastal safety, the Flemish government invests since 2011 in the implementation of the Master Plan for Coastal Safety.

Despite the fact that sand supply is an old and widely used protection technique, the design and the implementation of an efficient and sustainable nourishment is still a big challenge. Moreover, it is food for a public debate. Recent storms with high surge levels (in particular Xaver in December 2013 and Dieter in 2017) induced sharp and relatively high erosion cliffs and have led to critique in the media of having sand (and money) thrown into the sea.

To improve the knowledge of the Belgian coastal system, researchers from knowledge institutes and private companies with great interest and expertise in physical coastal processes joined forces in 2015 and set up the CREST project.

Figure 1. Sand cliff on a nourished beach after a storm

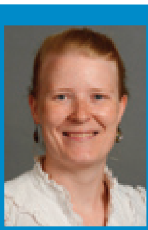
The main scientific objectives of this program included improving the understanding of coastal physical processes, of flood risk and impact, and of coastal resilience on the one hand, and on the other hand the more practical aspects of validating state of the art models with experimental data and defining climate scenarios for the Belgian coast. The most acute knowledge gaps identified in the physical system were: 1) the interaction of hydrody-namics and sediment transport at various spatial and temporal scales, 2) wave overtopping and wave impact forces on sea defenses including the risk for casualties in buildings on the sea dike for the specific case of a shallow sandy foreshore, and 3) the natural resilience of the physical system of the Belgian coast to storm impact.

For the final conference, held on 26 September 2019, the CREST results were summarized in several take home messages and presented to the public along four themes: 1) climate change including morphological evolution on long time scale (decades) for the Belgian coast as a whole; 2) morphodynamics on time scale of days (storms) to years (lifetime of nourishments) for two pilot areas; 3) physical processes and innovation in modelling; and 4) wave-dike inter-action. We illustrate a number of the take home messages below, for the full list and more detail the reader is referred to http://www.crest-project.be/sites/crestproject.be/files/public/CREST_TAKE%20HOME%20MESSAGES_EN.pdf linked from the homepage http://www.crest-project.be/en

THEME 1: Climate change including morphological evolution on long time scale (decades)

During a workshop in December 2018, organized by several stakeholders including CREST, it became quickly clear that *coping with long-term climate change involves many uncer-tainties* (http://crestproject.be/en/imis?module=ref&refid=311027).
A large contribution to the uncertainty regarding climate change is related to the uncertain worldwide climate policy development. Another large contribution to uncertainty is caused by the lack of knowledge on the possibility of rapid ice cliff failures in Antarctica. To support policy development, four climate scenarios for 2100 for the Belgian coast were defined in collaboration with research teams from all Belgian research institutes and universities. Three scenarios are based on IPCC (RCP2.6, RCP4.5, RCP8.5), and one scenario is based on the worst-case assumption of the most rapid failure of land ice, considered remotely possible. For sea level rise the four scenarios for 2100 predict respectively +50 cm, +60 cm, +85 cm and +295 cm rise compared to the 1990 sea level. Depending on the problem to be addressed, the time horizon put forward, the stakes at risk and the stake-holders involved, a balanced decision will have to be made and the appropriate tools will have to be used.

CREST showed that using the wind fields from climate model projections to estimate wave conditions and storm surges in the Southern North Sea, and assuming that the coastal



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Tina Mertens and Jake Monbaliu were the co-ordinators of the CREST project.

bathymetry will not change, extreme wave conditions and storm surges are not expected to change much by 2100. However, they will have a much larger impact because of sea level rise.

The Belgian coast is monitored on a regular basis over more than 30 years. This monitoring consists of two overlapping survey parts: the underwater bathymetric monitoring and the above water topographic monitoring. Together they cover a coastal strip of 1.5 km in width. This dataset was used to study the changes in the cross-shore profile from the sea to the coast. A sand balance was established for the active zone, from the top of the dunes or dikes to the depth of closure. Observed volumetric changes of the active zone were corrected for the sand works that were carried out, namely nourishments and dredging works near the harbors. For the Belgian coast as a whole, the result of this analysis shows a natural sediment supply from off-shore of the same order of magnitude as the artificial supply from nourishments (0,5 Mm^3/year or if it would be evenly spread over the entire length of the coast ~7.5 m^3/m/year). *This natural supply has contributed to the soft coastal defense.* However, this natural feeding is very variable along the coast. In the western and eastern part of the coast a net natural supply is observed, while in the central part of the coast a net loss has taken place. The middle coast has only been able to keep its ability to withstand storms thanks to nourishments. It is not fully clear why there is in total a net gain of sediments (more than supplied by nourishment) in the monitored coastal system. This needs further study to understand the impact on the more offshore coastal system which is characterized by sand banks and tidal gulleys on the sea floor. On decadal time scale the Belgian coastal dunes grow linear in time with a constant rate. Dune growth varies between 0 and 12.3 m^3/m/year with an average dune growth of 6.2 m^3/m/year, featuring large variations in longshore direction.

THEME 2: Morphodynamics on time scale of days (storms) to years (lifetime of nourishments)

During the CREST project several technologies were tested and evaluated to monitor beach morphology and it is clear that *the technology to follow evolutions in beach morphology is available.* Permanent static terrestrial laser scanning (PLS) allow for frequent scans (better than hourly) of the dry and intertidal beach with vertical accuracies better than 2 cm. A mobile LiDAR vehicle with RTK-GNSS in combination with an accurate inertial system (IMU) gives accuracies better than 1 cm at very high spatial resolution. Also, some unmanned aerial vehicle (UAV) photogrammetric surveys were obtained. In combination with traditional airborne LiDAR and ground surveys they can provide a wealth on topographic data to monitor and study beach morphology.
Dune growth is primarily caused by aeolian sediment input from the beach during west to southwest wind conditions (Figure 2). Transport rates depend on humidity and sheltering effects, but potential transports are relatively well quantified by a modified Bagnold type expression. The details of aeolian transport are quite complex, especially in the zones where there are steep cliffs. Such cliffs are typical after a winter storm (Figure 1) and for the chosen beach nourishment configuration of sand storage berms in front of the dyke.

Providing sufficient sand on the beaches not only strengthens the beach itself, but also contributes to strengthening the dunes. The increased replenishment efforts of the past years have realized permanently wider beaches on nourishment locations. Like with all beach nourishments, erosion rates increase initially, yet after a few years return to the long-term average. The wider beaches enhance the coastal safety level, the touristic use and resilience with respect to sea-level rise.
After a storm, our beaches recover at least partially, and this within a period of barely a few months. The storm Dieter in 2017 caused severe erosion and large sand cliffs at several locations along the Belgian coast. It is well known that beaches recover at least partially after storm disruption. This was also observed on a beach with dike section that was monitored more intensively during CREST. Five months later already one third of the eroded volume was recovered.

THEME 3: physical processes and innovation in modelling

Taking fundamental processes better into account is a good basis for understanding and simulating the patterns of coastal sediment transport. Sediment transport modelling in coastal areas remains a challenge, for example because of the variation in sediment characteristics (e.g. sediment size, sediment composition, cohesive properties, consolidation state) and variation in forcing conditions (storm conditions versus calm weather conditions). Many empirical transport formulations exist, each with its own range of applicability. It is believed that the next real step forward should be a better representation of fundamental processes in the sediment transport formulation. One of these processes is the energy dissipation due to sediment motion, which usually is not taken into account in turbulence closure models. During CREST, it has become clear that modeling of the particle-turbulence interaction needs a physics-based turbulence closure to model accurately sediment transport rates (sediment fluxes) in flows with high concentrations typically found close to the bottom.
It became also clearer that the road to efficient and accurate design of the optimized coastal defense systems of tomorrow involves a variety

Figure 2. Aeolian sand transport campaign. On the foreground three Modified Wilson And Cook (MWAC) sand traps are visible. Author: Glenn Strypsteen.

of tools. When dealing with wave overtopping processes such as overtopping volumes or wave forces on structures, there is no optimum model which can deal with the multi-scaled aspects at the same time. In order to provide a solution for real applications, coupling between numerical models can be employed, which enables complex modelling in an efficient and accurate way, taking advantage of the strengths of an individual model while avoiding limitations of the others. For example, the SWASH model can simulate wave transformation in very efficient way while it cannot deal with complex wave-structure interaction. The coupling of DualSPHysics and SWASH allows modelling both the wave transformation and the wave-structure interaction and attains a compromise between results accuracy and computational effort.

The FLIAT (Flood Impact Assessment Tool) model developed under CREST provides a solid basis for hinterland flood risk calculations (Figure 3). The model is cloud based with an object relational approach and allows a more accurate cost-benefit analysis of infrastructure adaptations for flood protection compared to other currently available approaches. It includes special features such as recognition of critical infrastructure and vital functions.

THEME 4: wave-dike interaction

Extensive laboratory tests to study wave impact on beach-dike configurations typical of the Belgian coast have been carried out (Figure 4).

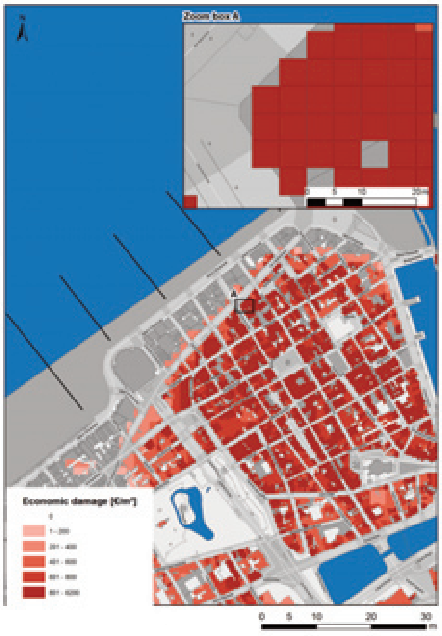

Figure 3. Flood risk calculation using the FLIAT model

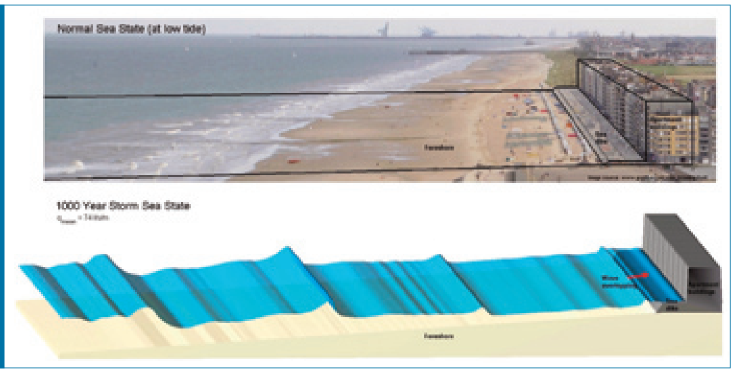

Figure 4. Testing the impact of a 1000-year storm event on a typical beach-dike configuration at the Belgian coast.

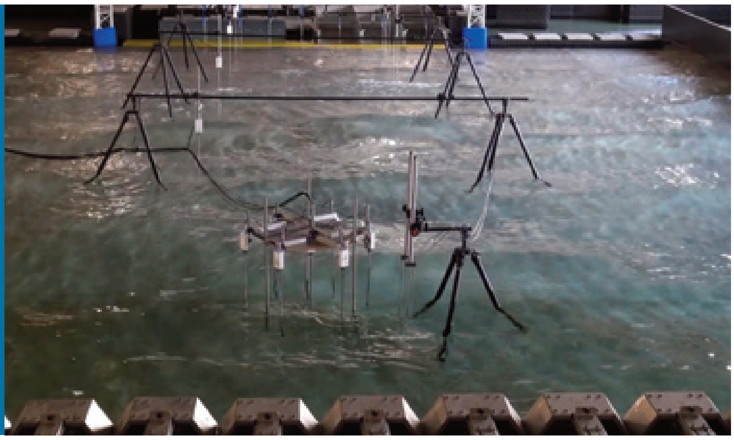

Figure 5. Directionally spread and oblique wave experiment in the wave basin at Flanders Hydraulics Research

In the wave flume of Ghent University (L x W x H: 30.0 m x 1.0 m x 1.2 m) storm conditions have been tested for four different beach slope angles (from mild to steep: i.e. 1/80, 1/50, 1/35 and 1/20) to investigate the effect of the foreshore slope angle and infragravity waves on the response (wave overtopping, wave impact) of sea dikes with very shallow to extremely shallow foreshores. For the same storm conditions a lower wave impact was measured for wider beaches and *it was concluded that wider beaches (lower slopes) reduce the impact of waves on dikes.* Infragravity waves play an important role. More energetic infragravity waves increase the wave impact and this further intensifies with steeper foreshore slope angles.

In the wave basin of Flanders Hydraulics Research (with an effective model area of L x W x H: 20.0 m x 12.0 m x 0.55 m) the effect of directional spreading and oblique wave incidence on wave overtopping and wave impact was tested for several storm conditions (Figure 5). Directional spreading was found to significantly reduce the wave overtopping and impact.

A large-scale experiment performed in the Deltares Delta Flume within the Hydralab+ WALOWA project allowed to investigate scale effects and provide experimental data for the validation of numerical models. Scale effects were found to be negligible compared to the uncertainties related to non-repeatability and model effects. Such large-scale experiments are invaluable for the validation and the inter-model comparison of numerical models. Measurements of flow velocity on the promenade and pressure array and load cell force measurements along the dike mounted vertical wall are currently being compared to output of three numerical models (OpenFOAM, DualSPHysics and SWASH). ■

Reference

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