XBEACH IMPLEMENTATION IN THE NEW NATIONAL COASTAL FLOOD RISK ASSESSMENT FRAMEWORK FOR THE DUTCH COAST

Rinse Wilmink, Rijkswaterstaat WVL – Ministry of Infrastructure and Water management (NL), rinse.wilmink@rws.nl
Robert McCall, Deltares, robert.mccall@deltares.nl
Robbin van Santen, Arcadis, robbin.vansanten@arcadis.com
Niels van Kuik, Rijkswaterstaat WVL – Ministry of Infrastructure and Water management (NL), niels.van.kuik@rws.nl
Stefan Pluis, Rijkswaterstaat WVL – Ministry of Infrastructure and Water management (NL), stefan.pluis@rws.nl
Anouk de Bakker, Deltares, anouk.debakker@deltares.nl
Henk Steetzel, Arcadis, henk.steetzel@arcadis.com

INTRODUCTION

Dunes and beaches protect large stretches of the Dutch coast against flooding from the sea. As prescribed by the Dutch Water Law, the Dutch dune coast is periodically assessed to ensure an acceptable level of flood risk in the hinterland. This safety assessment methodology is currently being renewed within the framework of the BOI program (Assessment and Design Instruments for flood defenses) to utilize the process-based storm impact model XBeach as replacement of the empirical dune erosion model DUROS+. The project consists of six steps: 1. XBeach model formulation improvements and model robustness, 2. XBeach calibration, 3. XBeach validation, 4. derivation of semi-probabilistic model input for the Dutch coast, 5. derivation of a failure definition and 6. implementing XBeach in a renewed flood risk assessment framework (Wilmink et al., 2020).

PROJECT GOALS

The main goal of the project is to increase the accuracy of the flood risk assessment of dunes in the Netherlands by implementing XBeach as dune erosion model and develop a user-friendly GUI and guideline for the assessment framework. Secondly, increase the application range of the assessment framework by including high(er) frequency storms (for coastal maintenance and permitting issues) and more complex coastal areas (such as wide beaches, outer delta's and multiple dune rows). Thirdly, capacity building and knowledge dissemination on coastal flood risk management among asset managers.

XBEACH IMPROVEMENTS AND ROBUSTNESS

This task focused on improving the accuracy and robustness of the XBeach model, while simultaneously reducing the computation time of simulations. As part of this work, improvements were made in the simulation of infragravity waves, as one of the primary drivers of dune erosion in 1D XBeach models under energetic wave conditions. This included the development of guidelines on the application of infragravity wave boundary conditions, and the development of model formulation to greatly improve the simulation of infragravity waves in directionally-spread seas in a 1D model. To remove scaling ambiguity, numerical model parameters that were derived for prototype scales, such as for instance the lower limit of water depth in which Stokes drift is computed, were cast into dimensionless formulations, thereby allowing better validation of the model with laboratory-scale observation. Furthermore, observed differences in sediment size sensitivity between XBeach and other dune erosion models used in the Netherlands (e.g., DUROS+, DurosTA) were used to develop a new grain size sediment transport calibration factor, the value of which was determined using (limitedly available) field validation data. Finally, a grid generation algorithm was developed to minimize the number of computational cells and numerical model parameter settings, including e.g., the morphological acceleration factor, where selected to minimize computation time while maintaining accuracy in the prediction of dune erosion.

XBEACH CALIBRATION AND VALIDATION

Key hydrodynamic and morphodynamic parameters of the XBeach model have been calibrated for dune erosion and breaching using data from large-scale flume experiments. The XBeach model and the calibrated parameter settings were subsequently validated using field data from over 60 cross-shore transects, under varying storm conditions, from 9 different international field cases. An example of a validation result is shown in Figure 1.

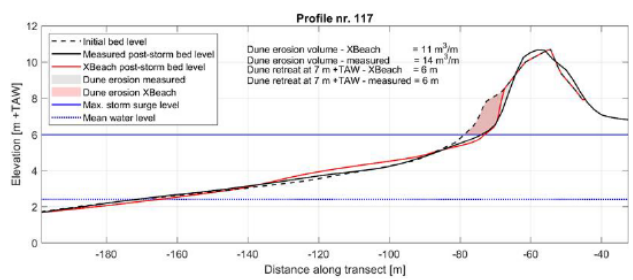

Figure 1 – Example of pre- and post- storm profiles (observed and simulated) of one of the morphodynamic validation cases: dune erosion along the Flemish Coast during the Sint Nicholas storm (2013).

The overall results of the validation in Figure 2 shows that XBeach is able to better reproduce dune erosion in the geographically varying field cases. The relative bias (3%) and spreading/scatter index (24%) are reduced significantly compared to DUROS+ (33% and 92% respectively).

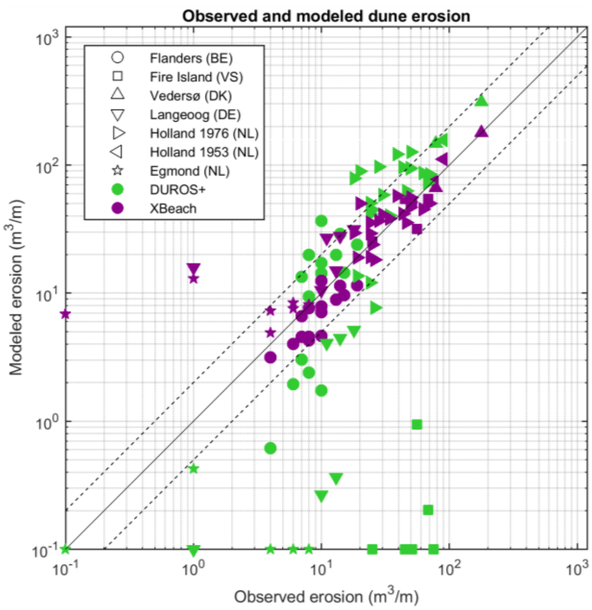

Figure 2 - Results of XBeach validation from seven morphological field datasets compared to the previous DUROS+ model.

DERIVATION OF A SEMI-PROBABILISTIC METHOD

Flood risk assessments in the Netherlands require an estimation of the probability of flooding of the hinterland due to failure of the flood defenses. In case of dunes, the probability of breaching is assessed. The use of XBeach in a fully probabilistic model would however be unfeasible for regular assessments due to the large number of simulations required and subsequent computational effort required. Therefore, a semi-probabilistic method has been derived that approximates the design point of a fully probabilistic analysis, using the result of a deterministic model simulation with calibrated boundary conditions.

DERIVATION OF FAILURE DEFINITION

Dune erosion is the only failure mechanism simulated by XBeach. Though a dune flood defense can still 'fail' the flood risk assessment due to processes that are not modelled by XBeach. A so-called minimum 'limit state profile' has been derived to account for these successive failure mechanisms, which include failure due to short wave overtopping and geotechnical instability of the remaining dune due to water level pressure gradients and groundwater exfiltration. This limit state profile is designed based on nearshore hydraulic conditions. If the limit state profile can be fitted in the remaining dune during the storm surge, the flood defense is considered as 'safe'. In practice, the limit state profile is fitted in the remaining post storm dune (after the XBeach simulation).

SETUP OF FLOOD RISK ASSESSMENT FRAMEWORK

The improved, calibrated and validated XBeach model, in combination with the semi-probabilistic method, forms the basis of the renewed flood risk assessment framework. To facilitate the use of this framework by coastal managers, a new user interface has been developed in the open-access software package MorphAn (Lodder and Van Geer, 2012; Van Geer, 2016). This interface allows for easy pre- and post-processing of data, setup of the XBeach models and analyses of the model results. In addition, guidelines have been developed and interactive workshops organized to support users with the application of the new assessment framework.

IDENTIFIED KNOWLEDGE GAPS

During the project various model formulations and parameter settings had to be derived. For most, a solid scientific solution or validation was found. However, the inclusion of some key processes had to be based on expert judgment with limited validation data available. We list and explain three here:

1. Effect of sediment diameter (D_{50}) on dune erosion volume.

During the project research was done on the sensitivity of simulating dune erosion in XBeach to varying grain sizes. Based on both laboratory and field data, no consistent relation could be found for the effect of (only) grain size on erosion volumes. Neither could a consistent grain size relation be found between other existing dune erosion models (DurosTA, CROSSMOR, DUROS+), where sensitivities to grain size varied between the models according to the profile shape, profile scaling, and hydrodynamic forcing conditions. Therefore, the calibration of the grain size sensitivity in XBeach was carried out using limited data from a subset of the field validation sites with particularly coarse (400 µm) and fine (174 µm) sand.

2. Effect of oblique incident waves on dune erosion.

Den Heijer (2013) and De Winter and Ruessink (2017) found XBeach to predict a greater amount of dune erosion under obliquely incident waves than under shore-normal directed waves, which is contrary to most conceptual models of dune erosion. As this effect is particularly difficult to validate in a laboratory setting, since this would require near-prototype scale simulation in a wave basin that allows for the development of alongshore flow, the validity of the oblique wave effect in XBeach will most likely need to be assessed using large sets of field data collected during energetic wave conditions. Data collected during e.g., the TU Delft RealDune project (Van Wiechen et al., 2022) will likely greatly aid to our understanding of dune erosion processes during oblique wave conditions (link).

3. Validity of infragravity wave formulation at XBeach model boundary.

In the current approach, the theoretical equilibrium bound infragravity wave is imposed as the infragravity wave model boundary condition. These bound waves often dominate the infragravity wave field during storms. The contribution of free infragravity waves is however not considered due to the current lack of knowledge on these waves, but these could have a non-negligible contribution (e.g. Rijnsdorp, Reniers and Zijlema, 2021). The ongoing

REFLEX project (Rutten et al., 2022) could help to shed more light on this process.

In the presentation all steps are elaborated in greater detail, as well as a discussion of the identified scientific knowledge gaps.

CONCLUSION

A new framework for coastal risk assessments for sandy flood defences (dunes) in the Netherlands has been developed, in which XBeach is used as a tool to predict dune erosion during extreme conditions (e.g., up to 1/100.000 year conditions) as well as high(er) frequent storm events (1/10 year conditions). In this project, XBeach has been extensively validated with field data and has become a more robust and user-friendly model. In addition, a failure definition through a 'limit state profile' has been (re)designed to account for failure due to successive failure mechanisms on top of dune erosion. The new tool has an increased accuracy and wider applicability range for coastal flood risk assessments as well as for future design or maintenance of sandy coastal defences.

REFERENCES

Den Heijer (2013): The role of bathymetry, wave obliquity and coastal curvature in dune erosion prediction, PhD Thesis, Delft University of Technology

De Winter and Ruessink (2017): Sensitivity analysis of climate change impacts on dune erosion: case study for the Dutch Holland coast, Climatic Change, vol. 141, pp. 685-701, DOI 10.1007/s10584-017-1922-3

Lodder and Van Geer (2012): MorphAn: A new software tool to assess sandy coasts.

Rijnsdorp, Reniers and Zijlema (2021): Free infragravity waves in the North Sea, Journal of Geophysical Research: Oceans, vol. 126, https://doi.org/10.1029/2021JC017368.

Rutten, Tissier, Zhang, Reniers, Van Wiechen, De Vries, Rijnsdorp, Mol and Wilmink (2022): Cross-shore transformation of bound and free infragravity waves off the Dutch coast, Proceedings ICCE 2022.

Van Geer (2016): Examples of the Software Tool MorphAn Applied in Coastal Management along the Dutch Coast. Coastal Management: Changing coast, changing climate, changing minds, pp. 59-68, ICE Publishing.

Van Wiechen, Rutten, Tissier, De Vries, Mieras, Anarde and Aarninkhof (2022): The effect of wave obliquity on dune erosion: a field experiment, Proceedings ICCE 2022.

Wilmink, McCall, De Bakker, Steetzel and Van Santen (2021): Development of a national coastal flood risk assessment framework for the Dutch coast using XBeach, Proceedings Coastal Dynamics 2021.

ACKOWLEDGEMENTS

This abstract is part of the project Plan for Sandy Coastal Defenses, financed by the Ministry of Infrastructure and Water Management of the Netherlands, STOWA, Rijkswaterstaat and regional water authorities Scheldestromen, Hollandse Delta, Delfland, Rijnland, Hollands Noorderkwartier and Fryslan.