

APPLYING XBEACH ON 7,300 KM COAST: COASTAL CLIFF RETREAT DURING A STORM

[Karl-Søren Geertsen](mailto:kagee@kyst.dk), Danish Coastal Authority, kagee@kyst.dk
Nanna Roland Knudsen, Danish Coastal Authority, narkn@kyst.dk
Per Sørensen, Danish Coastal Authority, PSo@kyst.dk

MOTIVATION

Denmark is surrounded by more than 7,300 km soft coastline considered at high risk of storm erosion. The presence of more than 13,000 groins, shore parallel breakwaters and revetments clarify the need of protecting infrastructure and property against coastal erosion in a changing climate. The Danish Coastal Authority is responsible for carrying out a national risk assessment evaluating the risk level of storm erosion today, and in 2070 and 2120.

This abstract focusses on the methodology for the calibration and validation of the numerical model Xbeach for calculating cliff retreat during storms using measured storm data. It is of highest priority to set up a model, which can perform on a national scale. In this work, it is shown that a single model setup is able to estimate the cliff retreat for all types of Danish coasts in both a 1D and 2D model approach.

METHODOLOGY

The risk of storm erosion is defined by the product of the probability of a retreat (in meters) of a coastal cliff during one storm and the value of the assets lost from the retreat. The retreat of sandy cliffs in Denmark is estimated by applying the Open Source Software XBeach. The retreat of moraine cliffs in Denmark has previously been studied by Frederiksen (2018) contributing to common literature on the subject by Halcrow (2007) and Earkie et. al (2014). In conclusion, moraine cliffs do not erode during single storm events, hence they are neglected in this project.

The wave phase averaged XBeach Surfbeat model is chosen for this project. The hydrodynamic input for XBeach constitutes of hindcast storm data from 60 hydrographic locations in the Danish waters from 1995 to 2017 (DHI, 2019a) from a coupled hydrodynamic and spectral wave model (DHI, 2019b). Based on the highest peak water levels, the five severest storms are selected. Water levels are adjusted so the peak matches the water level of a 50-, 100-, 500-, 1,000-, 5,000- and 10,000-year return period. Corresponding waves are not adjusted. The wave input data is converted to jonswap spectra comprising hourly sea states. The storm duration is set to 48 hours prior to and after the peak water level with a temporal resolution of 1 hour. The storm causing the largest cliff retreat is chosen. Effects of climate change is calculated by adding sea level rise from a 50- and 100-year climate scenario, respectively.

The pathway is constructed by combining a terrain model and a bathymetric model. The 1D XBeach model grid is gradually refined towards the coast with maximum cell size of 100 m and minimum cell size of 1 m. In this 1D model approach, all types of coastal protection measures are neglected.

1D MODEL CALIBRATION

Due to a strict project time plan, a less computationally demanding 1D setup is selected since only cross-shore sediment transport is considered. The XBeach model is calibrated at Vedersøe, exposed to the North Sea, to a severe storm measured in January 2005. Model parameters were analyzed in order to find the best model calibration results. Based on these analyses, the most applicable values of the investigated parameters were $\gamma = 0.55$, $D50 = 0.0004$ m, $\text{morfac} = 5$, $\text{dryslp} = 0.8$ and $\text{facua} = 0.3$.

The model is subsequently validated with historic storm data at four other coasts (Table 2). In total, the model is validated using seven different coastal profiles.

Table 1 - Overview of model cases and storm data

LOCATION	STORM
Vedersøe (west facing coast)	Jan - 2005
Havstokken (north facing coast)	Dec - 2013
Heatherhill (north facing coast)	Dec - 2013
Gedesby (east facing coast)	Jan - 2017

1D VALIDATION RESULTS

The calculated coastal cliff retreat rates and the measured retreat after a storm are shown in table 2 for all calibration and validation cases. Vedersøe 01 is the calibration run.

Table 2 - Measured and modeled cliff retreat [m].

LOCATION	MEASURED	MODELED
Vedersøe 01, high exposure	14	15
Vedersøe 02, high exposure	4	2
Heatherhill, medium exposure	0	1
Havstokken, medium exposure	8	8
Gedesby 01, low exposure	2	0
Gedesby 02, low exposure	2	1
Gedesby 03, low exposure	0	1
Gedesby 04, low exposure	3	1

2D MODEL EXTENSION

To further test the robustness of XBeach, an extension of the calibrated 1D model to a 2D model is conducted. The 2D model setup is tested on Vedersøe 1-2 and Gedesby 1-4 with same model parameters as found in the 1D-calibration study. In total, the 2D model setup is tested on six different coastal profiles.

The 2D model grid is refined gradually towards the coast with maximum cell size (100 m x 2 m) and minimum cell size (2 m x 2 m). The model domain is extended in both directions along the coastline to mitigate boundary effects close to the measured coastal profiles.

The 2D setup is constructed in the same way as in 1D,

where the topography and bathymetry used in the models are generated from lines of physical measurements just before the storm. The model results are compared to physical measurements after the storm event. The hydrodynamic and hydraulic input data are the same as those used in the calibration of the 1D model.

2D MODEL VALIDATION RESULTS

The physically measured coastal profiles before and after a storm event is presented in figure 1 and 2. The model results from 1D from the Gedesby and Vedersoe model cases respectively are plotted, along with the 2D modeled coastal profiles at the same locations.

CONCLUSION

This work showed that XBeach is capable of estimating the retreat of sandy cliffs during a storm for at least four different types of beaches using the same model parameters. This finding demonstrates the validity of applying XBeach as a numerical tool to estimate storm erosion on a national scale.

By extending the calibrated 1D model to a 2D model, it is found that the 2D model with the same model parameters predicts the cliff retreat as accurate as the 1D model. However, for some of the profiles, the 2D model delivered a better estimate of the cliff retreat. This important result will not only improve the cliff retreat estimates in future Danish risk assessments of storm erosion, but also add to the level of detail in calculating storm erosion in Denmark.

It is of greatest interest to apply the calibrated and validated model setup to investigate potential correlations between hydraulic, hydrodynamic, morphological input data and the corresponding dune retreat during a storm. To pose a dune safety equation as an analytical tool to continuously update the safety criteria for Danish dunes to withstand future climate scenarios is tremendously valuable.

ACKNOWLEDGMENT

This work has partly been carried out as a part of the Interreg V project Building with Nature (BwN).

REFERENCES

Halcrow group limited (2007): Risk assessment of coastal erosion, report made for Environment agency and Defra.
 Oumeraci, Kortenhaus, Schürenkamp (2012): Reliability assessment of Falster dike in Denmark. Report for Danish Coastal Authority.
 Earlie, Young, Masselink, Russel (2014): Coastal cliff ground motions and response to extreme storm waves, AGU publications.
 Frederiksen (2018): Undersøgelse af skrænterosion vha orthofotos, Internal report, Danish Coastal Authority.
 DHI (2019a): Wave and water level hindcast of Danish Waters, Spectral wave and hydrodynamic modelling, Setup, calibration and validation, report for Danish Coastal Authority
 DHI (2019b): Metocean Data of Danish Waters for Risk Analyses, report for Danish Coastal Authority

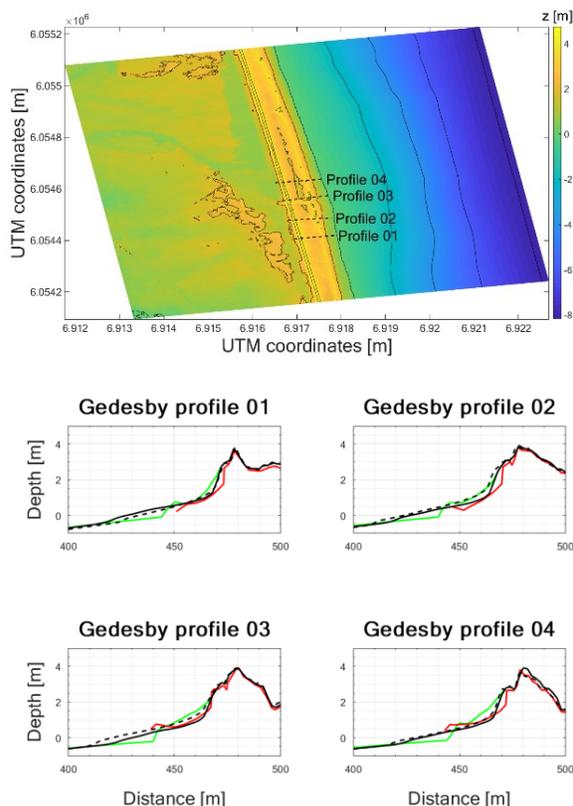


Figure 1 - 1D and 2D model validation results at Gedesby. Above: Location of Gedesby profiles. Below: Profile graphs of Gedesby profiles. Green: Before the storm. Red: Measured profile after the storm. Dashed black: 1D model result. Filled black: 2D model result.

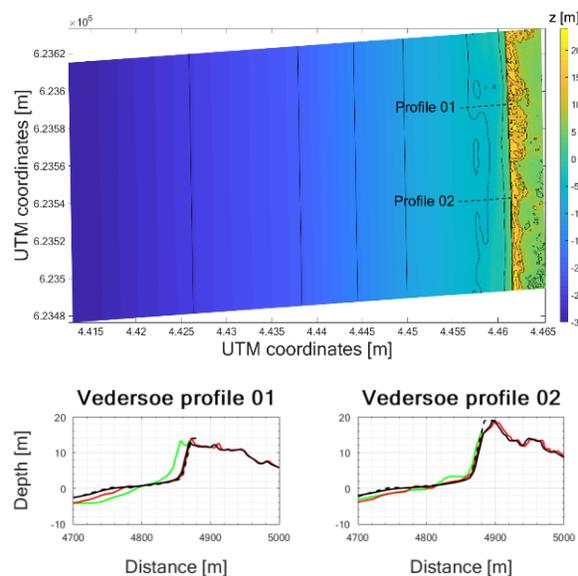


Figure 2 - 1D and 2D model validation results at Vedersoe. Above: Location of Vedersoe profiles. Below: Profile graphs of Vedersoe profiles. Green: Before the storm. Red: Measured profile after the storm. Dashed black: 1D model result. Filled black: 2D model result.