

# STORM IMPACT ON BEACH NOURISHMENT MORPHOLOGY IN A SHALLOW BAY

Anna Adell, Lund University & University of Copenhagen, [anna.adell@tvrl.lth.se](mailto:anna.adell@tvrl.lth.se)  
Gregor Luetzenburg, Geological Survey of Denmark, and Greenland, [grelu@geus.dk](mailto:grelu@geus.dk)  
Aart Kroon, University of Copenhagen, [ak@ign.ku.dk](mailto:ak@ign.ku.dk)  
Björn Almström, Lund University, [bjorn.almstrom@tvrl.lth.se](mailto:bjorn.almstrom@tvrl.lth.se),  
Caroline Hallin, Lund University, [caroline.hallin@tvrl.lth.se](mailto:caroline.hallin@tvrl.lth.se)

## INTRODUCTION

Designing coastal protection solutions that combines hard and soft techniques can be an appropriate measure to reduce wave impact on structures (Steetzel et al., 2017). The elevated bed level in front of the hard protection dissipates energy and thereby limits wave runoff and overtopping. This can increase the expected lifetime of the protection while also limiting the design dimensions and hence be a cost-effective alternative. In addition, the implementation of soft coastal protection measures in combination with hard structures can provide possible additional recreational and environmental functions.

The coastal area of Faxe Ladeplads in Zealand, Denmark is flood-prone during extreme events. The coastal stretch down drift the harbour is also subject to lee-side erosion. A beach nourishment was conducted in front of the rock revetment with the objectives to reduce wave overtopping onto the adjacent road and to restore the beach for recreation (Baden & Aarosiin-Hansen, 2017).

In the study area, the highest 10% of waves are responsible for 40-50% of the annual wave energy flux that arrives to the shore. This implies that the energy is concentrated in to only a few events per year. Therefore, it is important to understand the nature of morphological change driven by energetic events. Field measurements and observations, combined with numerical modelling has been conducted with the aim to monitor the morphological evolution of the nourishment and adjacent coastlines in order to assess the performance of the protection.

## METHOD & DATASETS

Field data collection was conducted at the site in Faxe Ladeplads, Denmark, during the period 2021-2023 and comprise both morphological profile surveys and hydrodynamic observations.



Figure 1: Map showing the field site and profile locations, the green area represents the placement of the nourishment.

A combination of RTK-GPS and single beam surveys were conducted to obtain comprehensive topographic and bathymetric assessment. The RTK-GPS technique covers the beach and shallow water depths until -1 m. Single beam profiles extended offshore approximately to -4 m depth and were collected with an echo sounder system from a zodiac boat. The map in Figure 1 shows the placement of the survey profiles A and B and the in-situ measurement equipment along with the depth contour lines. The most recent nourishment was performed 6 months prior to the first survey date and approximately 35 m<sup>3</sup>/m was supplied in profile A. Figure 2 shows the coastal protection under normal and extreme conditions.



Figure 2: Pre- and post-storm conditions showing the impact along the nourished stretch of coast. Photo: Anna Adell and Klaus Roenholt.

Water level observations are available from a tide gauge operated by the Danish Meteorological Institute (DMI) at a nearby harbor in Rødvig. Waves were measured using a surface acceleration buoy deployed at 7 m depth, and in the case of data gaps it is complemented with hindcast data from a regional wave model by Adell, et al, (2023).

## RESULTS

Figure 3 shows the hydrodynamic conditions during one selected survey period. Table 1 presents the conditions at the storm peak during the maximum observed conditions between two survey dates, recorded at the wave buoy at 7 m.

Table 1: Conditions during storm peak, 2021-12-27 12:00.

Max $H_s$ (m)	$T_p$ (s)	Direction (°N)	Water level (cm)
1.46	5.9	130	40

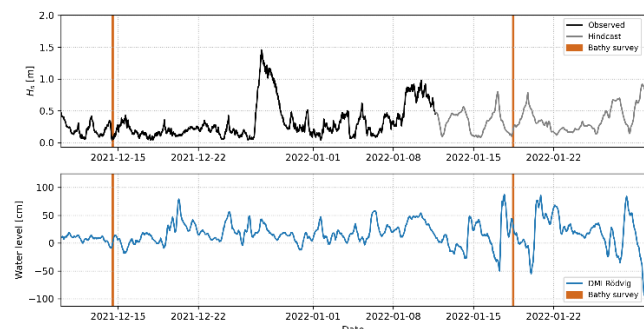


Figure 3: Hydrodynamic conditions during one survey period, Dec 2021 - Jan 2022.

Assessment of the profile records shows that the profile configuration differs over a relatively short longshore distance. Profile A displays a flat appearance where the slope between the 3- and 5 m contour is 0.0017 (1/600). The morphological response observed for profile A (Fig. 4 a & b) is represented by a formation of a beach berm and steepening of the foreshore slope, from 0.05 to 0.11. This is noticed as onshore deposition of material with elevation changes of maximum +0.35 m and -0.26 m around the mean water line.

Profile B has a distinct subaqueous platform at -3 m followed by a steeper slope of 0.0033 (1/300) down to the -5 m depth contour. Profile B experienced dominating subaqueous changes (Fig. 4 c & d) indicating a slightly different morphological response compared to A. Changes include reworking of the slip-face of the swash bar at depth -0.2 m, causing the profile to flatten in the process. Onshore bar migration is also observed, registered as elevation change of +0.4 m and -0.4 m at depth -2.5 m which corresponds well with the average depth of closure (DoC) during the storm event, calculated according to the definition by Hallemeier (1980).

Overall profile B shows more erosion in the deeper part. This is likely because the profile configuration for profile B has a steep slope and more rapid shift down to the deeper platform at -5.5 m. This would give less wave dissipation over the profile compared to profile A that has a milder slope and thereby experience more wave dissipation.

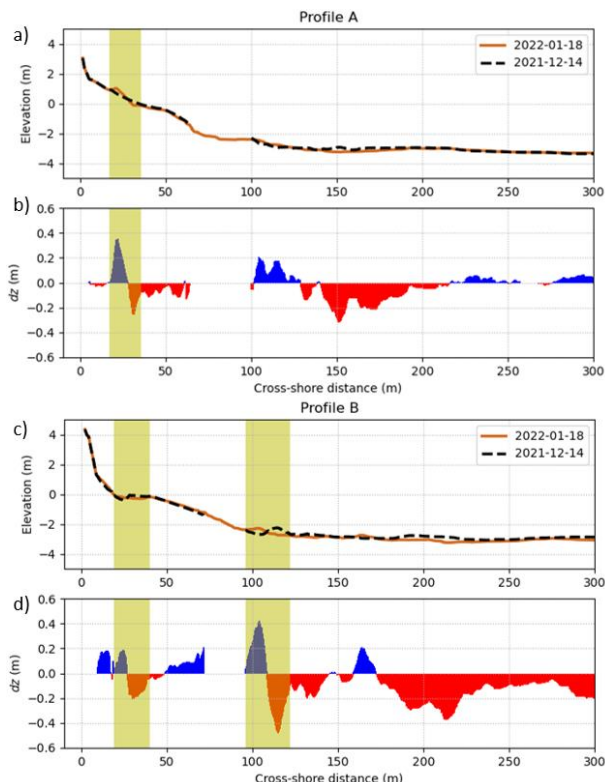


Figure 4: Morphological evolution and corresponding elevation change,  $dz$ , for profile A (a, b) and profile B (c, d).

## OUTLOOK

On October 20<sup>th</sup>, 2023, the area suffered the most extreme storm conditions in over 100 years, with a combination of extreme water levels (+169 cm) and strong easterly winds. Figure 2 shows the storm impact along a section of the coast, where the beach plane was eroded and deposited in a storm bar, giving elevation changes of about 1.5 m. In addition, part of the sea wall collapsed. This signal in the dataset is several orders of magnitude greater than the changes observed during moderate storm conditions discussed previously. Future work will focus on analyzing the coastal protection under extreme conditions.

## REFERENCES

- Adell, Almström, Kroon, Larson, Bertacchi-Uvo, & Hallin. (2023). Spatial and temporal wave climate variability along the south coast of Sweden during 1959-2021. *Regional Studies in Marine Science*, (63)
- Baden & Aarosiin-Hansen. (2017). Beach Restoration and Erosion Protection on the Inner Danish Coasts - A Case Study. *Coastal Dynamics*, (237).
- Hallermeier. (1980). A profile zonation for seasonal sand beaches from wave climate. *Coast. Eng.* 4 (C), 253-277
- Steetzel, van der Goot, Fiselier, de Lange, Penning, van Santen, & Vuik. (2017). Building with nature pilot sand foreshore Houtribdijk design and behaviour of a sandy dike defence in a lake system. *Coastal Dynamics*, (063).