PREDICTING 3D INTERACTIONS BETWEEN OFFSHORE ACTIVITIES AND SAND WAVE RECOVERY

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INTRODUCTION

The pressure on the offshore area is increasing rapidly, especially due to a need for green energy sources. These offshore developments, such as windfarms, require detailed predictions of future bed levels. However, dynamic bed forms, such as sand waves, complicate these predictions and threaten offshore constructions. Sand waves can grow up to 25% of the water depth, have wavelengths in the order of hundreds of meters and can migrate up to tens of meters per year. Extensive sand wave fields are found in among others the North Sea, Taiwan Strait, Irish Sea and Mediterranean Sea, and are especially present in shallow regions which are attractive for offshore developments. Understanding has been gained about the dynamics of these sand wave fields mainly through data analyses. However, data is often scarce, especially for cases where human interventions have taken place. Numerical models can give insight into the natural dynamics of the system as well as the interactions with our offshore activities. In this way we can improve our future bed level predictions and quantify uncertainties, due to, for example, extreme events. This will lead to more sustainable, cost-effective and safer designs of human interventions in sand wave fields.

In recent years, numerical models have greatly contributed to our knowledge about the sand wave system. We can now better explain their presence and absence and are unravelling the processes leading to their dynamics, such as non-tidal hydrodynamic forcing (Overes et al., 2023a). However, when human interventions take place, the system gets remarkably more complicated. Observations show that while some sand waves recover after dredging, others do not show any regrowth in the following years (see Krabbendam et al., 2022). Moreover, sand waves can grow back in different shapes or directions (see Larsen er al., 2020 and Figure 1), and recovery rates and shapes can vary greatly over small areas (Orsted, 2018). A number of processes, such as seasonal effects, remaining water depth and sediment availability, have been mentioned as possible causes for these differences in system response. However, up to now these possible causes remain speculations. Not enough data is available to carry out a proper statistical analysis, while offshore developments rely on empirical knowledge for predicting future bed levels after interventions. Using numerical models, more insight can be gained into the interactions between sand wave fields and human interventions. The goal of this study thus entails 1) to understand the dynamics behind sand wave recovery after interventions and 2) to predict future bed levels after interventions. This will be done through a case study in the Delft3D Flexible Mesh (FM) numerical model.

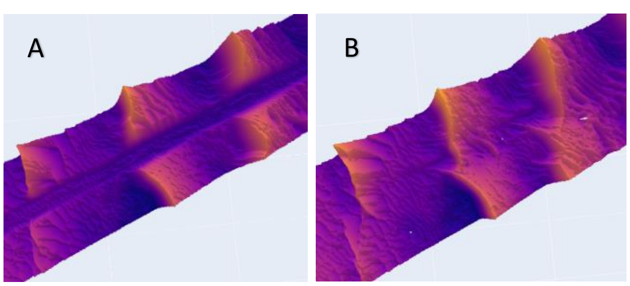

Figure 1 – Observed sand wave recovery after dredging at a location along the Nemo Link cable connection, in a 3D data view (colors indicate bed level, from purple (lowest) to yellow (highest)). Observations from measurements taken A) just after dredging of trench in April 2018 and B) in July 2021, 3 years after dredging.

METHODS

To capture the intricate interactions between sand wave fields and human interventions, high-resolution 3D morphodynamic models are necessary. The sand waves cause vertical variation in the flow and the interventions and possible 3D variations in the sand wave field (see Overes et al., 2023b) raise a need for 3D models. Using the newly developed Delft3D FM model, we are able to efficiently compute 3D hydrodynamics and sediment transport processes. New developments such as parallel computing and a dynamic timestep have greatly decreased runtimes. Combined with morphological scaling, trench fill-in in the years following the intervention can be simulated in a matter of days.

A case study is set up at a location in the North Sea, where a trench was dug to allow the installation of the Nemo Link electricity connection between Belgium and the United Kingdom. The two available measurement datasets, taken in 2018, right after installation and several years later in 2021 (see Figure 1), allowed for validation of the model results. The hydrodynamic forcing is based on the regional 3D Dutch Continental Shelf Model (DCSM) and contains tidal forcing, which is driving sand wave growth. The hydrodynamics are transferred to a local model using advection boundaries, which impose both water levels and velocities at inflow boundaries, while changing to Neumann type at outflow boundaries.

RESULTS

The first ever 3D sand wave field model including human intervention, which was set up for this study, showed the skill of the model in reproducing the processes leading to sand wave recovery. The model was well able to reproduce the tidal hydrodynamics in the area of interest. Even though there was only a 15° difference between the main current and the trench direction, the reversing tidal current was transporting sediment into the trench from both sides, due to its steep slopes (approximately 11°). This bed slope effect was computed using the Bagnold bed slope corrections and the related parameters for transverse and longitudinal slopes (α_{bn} and α_{bs} respectively) are vital to reproduce the infilling of the trench.

The model showed sand wave regrowth within the trench, as was observed in the measurements (see Figure 2). A sediment budget analysis was carried out to estimate the infill rate within the trench. The measurements show a total negative sediment budget, which represents an average lowering of around 0.12 m. Since no sediment is extracted from the model, it is not able to reproduce this average lowering of the seabed. A distinction is made between the area within the trench (indicated by the solid lines in Figure 2) and the area to the North and South of the trench. The modelled sediment infill in the trench is slightly underestimated (Table 1). Since slightly less sediment is transported into the trench, and the overall sediment loss is missing, the associated bed lowering North and South of the trench is underestimated in the model. However, correcting for the measured average lowering will improve the results significantly. Overall, the modelled sediment budgets show a good match with the measured sediment budgets.

Table 1 – Measured and modelled average elevation difference in model domain between 2018 and 2021, inside the trench and to the North and South outside the trench.

	North	Trench	South
Measured	-0.23 m	+0.80 m	-0.33 m
Modelled	-0.10 m	+0.65 m	-0.14 m

By excluding transverse bed slope effects the balance between sideways and direct infilling could be determined. While sideways filling was supplying most sediment into the trench, the sand waves would still regrow without this process. The tidal current is directly supplying sediment into the trench due to the small difference between the direction of the trench and the main tidal axis, combined with tidal ellipticity. Part of the sand wave growth can also be attributed to redistribution of the available sediment within the trench. When less sediment was supplied to the trench the sand wave trough level reached levels beneath the original trench level, potentially endangering the installed cable.

CONCLUSIONS

In this study we have shown the skill of the Delft3D FM model in reproducing the response of a sand wave field to dredging of a cable trench. The slight underestimation of the infill rate could be explained by the lack of non-tidal hydrodynamic forcing, such as storms, which drive high sediment transport rates over short periods of time (Overes et al., 2023a). When including also non-tidal forcing, specific storm event can be simulated, to estimate the fill-in in periods when work must be suspended due to adverse weather conditions. Using these local process-based simulations, engineering questions such as: 'how long does a trench stay open for further construction?' and 'will the system provide a natural sand cover to ensure safety of the cable?' can be answered and the dependence on empirical knowledge from different environments can be reduced. Designs of human interventions can then be adapted to better fit the environment in which they are installed. This will provide valuable insights for the challenges that lie ahead with the further development of the offshore area.

REFERENCES

Krabbendam, J. M., Roche, M., Van Lancker, V. R., Nnafie, A., Terseleer, N., Degrendele, K., & De Swart, H. E. (2022): Do tidal sand waves always regenerate after dredging?. Marine Geology, 451, 106866.

Larsen, S. M., Roulund, A., & Mcintyre, D. L. (2020): Regeneration of partially dredged sandwaves. Coastal Sediments 2019: Proceedings of the 9th International Conference, pp. 3026-3039.

Orsted (2018): Hornsea Project Three, Offshore Wind Farm, Sandwave Clearance Classification Note

Overes, P.H.P., Borsje, B.W., Luijendijk, A.P., Hulscher, S.J.M.H. (2023a). The importance of time-varying, non-tidal currents in modelling in-situ sand wave dynamics. Manuscript submitted for publication.

Overes, P.H.P., Borsje, B.W., Luijendijk, A.P., Dobrochinski, J. Hulscher, S.J.M.H. (2023b). UNDERSTANDING 3D SAND WAVE DYNAMICS FOR ENGINEERING PURPOSES. Coastal Engineering Proceedings, (37).

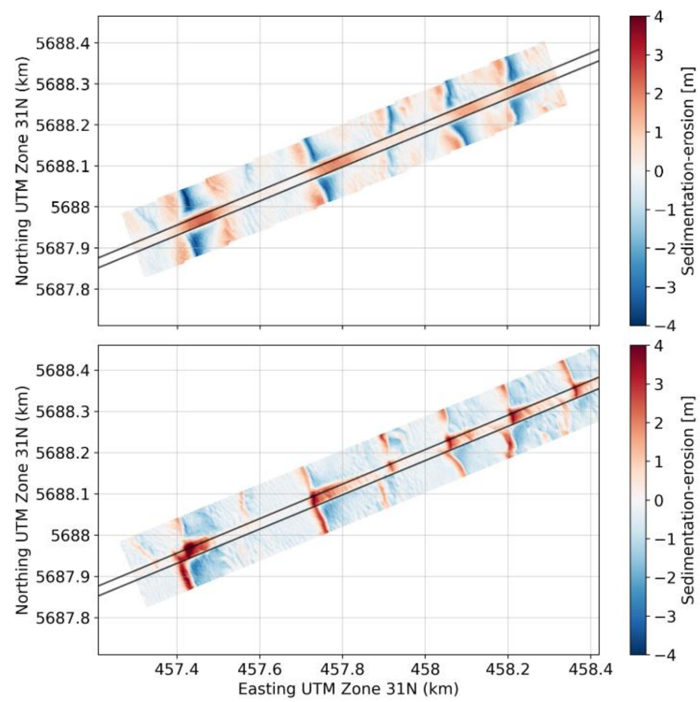

Figure 2 – Simulated (upper) and measured (lower) sand wave field recovery after dredging, between April 2018 and July 2021. Black solid lines show location of the trench, used for sediment budget analysis.