Development of a Saltwater-Wave-Current-Flume with Holding Tank and Water Treatment Plant

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MOTIVATION

With the ever-increasing demand for renewable energy sources, the significance of both cost-efficiency and lifetime assessment of offshore wind energy plants has been growing substantially (Zhang et al., 2013; Ziegler and Muskulus, 2016). This necessitates the development of more precise design guidelines (Haselibozchaloee et al., 2022). The support structure of an offshore wind turbine marks a key part by accommodating aero- and hydrodynamic loads. During structural design, the evaluation of hydrodynamic loads relies mostly on simplified analytical methodologies such as the MOJS equation (Morison et al., 1950). The involved drag and inertia coefficients are determined based on considerations such as flow regime and roughness. These determinations often stem from rudimentary experimental investigations in small- to mid-scale test facilities prone to scale effects (Jusoh and Wolfram, 1996; Tian et al., 2020).

Moreover, the initially smooth steel support structures undergo a significant roughness transition when immersed in saltwater, primarily due to the colonization of marine growth (Karlsson et al., 2022). Due to the significant impact of these load coefficients and the existing superficial understanding of wave-current-vegetation-interaction, enhanced experimental methods to investigate marine growth in realistic scenarios are urgently needed. However, large experimental facilities with the ability to control aquatic parameters are still not available.

To address this critical requirement, a Saltwater-Wave-Current-Flume (SWCF) has been meticulously planned and constructed. This cutting-edge facility enables investigations with live marine organisms by ensuring vital aquatic parameters within a controlled hydraulic experimental setting. **Therefore, this study focusses on the development of the SWCF and the required field methodology to initiate the settlement of marine growth in field studies and compare those with realistic artificial roughness in the SWCF. Thus, the methodologies for artificial roughness and real marine growth can be compared to improve experimental methodologies when investigating wave-current-vegetation-interaction.**

SALTWATER-WAVE-CURRENT-FLUME

The SWCF is designed and constructed at the Leichtweiß-Institute for Hydraulic Engineering and Water Resources of the TU Braunschweig. Characterized by its dimensions measuring 35.0 m in length, 3.0 m in width, and 2.5 m in depth, the flume features an investigation section extending over 14 m (cf. Fig. 1).

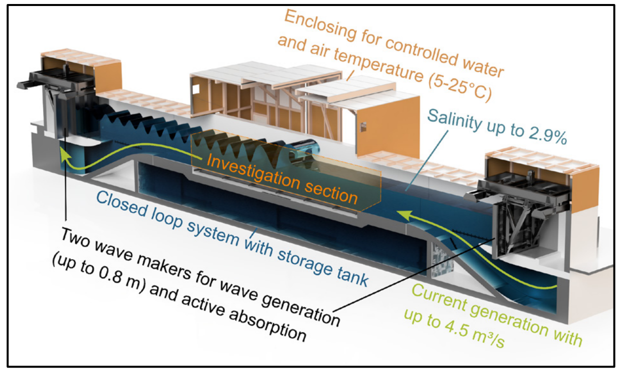

Figure 1 – Visualization of the SWCF and its main hydraulic characteristics.

Furthermore, the generation and active absorption of waves are accomplished by two opposing wave makers with wave heights of up to 0.8 m. Using two identical wave makers on both sides of the flume allows to generate and absorb waves in both directions and therefore investigate interactions of waves with opposing or following currents.

A unique feature of the SWCF is the water treatment plant, which enables the provision of ideal environmental conditions for marine growth within the flume and the holding tank (cf. Fig. 2).

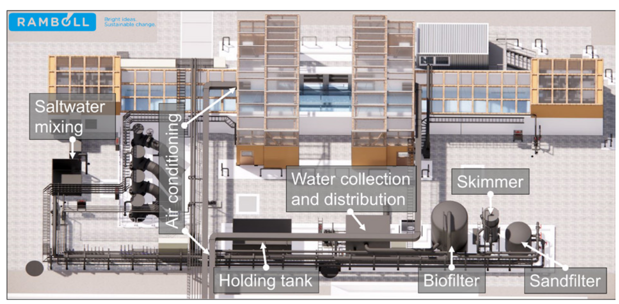

Figure 2 – Visualization of the water treatment plant for the SWCF.

The salinity levels can be controlled and set between 0.5% and 2.9% in the entire facility. Water treatment is conducted through a closed system equipped with a three-stage filter system consisting of a sandfilter, biofilter, and a skimmer with ozone treatment. This enables to control pH, O_2 and CO_2 values as well as temperatures within the range of 5 to 25°C to meet the requirements for marine growth such as blue mussels (*M. Edulis*). The SWCF is equipped with an enclosure and air conditioning system to maintain humidity levels below 60% and adjust the ambient temperature.

FIELD METHODOLOGY

Since the new opportunities of the SWCF will facilitate to introduce test specimens covered with marine growth into the flume, several cylindrical specimens with diameters of 0.10, 0.20 and 0.30 m are deployed in Wilhelmshaven and Helgoland (North Sea) for time periods between several months up to two years. Therefore, a field concept was established for surveying marine biofouling in Isbert et al. (2023). By regular inspection and photogrammetric data collection, the roughness parameters of various states of living marine biofouling can be tracked.

Photogrammetrically collected intermediate states of marine biofouling on test specimens were used to characterize roughness parameters such as roughness length, the material ratio also termed as Abbott-Firestone Curve as well as the frontal solidity (Chung et al., 2021). Subsequently, different methods of physical modeling were employed to replicate the roughness parameters on vertical cylinders, analogous to monopiles. Both simple techniques, such as using sandpaper (comparable to studies by Henry et al., 2016; Tian et al., 2020), and advanced surrogate modeling methods (Landmann et al., 2019; Marty et al., 2021) by resin-based 3D printing were used to model the roughness of marine biofouling. In this regard, Fig. 3 provides a visual impression of the observed roughness due to marine biofouling, the idealized replication by Computer Aided Design and the resin-printed roughness models.

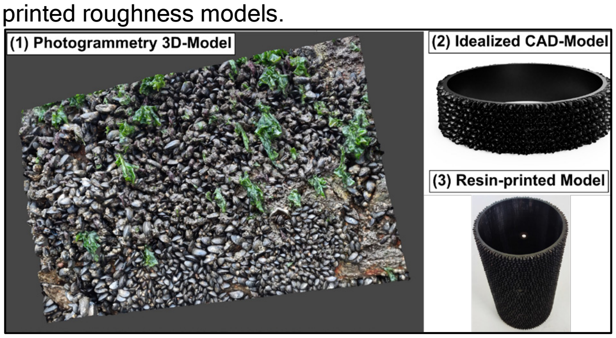

Figure 3 – Photogrammetry of marine biofouling (1), the derived CAD-model (2) and the 3D-printed model (3).

CONCLUSIONS

In response to the growing need for renewable energy, a cutting-edge SWCF is developed and under construction. First experiments within this facility will be conducted in early 2024 and entail a comparison of idealized roughness models employing materials such as sandpaper, carpet and surrogate models by means of 3D-printing methods to be compared with live marine growth. To advance experimental methodologies, modelling techniques for marine growth are reviewed and fed with information from regular photogrammetric recordings to document intermediate states of marine growth settlement.

The SWCF, located at the Leichtweiß-Institute for Hydraulic Engineering and Water Resources, offers a unique facility to conduct experiments involving wave as well as current loads combined with live marine organisms. Improving experimental methodologies of wave-current-vegetation-interaction are essential to understand the impact of e.g. marine growth on offshore wind support structures.

REFERENCES

Chung, D., Hutchins, N., Schultz, M.P., Flack, K.A., 2021. Predicting the Drag of Rough Surfaces. Annu. Rev. Fluid Mech. 53 (1), 439–471. doi:10.1146/annurev-fluid-062520-115127.

Haselibozchaloee, D., Correia, J., Mendes, P., Jesus, A. de, Berto, F., 2022. A review of fatigue damage assessment in offshore wind turbine support structure. International Journal of Fatigue 164, 107145. doi:10.1016/j.ijfatigue.2022.107145.

Henry, P.-Y., Nedrebø, E.L., Myrhaug, D., 2016. Visualisation of the effect of different types of marine growth on cylinders' wake structure in low Re steady flows. Ocean Engineering 115, 182-188. doi:10.1016/j.oceaneng.2016.02.023.

Isbert, W., Lindemann, C., Lemburg, J., Littmann, M., Tegethoff, K., Goseberg, N., Durst, S., Schürenkamp, D., Buck, B.H., 2023. A conceptual basis for surveying fouling communities at exposed and protected sites at sea: Feasible designs with exchangeable test bodies for in-situ biofouling collection. Applied Ocean Research 136, 103572. doi:10.1016/j.apor.2023.103572.

Jusoh, I., Wolfram, J., 1996. Effects of Marine Growth and Hydrodynamic Loading on Offshore Structures.

Karlsson, R., Tivefälth, M., Duranović, I., Martinsson, S., Kjølhamar, A., Murvoll, K.M., 2022. Artificial hard-substrate colonisation in the offshore Hywind Scotland Pilot Park. Wind Energ. Sci. 7 (2), 801-814. doi:10.5194/wes-7-801-2022.

Landmann, J., Ongsiek, T., Goseberg, N., Heasman, K., Buck, B., Paffenholz, J.-A., Hildebrandt, A., 2019. Physical Modelling of Blue Mussel Dropper Lines for the Development of Surrogates and Hydrodynamic Coefficients. JMSE 7 (3), 65. doi:10.3390/jmse7030065.

Marty, A., Schoefs, F., Soulard, T., Berhault, C., Facq, J.-V., Gaurier, B., Germain, G., 2021. Effect of Roughness of Mussels on Cylinder Forces from a Realistic Shape Modelling. JMSE 9 (6), 598. doi:10.3390/jmse9060598.

Morison, J.R., Johnson, J.W., Schaaf, S.A., 1950. The Force Exerted by Surface Waves on Piles. Petroleum Transations (AIME), 149-154.

Schanz, D., Gesemann, S., Schröder, A., 2016. Shake-The-Box: Lagrangian particle tracking at high particle image densities. Exp Fluids 57 (5). doi:10.1007/s00348-016-2157-1.

Tian, X., Li, D., Liu, G., Xie, Y., Deng, W., Xie, D., 2020. Experimental study on the hydrodynamic characteristics of cylinder with rough surface. J Mar Sci Technol 25 (3), 842-848. doi:10.1007/s00773-019-00684-7.

Zhang, Z., Chen, A., Matveev, A., Nilssen, R., Nysveen, A., 2013. High-power Generators for Offshore Wind Turbines. Energy Procedia 35, 52-61. doi:10.1016/j.egypro.2013.07.158.

Ziegler, L., Muskulus, M., 2016. Fatigue reassessment for lifetime extension of offshore wind monopile substructures. J. Phys.: Conf. Ser. 753, 92010. doi:10.1088/1742-6596/753/9/092010.