FROM GWK TO GWK+: EXTENSION OF THE LARGE WAVE FLUME TO A UNIQUE EXPERIMENTAL FACILITY FOR OFFSHORE AND COASTAL ENGINEERING RESEARCH

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INTRODUCTION

The Large Wave Flume (GWK) of the Coastal Research Centre, Germany, has been a well-known and extensively used experimental facility for coastal and offshore engineering research. Since its inauguration in 1983 about 180 large scale physical model tests were carried out in the approx. 300 m long, 5 m wide and 7 m deep flume, in order to advance knowledge and progress engineering design approaches on coastal structures, sediment transport, ecohydraulics and offshore renewable energies. Following an extensive research and design phase which commenced in mid-2017 incorporating funding proposals, international tender and procurement procedures, construction works commenced in September 2020 for a major extension of GWK to build the new GWK+. The Large Wave Current Flume, i.e. GWK+, stipulates unprecedented possibilities for physical modelling efforts on wave-current-structure-soil interactions. The flume went back into operation in September 2023 starting with the first project on soil liquefaction under progressive waves. There is a long list of future projects to be carried out in the “new” GWK+, the first of which all being related to offshore wind and wave energy research, not at least as the extension of the flume was funded by the German Ministry for Economic Affairs and Climate Action (BMWK) in order to promote research and development for offshore renewable energies. The unique modelling capabilities of GWK+ are likewise attractive for unique and novel research approaches related to the fields of coastal or ecological engineering. Research on the stability of dune vegetation and structures on dikes are planned to commence in late 2024 until mid-2025. The present manuscript and talk at ICCE2024 will primarily provide insight into the new features and testing potentials of GWK+ and discuss future challenges in the realm of offshore renewable energy and coastal engineering research where physical model experiments in GWK+ are supposed to make a major contribution.

NOVEL FEATURES OF GWK+

The extension of GWK to GWK+ comprises three main features: (1) a new wave maker, (2) a new current generation system and (3) a new deep section. The total flume dimensions did not change since the concrete flume infrastructure was kept, but more than 1/4 of the flume was demolished in order to construct the inlet/outlet structures of the current generation system as well as the deep section. The new wave maker (Figure 1) is a piston-type, dry back wave maker driven by a total of 8 servo motors with a maximum total power of about 1 MW. With a maximum operational stroke of 7.2 m, a maximum velocity of 2.6 m/s and a maximum acceleration of 3.0 m/s², the wave maker allows for a maximum wave height of about 3 m at a maximum period of about 10 s, almost doubling the capabilities of its predecessor. Even if the maximum wave conditions to be generated might be restricted when reflected waves are actively absorbed, the new wave maker enables experiments on larger scales and even more realistic, but controlled testing conditions to progress the development and prove the robustness of marine structures under extreme metocean conditions.

Figure 1 - 3D model of the new wave maker in GWK+.
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The new current generation system consists of 2 inlet and outlet structures in a distance of 152 m. The flow can be adjusted bidirectionally into the flume through an opening at the bottom and the flow profile can be optimized with 8 individually controllable guiding vanes in each opening (Figure 2, left). The inlet and outlet structures are connected by 2 pipelines, each with an internal diameter of 2 m, and a central underground pumping station. The bidirectional flow is generated by ship thrusters installed in the pipelines, as only those enable a change of the flow direction during operation by adjusting the angle of the propeller blades and are mechanically robust in pushing water-sediment mixtures through the pipelines.

Figure 2 - Inlet/outlet structure with guiding vanes (left) and view through 2 m diameter pipe on ship thruster (right).
© grbv (left); FZK (right)

The maximum total power of both thrusters is limited to 1 MW, allowing for a maximum discharge of 20 m³/s, which corresponds to an average flow velocity of 0.8 m/s at the maximum water depth in GWK+ of 5 m. In addition to the current generation, filling and emptying of the flume can be controlled simultaneously in order to allow mimicking realistic tidal cycles with both alternating currents (flood and ebb-tide) and changing water levels.

The new staggered deep section (Figure 3) is located in the middle between the inlet and outlet structures. The floor is lowered by 2 m over a length of 28 m and over the entire width of the flume. A shorter unit of 8 m length is lowered another 4 m, so that maximum bedding depths of ca. 6 m are possible for configurations with a geotechnical focus. The 28 m long shallow pit allows for the installation of sea beds flush to the concrete bottom of the flume and thus for most realistic testing conditions without any artificial disturbance of the waves and/or currents. The 6 m deep pit is intended for more realistic bedding conditions of marine infrastructures and enables the examination of deep foundations with their degradation effects and investigations of non-linear structure-soil interactions under realistic wave and/or current loads. Like the inlet/outlet structures, both pits can be covered with concrete slabs if a flat solid floor is required.

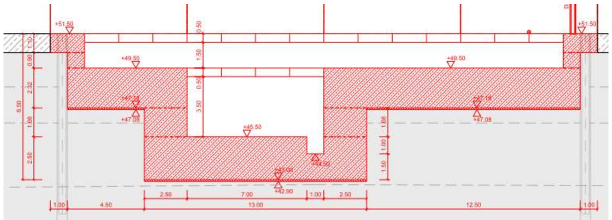

Figure 3 – Technical drawing of the staggered deep section. © grbv

RESEARCH CHALLENGES AND OPPORTUNITIES

With these briefly outlined new technology features, the GWK+ becomes an unique large-scale laboratory facility to address future research challenges in the realm of offshore renewable energy production, coastal and ecological engineering. Versatile possibilities to simulate the natural interactions of waves, currents, soil and structures in a controlled laboratory environment on a large scale provide an optimum basis for fundamental scientific studies as well as applied research and technology development with industry. The following examples shall only but shortly demonstrate where physical model experiments in GWK+ will play an important role.

In the transformation of the global energy system the massive expansion of offshore renewable (or blue) energy plays a key role in achieving a sustainable and independent energy supply. Typical technologies for harnessing renewable energies include the generation of electricity from wind (e.g. bottom-fixed and floating structures), waves, currents, tides, and floating solar photovoltaic plants. Technologies in exploiting salinity and temperature differences in offshore and coastal regions are supposed to inevitably grow as another supporting pillar for green energy production and storage in the coming decades. Co-utilization of space (multi-use), e.g., combining electricity and hydrogen production, pumped marine energy storage (e.g. artificial energy islands) or combinations with aquaculture, fisheries or carbon storing in deep marine undergrounds or in coastal ecosystems are already on the brink of realization and will have to be considered in any future offshore renewable energy strategy. These overarching objectives demand technologies that today are in the development or prototype stage (low TRL) and concentrate on untapped potentials, with yet unknown environmental side effects which are demanded to be quantified in advance. Yet, this expansion can only succeed with strong scientific support by objectively and systematically investigating structural ultimate load limits and the potential of harmful environmental impacts though installation and operation of offshore structures.

On the other hand, climate change effects like rising sea levels, more intense storms and climate extremes call for expedited action on strengthening coastal protection infrastructure and new strategies in coastal adaptation. At the same time, ecosystem-based coastal protection measures still require a better understanding of their functioning and efficiency. Marine infrastructures require innovative designs as coastal space is highly contested. Innovation cycles demand for shorter and streamlined optimization and large-scale testing remains to be of utmost importance in this context, particularly if realistic conditions consisting of a complex superposition of waves, currents, induced sediment transport and structural interaction can be modelled with minimal scaling effects.

CONCLUSIONS AND OUTLOOK

The Large Wave Flume (GWK) has recently been upgraded to the Large Wave Current Flume (GWK+) and is back in operation since September 2023. The new features (more powerful wave maker, current generation system and staggered deep section) allow for unprecedented large-scale physical model tests to investigate the interactions of waves, currents, soil and structures in a controlled laboratory environment. This is supposed to provide a significant contribution addressing current and future research challenges like:

- Optimizing energy production and minimizing side effects on marine ecosystems by developing technologies for energy conversion, decentralized storage, reduction of Levelized-Cost-of-Energy.
- Testing of concepts for multi-use options (hydrogen production, sustainable aquaculture) in compatibility with maritime spatial planning and legal requirements.
- Advancement of sustainable climate adaptation concepts for coastal protection systems.

The group of authors would be delighted to present and discuss the GWK* and further research challenges at the conference and how to jointly address them in GWK+ in reference to any broader collaborative effort in the future, e.g. Hydralab follow-on initiatives.