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DEVELOPMENT OF AN OUTDOOR WAVE BASIN FOR LONG-TERM MODEL TESTS WITH REAL VEGETATION FOR GREEN COASTAL INFRASTRUCTURES

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ABSTRACT

The demand for physical model tests with real vegetation is increasing due to the current trend to elucidate the performance and durability of green coastal infrastructures, also to ensure and promote ecosystem services of the environment. To address this, a new outdoor wave basin (OWB) at the Ludwig-Franzius-Institute in Hannover (Germany) was built in August 2017 following recent guidelines for physical modelling. This paper reviews the general characteristics and the ongoing development of the new OWB based on the current research project Ecodike. This project aims to provide first insights into the long-term development of the ecosystem services of different grass revetments. The Ecodike project proves the compatibility of high ecological value and safety standard of sea dikes by focusing on the resistance and the ecological value of these grass mixtures. Upcoming projects are described briefly to highlight how the new OWB can be used to investigate green coastal infrastructures in greater detail. The basin enables the conduction of investigations using either fresh or seawater with wave load under controlled natural conditions. The first planned experiments are simulating a constant wave load for up to 10 hours every third week on a natural dike and are expected to start in late 2018.

KEYWORDS: outdoor wave basin, long-term development, vegetation development, ecosystem services, nature based

1 INTRODUCTION

A deeper understanding of the interactions between vegetation and hydraulic boundary conditions is essential for a sustainable design of green coastal infrastructures in order to ensure and even enhance structure and functioning of ecosystem services (Jones et al., 1994; Hastings et al., 2007). In the past, investigations were conducted to estimate the dissipation of hydrodynamic energy by vegetation for various conditions and functions (Järvelä, 2002). For example, the investigations of the failure of grass cover layers at seaward and shoreward dike slopes by Piontkowitz, 2009 or through the Sheldebak test in 1994 (TAW, 1997). However, most of these investigations used either artificial vegetation or focused on certain life stages of the particular vegetation by conducting only short-term physical model tests (Silinski et al., 2015; 2016; Strusínska-Correia et al., 2013; Möller et al., 2014). Following the ecosystem engineering approach to management (EAM) of infrastructure by Hastings et al., 2007 and the Building with Nature (BwN) approach by de Vriend, 2014, it is essential to investigate the long-term development of nature-based sustainable solutions for green coastal infrastructures. The capability for adaptation of vegetation to hydraulic load can only be triggered and identified with long-term physical model tests under controlled boundary conditions. Recently, Silinski et al., 2017 showed that the wave dissipation due to specific vegetation properties is affected by wave exposure. In this case, the ecosystem services of tidal marsh vegetation vary significantly between locations with different hydraulic boundary conditions. These findings should be considered in ecosystem-based coastal protection measure with real vegetation. Thus, an increasing demand for the highly interdisciplinary physical model tests with real vegetation and guidelines for the conduction of these experiments arises. Lara et al., 2016 reviewed these issues and pointed out the complexity by defining a guideline for experiments with real vegetation in laboratories. Concerning the conduction of long-term physical model tests, it is of capital importance to mimic the natural conditions. Accordingly, field studies are auspicious to deliver the most reliable results. However, these results of field studies imply uncertainties through a lack of controlling and monitoring methods regarding the complex and transient boundary conditions during the field studies (Yang et al., 2008; Coops et al., 1996; Paul & Amos, 2011). More controlled boundary conditions are essential to develop profound knowledge with a detailed understanding of the interactions between vegetation and biotic and abiotic factors. Thus, an outdoor wave basin is the most consistent and costs efficient method for the development of green coastal infrastructures with ecosystem services of regional vegetation, (Lara et al., 2016).

1.1 Motivation

Construction and design processes of coastal infrastructures along the European coastlines adhere the paradigm to protect and safeguard reliably the coastal hinterland from wave attack and storm surges. Following these standards, coastal protection structures provide only poor ecosystem services in any proper design or maintenance approach. According to the ecosystem engineering approach, a high potential for increasing the ecosystem services of coastal infrastructures while preserving or possibly even enhancing the existing safety standards can be found in coastal infrastructure with vegetation (Hastings et al., 2007). To improve the design and maintenance of those compound coastal infrastructures, a profound understanding of the complex long-term interactions between wave load and vegetation development is inevitable

(Szmeja & Galka 2008; Eisenmann 2015). Thus, a new outdoor wave basin (OWB) has been developed and installed in the Ludwig-Franzius-Institute in Hannover (LuFI, Germany) to achieve these objectives. The first model in the OWB is a typical sea dike in prototype scale which is tested under realistic and long-term wave loading for innovative monitoring approaches within the Ecodike project (see Chapter 3).

The aim of the Ecodike project is to enhance the ecosystem services of dikes and revetments while preserving or possibly enhancing the existing safety standards. A controlled investigation of the effect of wave load on the vegetation development and resistance for sea dikes is required in order to determine their suitability as grass revetment. The previous dike monitoring project at LuFI in Hannover focused on monitoring approaches for the detection of percolation without wave load. For the present research questions of the Ecodike project, the generation of waves is required. Because of the limitations of the former test stand, it was decided to renew the complete test stand by building a new outdoor wave basin. This outdoor wave basin should be more durable than the old test stand which was built out of a wood construction and a plastic sealing membrane. Consequently, a concrete basin was built in August 2017 enabling multiple and faster model constructions due to the use of heavy machines inside the basin. Furthermore, the former test stand concept was extended by building a complete basin without the necessity of the model dike as fourth wall.

2 OUTDOOR WAVE BASIN

This chapter describes the general facility characteristics. The potential for future extensions is pointed out in the following sections. Therefore, the location, the basin characteristics, the wave maker, the water transfer, and the measuring equipment are reviewed.

2.1 Location

The OWB is located next to the large wave flume (GWK) of the Coastal Research Centre (Forschungszentrum Küste, FZK) and the 3D-wave-current-basin at the facilities of the LuFI in Hannover Marienwerder. The LuFI has access to a total of almost 16,800 m² sheltered laboratory space (240 m x 60 m) and 24,000 m² of outdoor space including the OWB. The various experimental facilities allow a year-round operation of hydraulic models. Due to a direct connection to the neighbored shipping channel an additional natural water reservoir is available besides the groundwater connection via a drain sump. The entrance of the OWB is designed for easy access with heavy lorries and to enable direct unloading of bulk good inside the basin. Nevertheless, it is possible to use wheel loaders inside the OWB with up to 40 t for a fast model construction.

2.2 General facility characteristics

The OWB is 24.10 m long and 14.2 m wide, containing a 12.55 m long and 14.2 wide deep section (see blue rectangle in Figure 1 B). The maximum water levels are 0.8 m at the wave maker and 1 m in the deep section. The surrounding walls have a height of 1 m at the wave maker position and 2 m at the deep section which enables water levels up to 2 m for certain model setups. For example, see the described model setup in Chapter 4 Figure 5. The OWB is also designed for investigations with seawater. Those experiments are conducted using a flexible PVC water tank as a closed system with water treatment next to the OWB (see section 2.4). For remote sensing investigations, a 10 m high observation tower is available next to the OWB (see Figure 1 A). The empty basin is shown together with the general wave maker position marked with a green rectangle in Figure 1 B.

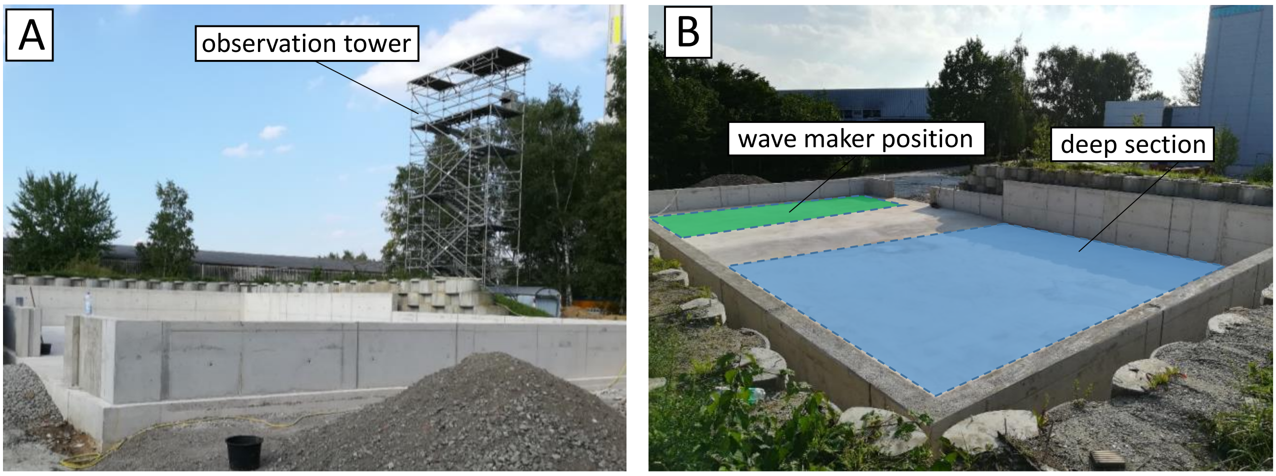

Figure 1: New outdoor wave basin during construction with observation tower (A) and empty basin after finishing the concrete works (B) at the end of August 2017.

The deep section on the right-hand side in Figure 2 is 0.2 m lower than the marked wave maker position. This allows space for toe protection for model dikes (see Chapter 3) or the root development for model setups with imbedded vegetation (see Chapter 4).

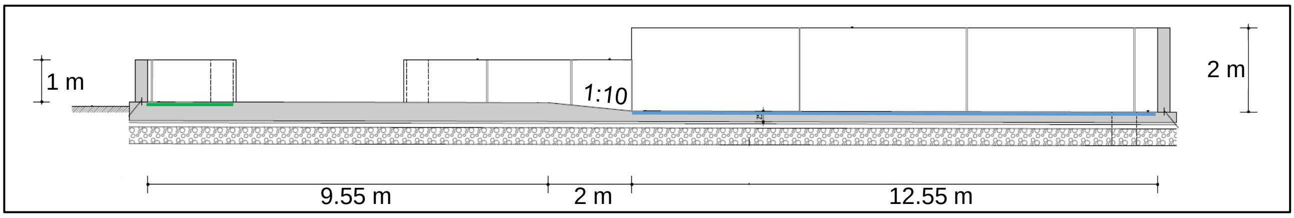

Figure 2: Profile of the outdoor wave basin with wave maker position (green) and deep section (blue).

2.3 Wave maker

The DHI piston type wave maker system is made of three independent wave maker elements with an adjustable wave paddle width of 3 to 5 m, allowing wave generation over the total width or if necessary only in a selected section of the basin. The piston type wave maker elements are driven by one hydraulic cylinder each and are capable to generate a maximum stroke of 0.30 m. The wave maker motion and acceleration are controlled with a PC with Ethernet connection to the wave maker. The signals for the generation of irregular waves are computed from empirical energy density spectra (e.g. JONSWAP). The maximum water level at the wave maker (0.6 m) allows to generate wave heights up to H_s = 0.25 m in periods of up to T_p = 3 s (see Figure 3 A). Figure 3 B shows wave maker elements with a width of 7 m, which can be placed in the entire basin and are fixed by their own weight and additional concrete blocks.

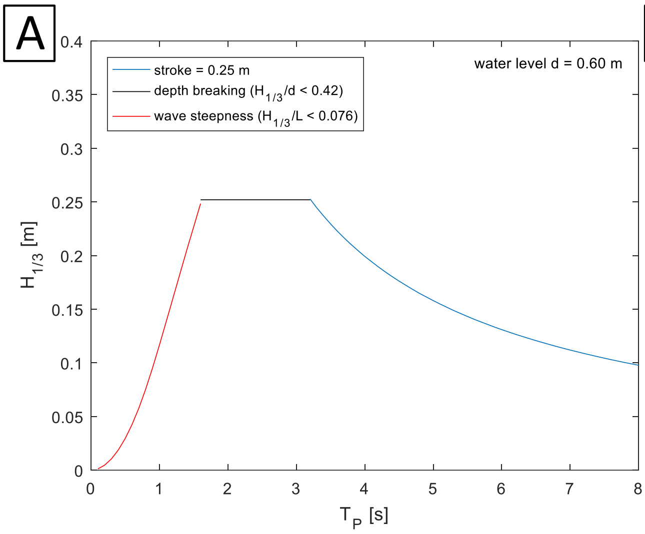

Figure 3: A) Wave parameters for OWB (theoretical values, 90 % practical reachable) and B) Two DHI piston type wave paddle elements with a maximum width of 7 m and height of 1 m.

2.4 Water transfer system

Filling the basin to the maximum water level of 0.6 m respectively 0.8 m in the deep section takes 2-4 hours depending on the constructed model. For the generation of the maximum water level, 240 m³ of water are required. The OWB is filled either through freshwater from the neighbored shipping channel or by groundwater through the neighbouring drain sump. To avoid disturbance due to critical biological and chemical composition or water temperatures a multiparameter water quality probe is deployed for the water quality monitoring during the experiments. Furthermore, the OWB is designed for experiments with seawater. Therefore, a highly durable flexible PVC water tank will be available to restore seawater next to the OWB. Experiments with seawater have to be conducted in a closed system to prevent corrosion of the general water transfer system at the existing infrastructure. Since the capacity of the flexible PVC water tank is limited, a water treatment can be installed to ensure the water quality during but also between the experiments.

2.5 Measuring equipment and data acquisition

The LuFI has a multitude of measuring systems for the investigation of hydraulic and coastal engineering issues available. Since the OWB is not roofed during the first project, mainly robust measuring devices are installed permanently. For the current project, a meteorological station, pressure sensors, a multiparameter water quality probe and velocimeters are deployed all the time. Additionally, 3D laser scans, ultrasonic sensors or hyperspectral measurements are only conducted during the experiments. A control room for data acquisition and wave generation are available in front of the OWB. Moreover, the indoor facilities of the LuFI offer further office workspaces and conference rooms.

3 CURRENT PROJECT - ECODIKE

The main objective of the Ecodike project is to enhance the ecological value of dikes and revetments for coastal protection structures. Therefore, the joint project with seven institutes[1] of different areas of expertise was started in October 2016. The first step was the development of a test vegetation based on field and multivariate parameter studies. This leads to different grass mixtures with increasing ecological values, for example, an increasing amount of herbs. Physical model test are conducted to evaluate the practical safety standards of these test vegetations and its application as revetments for sea dikes. An innovative monitoring approach is used to monitor the long-term vegetation development under wave load. To identify the effects of wave load on the long-term vegetation development of the test vegetation, the seaside slope of a typical sea dike, containing a sand core and a 0.3 m clay layer, was constructed in the OWB. The model dike was constructed with a height of 1.5 m, a width of 14.2 m and a slope of 1:6 (see Figure 4 A). According to the guidelines for experiments with real vegetation defined by Lara et al. 2016, original clay material for dike construction was transferred from the coast of the North Sea to Hannover to create natural conditions for the test vegetation. The model dike is divided into two sections in order to investigate the vegetation development with and without stresses induced by wave loads. Each of these sections is further divided into four subsections containing four test vegetations with different ecological values. For the upcoming vegetation period (spring 2018), the test vegetations are exposed to wave load with wave heights of 0.10 to 0.25 m and periods of 1 to 3 s for up to 7 to 10 h every second week. Additionally, the first test vegetation is exposed to salt stress by watering with seawater to mimic the conditions at the North Sea. Furthermore, short test sets with regular waves are conducted to estimate wave run-up heights and maximum flow velocities on the dike for different stages in the anticipated lifetime of the target vegetation. After the vegetation period, the vegetation development (for e.g. root depth and density, coverage index, species composition) and the resistance of the dike is quantified and analyzed with shearing stress and pullout tests. Figure 4 B shows the prepared model dike covered with a fleece to protect the slope against erosion and settlement of unwanted vegetation during the winter months.

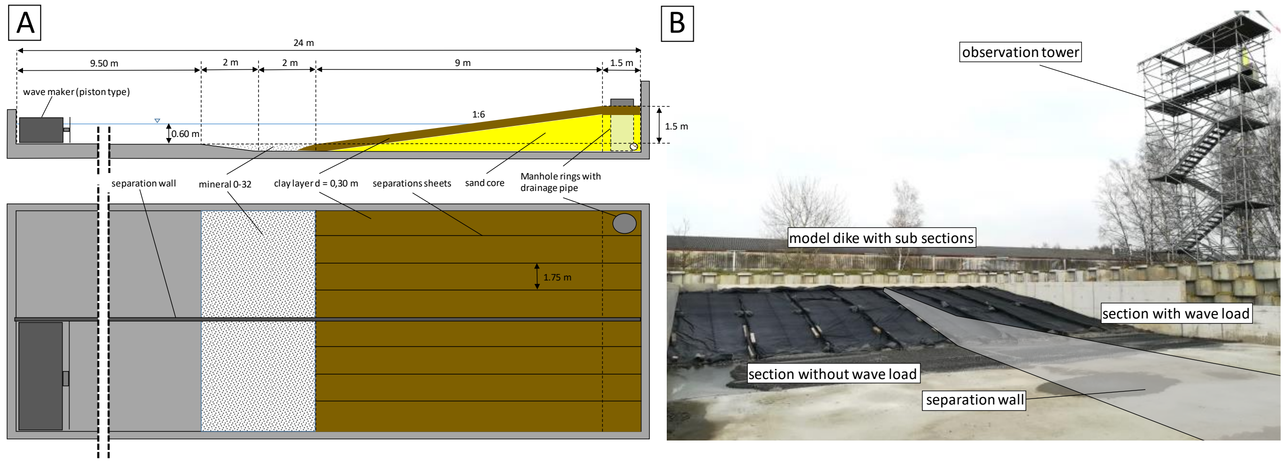

Figure 4: Model setup for the Ecodike project (A) and constructed model dike with two sections containing four subsections covered with protection-fleece during the winter months in February 2018 (B).

4 OUTLOOK

In this chapter exemplary and upcoming model setups are briefly presented to highlight the potential of long-term investigations with real vegetation as well as large-scale investigations for dike failure development.

The understanding of the development of dike failure is an unreliable part of modern flood management. With the OWB a 14 m long and up to 2 m high dike can be constructed to investigate the damage development through manually triggered initial damage. Therefore, a recirculation water transfer system can be installed to control the water level on the right-hand side in Figure 5. Thus, a constant hydraulic gradient is generated during the failure development of the dike.

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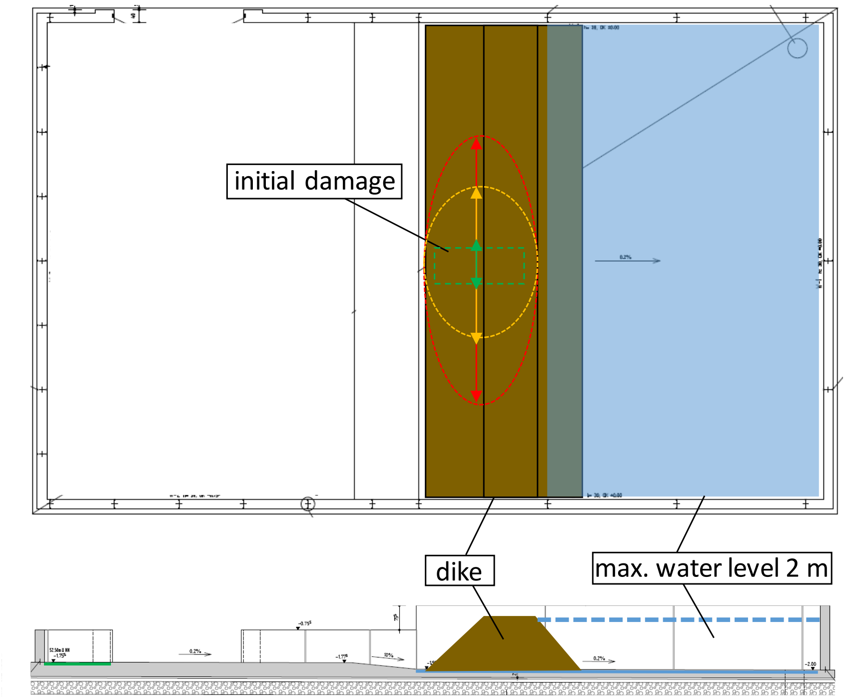

Figure 5: Theoretical model setup for dike failure development investigations for flood management approaches. Initial damage (green), damage development (orange) and equilibrium state (red).

Another model setup is used to investigate the restoration of seagrass meadows by artificial seagrass during the initial phase. The artificial seagrass must guarantee the sheltered conditions that are needed for the natural seagrass to grow. The natural seagrass must be able to withstand hydrodynamic forces induced by waves. Therefore, an optimized dimensioning of the artificial seagrass must be developed to achieve enough energy dissipation (Villanueva et al., 2017). Long-term experiments are conducted using seawater to estimate the survival rate of the natural seagrass for the defined hydraulic load. Figure 6 shows the general model setup with supplementary wave absorption elements in the deep section. A natural seagrass meadow with an area of 130 m² is investigated with this model setup.

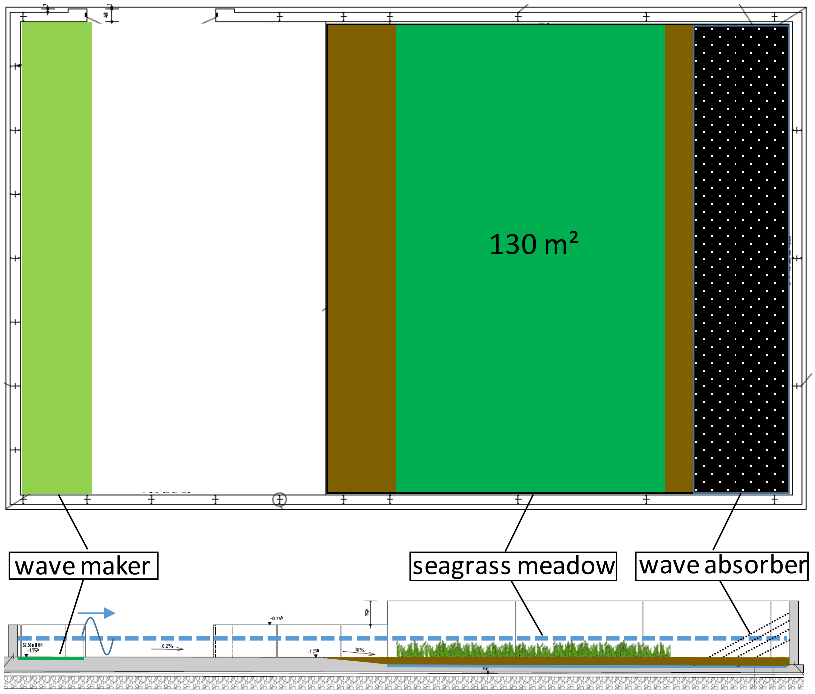

Figure 6: Model setup with seagrass meadow and supplementary wave absorption.

A further model setup focuses on the degradation process of different materials for applications in coastal and harbour engineering. For instance, investigation of the complex interactions between the protection against erosion by biodegradable geotextiles and their degradation processes under hydraulic load and controlled natural conditions. Long-term investigations with seawater are conducted to estimate the resistance and the functionality of the geotextile during the degradation process.

5 CONCLUSION

The construction and the ongoing development of the new OWB at the LuFI enables new and innovative ways to investigate green coastal infrastructures with ecosystem services. The long-term investigations are extending the current knowledge of the long-term development of the ecosystem services while leading towards more ecologically friendly and sustainable coastal protection measures.The Ecodike project provides first insights into the long-term development of the ecosystem services of different grass revetments (see Chapter 3). Focusing on the resistance and the ecological value of these grass mixtures it is proving the compatibility of a high ecological value and safety standard of sea dikes. Furthermore, the upcoming projects can be used to enhance the knowledge of a multitude of issues resulting from the postulated ecosystem-based solutions for coastal protection measures. Three exemplary model setups were discussed regarding their potential to enhance the understanding of green coastal protection structures (see Chapter 4). A significant update of the state of the art for these infrastructures is expected in the next decade.

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