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WAVE LOADS ON HYDRAULIC STRUCTURES

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1 INTRODUCTION

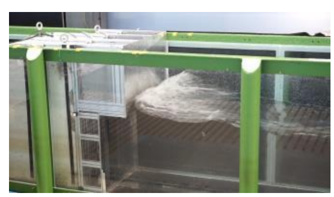
Hydraulic structures are essential for flood protection, water management and navigation in coastal, delta and lake regions. Their importance will continue to grow in the coming years and decades, because of two main factors. Firstly, because of the consequences of climate change and sea level rise. Secondly, because of the continuous development and urbanization of coastal, delta and lake regions, with an increase in the value of the assets and activities in those locations combined with more strict safety requirements. Those factors will lead to the construction of a series of new hydraulic structures and the renovation of several existing structures around the world.

Wave loads acting on such hydraulic structures are crucial for their design and safety assessment. This study addresses two different types of wave loads acting on hydraulic structures: confined wave impact loads and bimodal wave loads. To this end, a series of laboratory experimental test campaigns were carried out in a wave flume.

2 RESEARCH ON WAVE LOADS

In this research, two main types of wave loads are studied. Firstly, non-breaking impulsive confined wave impact loads acting on vertical hydraulic structures with overhangs (i.e. solid protruding horizontal structural elements located around the still water level). Secondly, non-breaking non-impulsive wave loads acting on vertical hydraulic structures, caused by unimodal and bimodal incident wave conditions. To this end, several physical modelling experiment campaigns were carried out at the wave flume at the Hydraulic Engineering Laboratory at the Delft University of Technology (see Figure 1). Those two different wave load types will be described in more detail in the subsections hereafter.

a) General overview of the wave flume test area

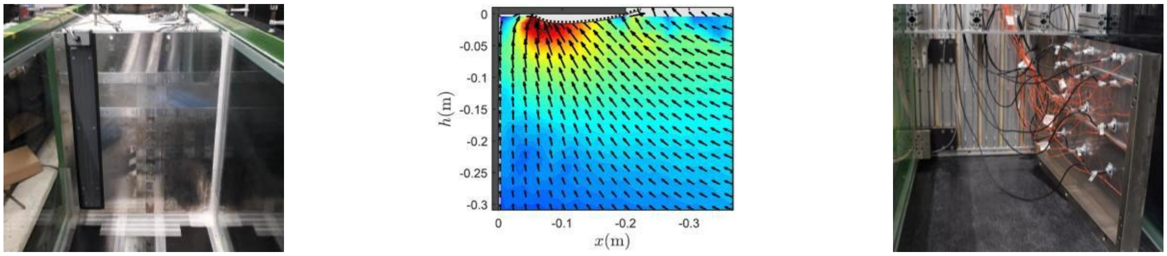


b) View during a confined wave impact

Figure 1. Experimental laboratory setup (De Almeida and Hofland 2020a).

2.1 Confined wave impact loads

Confined wave impacts are relevant for the design of coastal hydraulic structures (Castellino *et. al* (2018), Martinelli *et. al* (2018)), as non-breaking incident wave fields can lead to impulsive loadings on such structures. Also due to sea level rise, present-day structures which are not exposed to wave impacts could be exposed to impulsive wave loads in the future. Such impulsive loads take place due to the interaction between the wave field and the structure geometry. This type of wave impact has been previously studied in De Almeida and Hofland (2020a, 2020b, 2021). Innovative physical modelling methods and techniques have been used during these experiments, see Figure 2. Figure 2a shows an instrumented vertical wall test structure featuring pressure sensors, load cells and a wall-wave-gauge, among other instruments present in the laboratory experiments. Figure 2b shows the use of an LED Particle Image Velocimetry (PIV) developed at Delft University of Technology, able to measure the wave velocity field before, during and after a wave impact. Figure 2c shows an instrumented flood gate with accelerometers and strain gauges to measure the dynamic response of such structures to impulsive wave impact.

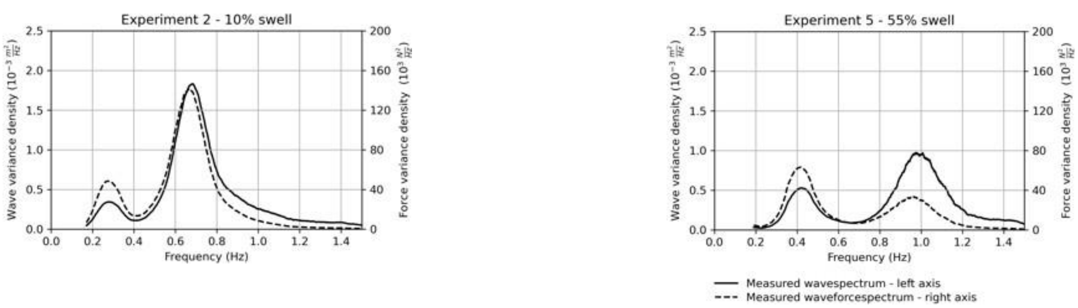


a) Instrumented vertical wall with wall-wave-gauge (De Almeida and Hofland 2020b) b) LED PIV measurements on confined wave impacts (Bakker *et. al* 2021) c) Accelerometers and strain gauges to measure the structure response (Tieleman 2022)

Figure 2. Innovative physical modelling techniques applied to wave loads and response.

2.2 Bimodal spectra wave loads

Traditional wave loading formulae have considered unimodal incident wave fields. Nevertheless, diverse coastal hydraulic structures are subjected to bimodal incident wave fields, combining sea and swell waves. To this end, a method to calculate bimodal wave loads based on linear wave theory has been investigated by Tuin *et al.* (2022). To assess this, laboratory experiments were carried out considering bimodal incident wave spectra, where the corresponding bimodal wave loads were measured. These test results confirmed that small swell wave contents in the incident wave spectra have a significantly larger effect on the corresponding force spectra (see Figure 3). Furthermore, the application and suitability of conventional wave loading formulae such as the one from Goda have been assessed, leading to design recommendations regarding the conservative and non-conservative use of Goda's formula. Given the use of the new insights obtained by wave flume testing more information is available for the assessment of present and future hydraulic structures.



a) Incident wave spectra with 10% swell b) Incident wave spectra with 55% swell

Figure 3. Effect of bimodal incident wave spectra in wave forces spectra (Tuin et. al 2022).

3 CONCLUSIONS

This paper presents recent developments and case studies regarding wave loads acting on coastal hydraulic structures, based on wave flume laboratory experiments. Such developments can contribute to the design of more reliable coastal hydraulic structures, in particular when such structures are susceptible to dynamic behaviour under such wave loads.

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