LARGE SCALE EXPERIMENTS ON THE INTERACTION OF A CAISSON BREAKWATER WITH BREAKING WAVES
Dimitris Stagonas(1), Andrea Marzeddu (2), Mariano Buccino (3), Mario Calabrese (3), Davide Banfi (4), Diego Vicinanza (5), Jens-Peter Kofoed (6), Arthur Pecher (6), Peter Frigaard (6), Csaba Pakozdi(7)

(1) UCL, UK, E-mail: d.stagonas@ucl.ac.uk
(2) LIM-UPC, Spain, E-mail : andrea.marzeddu@upc.edu
(3) Università di Napoli Federico II, Italy: buccino@unina.it, calabres@unina.it
(4) Plymouth University, UK: davide.banfi@plymouth.ac.uk
(5) Seconda Università di Napoli, Italy: diego.vicinanza@unina2.it
(6) Aalborg University, Denmark: jpk@civil.aau.dk, alsps@civil.aau.dk, pt@civil.aau.dk
(7) Norwegian Marine Technology Research Institute (Marintek), Norway E-mail: Csaba.Pakozdi@marintek.sintef.no

Tests looking at the interaction of a caisson breakwater with steep, breaking waves are outlined here. 4 different wave generation methodologies were employed allowing for experiments with regular, irregular, focused and tailored made waves. The emphasis, however, is given in tests with focused waves, which resulted in impulsive conditions at the face of the caisson. Amongst our objectives was to look at the mechanisms occurring when a wave breaks at the structure and to investigate the validity of tactile pressure sensors. As such, for all experiments, pressure, force and surface elevation measurements were complimented with high speed and high definition video records. In addition, a pressure mapping system employing tactile pressure sensors was deployed in combination with force panels, both positioned at still water level. Although at a very early stage, data analysis yields promising results.

1. INTRODUCTION

Although caisson breakwaters are mainly deployed in deep waters, the high irregularity of real sea states suggests that they will still be subject to the effects of breaking waves. High and steep approaching waves may break at the face of the structure and induce forces with magnitudes more than 5 times greater than quasi-static loads and rise times in the order of 1ms. For this, contemporary design guidelines suggest that within a probabilistic framework the effect of breaking waves must be considered, e.g. Oumeraci (1994), Allsop et al. (1996c) and Oumeraci et al. (2001).

Based on hydraulic tests and field observations, extensive methodologies for the prediction of pulsating and impulsive loads have been developed, e.g. Goda (1985) and with continuous research their accuracy increases, Cuomo et al. (2010), Frigaard et al. (1998). Nevertheless, knowledge on the complex hydrodynamic mechanisms involved and on the coherence of the pressures induced upon breaking is still not well advanced.

Observations on the former indicate that three different mechanisms occur during the impact of a wave at a structure with vertical face, impact pressure generation, up-rush/downfall and wave reflection but further understanding is limited. With regards to impact induced pressures, Hull and Muller (2002) reported that maximum pressures occur near or at still water level, however the spatial resolution of their experimental measurements was subject to the limitations of instrumentation (pressure transducers) used.

In the current work, the interaction of a caisson breakwater with high and steep waves is investigated. It is envisaged that the data produced will aid on further understanding the mechanisms occurring during the impact and form a very useful set for the validation of CFD models. In the same time the use of tactile pressure sensors may provide unique data on the coherence of impact induced pressures. It is anticipated, that the further validation required for the use of such sensors will come through their combined use with force panels.
In the remainder, the experimental arrangement and the tests conducted are described in section 2, preliminary results of the ongoing analysis are presented in section 3, while section 4 gives a summary of the work.

2. METHODS

2.1 THE EXPERIMENTAL ARRANGEMENT

All hydraulic model tests reported here were conducted in the Ocean Basin (80x50x10m), at Marintek, in Trondheim Norway, Figure 1. The basin is equipped with a floating bed and the water depth can be reduced to 10m. All tests for the specific project were conducted at a water depth ≤1m; namely tests were conducted with water depths of 1m, 0.90cm, 0.85cm and 0.82cm. It should, however, be noted that at the water depth at the wavemaker remains at all times fixed to 10m and it is sharply reduced to the working level at a distance of about 2.5m from the wavemaker.

The model caisson was made of steel and its center (x=y=z=0) was located 34.74m from the wavemaker. The caisson was mounted on a steel base comprising of a 1:3 slope at the shoreward side (towards the wavemaker), an 1:1.5 slope at the seaward side and a plateau, which in turn was welded on the bed in order to provide the required rigidity, Figure 2.

2.2 INSTRUMENTATION

In total, 50 channels were sampled instantaneously. Amongst them:

- 21 wave gauges positioned between the wavemaker and the structure and at the structure; sampled at 200Hz and filtered at 20Hz.
- 11 pressure transducers placed on the model caisson at areas where pulsating conditions were anticipated. All 11 transducers were sampled at 2.4kHz and the signals were filtered at 250Hz.
- 8 HBM P8AP pressure transducers placed on the model caisson at areas where impulsive conditions were anticipated. All 8 transducers were sampled at 9.6kHz and the signals were filtered at 2kHz.
- 6 accelerometers measuring the horizontal and vertical acceleration of the wall, the panel and the beam used to stiffen the area where the force panels were located. All accelerometers were sampled at 9.6kHz and filtered at 2kHz.

In addition to the wave gauges, the model caisson is equipped with four different types of pressure measuring instruments. 11 pressure transducers, UNIK 5000 and 8 HBM P8AP pressure transducer
are installed at the front, left section of the box and at the back; for the latter 4 of the 11 UNIK 5000 are used. In the same time, 4 force panels, 45x45mm, are placed at SWL and 2 pressure pads, 71x71mm are positioned on top of 2 of the force panels, Figure 3. Finally, 6 accelerometers were placed inside the model caisson and behind the latter 2 force panels. At this point it should be noted that the pressure pads are sampled by an independent data acquisition system at a frequency of 4032Hz; the two data acquisition systems are manually ‘synchronized’. The location of all pressure and force measuring equipment is illustrated in Figure 3.

In addition, video records of the wave propagation and the interaction of the wave(s) with the model caisson were generated with two high definition cameras and one high speed (200fps) and high definition camera. All three cameras were located at the side of the basin and an example of the records acquired is given in Figure 4.

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**Figure 3:** Positioning of the force and pressure measuring equipment: the tactile pressure sensors employed with for the pressure mapping system where placed on top of the force panels and they are depicted here within the yellow frame.

**Figure 4:** Snapshot from video records acquired with the high speed/high definition camera.
3. OVERVIEW OF THE TEST PROGRAM AND PRELIMINARY RESULTS

The test program was set-up with the aim to initially define the wave conditions giving the steepest waves with the highest possibility to break at the structure. As such tests with regular, irregular and tailor made waves were initially conducted without the model caisson; the input signal for the tailor made waves was very kindly provided by Prof. Alessandro Toffoli. Accordingly it was decided that emphasis was to be given in tests with focused waves which resulted in steeper waves near the structure. For the generation of focused wave the methodology described in Baldock et al (1996) was employed. Experiments were conducted with various combinations of * the theoretical focusing point with *, the linear wave height at focus and *, the water depth. Although laborious and time consuming, this procedure resulted in nearly-breaking, breaking and broken waves.Figure4 gives an example of a focused wave breaking at the caisson.

The methodology followed for the analysis of the videos is described in Vousdoukas et al. (2012). In principle, the water jet position is monitored by sampling pixel intensities along vertical transects on the caisson and along horizontal transects on the rulers Figure 5. The jet velocity is derived from the time history of the jet’s tip position (red line in Figure 5), and its thickness is estimated as a function of the length of the blade/ruler remaining exposed to air (blue and green lines in Figure 5). Figure 5 gives an overview of the result following the analysis. The first subplot presents the evolution of the jet/wave at the face of the caisson, the subplot in the middle refers to the first ruler (blue line in Figure 5) and the lower subplot to the second ruler (green line in Figure 5). Here, the velocity and thickness of the highly aerated part of the jet was calculated to about 7m/s and 0.05m respectively.

Examples of surface elevation and pressure measurements are presented in Figure 6; measurements at the middle of the caisson are only considered here.
For this project, pressure pads were also used in combination with force panels. This formed the base for an extended, ongoing collaboration between UCL, UPC and University of Southampton which looks deeper on the details of the use of pressure pads. The performance of the pressure pad is compared against load cell measurements for impacts generated with a pendulum but also for impacts generated by water jets, Figures 7 and 8 respectively.

**Figure 6:** Examples of surface elevation, force and pressure measurements

**Figure 7:** Load cell (with red) and tactile pressure sensor (with blue) measurements for impacts with a pendulum; on the left tests conducted at UCP and on the right tests conducted at Marintek

**Figure 8:** Example time histories of load cell (red line) and tactile pressure sensor measurements (blue line) for impinging water jets; the load cell was sampled at 4.8kHz and the tactile sensor at 4kHz.
4. SUMMARY

This work looks at the interaction of a caisson breakwater with steep and breaking waves. Emphasis is given on tests employing focused waves, which resulted in impulsive conditions at the structure. Pressures, forces and surface elevation were measured at multiple locations and the interaction of the incoming wave with the caisson was recorded at high speed and high definition. In addition a pressure mapping system was used in conjunction with force panels. It is anticipated that the analysis of the data will provide further insights on the evolution of the mechanisms involved when a wave breaks at vertical structure. In the same time, this work formed the base of an ongoing collaboration between UCL, UPC and the University of Southampton, which at the finer details of the use of the pressure mapping system; this research effort has already yielded promising results.

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