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Autonomous measuring system of overtopping wave impact pressure in real field conditions

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Abstract:

Overtopping wave impact is a real threat for coastal urbanized areas. A better understanding of this physical process in real field conditions is critical to implement effective tools for both coastal risk assessment strategies and civil engineering design guidelines. However, field studies on this topic are sparse because of the difficulty of measuring impact forces generated by overtopping waves under real conditions with traditional instruments. This study aims to present an innovative autonomous device, the Wave overtopping ImPact station, designed to measure overtopping wave impact pressures on a vertical structure during energetic wave conditions. A prototype station is first tested in a laboratory facility in the framework of a dam break experiment to assess its ability to measure pressure signals typical of a bore front impacting a vertical wall. The station is then deployed in real conditions on top of the seawall at the Grande Plage of Biarritz during a moderately energetic event. The results of this campaign highlight the potential of this impact station to provide new insight into the relation between incident wave conditions and characteristics of assailing forces induced by overtopping waves.

Keywords:

Overtopping wave impact, Autonomous monitoring system, SCADA system, Field campaign, Dam-break.

1. Introduction

In densely urbanized coastal areas, sea defences at the shoreline must respond to two different objectives: (i) protect the shoreline infrastructures from erosion and flooding (VAN DER MEER, 2018) and (ii) provide safety standards for human activities developed on the crest of it (ALTOMARE *et al*., 2020). Due to the ongoing climate change causing a global sea-level rise, the exposure of coastal cities to overtopping hazards is becoming a key challenge for many stakeholders in charge of coastal management strategies. The proper design of coastal defence infrastructures and the relevant assessment of the risk for human activities along the waterfront require a reliable evaluation of key physical quantities, especially the potential overtopping wave impact intensity. Since overtopping wave impact is a complex phenomenon occurring at the end of wave propagation and mostly during stormy conditions, it is challenging to capture with field measurements. Consequently, the current knowledge about the characteristics of overtopping wave impact forces is mostly derived from laboratory studies carried out considering idealistic configurations (DE ROUCK *et al*., 2012). These studies showed that the post-overtopping wave impact total force exerted on a vertical plate is generally composed of a double peak. The first one is the dynamic peak generated by the bore impacting the vertical plate with a concentration of force at the bottom. The second one corresponds to a quasi-static peak generated by the wave run-up on the vertical structure and the subsequent water down-rush. More recently, STREICHER *et al*., (2018) and CHEN *et al*., (2016) have highlighted the need to study overtopping wave impact close to the real scale and for irregular wave forcing. Indeed, an overtopping wave is a very turbulent phenomenon and the effect of air entrainment on the impact is difficult to reproduce in small-scale experiments for the dynamic peak. Moreover, infragravity waves and wave interaction within a group of waves (reflection, bore catching) are crucial to understand overtopping wave processes which imply to work with realistic irregular wave fields. As extreme wave hydrodynamic conditions cannot be reproduced at scale 1:1 in a 2D laboratory configuration, the development of a specific measuring system capable to characterize overtopping wave impact on a real site is required. In this context, our study aims to present an innovative Wave overtopping ImPact measurement device, hereinafter designated by the “WIP station”, designed to measure impact pressures during energetic wave conditions. In the following, the characteristics of the WIP station are first presented. The data acquisition system is then tested during a laboratory experiment figuring a bore impact on a dry bed generated by a dam break. Finally, we present the results of the first test field deployment of the WIP station followed by a preliminary analysis of the measured pressures recorded during an overtopping event.

2. Material and method

2.1 Presentation of the WIP station

The WIP station design is illustrated in figure 1 The front part of the system is composed of a vertical plate (figure 1(a)) of 1.7 m x 0.6 m equipped with 9 piezoresistive pressure sensors KELLER PR-25Y located in the center along a vertical axis. The output of these sensors is an electronic signal with values ranging between 4 and 20 mA converted into a pressure signal using a linear function. The maximum sampling frequency is 10 kHz. The range of measured relative pressures is 0 to 1 bar for the lowest sensor and 0 to 0.5 bar for the others. The eigenfrequency of the marine aluminium frame is approximately 70 Hz. The data acquisition system is powered by a 12 V car battery that offers two days autonomy. It is composed of a real-time embedded industrial controller CompactRIO that ensures synchronized high-frequency data acquisition that is connected to a Raspberry Pi to allow a remote control using the supervisory control and data acquisition system PyScada (SCHRODER & LAVAYSSIERE, 2013).

(a) (b) (c)

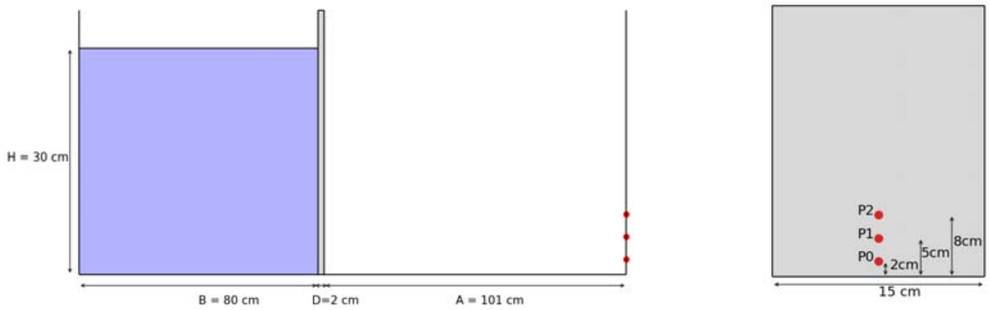
Figure 1. (a) Location of the pressure sensors on the WIP station. (b) Illustration of the deployment. (c) Location of the different measuring systems.

2.2 Laboratory validation experiment

2.2.1 *Experimental set-up*

The prototype WIP station was first tested during a laboratory experiment to measure impact pressures generated by a dam-break flow propagating over a dry bed. The experimental setup of this experiment is similar to LOBOVSKY *et al*., (2014). It allows to reproduce on a reduced scale the hydrodynamic conditions close to those of an overtopping wave impacting a vertical wall. The main objectives of this preliminary experiment were to verify the ability of the WIP station acquisition chain to precisely capture the different phases of the pressure signal evolution during the impact of the bore on the vertical structure, as well as the synchronization between the pressure sensors.

A series of experiments was carried out in a 2 m long, 0.4 m high, and 0.15 m wide rectangular reservoir. The experimental setup is schematized in figure 2(a). On the left side, a 2 cm-thick door delimits an 80 cm long tank initially filled to a height of 30 cm with water. The downstream part of the tank, which was initially dry, was delimited by a vertical plate located at 1.01 m from the removable door. The vertical plate at the end of the tank was equipped with 3 of the WIP station pressure sensors aligned on the vertical axis in the center (figure 2(b)). Sensor P0 is located 1 cm lower than the sensor 3 and 5 mm higher than the sensor 2 of the experiment carried out by LOBOVSKY *et al.*, (2014), and P2 is exactly at the same location as their sensor 4. The acquisition frequency of the piezoresistive sensors were set to 10 kHz to measure precisely the local short peak duration generated during wave impact. Furthermore, they were synchronized with a video acquisition system composed of a GoPro® camera capturing images at 120 FPS.



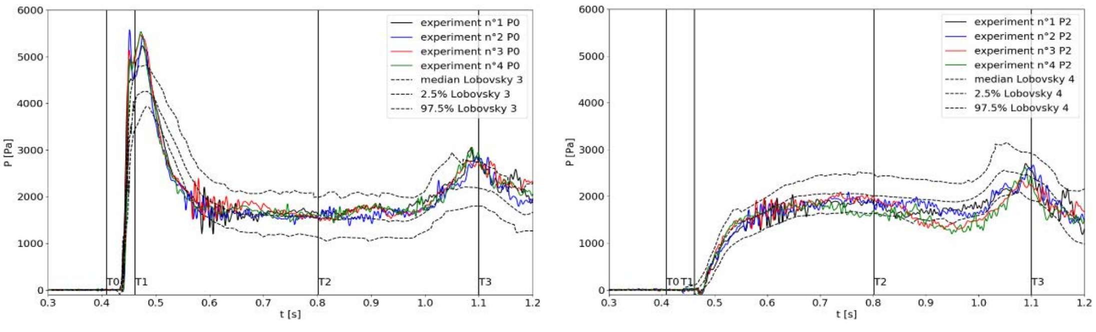
(a) *(b)*

Figure 2. Experimental set-up dam-break geometry (a), location of pressure sensors on the vertical plate (b).

2.2.2 *Analysis of the measurements*

The dam break experiment was reproduced during four tests. The four pressure signals corresponding to sensors P0 and P2 are plotted respectively in figure 3(a) and figure 3(b). The signal shape obtained from the four tests is very similar at both measuring points. This testifies of the good repeatability of the experimental conditions and of the measurements by the station. Additionally, the comparisons with the pressure signals measured in LOBOVSKY *et al.*, (2014), which are also plotted in figure 3 at the closest positions to those of our experiment, show a consistent evolution of the signals captured by our measuring device.

The shapes of the signal time series measured at P0 and P2 are in overall comparable except at T1, which corresponds to the time just after of the bore arrival. At that time, the highest peak pressure is recorded by P0, i.e., the lowest pressure sensor that receives the full impact. This peak is characteristic of the impulsive component of the pressure signal. The mean maximum value computed from our four tests is 5,45 kPa. The mean rise time required to reach the peak pressure was estimated based on LOYSEL *et al.*, (2012): it reaches 43 ms. Finally, the mean pressure impulse is equal to 450 Pa*s. Pressure peak, rise time and pressure impulse measured for the impulsive component are comparable with values computed by LOBOVSKY *et al.*, (2014) respectively ranging between [411-1518] Pa*s, [0.002-0.08] s and [3596-7300] Pa.



(a) (b)

Figure 3. Time series of the impact pressure signals measured at sensors P0 (a) and P2 (b) for our four tests, and data collected at sensors 3 (a) and 4 (b) in LOBOVSKY et al., (2014).

A series of 4 video images representing the temporal evolution of the free surface profile during the impact is displayed in figure 4. At the time instant T0, the bore tip gets in contact with the bottom of the vertical plate with no impact on pressure sensors yet. The dynamic peak pressure occurs at T1, when the vertical deviation of the water impacting the wall begins. At T2, the pressure signals at P0 et P2 are quasistatic with values around 2 kPa followed by a secondary peak around 2.8 kPa that occurs at time T3 on both sensors. The quasi-static pressure is measured when the run up along the vertical plate has reached its maximum value. Finally, the second pressure peak measured at T3 is due to the vertical down rush of water falling back in the water volume accumulated in front of the vertical structure.

(T0) (T1) (T2) (T3)

Figure 4. Video frames of the free surface (at T0 = 0.409 s, T1 = 0.461 s, T2 = 0.802 s, T3 = 1.100 s) showing the creation of the runup jet along the vertical plate and its fall under gravity on the underlying water body. Synchronized time with figure 3.

3. Field deployment of the WIP station

3.1 Conditions

The deployment of the WIP station in field conditions was performed on the seawall of the Grande Plage of Biarritz, on the 4th of March 2022 at high tide during spring tide (figure 1(b) and 1(c)). The objective of this first field deployment was to test the WIP station during overtopping wave impacts for moderate nearshore wave conditions. The Grande Plage of Biarritz, located on the French Bask coast, is an intermediate-reflective embayed beach, which is characterized by a sandy foreshore ending with a promenade (MORICHON *et al.*, 2018). It is part of an urbanized environment exposed to energetic storms and overtopping waves during winter. During the test, the offshore wave conditions were measured by a directional wave buoy moored in 50 m water depth and corresponded to a significant wave height of 3 m and a peak period of 15 s. The WIP station was deployed at the seaward limit of the upper beach promenade (figure 1(c)-1), vertically aligned with the small vertical wall of 30 cm. Additionally, to estimate the overtopping water column height, an RBR pressure sensor was fixed on the vertical wall 15 cm above the sand level (figure 1(c)-2). This dispositive was complemented with a Gopro® camera (figure 1(c)-3) to monitor incoming bores characteristics over the swash zone prior to the impact. The impact station was set to measure impact pressures for 1.5 h around high tide at a frequency of 10 kHz. The RBR sampling frequency was set at 2 Hz and the camera continuously recorded images at 60 fps for 1 h.

3.2 Data analysis

During the field experiment, five small impacts on the seawall of highly aerated overtopping broken bore were measured by the three lowest sensors P0, P1, and P2. Measurements recorded during the most significant impact are displayed in figure 5 together with a sequence of snapshots taken at different time instants. The duration of the corresponding overtopping event is 4.5 s from the first contact of the incident bore with the WIP station to its full reflection. The maximum value of the pressure was measured by the lowest sensor P0 and reached 2.5kPa. The shape of the time series of the pressure signals recorded by the 3 sensors are very similar. The pressure increase is first gradual and consistent with the evolution of the pressure measured by the RBR. Then, the recorded signals oscillate around an average value (1550 Pa) before decreasing back to 0. This behaviour is comparable of the quasi-static component of the dam break experiment analysed in 2.2.2. However, the impulsive component that was captured in the laboratory experiment was not observed on any of the pressure sensors. The analysis of the synchronized video images with pressure signals (figure 5 (b)) gives a better insight into the conditions that lead to the evolution of the pressure during the impact. At T1, the sensors start to record a signal corresponding to the beginning of the runup of the flow along the WIP station. At that time, the station is submerged by a very aerated mass of water that keeps rising up to T2. The rundown of the flow occurs between T2 and T3. The pressure drops earlier on the highest sensor P2 and then does not change.

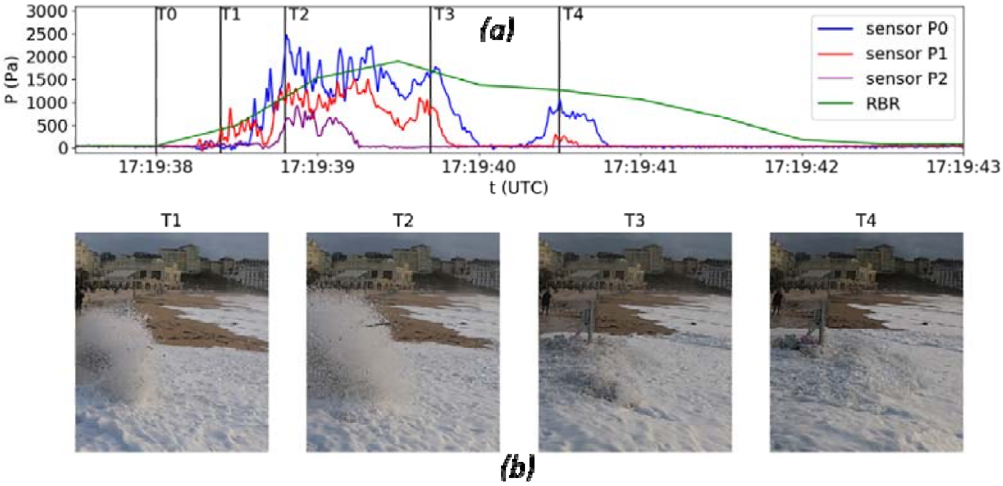


Figure 5. Overtopping impact pressure signals and corresponding frames to different impact phases.

At the two lowest sensors P0 and P1, the decrease of the pressure is followed by a second smaller peak occurring at T4 at the end of the vertical water down rush, almost 1s after T3. The analysis of the snapshot at T4 (complemented with the analysis of the full video) suggests that this second peak results from the interaction in front of the WIP station between the reflected water body traveling seaward with the incoming bore still traveling shoreward. This interaction results in a secondary shoreward water motion impacting the WIP station at least up to P1.

4. Conclusion

This study presents the development of the innovative Wave overtopping ImPact (WIP) station, which aims at measuring impact pressures in real conditions during energetic wave regimes. The analysis of a laboratory experiment and of a first field test was presented. The obtained result highlights the potential of the WIP station to provide more insight into the impact process related to the interaction of an overtopping wave with a vertical structure. The next step of this work will be to deploy the device again targeting more severe overtopping events. In order to link the measured pressure peaks and the maximum forces with the different typologies of hydraulic jumps, the coupling of the measured pressure analysis with video captures of the water free surface will be reconducted. This future database should not only support a better understanding of the dynamics of the impact of overtopping waves, but it will also be used as reference data for the validation of numerical models that can eventually be used, for example, to test and validate mitigation of scenarios of coastal flooding risk.

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