Experimental investigation of parameters influencing hydrodynamic loads generated by breaking wave impacts on floating offshore wind turbines

Florian Hulin(1,2,3), **Alan Tassin**(2), **Jean-François Filipot**(1), **Nicolas Jacques**(3)
(1) France Énergies Marines, Plouzané, France
(2) Ifremer, RDT, F-29280 Plouzané, France
(3) ENSTA Bretagne, UMR CNRS 6027, IRDL, 29806 Brest Cedex 09, France
florian.hulin@france-energies-marines.org

1 Introduction

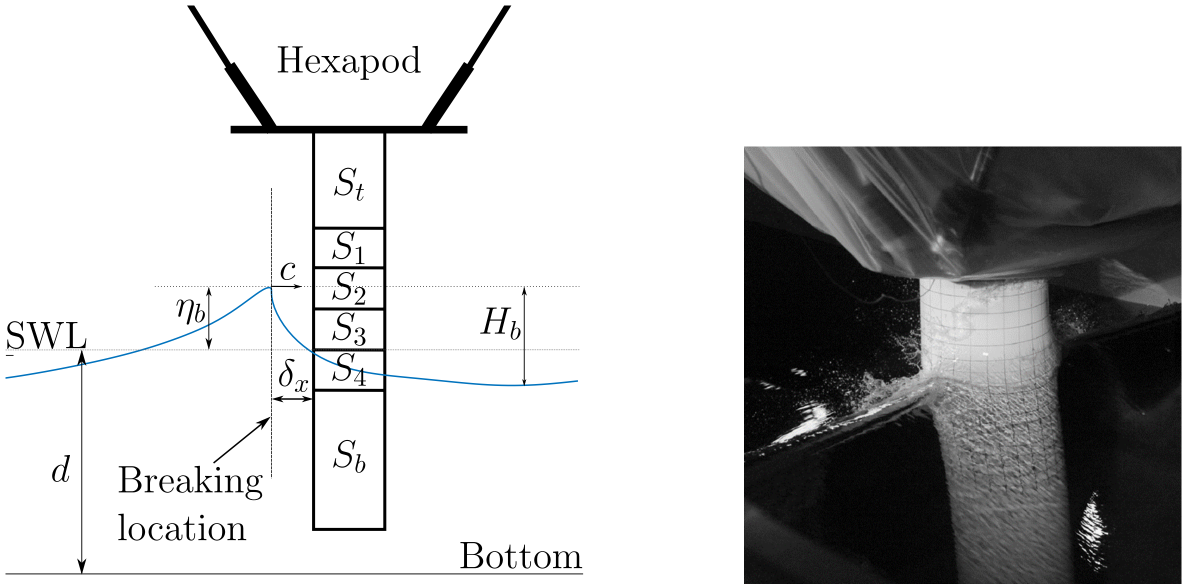
The development of offshore wind turbines has renewed the interest in the prediction of the severe loads induced by breaking waves on offshore structures. In the last decades, various formulas based on experimental results were developed to predict the impact force that may be expected on fixed offshore structures from a given wave ([1]) or a given sea state ([2]). We report here on the experimental campaign conducted within the DIMPACT project, which aims at better characterizing the loads generated by breaking wave impacts on floating offshore wind turbines (FOWT). This work benefited from government support managed by the Agence Nationale de la Recherche under the program Investissements d'Avenir with the reference ANR-10-IEED-06-34. Experimental tests were carried out to measure breaking wave impact loads on a vertical cylinder. A particular attention was devoted to the load evolution as a function of the distance between the cylinder and the breaking location and to the effect of the FOWT pitch and surge motions.

2 Experimental setup

The experiments were carried out in Ifremer's wave flume. The flume is equipped with a piston-type wave maker. A vertical cylinder with a diameter of 40 cm was placed in the breaking zone (fig. 1a). The cylinder was fixed to a six degree-of-freedom motion generator, hereafter named the hexapod. The cylinder is divided into 6 sections. Four of them, labelled S_1 to S_4 (fig. 1a), are instrumented. They are composed of an inner part and an outer part. The inner parts are bolted together and to the upper and lower sections to form the backbone of the mockup. The outer parts are fixed to the inner part through a 4-component load cell. The force and torque along the two horizontal axis are measured independently on each section.

3 Wave generation

The phase focusing method was used to generate waves breaking in the vicinity of the mockup (fig. 1b) using a JONSWAP spectrum. They were first modeled using a fully non-linear potential flow (FNPF) solver developed by S.Grilli ([3]) to precisely adjust the breaking location before being generated in the flume. We define the breaking location as the position of the vertical part of the free surface at the time instant at which the tangent of the free surface becomes vertical locally. The accuracy of the free-surface profiles predicted numerically was assessed experimentally through the measurement of the profiles along the wall of the flume using a high-speed video camera.

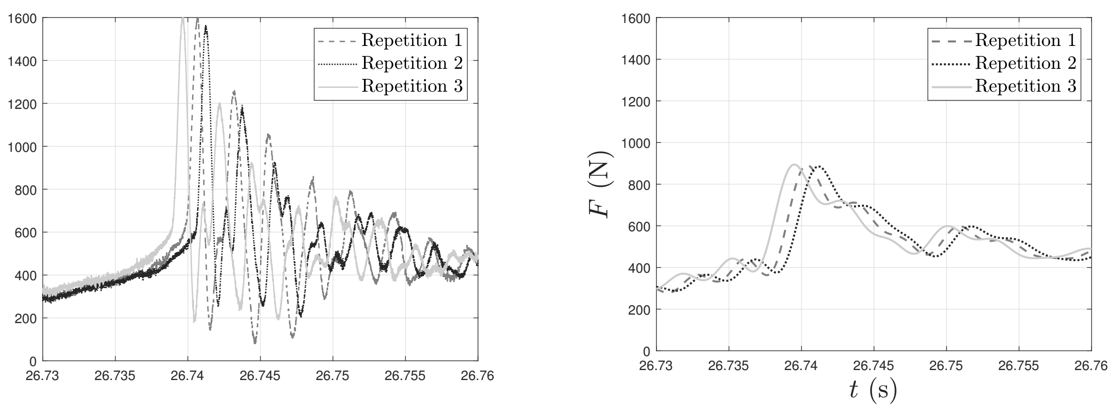


(a) (b)

Figure 1: (a) Description of the experimental set-up and (b) picture of a breaking wave impacting the mockup.

4 Wave force measurements

Typical wave impact signals obtained during the experiments are presented in fig. 2. The three curves correspond to three repetitions of the same impact conditions. Fig. 2a presents the raw force measurements along the x-axis while fig. 2b depicts the 300 Hz low-pass filtered signals. The repeatability is deemed satisfactory, although a time shift of a few ms is observed between the different runs. The impulsive nature of the impact loads induces



(a) (b)

Figure 2: Sum of the (a) raw and (b) 300 Hz low-pass filtered force signal on the four sections along the x-direction for 3 repetitions of an impact.

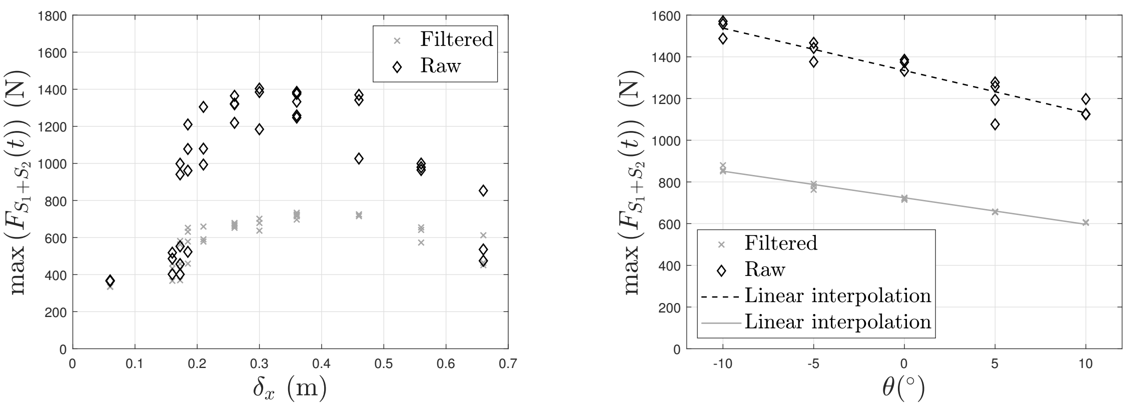
structural vibrations of the mockup which induce important oscillations of the force signal. These oscillations may be eliminated by applying a low-pass filter to the force signals.

5 Results

In this section we investigate the influence of different parameters affecting the maximum impact load acting on the two top sections. This analysis is performed on the raw measurements as well as on the filtered measurements.

5.1 Distance between the front face of the cylinder and the breaking location

For a given breaking wave, there is an interval of locations for the cylinder in which hydrodynamic impact occurs. The resulting load depends on the cylinder position in the interval. Let δ_x be the distance between the front face of the cylinder and the breaking location (fig. 1a). Impacts were carried out for a progressively increasing δ_x while the impacting wave was kept the same. The evolution of the measured maximum impact load as a function of δ_x is depicted in fig. 3a. A steep increase of the load occurs around $\delta_x = 0.18$ m. Simultaneously, the maxima of the raw and filtered signals start diverging at this point. This indicates that the structural response becomes more important, which can be induced either by a higher hydrodynamic load or a steeper increase of the hydrodynamic load. Larger values of δ_x lead to a plateau followed by a slow decrease of the maximum impact force.



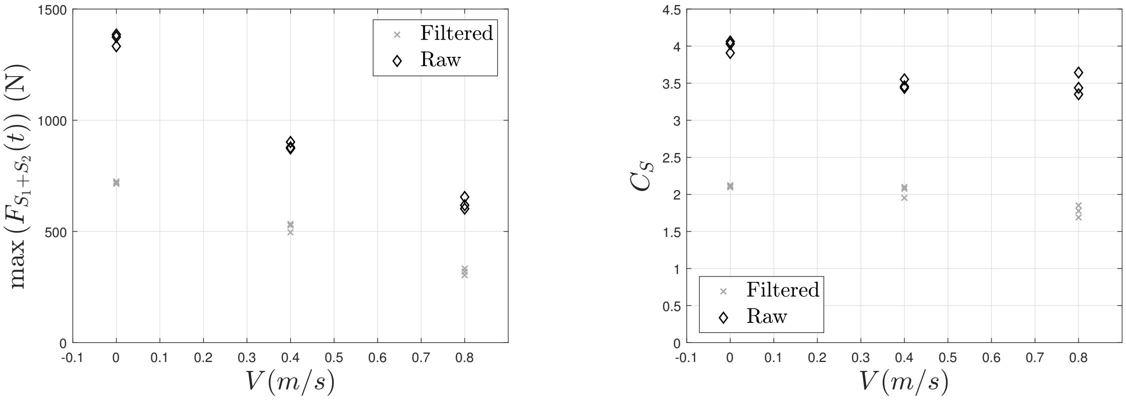
(a) (b)

Figure 3: Maximum force measured on the 2 sections during wave impacts (a) at different positions and (b) for different pitch angles.

5.2 Influence of the pitch and the surge

FOWTs may present a pitch angle or a surge motion during impact. We investigated the influence of the pitch angle in the range [-10°, 10°]. The maximum impact force is plotted as a function of the pitch angle in fig. 3b. The evolution of the impact force with the pitch angle is almost linear in the considered range.

The evolution of the maximum impact load as a function of the mockup velocity is depicted in fig. 4a. The mockup kinematics was chosen so that the mockup velocity is constant around the instant of impact. Fig. 4b presents the results in terms of slamming coefficient C_S, i.e. the maximum impact force divided by $\lambda \eta_b \rho R (c_{crest} - V)^2$, where c_{crest} is the speed of the crest computed numerically, η_b the breaking height (fig. 1a), ρ the water density and λ the curling factor, arbitrarily taken equal to 0.5. It appears that C_S does not vary much with V, which supports the idea that a wave impact with velocity can be treated as a wave impact at the relative velocity between the wave and the structure.



(a) (b)

Figure 4: (a) Evolution of the maximum measured force on the two upper sections and (b) of the corresponding slamming coefficient as a function of the mockup horizontal velocity.

6 Conclusions and future work

The evolution of the maximum impact force as a function of the distance between the cylinder front face and the breaking location was determined for a given plunging breaking wave. A sharp increase of the maximum load associated to a stronger structural response occurs at a distance of 18 cm. The experiments with different pitch angles have shown that the maximum impact load evolves linearly as a function of the pitch angle in the range [-10°, 10°]. The experiments with a horizontal velocity of the mockup have shown that an impact with velocity can be treated as an impact at the relative velocity. These results are an important step into the introduction of FOWT motions in the estimation of the loads associated to breaking waves that may be encountered by a machine.

In order to eliminate the important oscillations introduced by the vibrations of the mockup, a novel methodology showing convincing preliminary results is currently being developed to compensate for the dynamic structural response affecting the load signals. Other types of breaking waves will be investigated in the upcoming second experimental campaign. It is anticipated that the results of the second experimental campaign and the novel compensation methodology will be presented at the conference.

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