Postdoctoral researcher proposal

Measuring and analyzing sea states and wave breaking statistics in a wave basin for Offshore Wind Turbine applications

3DWaveBI project : 3D Wave Breaking Impacts
Institut Polytechnique de Paris / Ecole des Ponts

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Context
The design and survival of offshore structures is determined by wind and wave impacts, and accurate knowledge of wave forces is an essential step in the design of Offshore Wind Turbines (OWT's). Structures are designed considering both the operation of the structure under normal conditions, and its survival under extreme conditions, using a series of Design Limit Cases (DLC's). To evaluate the survival of OWT's, it is necessary to estimate the maximum load that is expected during the structure's lifetime, which is known as the ULS (Ultimate Limit State). Then, a security factor is applied to take into account the uncertainties the method used to define the maximum load and to define the acceptable level of risk [WG20]. In industrial studies, the maximum load is estimated with the wind and wave conditions with a 50-year return period, which are calculated using semi-probabilistic approaches, as defined by international standards [IEC09,DNV14]. These methods thus require an accurate estimation of the local sea state around the structure. However, the stochastic nature of the environmental conditions (e.g. wind, waves) contributes to the technological difficulties in estimating the maximum load, which remains a significant limitation in applying this approach [WG20].

One of the main objectives of the 3DWaveBI project is to improve the estimation of 3D local wave conditions and wave forces on structures in irregular and multi-directional sea states, including wave breaking impacts, in particular for sites with complex bathymetry, to improve the estimation of the ULS. To this day, there is a lack of openly available data to validate 3D wave propagation and wave-structure interaction models because of the challenges in measuring accurately the spatial and temporal variability of wave conditions and wave forces on structures at scales of a wind farm. High spatial and temporal resolution observations of 3D wave fields and their impacts on structures are thus needed [CTM12]. The 3DWaveBI project aims to respond to these needs with two main goals :

- to improve 3D models of wave propagation and resultant wave forces, including breaking waves, and
- to create a laboratory data set characterizing the propagation, transformation, and breaking of irregular and multi-directional waves, including wave impacts on a structure, over a spatially variable bathymetry to validate the modeling approaches.

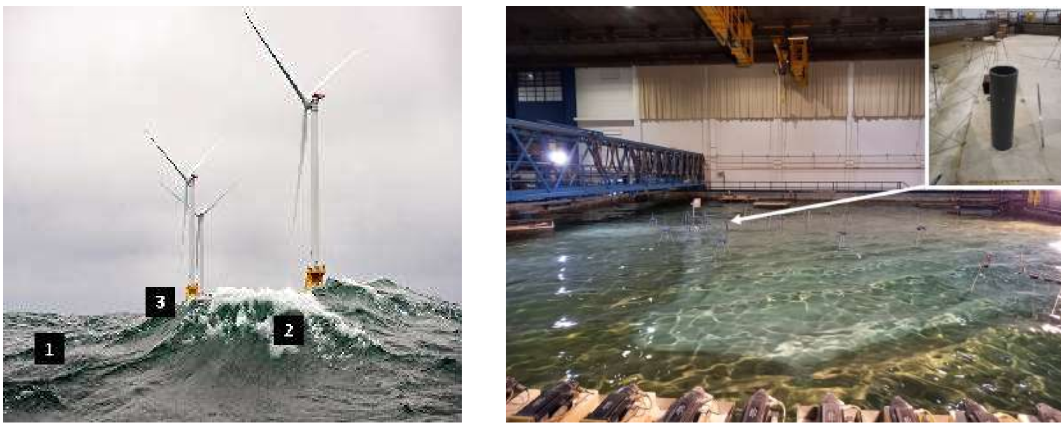


FIGURE 1. (left) Identification of the three zones of interest : (1) the propagation of irregular waves, (2) characterization and statistics of breaking waves, and (3) wave forces on a structure. (right) Physical model (1/40 scale) of these three domains in a 3D wave tank with a variable bathymetry, instrumented with wave gauges to measure wave conditions throughout the tank, a cylindrical structure equipped with a force transducer (zoom at top right) that represents a fixed wind turbine, and 2 camera systems (not shown) to observe the spatial distribution and to characterize wave breaking at the free surface and locally at the structure.

This project began in 2020 with the thesis project of Sunil Mohanlal (ENPC, 2020-2023), which is focused on improving numerical modeling of 3D wave propagation and breaking in a NWT (Numerical Wave Tank). The three main main scientific challenges of the thesis are related to the three physical domains shown in Figure 1, left) :

(1) accurate estimates of wave propagation over a variable bathymetry at the scale of an offshore wind farm using a fully nonlinear and dispersive 3D model base on potential flow theory (code NWT);

(2) characterization of wave breaking, and taking these effects into account in the 2D [MHYSrev] and 3D versions of the model; and

(3) improvement of the estimation of wave forces, and in particular breaking waves, on offshore structures.

The first laboratory experiments took place in July 2022. A defect in the wavemaker is currently being repaired, and the experiments are scheduled to start again in September 2023.

Scientific project Within the 3DWaveBI project, the objectives of the postdoctoral researcher are focused on the completion of the laboratory experiments and the analysis of the experimental data to characterize the spatial variability of sea states and associated wave breaking statistics, as well as the wave forces on a fixed cylindrical structure for breaking and non-breaking waves. The three spatial domains of interest identified at sea (Figure 1, left) are represented at a 1/40 scale in the 3D wave tank at the Chatou laboratory (Figure 1, right).

The preparation of the laboratory experiments was completed in 2022 to be able to characterize (1) the wave field, (2) the spatial variability of wave breaking statistics, and (3) the wave forces on the structure. In this study, it is of particular interest to study wave propagation over a variable bathymetry (an idealized "dune"), which is often neglected in commonly used engineering models of wave breaking forces on a structure. The goal here is to create a database that may be used to validate existing empirical and numerical modeling approaches, as well as new approaches proposed within the context of the project.

In the wave tank, at the largest spatial scales, representative of part of a wind farm, the irregular and multi-directional wave field is measured using approximately 15 wave gauges placed throughout the domain (shown in Figure 1(right)). A cylindrical structure, representative of a monopile (Figure 1(right), zoom) is installed at the crest of the "dune". In addition, a high resolution camera (25 megapixels) is installed in the ceiling of the laboratory (13m above the wave tank) to complement the wave gauge measurements with planview images of the free surface (x, y, approximately 5m by 5m) to identify the wave breaking zones by the presence of whitewater generated during breaking (Figure 2). A second, high frequency camera (recording up to 160,000 images per second (i/s)) is installed at the side of the wave tank with a vertical field of view (y, z) to characterize the wave breaking (e.g. type, time of impact, and velocity). The camera is synchronized with a 6-axis force transducer (recording at 1000Hz) integrated in the cylindrical structures to measure wave forces on the structure (Figure 2).

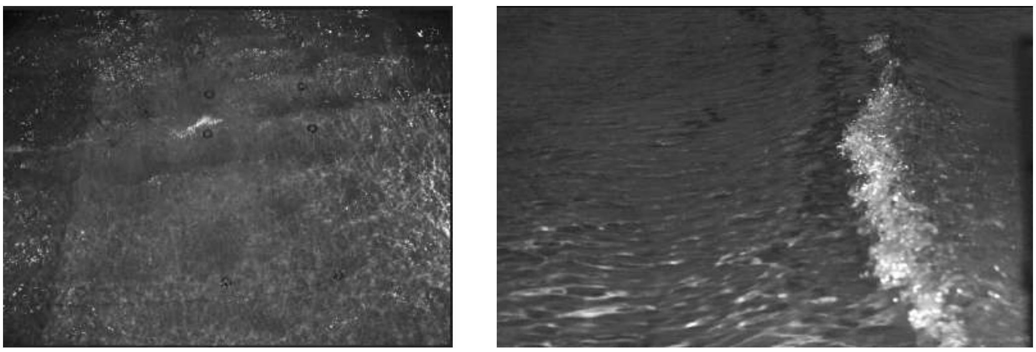


FIGURE 2. Images (left) from a high resolution camera (25 megapixels) installed 13 m above the wave tank with a planview of the free surface to identify wave breaking zones via an image analysis algorithm, and (right) a high frequency (1 kHz) camera installed with a vertical field of view of the waves impacting the cylinder to characterize the type and phase of wave breaking. The camera is synchronized with the force transducer measurements when the structure is present.

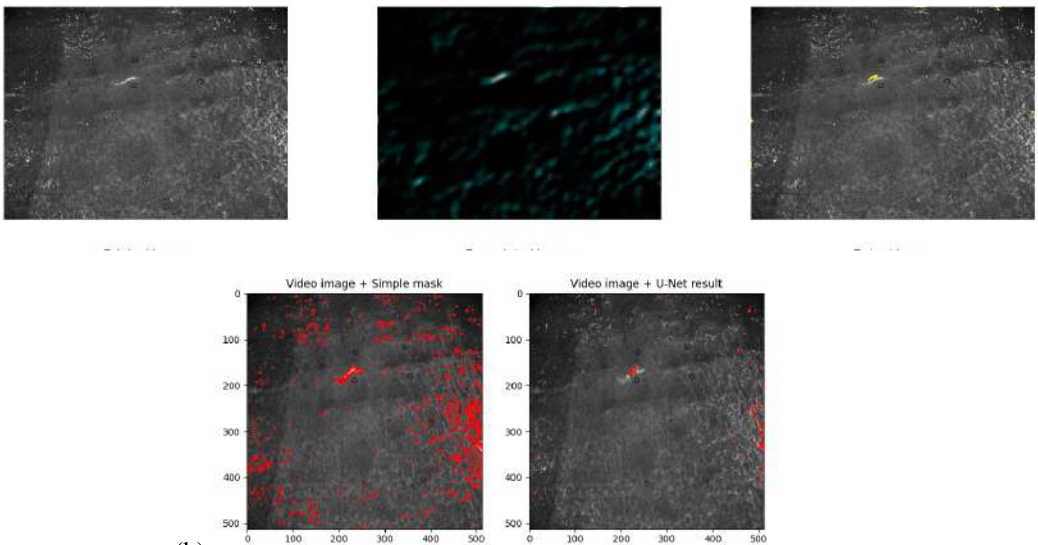
The scientific challenges of this project are related to the technical and theoretical aspects and analysis of :

(1) the observation of wave breaking in the wave tank, in particular the lighting to improve the image quality and analysis (for both cameras simultaneously) ;

(2) the optimization of image analysis techniques to identify wave breaking zones by the foam generated during breaking (e.g. threshold, AI methods) ; and

(3) the characterization of the spatial sea state variability, and the temporal variability of wave forces on the structure to evaluate currently used wave force estimate models.

This work is based on an experimental protocol that was put in place in 2022, and the experiments are scheduled to continue in the fall of 2023 with 2 series of tests focused on measuring complex (irregular, nonlinear) sea states with and without the presence of the structure, for 2 water depths, and a variety of wave conditions defined to be representative of real sites. Several wave breaking identification image analysis techniques are currently being tested, including an approach being developed during the thesis project (e.g. Figure 3, a), as well as a deep neural network approach applied for waves in intermediate water depths [SGFLD21] and a convolutional neural network approach applied in the wave breaking zone [SCV21] (e.g. Figure 3, b).



(a)

(b)

FIGURE 3. Preliminary tests of image analysis techniques used to identify the wave breaking zones by the generated foam using : (a) a convolution and threshold approach (yellow zones), and (b) the U-Net approach adapted from [SCV21] (red zones).

Results

The results of this work will be presented in the scientific community via workshops and conferences (e.g. B'Waves, ISOPE, EWTEC, ICCE, ...), as well as with industrials and throughout the E4C network.

Budget

Postdoc 24 mois - 140 k€
Conferences, training session - 12 k€
Publications - 6 k€
Experimental material (lights, diffusive fabric, pressure sensors, etc.) - 30 k€
Computer material - 12 k€ (laboratory computer, hard drives for data storage)
TOTAL : 200 k€

Contact

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