16èmes Journées de l'Hydrodynamique

27-29 novembre 2018 - Marseille

CENTRALE MARSEILLE

irphé Institut de Recherche sur les Phénomènes Hors Equilibre

CARACTERISATION DES ETATS DE MER EXTREMES ET DE LEUR DEFERLEMENT POUR LES EMR

EXTREME SEA STATES AND WAVE BREAKING CHARACTERIZATION FOR MRE ACTIVITIES

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Résumé

Cet article présente une expérience du projet DiMe visant à capturer des états de mer extrêmes et leur déferlement. Ces observations, collectées depuis le phare de La Jument, sont destinées à améliorer la connaissance des conditions extrêmes à considérer pour le dimensionnement des convertisseurs d'énergies marines renouvelables. Des analyses prélimaires des observations sont présentées, incluant les données de stéréo-vidéo, de radar en bande-X et d'accéléromètres.

Summary

This paper presents a field experiment part of the DiMe project and aiming at capturing extreme sea states with a focus on their wave breaking properties. These observations collected from La Jument lighthouse, are intended to help in refining the design conditions for Marine Renewable Energy (MRE) Converters. Preliminary analyses from the field observations are presented, which include stereo-video, x-band radar and accelerometers data.

I – Introduction

The design of any marine structure, including MRE converters, relies among other parameters on the knowledge of the most extreme sea states that will possibly be faced by the structure over its lifetime. The corresponding characteristic 100 or 50-year wave is then used to compute inertia and drag forces based on Morison theory ([10]). It is also now well acknowledged that in presence of breaking waves an additional impact or slamming force should be added. Indeed, at breaking onset, the horizontal fluid velocities below the free surface reach or even exceed the wave phase speed over a vertical portion of the wave crest. The wave crest (or at least part of it) behaves then as a wall of water moving at the phase speed and its encounter with a marine structure results in a violent impact, yielding a large and impulsive force. This breaking wave impact force must be considered in the marine structures design since it can exceed several times the magnitude of the combined drag and inertia forces, though over a very short time interval [15]. Because of this short impulsive force, breaking waves can excite specific structural modes of marines structures. For instance, [6] noted that only breaking waves where able to excite the second mode of oscillation of a 2MW fixed offshore wind turbine deployed at the Blyth wind farm (United Kingdom). The same authors further used this property to compute breaking waves statistics from the monitoring of the wind turbine oscillations.

The severity of the breaking waves, hence the magnitude of their induced force on the structures further depends on the type of breaking ([11]): the most gentle ones, known as spilling breakers are initiated by a modest jet located in the direct vicinity of the wave crests, while plunging breakers are characterized by a much more intense and large jet, projecting far away from the pre-breaking position of the crest maxima, enclosing an air pocket during the process.

The importance of breaking waves induced forces is acknowledged is the international standards detailing the design recommendations of marine structures. For the design of offshore wind turbines, the reference document is the 61400-3 report ([4]) produced by the International Electrotechnical Comission (IEC). It advises to consider the wave breaking impact forces based on [14]'s model. One key remaining issue to provide the relevant input to the model of Wienke & Oumeraci is the definition of the breaking waves statistics and characteristics at one particular site in design conditions. Among the scientific questions that are still open regarding breaking waves we would like to point out the following:

1. How many waves break per hour at a single location?
2. What are their wave height?
3. How are they distributed along the wave scales?
4. What is the along-crest extent of the breaking?
5. What is the type of breaking (spilling-plunging) of each of them?
6. Accordingly, over what portion of the front face the fluid velocities should be considered equal or greater than the phase speed?

All these questions are still open because the understanding of the wave breaking physics is still poor. For instance, until recently there was no concensus regarding a universal breaking criterion. [9] demonstrated that regular waves over a flat bottom are stable until $kH/tanh(kd) = 0.88$, with k the wave number, H the wave height and d the water depth. In deep water this leads to the familiar $H/L = 1/7$ threshold with $L = 2\pi/k$ the wave length of an individual wave. This theory is not directily applicable to irregular waves propagating over a possibly varying bottom. A paper from [1], suggests that any deep or intermediate water wave with a ratio u_c/C greater than 0.85 will inevitably and shortly break. Preliminary results from [13] show that this breaking limit could also be valid in shallow water. We note however that all those findings where produced through numerical simulations and should be validated with field observations, especially in storm conditions for marine structure design purposes.

The DiMe project has been designed to address the characterization of the wave breaking properties of extreme sea states. The first step of the project consists in documenting the extreme sea states are their breaking properties. Observations of storm seas is possible with wave buoy or current profilers (when they resist the storm) but these instruments do not provide any direct information regarding the geometry of the waves or there breaking statistics. Observations from satellites can also providing valuable information regarding extreme seas but rather on integral parameters such as the significant wave height. In the next section we will present a field experiment conducted from a lighthouse at sea that is expected to provide observations of wave breaking in storm conditions in intermediate to shallow water depth. These findings will be used to validate the development of new wave breaking statistics parameterizations intended to the engineers designing the MRE converters. We hope this will be usefull in improving the survivability skills of the MRE systems. Because wave breaking is the largest energy sink in storm seas, the new formulations developed in the project will be used to propose improvements in the source terms of phase average spectral wave model. The project further includes efforts in the representation of shallow water wave breaking by investigating the validity of a new breaking parameter proposed earlier for the deep and intermediate water depths by [1]. Preliminary results are presented in a companion paper ([13]). We expect that all the relevant results will be the basis for a set of recommendations to be used for revising the standard document addressing the extreme design of MRE systems.

Because all these topics can not be covered in a single paper and also because most of them are still in progress, we have chosen to focus on the field experiment mentioned above and aiming at documenting the extreme sea states and their breaking properties.

II – Wave breaking observations in extreme conditions

II – 1 Description of the field experiment site

This axis of the DiMe project aims at collecting and interpreting observations of sea states and their breaking in storm conditions. The site chosen is La Jument Lighthouse (see Figures 1 and 2) which presents three main advantages:

1. The lighthouse lies over a rocky platform that drops abruptly on its western boundary, the water depth ranging between 50 and 100m at a few hundred meters from the lighthouse.

2. The upper deck of the lighthouse is located at about 45m above the mean sea level, making the observation of very high sea states possible with a large field of view and a minimal shadowing effect.

3. An analysis of the HOMERE database ([2]) shows that the 10-year significant wave height at La Jument (in 50m depth) is equal or larger than the 100-year significant wave height of most of the French Channel and Atlantic coastline.

Figure 1: La Jument lighthouse hammered by a large breaking wave. Copyright C. Cain.

This makes this site an exceptional location for the study of extreme sea states.

The field work from La Jument allowed for the deployment of an X-band radar and of a stereo-video system. The measurement system is completed by a wave buoy and and ADCP deployed by Shom in the domain covered by the stereo-video and X-band radar. This experiment also includes accelerometers mounted on the lighthouse structure to infer the buidings displacements under wave loads. All the instruments deployed at the lighthouse are remotely triggered during storm conditions. The stereo-video system reproduces the sea surface in three dimensions and its evolution in time. It provides unique information regarding the relation between wave properties (3D geometry) and wave breaking occurence. The X-band radar capture a larger field of view (a few km^2, vs few 10 000 m^2 for the stereo video) and attempts to develop a method to exploit the backscatter data for wave breaking statistics quantification are ongoing.

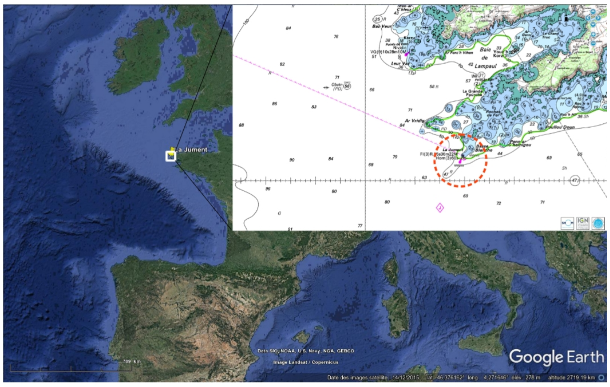

Figure 2: Location of La Jument Lighthouse (shown by the red dotted circle). The land in the upper right part of the enclosed figure corresponds to a section of Ushant Island.

II – 2 First output of La Jument experiment

DiMe's instrumental deployment on La Jument took place on December 5 and 6 2017. Because the access to the lighthouse by sea is hazardous, and the material boxes and people were too numerous, we relied on the civilian security helicopter to reach La Jument.

The team composed of people from Shom, France Energies Marines, Cerema, Ifremer, HZG and Phares & Balises spent about 24h on the lighthouse and installed the stereo video system, the X-band radar and three accelerometers on the lighthouse. This experimental setup has been completed by the deployment of a datawell directional waverider buoy and an Nortek AWAC instruments both moored by Shom at respectively 200m and 3km to the West of the lighthouse. The stereo-video cameras are mounted on each side of a hut located just below the lantern and looking approximately SW. Both cameras are equipped with sprinklers and wipers enabling to clean them before each acquisition and during extreme sea states conditions. The systems are connected to a computer hosted in the generator room of the lighthouse. Before each storm events, the generators were started remotely by Phares & Balises. Then an access to the computers was enabled by a 4G internet connection. One main issue with these systems is the volume of data to be stored: each 30min acquisition results in roughly 200 GB of data. This system has enabled to collect 7 TB of storm waves, corresponding to about 35 hours of observations collected between December 6 2017 and January 15 with significant wave height reaching 12.7m in the area of the lighthouse. These data are currently analyzed as illustrated in Figure 3.

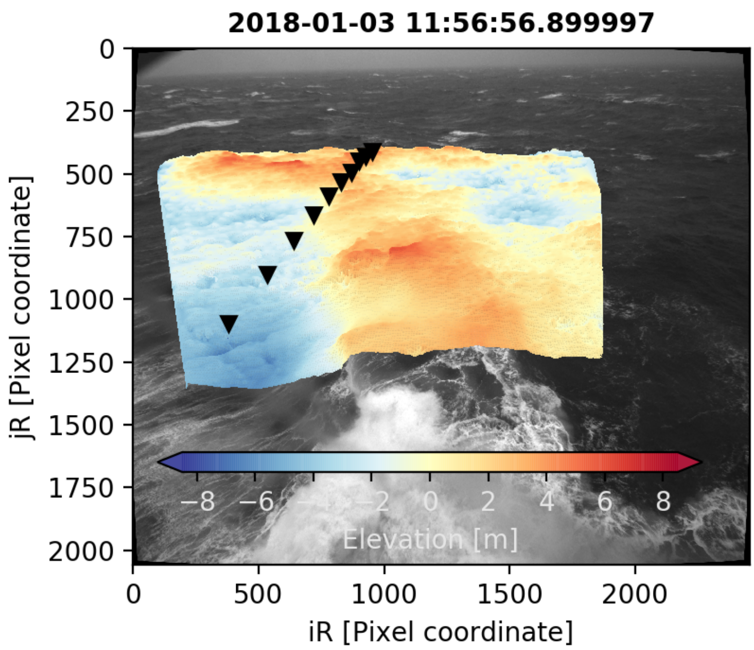

Figure 3: Sea surface elevation reconstructed from the stereo-video system deployed on La Jument lighthouse. The color scale suggests the wave height from crest to trough exceeds 10m. The reconstruction was made using the WASS code (Benetazzo et al., 2015).

The main output of the analysis will be enhanced information regarding the characteristics of large breaking waves including their geometry and their statistics of occurrence. One key aspect is the investigations of intermediate water depth effect on the wave breaking process. In deep water, nonlinear group modulations e.g. [2] are thought to be the main driving process for the breaking onset of dominant breaking waves. In shallow water the shoaling and shortening of waves leads to wave crest instability and wave breaking when the waves height reach a fraction of the water depth (e.g. [3]). In intermediate water depth both effects are probably competing and very little is known regarding the breaking properties in this situation.

The X-band radar data have already been analyzed in the aim of extracting information regarding wave breaking. Studies on the observation of wave breaking with different instruments have shown that one recognizable feature breaking among others in X-band radar signal is sharp jumps in the back-scattered intensity that are known as 'sea spikes' ([7]). Indeed, radar return from sea surface is mostly explained by Bragg diffraction on sea clutter, but other phenomena start to play a role when the radar beam meets breaking waves. The physical processes that lead to these sea spikes are not yet fully understood, but it is agreed that they are definitely a signature of breaking events. Using these observations, it seems possible to derive wave breaking statistics from radar data. This work has been done in a study by [12], where they used data from a fixed antenna X-band radar. Moreover, it has been shown previously that the presence of so called 'sea spikes' in the radar signal might not be sufficient to indicate we breaking because steep waves or other singular phenomena can also be responsible for these features ([8], [3]).

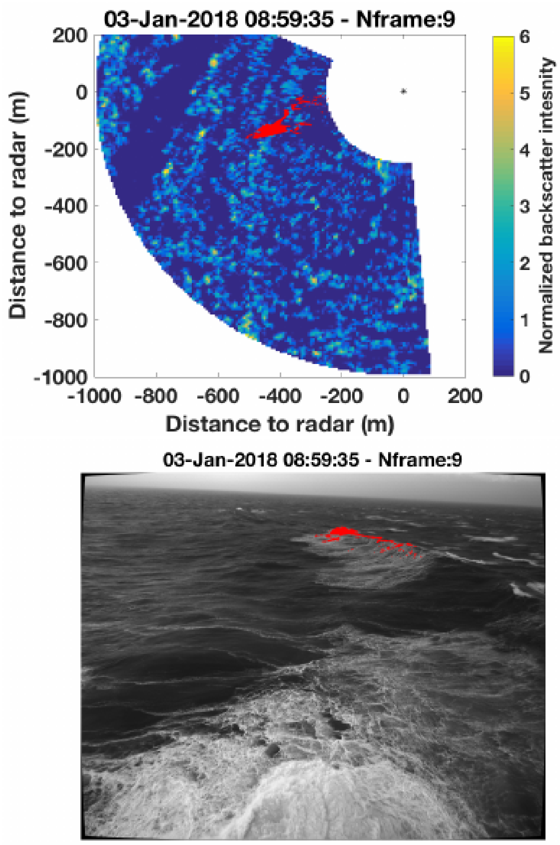

Figure 4: Collocated images from a breaking event from radar measurement (top) and from the video (bottom). From Vignes (2018).

To investigate the signature of the breaking events in the x-band bascattered intensity we used the combined information of the x-band and stereo-video observations that we managed to correlate in space and time (see Figure 4). Our preliminary results suggest that the signature of the breaking events is complex to distinguish from those of other steep waves. Actually, it seems that steep wave crests render the highest back-scattered signal. Broken waves have already lost part of their energy and are probably not the steepest waves in the field. Efforts were done to back propagate the broken waves to their "highest steepness state" to detect any change in the backscattered signal. However, the first results do not show any evidence of a sharp transition of the backscattered signal along the wave breaking process. The study will be pursued through the analysis of the Doppler effect that gives access to the wave orbital velocities. Because, the back-scattered intensity map (see Figure 4) can be used to track crest in time in space, the radar could provide an estimation of the ratio orbital velocity over phase speed that can be used to capture breaking occurrence. This method requires to set the radar antenna to a fixed azimuth for, say 30 min and this was not done during the last field experiment. This is part of the experimental plan for the winter to come. Another obvious research topic that will be addressed is the use on the radar and stereo-video camera observation that can be correlated in time and space, as shown by Figure 4. The dataset at hand is therefore an opportunity to progress on the extraction of wave properties (e.g. wave height) in a wave-by-wave framework from the radar backscattered signal, extending the work of e.g. [5].

Finally, the analysis of the accelerometers data has just started and correlation with the wave information in a wave-by-wave framework are in progress. Preliminary results suggests that in storm conditions a very limited subset of the waves produces large accelerations in the lighthouse. Our investigations will aim at unveiling the characteristics of these few waves: are they exceptionally larger and or steeper? Is their angle of approach different? Are these waves breaking on the lighthouse? If so at what stage of their breaking process are they when they impact the lighthouse?

III – Conclusions

The DiMe project, started in March 2017 has already allowed the deployment of wave sensors at a unique location, La Jument lighthouse for observing extreme sea states and breaking waves similar to those to be encountered by MRE systems deployed in coastal areas. One key aspect is the investigation of the wave breaking properties of extreme sea states evolving in intermediate waters, on which very little is known though this is of great importance for the design of MRE converters deployed in coastal areas, such as the future floating offshore wind turbines. The first field experiment of the 2017-18 has already enabled to capture of several extreme sea states whose properties are currently under investigations. The cross analysis of the stereo-video, x-band, accelerometers, in situ sensors is expected to refine the knowledge of these extreme sea states and this information will be transferred to the MRE industry throughout the project.

IV – Acknowledgements

This work has been done in the frame of the DiMe project, which benefits from government support managed by the Agence Nationale de la Recherche under the program Investissement d'Avenir with the reference ANR-10-IEED-0006-14. We are grateful to Phares & Balises team who made the La Jument experiment possible with strong support in the preparation, deployment and acquisitions of the data.

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