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Evaluation of the PhD thesis titled "Effect of the breaking wave shape on the temporal and spatial pressure distribution around a monopile support structure" by Mr. Duje Veic at the Institute of Hydro-engineering of the Polish Academy of Sciences

The PhD thesis by Mr. Duje Veic address an important topic in the field of offshore engineering, specifically the interaction of breaking waves with marine constructions. In current practice, the Morison formula is used to determine wave forces on a slender cylinder for non-breaking waves using the wave kinematics determined by the far-field conditions. For structures that are considered to be large compared to the incident waves, diffraction theory is used. The case of slender structures assumes higher importance currently due to their wide spread application as support structures to offshore wind energy turbines, which are increasingly being seen as the major source of renewable energy for the future. Due to the margins in the field of renewable energy and intense competition with the existing traditional sources of energy, the offshore renewable energy industry has to reduce the cost of construction so as to provide energy at competitive rates. In order to reduce the infrastructure costs, the design needs a higher level of optimisation, while maintaining a high enough safety against failure. Therefore, there is an urgent need to obtain more knowledge about the precise interaction of breaking waves with slender offshore structures. The major challenge in achieving this is that unlike in the case of non-breaking waves, the Morison formula cannot be directly applied to calculate the wave force on the structure. In current practice, the offshore oil and gas industry operates with large factors of safety depending on the visibility of the location of impact from the superstructure. In order to overcome this challenge in an optimal manner without endangering the survivability of the structure, several researchers have suggested different methods to evaluate breaking wave loading.

As described in the PhD thesis, the major experimental campaigns on this subject have been presented in works such as Suliz et al. (2005), Wienke and Oumeraci (2009), Suliz and Paszake (2007), Suliz and Paprota (2008, 2009), Arntsen et al. (2011) and Hildrebrandt and Schulrmann (2012), many of them using a vertical cylinder as the subject of the investigations. In the experiments, a major challenge to the accurate determination of the breaking wave impact loading is the large scatter in the peak value of pressure. In addition, the total hydrodynamic force on the structure is determined by a system of force transducers and strain gauges installed at the top and bottom of the cylinder. The cylinder responds to the impact of the breaking wave and vibrates at its natural frequency and this is also seen in the pressure measurements. Therefore, the measured forces actually include the total hydrodynamic force and the response of the cylinder under the loading. Several researchers have proposed different approaches to separate the response from the measured signal and obtain the total hydrodynamic force on the cylinder. A challenge associated with this has been the resolution of the pressure measurement around the cylinder that introduces uncertainties in the accurate calculation of an instantaneous impact event. The current PhD thesis aims at addressing this problem through numerical and experimental investigations to extend the understanding of breaking wave impact loading on a cylinder.

The PhD thesis presents a numerical analysis to evaluate impact pressures with high spatial and temporal resolution. The stated main objective for the PhD thesis is the investigation of the effect of breaking wave shape on load distribution arising from breaking wave impact on a monopile. The simplification of a rectangular load distribution is assumed in engineering practice leads to erroneous results in the calculation of wave loading. Therefore, the PhD thesis explores a relationship between the breaking wave shape and the distribution of wave loading on impact. High resolution pressure measurements and numerical simulations are attempted to achieve these objectives. The experiments are carried out at the Deltares facilities in Delft, The Netherlands. The results from the experiments are also used to validate the numerical model before further analysis is carried out. The numerical wave tank provided by the waves2foam toolbox to the CFD library Openfoam is utilised for this purpose. Given that most of the numerical models have assumed an incompressible fluid and the possibility of an escape for the wave crest around the cylinder, the current thesis explores the inclusion of compressibility effects in the numerical model.

The thesis presents experimental results with 10 pressure sensors along the length of the monopile in the wave impact region, breaking wave impact on a flat bottom and on a sloping bottom with different slopes, different incident wave heights and periods, and irregular waves with identification of breaking events. The experimental results are used to validate the numerical model. The numerical investigations include the study of the effect of the assumption of compressible and incompressible fluids in the simulations. Several statistical relations and load distributions are calculated, presented and analysed. The presented work is novel due to the study of the different aspects mentioned above.

The major results from the presented work demonstrate the following and introduce new knowledge into current literature, making an advancement to the current state of the art in the understanding of breaking wave impact on a monopile. The current study conducted experiments and simulations to study a 50-year storm event with more than 10000 irregular waves used in the study. It is found that the maximum measured force did not correspond to the most violent wave breaking stage. The numerical model showed that the maximum impact force is obtained when the monopile is moved 1.25R upstream with a 400% increase in the measured force from a similar breaking event. A need for a statistical procedure to determine the probability of occurrence of the most violent events and corresponding maximum breaking wave loading is elucidated. The numerical simulations are

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carried out for a monopile place on a flat bed and at the crest of a slope. In the case of the sloping bottom, the wave has an opportunity to shoal and therefore increase in wave height and result in a strongly breaking wave which produces a large impact loading on the monopile. It is observed that the highest impact pressure occurs in the region below the overturning wave crest, where the overturning wave crest meets the wave run-up on the structure. It is also observed that the area of impact loading is higher than that assumed in current engineering practice. The value of the slamming coefficient is found to be inversely proportional to the steepness of the breaking wave front. In this way, a relationship is established between the breaking wave shape and the resulting wave loading on impact. The simplified assumption of a rectangular distribution is found to be not representative of the real load distribution due to the impact of a breaking wave on a monopile. Finally, the effect of compressibility in the calculation of the breaking wave impact loading is investigated using the numerical model. It is seen that the inclusion of the compressibility of the air phase results in somewhat higher peak impact forces. There are strong oscillations observed in the decay stage, whereas the impact loads in the ringing phase are almost identical for the simulations with and without the assumption of compressible fluids.

The presented PhD thesis explores an important subject area in the field of ocean and offshore engineering, is scientifically sound, well-composed and extends the current knowledge regarding the interaction of breaking waves with a monopile beyond the current state of the art. New knowledge is obtained and some aspects that should be subjects of further investigation come to light. With this in mind, the following minor weaknesses in the presented thesis can be commented upon. The study with the numerical modelling including compressibility of the air phase show differences from the results obtained using the assumption of incompressibility. While the difference is expected, the result due to the cushioning effect from the compression of air under wave impact would be to reduce the total hydrodynamic force experienced by the structure. The author does mention this as well. On the other hand, the numerical results show a marked increase in the calculated forces under the assumption of compressible air. This points towards a need for further understanding of not only the interaction under compressible assumption, but also the numerical methods involved in the calculation of the RANS equations under this scenario. The thesis lacks an in-depth explanation and analysis of the numerical modelling of compressible flows in impact scenarios. Another shortcoming of the presented research is the quality of resolution of the free surface using the volume of fluids method. While the thesis elaborates upon the importance of a sharp representation of the free surface, only the VOF method is used to obtain the free surface. This method is highly susceptible to diffusion and needs artificial compression. The representation of the free surface is highly dependent on this process, therefore making it a rather unsuitable method for investigating scenarios where a sharp interface is necessary. This could be achieved using methods that provide a sharp representation of the free surface such as the level set method.

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The presented research work on the interaction of breaking waves with a monopile with application towards offshore wind turbine substructures makes a contribution to the current literature and brings to light areas of research that need more study. The findings from this research work can be deemed sufficient to fulfil the criteria for the grant of a PhD degree. The presented PhD thesis is therefore recommended for a public defence and for consideration of the award of the PhD degree to Mr. Duje Veic.

I confirm that the dissertation of MSc. Eng. Duje Veic entitled "Effect of the breaking wave shape on the temporal and spatial pressure distribution around a monopile support structure" fulfils the requirements determined in the Act of 14th of March 2003 about academic degrees and an academic title and degrees and a title in the field of Arts (Journal of Laws 2003 No. 65 Statue 595 with further changes). Therefore, I apply for admission of MSc. Eng. Duje Veic to a public defense of the thesis.

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