Conclusion

Estimation of the breaking wave loading on cylindrical structures in engineering practice is based on evaluation of the non-impact and impact part of the total force. The non-impact force is generally calculated by applying the Morison's equation based on the stream function wave kinematics. The impact force is generally estimated assuming the rectangular load distribution along the area of the impact. The parameters of the rectangular load distribution are usually defined with the curling factor $\lambda \approx 0.4$ and the slamming coefficient $C_{sr}=3\text{-}2\pi$. The value of the slamming coefficient $C_s=2\pi$ is based on the solution of the theoretical model which solves the impact of infinitely long cylinder on the calm water with a constant speed. The curling factor estimations are obtained semi-empirically as a function of the measured impact force and the theoretical value of the slamming coefficient.

The magnitude of the impact force in experimental measurements is not easy to determine, as measurements are affected by the vibration of a structure. Application of a filtering procedure removes the effect of the structural vibrations, however, the filtering procedure also affects the oscillatory behaviour of the impact force which could be correlated with the compressibility effects of air pockets. The effect of air compressibility is usually neglected in the analysis of the breaking wave loads on cylindrical structures. The general explanation is that air pocket generated between the overturning wave jet and the cylindrical structure has open lateral boundaries, which allows a free air flow.

This study includes experimental and numerical analysis of a breaking wave interaction with a monopile structure. Conducted experiments include simulation of a 50-year storm condition where more than 10000 irregular waves are generated. The maximum measured force obtained in an analysis conducted for a flat sea-bed condition does not correspond to the most violent breaking wave stage. The results of the numerical model for the identical breaking wave event, but with the monopile translated $1.25R$ upstream, provide 4 times higher magnitude of the impact force. This shows a need to develop a statistical procedure to include the probability of occurrence of the most violent breaking wave stage in a breaking wave load analysis. The maximum measured force obtained for sand-bar cases corresponds to the most violent breaking wave stage. The impact part of a total force for these cases calculated on the bases of a simplified approach with a rectangular load distribution and $\lambda \approx 0.4$, $C_{sr}=2\pi$, is more than 3 times higher than the measured impact force.

The goal of the study is to investigate the effects of the breaking wave shape on the impact loads on a monopile structure. The results of the study are obtained by employing the numerical model which is based on the solution of the Navier-Stokes equations and VOF technique. The computational grid sensitivity analysis shows that characteristics of the impact force strongly depend on the thickness of the air-water interface. In order to reach a converged solution, the computational grid resolution in the zone of the wave impact must be very fine. The results of the applied incompressible numerical model agree very well with the results of the conducted experimental measurements.

The non-impact part of the computed breaking wave force is compared with the solution of the Morison's equation that is based on the stream function wave kinematics. For cases when steepness of the breaking wave front is low, the application of the Morison's equation results in a relatively good approximation of the non-impact force. As the steepness of the breaking wave front increases, the Morison's equations is not adequate for the calculation of wave loads.

The numerical results show 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. The analysis shows that at this location the breaking wave impact is maximum and the slamming coefficient is about $Cs=2\pi$. Away from the peak region, wave impact loads decay rapidly. The area of the impact load on the structure is significantly higher than the impact area defined and applied in engineering practice. The area under the computed impact load distribution can be represented by an equivalent rectangular area. Considering the geometrically defined curling factor, corresponding values of the slamming coefficients are scattered in the range $C_{sr} = \pi$ - 2π. The results show that the value of the slamming coefficient is inversely proportional to the steepness of the breaking wave front. Therefore, the approximation of the vertical load distribution by a rectangular is a simplification which cannot uniquely approximate real load distribution arising from breaking wave attack on a monopile structure.

The derived numerical results encourage us to propose an alternative method for the calculation of impact forces which can be further developed and eventually used for a preliminary analysis. The investigations show that the non-impact wave loads may be derived from the Morison equation based on the kinematics obtained directly from the NS/VOF solution, while the breaking wave impact forces may be assessed by applying the proposed diagram of the temporal vertical load distribution, Cs(t,z).

The effect of the air compressibility is investigated for the model and prototype conditions. The impact loads for model conditions are characterized by strong oscillations in a decay stage, while for prototype conditions, the oscillations of the impact forces in a decay stage are of secondary importance. The impact loads in rising phase are almost identical for the model and prototype conditions. This applies to both, the incompressible and compressible case. The peak impact force obtained by applying the compressible model is higher than the peak impact force obtained by applying the incompressible model for both the model and prototype conditions.