A CFD Study of Numerical Wave Tanks

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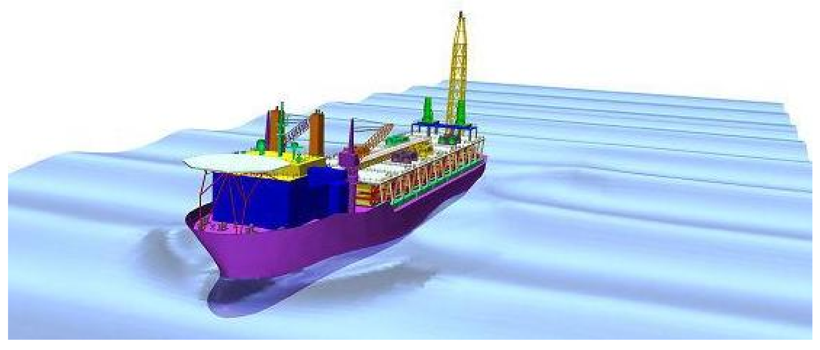
Introduction

Ships, cage aquaculture, offshore wind turbines and offshore platforms are examples of structures that operate in oceanic environments, constantly under influence of complex forces from wind, current and waves. In particular, waves are important during a design phase, as it causes motions and loads. Experiments in wave tanks and flumes are among the most commonly used methods for wave research today. As this is time consuming and expensive, this has led to the creation of Numerical Wave Tanks (NWTs). Lately, Computational Fluid Dynamics (CFD) has been applied to generate NWTs with a various of different numerical modeling techniques [1].

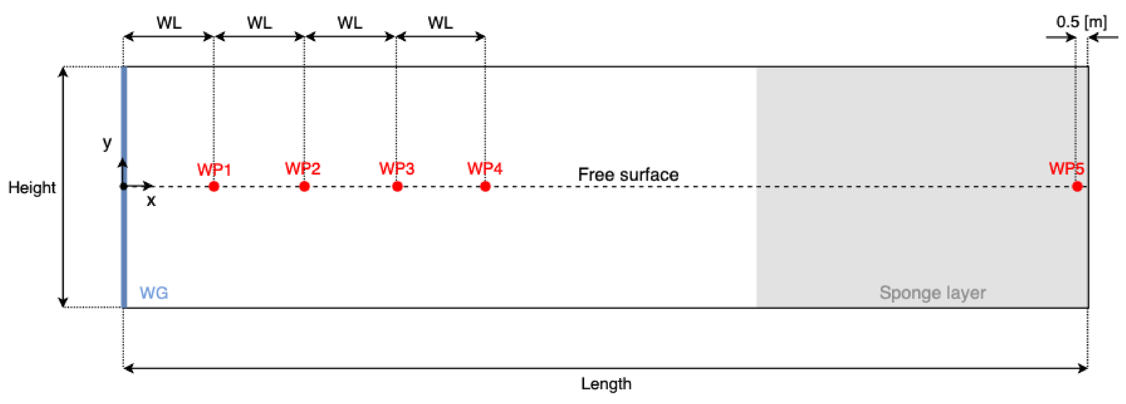
Illustrative photo from [2].



Stability and accuracy are essential to the performance of NWTs, and accurate wave generation are among the existing technical difficulties. Therefore, it is necessary to explore appropriate wave generation methods, that can reproduce actual marine conditions. The aim of the present work are, therefore (1) Performing a series of dependency studies considering the effect of varying setup parameters of importance in full scale. (2) Develop guidelines that will allow wave-capturing presented with alternative approaches for wave generation. (3) Perform a validation of the simulated waves against numerical results to analytical solutions.

Modeling and Software

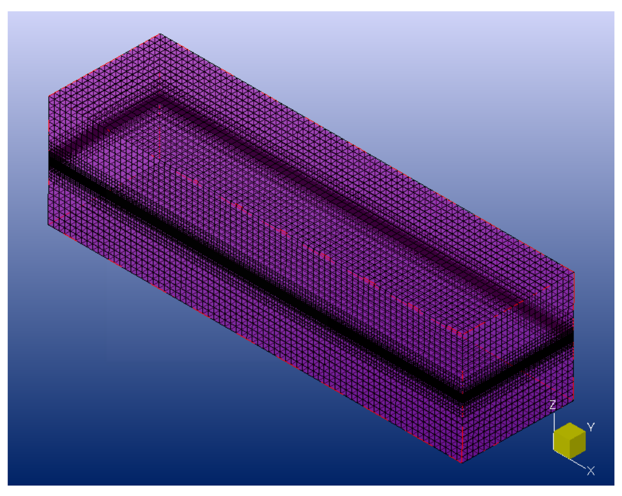
This thesis mainly performed 2D simulations, and additionally a preliminary 3D investigation. Two methods of generating waves were studied: (1) Internal Wave Generator (IWG) and (2) Wave Generator (WG). The applied CFD software, FINE/Marine, is based on Reynolds Averaged Navier-Stokes Equations, and it applies the Volume of Fluid method to model the free surface.



Schematics of the NWT are presented in the above figure for the case using IWG. Wave Probes (WP) were used to capture the free surface elevation in time. Boundary conditions applied were updated hydrostatic pressure for the lower and upper boundary, external far field condition for tank end and either far field or WG at the inlet. Sponge layers were used for wave damping.

Simulations of regular sinusoidal waves were simulated in 80 [s], and irregular simulations in 500 [s]. All computations used a relatively coarse time step size of 0.01 [s].

Mesh generation was performed using an initial mesh, and applying additional refinement around an internal surface representing the free surface. For the irregular analysis, Adaptive Grid Refinement (AGR) procedures were used. The figure to the left illustrates how the mesh was concentrated around the free surface.

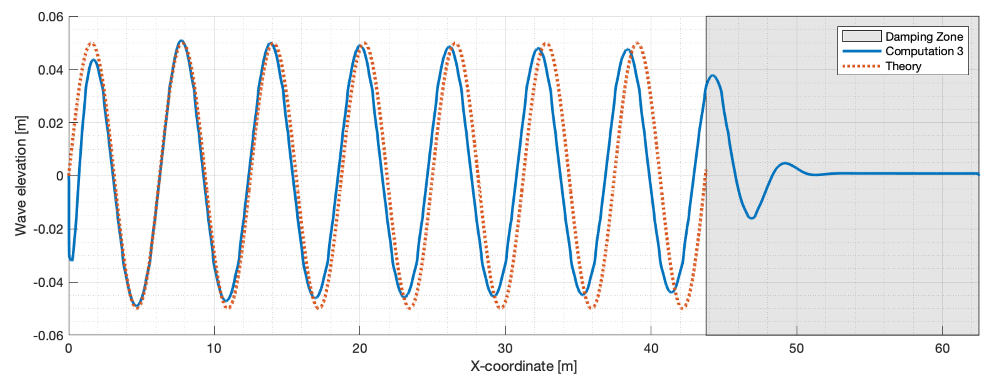


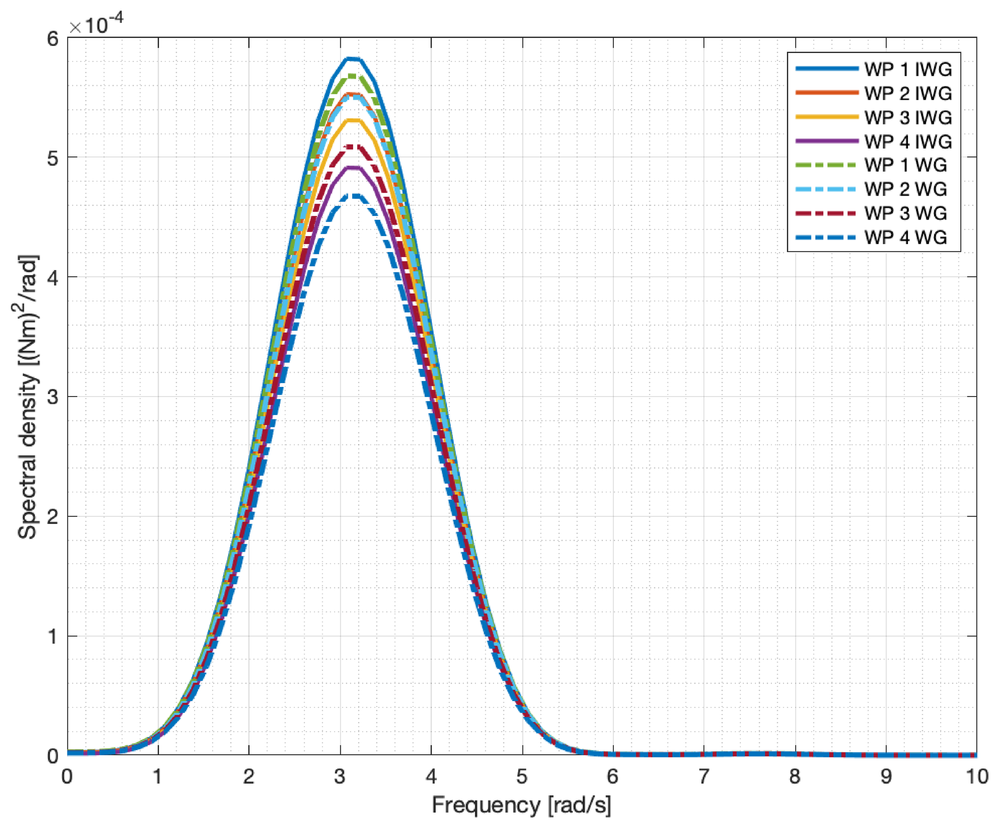
Abbreviations

AGR	Adaptive Grid Refinement
CFD	Computational Fluid Dynamics
IWG	Internal Wave Generator
NWT	Numerical Wave Tank
WG	Wave Generator
WP	Wave Probe

Results

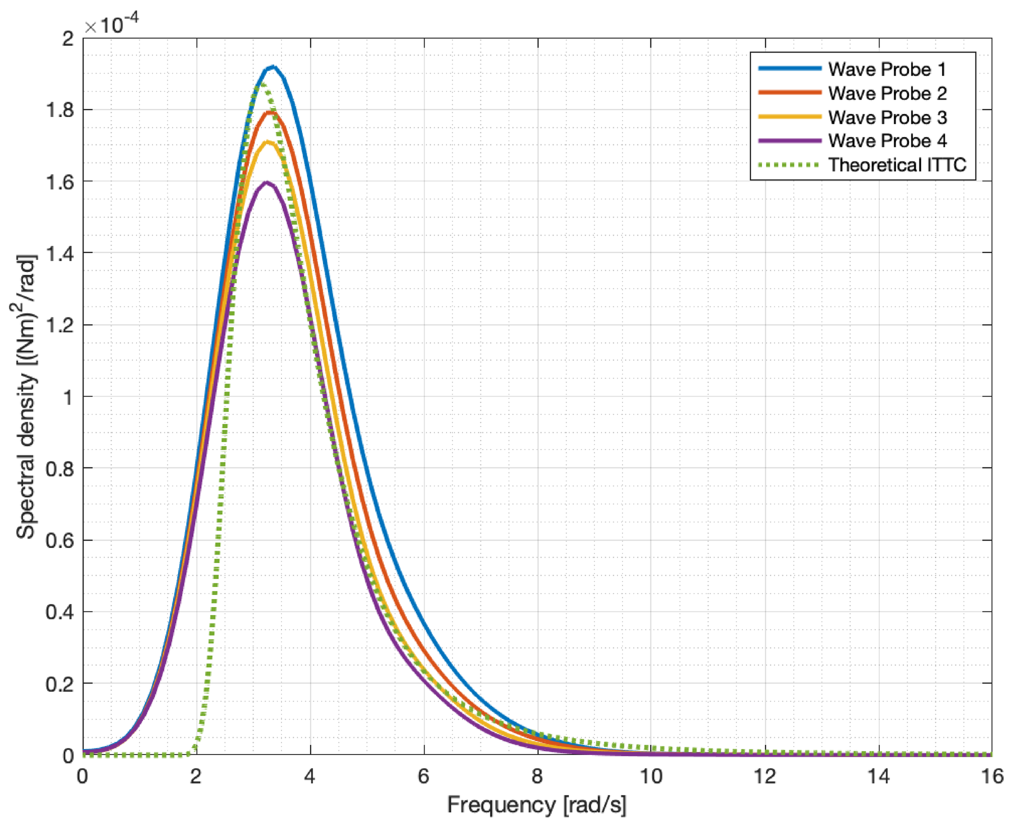
In this poster a small part of the results are presented. The first two figures are from a regular analysis comparing the two wave generation methods. In the figure below and to the left, the isoline representing the free surface downstream the NWT are presented compared to theory. Theoretical height is 0.1 [m], and the simulation wave height error stays below 1.1%.

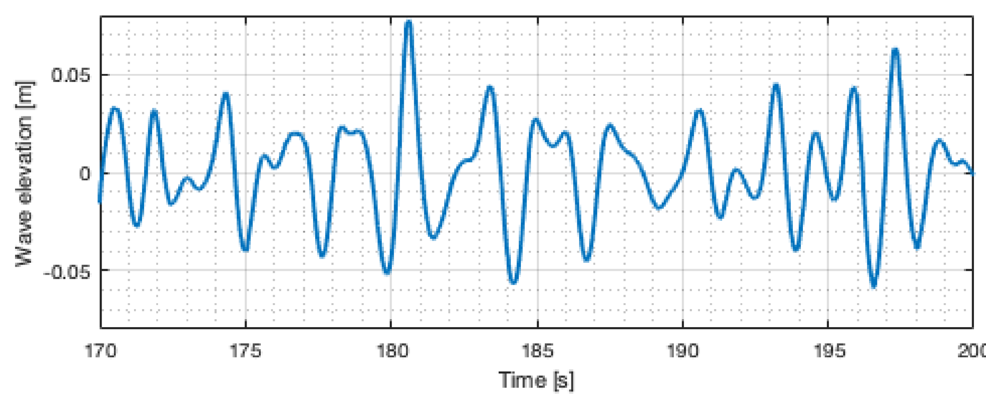




In the figure to the right, wave spectrums of computations using IWG (whole line) and WG (dotted line). Total wave energy decrease downstream the tank, and are higher by use of IWG than WG. Peak frequency of the simulated waves deviates with −2% of the intended theoretical frequency.

The next two figures are from an irregular analysis using the WG. To the right a figure of the free surface elevation at WP 2 is presented. Energy spectrums from each WP are plotted in the figure to the left, showing relatively good results compared to theory. Some low-frequency waves give a deviation from theory from $0 - 2$ [rad/s]. These irregular analysis also show that some energy losses down the tank are experienced.





Conclusions

The analysis showed that FINE/Marine generate regular sinusoidal waves with high accuracy using both wave generation methods with the proposed guidelines. However, the guidelines showed some limitations with steep waves using WG, where the damping zone was insufficient. Additionally, different damping behaviour for the two wave generation methods were detected. Finally, loss of wave energy downstream the NWT were experienced during all simulations.

Further work should involve an extensive damping zone efficiency study in 2D. Then an investigation of the low-frequency contributions to the irregular spectrums should be performed. Following, the domain should be extended into 3D and compared to the validated 2D waves.

Acknowledgements

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References

[1] Xiaojie Tian et al. Numerical and experimental studies on a three-dimensional numerical wave tank. *IEEE Journals & Magazines Access 2018*, 6, 2018.

[2] Stephen Ferguson. Numerical towing tanks, a practical reality? *The Maritime Executive*, 2015.