Hydrodynamic assessment of a floating wave energy device

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Motivation and Background

Ocean waves is an energy source in order of terrawatts worldwide, which to date has not been commercialized. There has been a recent boom in wave energy related research and development over the last years due to the rapid climate changes and the need to replace fossil fuels as the world's main energy source. EDRMedeso have been apart of an ongoing project lead by the Ocean Energy Systems Task 10 Wave Energy Converter Modeling verification and validation group. The group was established under the OES Technology Network program under the International Energy Agency, with an objective of assessing the accuracy of, and establishing confidence in, the use of numerical models in wave energy converters(WEC). That is the background of this master thesis, which was proposed by Dr. Ken-Robert G. Jakobsen at EDRMedeso.

Scope

A hydrodynamic assessment of floating wave energy devices using the panel method. ANSYS Aqwa is the simulation tool used to perform the simulations. Firstly, a sphere geometry will be evaluated, before moving on to a more complex WEC geometry(see figures under "Numerical Model"). The results will, for the sphere, be validated against analytical and other numerical results. In the case of the WEC float, the results will be compared to experimental results obtained in Sandia National Laboratories[1]. An important goal of the project is to establish in what areas the panel method performs at sufficient accuracy and where it lack necessary modeling levels. If time allows, a geometry study will be performed to optimize the WEC design with respect to energy output.

Conclusion

The obtained results from the assessment of the sphere suited well with theory and with the results obtained by other participants in the IEA OES Task 10 project. Through comparison with linear and weak nonlinear analysis, it was found that accounting linear effects only isn't necessarily enough to precisely describe the behaviour of a floating buoy when PTO damping is considered. This was especially visible in steep waves. Further investigation of the WEC float geometry is still ongoing. As of now it's seen that the Aqwa simulations underpredicts the heave force some. From a learning perspective, the experience gained through the work in this thesis has given a fundamental understanding and insight in the field of wave energy and the theoretical foundation of commercial softwares based on the panel method.

References

[1] Ryan G. Coa, Giorgio Bacelli, David Patterson, David G. Wilson: *Advanced WEC Dynamics Controls FY16 Testing Report*, Sandia National Laboratories (2016)

[2] Johannes Falnes: *A review of wave-energy extraction*, Elsevier Ltd (2007)

Numerical Model

The motion of a floating structure in time-domain can be represented by Cummin's equation[2]. It's a second order differential equation with a convolution integral, which for a 1DOF heave problem can be written as

$$(m + A_{r\infty})\ddot{x}(t) + \int_0^t K_r(t-\tau)\dot{x}(\tau)d\tau + Cx(t) = F_e(t) + F_u(t) \equiv F_{ext}(t) \tag{1}$$

where m is the body mass, C is the restoring-force coefficient, $A_{r\infty}$ is the asymptotic value of the added mass when $\omega \to \infty$ and $K_r(t)$ is the impulse-response function for the radiation force. F_e is the excitation force due to incoming waves and F_u is an intentionally applied force from the control and PTO system which is represented by a liner damping force. The theoretical optimal PTO damping yields

$$B_{opt} = B_r\sqrt{1 + \left(\frac{C_r - \omega^2(m + A_r)}{\omega B_r}\right)^2} \tag{2}$$

where B_r is the radiation damping in heave and A_r is the added mass. The wave excitation forces are provided by the Boundary Element Method(BEM). ANSYS Aqwa is the software used to perform the simulations. Through a perturbation approach, Aqwa can provide solutions up to second order variations. The non-linear effects of interest in this thesis is mainly the non-linear hydrostatic and Froude-Krylov forces. The figures below shows the dynamic pressure distribution along the sphere model and the WEC model when exposed to arbitrary incoming waves.
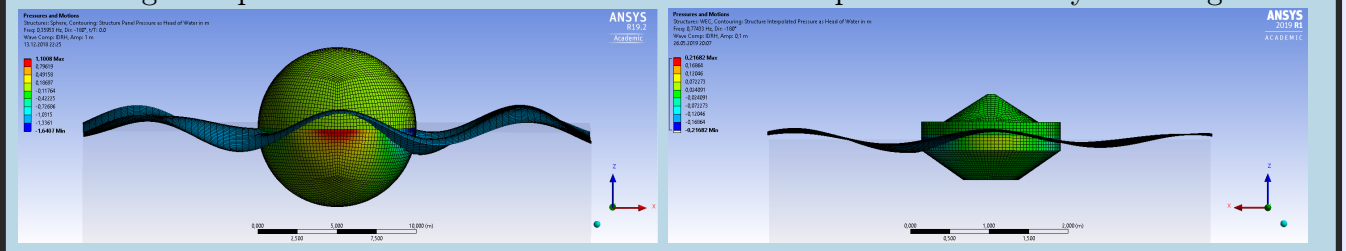
Results

The effect of the PTO system on the sphere can be observed in the heave position RAO in the leftmost upper figure. This reduction in relative motion can be seen as a consequence of the energy absorbed from the system through the powertake-off system. The upper figures in the centre and to the right shows the effect of including non-linear hydrostatic and Froude-Krylov forces(NLINS) compared to pure linear analysis(LINS) for a wave steepness of S=0.005 and S = 0.01. The NLINS simulation predicts a reduced heave response for steep waves with period above 6s. This is due to geometric non-linearities, which effect is increasing when the ratio of wave height and sphere diameter is increasing. These results indicates that including linear effects only isn't sufficient to fully capture the behaviour when PTO damping is considered.
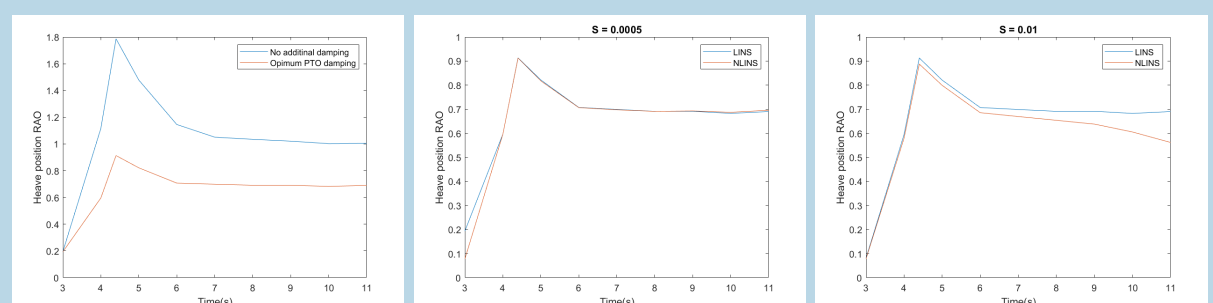
The model of the WEC float is currently being evaluated, hence results regarding energy absorption and optimal geometry are limited. Nevertheless, an important remark is that the results from the simulations coincide with the physical experiment performed by Sandia Laboratories [1]. The figures below illustrates the oscillating heave force and the power spectral density(PSD) of the heave force from a diffraction test(DF1). As can be seen in the leftmost figure below, the simulation in Aqwa underpredicts the heave force amplitude. In the PSD plot it's seen that both the first and second order peak is well resolved in the simulation.