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CCP-WSI Blind Test Series 3: A Nonlinear Froude–Krylov Modeling Approach

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Mathematical models are essential for the effective design of wave energy converters and hence for the achievement of economic viability and industrial feasibility. Despite the fact that the wave energy field is at least 45 years old, there is still a clear lack of standardization of modeling techniques and a large amount of room for increasing confidence in hydrodynamic models. The Collaborative Computational Project in Wave–Structure Interaction (CCP-WSI) project aims to define a level playing field of comparison for a plurality of models, evaluating their performance. This paper implements a computationally convenient approach to represent nonlinear Froude-Krylov forces, along with the inclusion of nonlinear kinematics.

INTRODUCTION

Accurate and reliable mathematical models are imperative in modern offshore renewable and ocean engineering applications, in order to reduce margins of uncertainty that are currently affecting every stage of the design process. On the one hand, a trustworthy prediction of structural loads is essential to ensure the safety of personnel and/or components, while avoiding oversizing the structure and excessive safety coefficients. On the other hand, in wave energy applications, the effectiveness, and hence the economic viability of the device, strongly depend on the representativeness of the mathematical model (Giorgi and Ringwood, 2018f; Ringwood et al., 2018).

Although the "modeling problem" of wave energy converters (WECs) is at least 45 years old (Salter, 1974), it is still far from being settled. Early linear WEC models, naturally germinated from classic ocean engineering, are usually not fit to accurately describe the wave energy problem because the objective of WECs is to exaggerate the motion and maximise power absorption (as opposed to motion stabilization). The inclusion of nonlinearities is essential for achieving higher accuracy, but it also requires an increase in model complexity, hence computational burden. In the pursuit of the best compromise between model fidelity and computational time, a large number of nonlinear models have appeared in recent years (Penalba, Giorgi, and Ringwood, 2017). The performance of each model strongly depends on the specific device shape (Penalba, Merigaud, et al., 2017), dimension (Clément and Ferrant, 1988), installation site (Giorgi and Ringwood, 2018a), conversion principle (Giorgi and Ringwood, 2018b), and operational condition (Giorgi and Ringwood, 2017). Furthermore, there are different accuracy/computational requirements according to the model's purpose (i.e., design, model-based control, simulation, survivability, etc.). Therefore, although comparison between different modeling approaches is a challenging task, recent years have witnessed the pressing need for consistent model evaluation and standardization (CCP–WSI, 2016). A shared effort from several players in the wave energy community led to a modeling competition (Garcia-Rosa et al., 2015), the International Energy Agency Ocean Energy Systems (IEA-OES) project (Wendt et al., 2017), and, finally, the present Collaborative Computational Project in Wave–Structure Interaction (CCP-WSI), of which this work is a part.

The objective of the CCP-WSI project is to define a level playing field for model comparison, with clear metrics and supportive experimental data; however, the participants have no access to these data (blind test results), so tuning the models based on the expected results is not possible. The modeling approach proposed in this paper is based on partially nonlinear potential theory, with the inclusion of nonlinear kinematics (Fossen, 2011) and analytical nonlinear Froude–Krylov (NLFK) forces (Giorgi and Ringwood, 2018c). Such a model purports to achieve a higher level of accuracy (compared to a fully linear model) at a small fraction of the computational time required by fully nonlinear models.

EXPERIMENTAL TESTS

The focus of the CCP-WSI Blind Test Series 3 is to study hydrodynamic interactions between small bodies and large and steep waves, in order to be representative of point-absorbing WECs in harsh sea states, at the boundary of the power production region. In order to replicate extreme wave conditions, focused waves are considered, which are created by applying the NewWave theory (Ning et al., 2009) to a Pierson–Moskowitz spectrum (significant wave height H_s), so that all frequency components arrive with zero phase angle at the focus location, where the device is placed. Three waves are considered, with the same peak frequency (f_p) but increasing amplitudes (A), hence steepness (kA), which is an indicator of nonlinearity. Table 1 tabulates waves characteristics and identification codes (ID), while Fig. 1 shows the time traces, only in the time window considered for the comparison (between 35.3 s and 50.3 s). In the simulations performed for this work, the components of the free-surface eleva-

ID	A [m]	f_p [Hz]	H_s [m]	kA
1BT3	0.2	0.4	0.274	0.128778
2BT3	0.3	0.4	0.274	0.193167
3BT3	0.32	0.4	0.274	0.206044

Table 1 Blind test series 3 (BT3) incident wave identification number (ID), amplitude (A_n), peak frequency (f_p), significant wave height of the original Pierson–Moskowitz spectrum (H_s), and wave steepness (kA)

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KEY WORDS: Nonlinear Froude–Krylov force, experimental tests, CCP-WSI blind tests, wave energy converters, WECs, focused waves.