Software Framework to accelerate BEM Linear Wave Load Program using OpenMP (OREGEN-BEM)

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ABSTRACT

An advanced computing platform for offshore renewable energy systems of generic configuration (OREGEN) is being developed. As input to the platform, a frequency-domain multibody interaction (potential flow) program based on the boundary element method has been developed with a parallel algorithm to improve computation efficiency, which is important for multibody and complex geometries, such as the wave energy converter (M4) system that has four-eight floaters. In this paper, a new boundary element method program called OREGEN-BEM is developed, where the OpenMP algorithm has been employed at different modules and layers. To our knowledge, there is limited research on applying OpenMP parallelization to the boundary element method with potential flow theory at the software framework level. This paper presents the software framework, data storage structure, such as the Green function and its derivatives and velocity potentials, and techniques of the parallel loop. The benchmark study is conducted in three cases, including single-body and multiple-body systems, against the numerical results from the commercial software and open-source codes. The comparison results demonstrate the newly developed program agrees well with its competitors. Furthermore, it also has a significant advantage in computational speed.

KEY WORDS: OpenMP; Boundary element method; hydrodynamic; Parallel.

INTRODUCTION

In the last few years, many concepts for offshore wave energy conversion have been conceptualized and scaled/full-scale devices have been deployed in open ocean (McCabe, 2006; Nguyen, 2020; Santo, 2020).

For numerical modeling, the wave energy developer mainly depends on commercial software to model their devices, which is a financial burden for the developers. To reduce the cost related to the linear numerical simulation, fully nonlinear potential flow, computational fluid dynamic models, and smoothed-particle hydrodynamics are not a primary choice. Right now, linear hydrodynamic wave-structure interaction analysis based on the potential flow theory is still the main analysis tool. There are different commercial software and open-source programs that can be accessed. Among them, the commercial software, Wamit (LEE, 1996), Wadam (DNV Software, 2017), HydroStar (Taniguchi and Kawano, 2003), and OrcaWave (Orcina, 2023) have been extensively validated through the comparison of code-to-code, the analytical solution, and the wave-tank experimental testing data. Besides, the well-known open-source programs like NEMOH (Babarit and Delhommeau, 2015) and HAMS (Liu, 2019) have been released and are widely used in the renewable energy community. However, each program has its own pros and cons. A detailed introduction of their capacity and limitation can be found in (Sheng, 2022). However, each code has its limitation. The wave energy converter system (WEC) or the new hybrid wind-wave power system combining the floating offshore wind turbine system (FOWT) and WEC has some typical characteristics, wave-body hydrodynamic interaction, body-body hydrodynamic interaction, multiple floating bodies, non-symmetric distribution of the floating body (Stansby, 2022). These characteristics raise new requirements for the program. For example, the idealized program must be fast so that the time cost is low in the shape optimization of the WEC. To meet these challenges in the offshore renewable energy community, a new computational platform called OREGEN is being developed, and it contains a frequency-domain (FD) solver and a time-domain (TD) solver (Li and Stansby, 2022).

This paper presents the computational model for evaluating the hydrodynamic linear wave loads based on the boundary element and the parallel OpenMP algorithm. The rest of the contents of the work are arranged as follows; First, the theoretical formulation in terms of code implementation purpose is briefly introduced. Second, the software framework, the data storage structure, and the parallel technique of important blocks are presented. Third, the validation study is presented for both single-body and multi-body floating systems.

THEORETICAL FORMULATION

Three right-handed coordinate systems are defined to describe the hydrodynamic wave loads computation of the multibody floating system. Figure 1 depicts the global coordinate system (GCS), body-fixed coordinate system (BCS), and wave coordinate system (WCS). In the BCS, the origin point is located at the center of the body, X is positive forwards, Y is positive to the port side, and Z is positive upward. The GCS is fixed with the Earth, x is positive forwards, y is positive to the port side, and z is positive upward. The origin of the WCS coincides with the origin of the GCS, and its Z-axis is positive upward, and X axis is inverse of the X-axis of the GCS, and the right-handed rule forms Y axis.

The computation of hydrodynamic loads on multi-body floating system is considered. The key to studying the wave-structure interaction problem is solving the total velocity potential of the floating body with a regular wave propagating in deep water. The total velocity potential at a flow-field point X is written as (Li, 2018),