

Features of QALE-FEM and Its Applications to Nonlinear Wave Hydrodynamics

Q.W. Ma and S. Yan

School of Engineering and Mathematical Sciences, City University
London, United Kingdom

ABSTRACT

Although nonlinear wave hydrodynamics has received a very large number of studies over the last three decades, computation of very steep and/or overturning waves, their loads on offshore structures as well as responses of the floating structures is still of a very challenge and time-consuming task, particularly associated with fully nonlinear interaction between waves and three-dimensional (3D) freely-floating structures, for which the results are very limited at present. Recently, a method called QALE-FEM (Quasi Arbitrary Lagrangian-Eulerian Finite Element Method) has been developed by the authors of the paper, which is based on full nonlinear potential theory (FNPT). The method can be and has been applied to various nonlinear wave problems including overturning waves and also to fully nonlinear and fully coupled interaction between waves and structures. Numerical investigations have shown that the QALE-FEM can be many times faster than other methods based on the same theory and can produce results that agree reasonably well with experimental data available in literature. This paper will discuss the main features of the method and present some typical examples to demonstrate its flexibility and powerfulness.

KEY WORDS: Overturning waves; Floating structures; Nonlinear water waves; Potential flow; QALE-FEM method.

INTRODUCTION

So far, a large number of studies have been carried out on waves and wave-body interactions. However, computation of very steep and/or overturning waves, their loads on offshore structures as well as responses of the floating structures is still of a very challenge and time-consuming task. Because of the strong nonlinearity involved sometimes, solutions based on linear or other simplified theories may be insufficient and so fully nonlinear theory is necessary. Two types of fully nonlinear models, i.e. NS model (governed by the Navier-Stokes and the continuity equations together with proper boundary conditions) and FNPT models (fully nonlinear potential model), may be used. The latter are much easier and needs less computational resource than the former with satisfactory accuracy if waves are not breaking and/or structures involved are large. The FNPT model is chosen in our work.

The problems formulated by FNPT model are usually solved by a time marching procedure. In this procedure, the key task is to solve the boundary value problem by using an numerical method, such as the boundary element or desingularized boundary integral methods (both are shortened as BEM in this paper) and the finite element method (FEM). The BEM has been attempted by many researchers, such as Vinje & Brevig (1981), Lin, Newman & Yue (1984), Kashiwagi (1996), Cao, Schultz & Beck (1994), Celebi, Kim & Beck (1998), Grilli, Guyenne & Dias (2001) and Guyenne & Grilli (2006). The FEM has been developed by Wu & Eatock Taylor (1994) for 2D cases and by Ma, Wu & Eatock Taylor (2001) for 3D cases. More review could be found in Ma & Yan (2008) and Yan and Ma (2008).

Compared with the BEM, the FEM requires less memory and may be computationally more efficient to deal with fully nonlinear problems, as indicated by Ma, Wu & Eatock Taylor (2001) and Wu & Eatock Taylor (1994). In the conventional FEM, the computational mesh, which is usually unstructured for complicated geometries, needs to be regenerated at every time step to follow the motion of waves and floating bodies. This may take a major part of CPU time and so makes the overall simulation very slow. To overcome the difficulty, Ma and Yan (2006) have recently developed a method called QALE-FEM (Quasi Arbitrary Lagrangian-Eulerian Finite Element Method). The main idea of this method is that the complex unstructured mesh is generated only once at the beginning of calculation and is moved at other time steps to conform to the motions of boundaries. The method can be and has been applied to various nonlinear wave problems including overturning waves and also to fully nonlinear and fully coupled interaction between waves and structures. Numerical investigations (Ma & Yan, 2006 and Yan & Ma, 2008) have shown that the QALE-FEM can be many times faster than other methods based on the same theory and can produce results that agree reasonably well with experimental data available in literature. This paper will discuss the main features of the method and present some typical examples to demonstrate its flexibility and powerfulness.

FEATURES OF THE QALE-FEM

As pointed out above, the QALE-FEM is based on fully nonlinear potential theory to model the waves and on the fully nonlinear