Nonlinear Wave Structure Interaction using Finite Element Method based on Spring Analogy Techniques

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ABSTRACT

The simulation of interaction of nonlinear waves with structures has been investigated by several investigators adopting Boundary element Method (BEM) and Finite Element Method (FEM). In handling complex geometries using FEM, simulation with unstructured mesh is required. The two options that are available in handling unstructured mesh are: regenerating the mesh for each time step, requiring a higher computational cost and the mesh moving procedure widely used in solid mechanics. In this paper, the application of two different spring analogies (Vertex and Segment methods) on the simulation of nonlinear free surface waves and its interaction with a submerged structure is reported. The numerical method has been extended to generate solitary waves, the results of which have been compared with laboratory tests that include the wave kinematics using PIV measurements.

KEY WORDS: FEM; unstructured mesh; nonlinear waves; vertex method; segment method; Solitary waves; PIV measurements.

INTRODUCTION

The simulation of nonlinear waves based on time-domain has gained tremendous momentum due to the recent improvements in numerical techniques and computational power. This has been modelled by using BEM and FEM. In modeling complex geometry or for the simulation in the presence of floating bodies, one needs to resort to an unstructured mesh simulation for FEM based codes. In the case of structured mesh, the regeneration of mesh at every time step is evaluated based on the new free surface nodes with the vertical elevation calculated using a simple formula as proposed by Wu and Eatock Taylor (1994). The computation is inexpensive and thus regeneration of mesh nodes can be done with ease. In the case of unstructured mesh, one has to resort to the external mesh generation code (First approach) or commercial CFD mesh generators (second approach). While using the first approach, regeneration of mesh is possible at every time step by invoking the external code from the source code, whereas, in the second approach, it is not possible to update at each of the time step automatically. Wang and Wu (2006) used the first approach of regenerating the mesh at every time step using the public domain code called BAMG. In the second approach, one can use the commercial CFD mesh generators like GAMBIT, ICEM-CFD to create the initial mesh. Then at every time step, a mesh moving technique like Laplacian smoothing, Torsional spring or spring analogy method can be adopted to update the new nodal position. The second approach is more popular in the field of aerodynamics and is similar to Arbitrary Lagrangian and Eulerian (ALE) method. Sudharsan et al. (2004) compared the above three different mesh movement techniques for the nonlinear free surface problem and concluded that the spring analogy is more efficient in handling complex geometries. There are two different methods usually used in spring analogy: one is the vertex method and the other is the segment method. The vertex spring analogy was originally used for smoothing a mesh after its generation or refinement. The segment spring analogy was developed for the deformation of the mesh in a moving boundary problem. Both the normal vertex and spring methodologies led to a skewed mesh near the boundary. Hence, the method has been improved by using modified stiffness by Blom (2000) with a suggestion, that the stiffness be increased for the boundary layers compared to the interior layers. Sudharsan et al. (2004) assumed the stiffness only on the boundary layer and concluded that vertex method is superior to all available methods for investigating wave-structure interaction problems. However, by adopting the stiffness in such a way that the adjacent layers (i.e., across the water depth) were also stiffened, Ma and Yan (2006) with the segment method showed promising results. Hence, in the present study both the segment and vertex methods of spring analogy have been considered to test its suitability. In the following sections, formulation of the problem and an overview of both vertex and segment methods are discussed in detail in order to understand the physics behind these methods. Later, the difference between the methods has been analysed based on the mesh quality during the simulations, validated with the solitary waves and PIV measurements and then applied to the problem of propagation of nonlinear waves over a submerged trapezoidal bar.