Engineering Analysis with Boundary Elements 35 (2011) 140–147

Contents lists available at ScienceDirect

Engineering Analysis with Boundary Elements

journal homepage: www.elsevier.com/locate/enganabound

A coupled ES-FEM/BEM method for fluid–structure interaction problems

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ARTICLE INFO

Article history:
Received 14 April 2009
Accepted 5 May 2010

Keywords:
Numerical methods
Meshfree methods
Fluid–structure interaction
Finite element method (FEM)
Edge-based smoothed finite element method (ES-FEM)
Boundary element method (BEM)

ABSTRACT

The edge-based smoothed finite element method (ES-FEM) developed recently shows some excellent features in solving solid mechanics problems using triangular mesh. In this paper, a coupled ES-FEM/BEM method is proposed to analyze acoustic fluid–structure interaction problems, where the ES-FEM is used to model the structure, while the acoustic fluid is represented by boundary element method (BEM). Three-node triangular elements are used to discretize the structural and acoustic fluid domains for the important adaptability to complicated geometries. The smoothed Galerkin weak form is adopted to formulate the discretized equations for the structure, and the gradient smoothing operation is applied over the edge-based smoothing domains. The global equations of acoustic fluid–structure interaction problems are then established by coupling the ES-FEM for the structure and the BEM for the fluid. The gradient smoothing technique applied in the structural domain can provide the important and right amount of softening effects to the "overly-stiff" FEM model and thus improve the accuracy of the solutions of coupled system. Numerical examples of acoustic fluid–structure interaction problems have been used to assess the present formulation, and the results show that the accuracy of present method is very good and even higher than those obtained using the coupled FEM/BEM with quadrilateral mesh.

1. Introduction

Interior and exterior acoustic problems commonly found in engineering applications require a proper handling of the interaction between the vibrating structure and the acoustic fluid field. Analytical solutions to these acoustic fluid–structure interaction problems are only available when the structures have simple geometries with simple settings. For more realistic problems with complicated geometries, it is impossible to find analytical solutions, and hence effective numerical methods are required.

The finite element method (FEM) is currently the most widely used numerical method for the dynamic behavior of structure, acoustic and fluid–structure interaction problems. It has been implemented with a displacement formulation for the modeling and simulation of the fluid–structure interaction problems [1]. Alternative displacement–pressure formulation [2] and the combined formulations [3] were also performed. It is known that the FEM has its limitations in modeling infinite domains. Using the boundary element method (BEM), which requires a discretization of only the boundary of the acoustic domain, the Sommerfeld radiation condition is automatically fulfilled by the fundamental solution. This makes the BEM superior to the FEM in many cases especially for exterior problems, such as the wave propagation or radiation in infinite domains. In addition, the BEM offers the advantage in the discretization compared with the FEM. In order to take advantage of both the FEM and the BEM, coupled finite element method/boundary element method (FEM/BEM) approaches have been proposed [4–13]. Coupled techniques between the meshfree methods and the BEM have also been developed [14].

It is well-known that the "overly-stiff" property of FEM models usually results in a significant loss of accuracy in the numerical solution [2,15]. This is particularly true for acoustic problems, in which the waves propagate with artificially higher speeds than the actual ones in the media leading to the dispersion error [16]. Naturally, the coupled FEM/BEM models also possess the "overly-stiff" property due to the use of FEM model. It is thus of great importance to develop an effective numerical approach that addresses this issue. Liu [17] has discovered that the generalized gradient smoothing technique offers an excellent general approach to reduce the "over-stiffness". To ensure the stability

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doi:10.1016/j.enganabound.2010.05.003