Numerical Simulation of Local Scour under a Submarine Pipeline Using a Cartesian Cut Cell Approach

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ABSTRACT

A two-dimensional numerical model for local scour under a submarine pipeline is established. By using finite volume method with SIMPLEC algorithm, the unsteady Navier-Stokes equations combined with k-ω turbulence model are solved. A cut cell approach enables the model to simulate the scour process from sitting-on-bed-pipeline status to suspended-pipeline status without re-generating the mesh in conventional sense. The transports of bed load and suspended load of uniformly noncohesive sediment are modeled to simulate the local scour process.

KEY WORDS: local scour; submarine pipeline; finite volume method; cut cell approach; k-ω turbulence model.

INTRODUCTION

Submarine pipelines placed on an erodible seabed are often suffering local scour. The local scour create scour hole underneath the pipeline, which make the pipeline suspended and facing the risk of fatigue damage due to vortex induced vibration. Understanding the scour processes is necessary for taking proper anti-scour measures. Many researchers had conducted laboratory experiments on this subject, for example, the works done by Mao (1986), Ibrahim and Nalluri (1986), Fredsøe and Hansen etc. (1988) and Chiew (1990). The accumulated knowledge about scouring around various marine structures including pipelines had been reviewed by Sumer and Fredsøe (2002). Meanwhile, the numerical models are also developed, from the potential flow model of Hansen and Fredsøe etc. (1986), discrete vortex model of Sumer and Jensen etc. (1988), to the now commonly adopted Navier-Stokes equation models combined with various turbulence closures, such as Van Beek and Wind (1990), Li and Cheng (1999, 2000, 2001), Boers (1999), Liang and Cheng etc. (2005a, 2005b), Lu and Li etc. (2005).

In existing numerical study of local scour around a submarine pipeline, as the geometry of the scour hole keeps changing, usually a body-fitted mesh must be re-generated accordingly. At some special stage of scour developing, for example, at the instant when suspended pipeline sink and reach the bottom of the scour hole or when the partially buried pipeline separate with the seabed due to scour, the topography of the scour hole geometry totally changed. In those cases the property of the mesh get worse, often cause convergence problem, and lead to interruption of the computation. For this reason, the complete local scour stage shifting from buried pipeline to suspended pipeline, or vice versa, has not been numerically reproduced so far, at least has not been published.

To overcome the difficulties encountered in regenerating the mesh in scour hole, a cut cell approach embedded in finite volume method is used. The basic idea of cut-cell approach is to cut solid bodies out of a background Cartesian mesh. This method was firstly developed to study the potential flow around complex geometries, such as multi-element airfoil encountered in aerospace industry (Berger and LeVeque, 1989; Zeeuw and Powell, 1993). Then it has been successfully applied to many fields, such as shallow water flows (Causon and Ingram etc., 2000; Causon, DM, Ingram etc., 2001), incompressible viscous flows (Qian and Causon etc., 2001; Gao and Ingram etc., 2007), and flows involving moving material interfaces (LeVeque, and Shyue, 1996; Lin, 2007). In this approach, a Cartesian structural grid is constructed and remains stationary in computation. Besides the grid cells completely locate in fluid domain, there are cut cells crossed by the solid boundaries of pipeline and deformed seabed, and blind cells locate within the outlines of solid bodies or underneath the sea bottom. The cut cells need to be specially treated in computation. No conventional mesh regeneration is need except necessarily updating of the cut cell list. To overcome the difficulties encountered in regenerating the mesh in scour hole, a cut cell approach embedded in finite volume method is used. The basic idea of cut-cell approach is to cut solid bodies out of a background Cartesian mesh. This method was firstly developed to study the potential flow around complex geometries, such as multi-element airfoil encountered in aerospace industry (Berger and LeVeque, 1989; Zeeuw and Powell, 1993). Then it has been successfully applied to many fields, such as shallow water flows (Causon and Ingram etc., 2000; Causon, DM, Ingram etc., 2001), incompressible viscous flows (Qian and Causon etc., 2001; Gao and Ingram etc., 2007), and flows involving moving material interfaces (LeVeque, and Shyue, 1996; Lin, 2007). In this approach, a Cartesian structural grid is constructed and remains stationary in computation. Besides the grid cells completely...