ABSTRACT

A tsunami may result in severe local scour and causes heavy damages on structures in the coastal area. In this paper, a 3D multi-phase rheological model that incorporates the quadratic Bingham model is developed to simulate the local scour problems. A quadratic term is added to the traditional Bingham model to represent the effect of sediment collision. We carefully validated the model with an analytical. Very high consistency can be seen in terms of the velocity profile and location between the shear zone and plug zone. This model is then used to study the local scour problem in the laboratory. We conclude that the newly developed quadratic Bingham model is capable of simulating the complex local scour and mud slide problems.

KEY WORDS: VOF, multiphase rheological models, Bingham model, local scour, tsunami bore

INTRODUCTION

When a tsunami propagates to the inland area, the long wave transfers into tsunami bore and the energy is dissipating. During this run-up process, the coastal structures suffer the strong bore impact as well as the sever scour problem. After that, a run-down process makes the scour issue more serious. The scour problem can be observed in many tsunami events (Fig. 1). For example, in the event of 2004 South Asia tsunami, a 5 m wide and 1.5 m deep scour hole was found at the elementary in Kalapakkam, India (Borrero et al., 2005). Many sever local scours were reported in Banda Aceh, Indonesia, and in Sri Lanka (Liu et al., 2005). Also, after the event of the 2011 Great East Japan tsunami, many photos were taken in Japan presented serious scour and soil liquefaction around buildings (Wu, 2011).

The key issue of the scour problem is the maximum scour depth. The scour induced by the horseshoe vortex around the pier foundation is called local scour, which is the most common cause of structure failure during flooding events. In the past few decades, the estimation of scour depth relied heavily on empirical formulae. One example is Lacey’s formula developed in 1930, where the scour depth is related to the discharge, sediment particle size, and some other empirical parameters. Following Lacey’s formula, several prediction methods became available (e.g., Melville, 1992; Rahman and Haque, 2002). However, most of these methods are empirical or semi-empirical, and are only applicable to a limited range of hydraulic conditions.

In the laboratory studies, Melville and Raudkivi (1977) placed circular cylinders on a rigid bed and studied the flows on a flat bottom, developing scour hole, and developed scour hole. They found the downward current is positively correlated to the size of the scour hole. Richardson and Davies (1995), Melville and Coleman (2000), and Sumer and Fredsoe (2001) studied the scour experiments under a constant current. They focused their discussions on the effects of horseshoe vortex and vortex shedding. Dey and Barbhuiya (2005) found strong turbulent in the scour hole. Ettemma et al. (2006) found that the size of turbulent is important to the size of scour hole, and the laboratory scale will limit the analysis towards the field scale (Ettema et al., 1998; Lee and Sturm, 2008).

OVERVIEW OF MODELS

In numerical studies, many researchers solved shallow water equations with empirical scour depth formula by using CCHE2D, a two-dimensional numerical hydrodynamic model developed at the National Center for Computational Hydrodynamics and Engineering of the University of Mississippi. However, the depth integrated assumption impeded the accuracy on describing the 3D horseshoe vortex around the cylinder. Therefore, efforts were made to couple the sediment transport theory with the Navier-Stokes (NS) flow solver. Mao (1986) applied a modified potential flow theory and sediment continuity equation to the simulation of a scour below a long cylinder on a sandy bottom subjected to a mean current. For this purpose, an empirical sediment transport formula was developed. Olsen and Melaaen (1993) solved steady state NS by finite-volume method. However, neglecting the transient term made the result inaccurate. Despite the defect, their result showed that the 3D simulation on the scouring hole with complex geometry was doable (Zhao, 2010). Olsen and Kjellesvig (1998) improved Olsen and Melaaen’s (1993) model to solve for unsteady NS equation. Richardson and Panchang (1998) also solved unsteady 3D model on flat and rigid bed. They compared the flow field around the bridge piers with the experimental data done by Melville and Raudkivi (1977) with good agreement. Li and Cheng (2000) solved the NS