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Procedia Engineering 170 (2017) 202 – 209

Procedia Engineering

www.elsevier.com/locate/procedia

Engineering Physics International Conference, EPIC 2016

Numerical Simulation of Sediment Transport along a Channel with Underwater Sill

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Abstract

Sediment prevention structures such as underwater sill (UWS) may be used to divert the sediment movement, and prevent it to enter the port basin or navigation channel. In this study, a quasi 3D-numerical model called multilayered model based on the Method of Characteristics was utilized to simulate the flow, and a particle tracking method was developed to simulate the sediment transport around an UWS. A straight channel with an UWS approximately a half way between upstream and downstream boundaries was simulated. The height of the UWS was varied to observe the effectiveness of such structure against sedimentation. The influence of UWS on flow and sedimentation pattern, vertical distribution of suspended sediment concentration, and the implication of effectiveness of underwater sill structures to control the flow and reduce sedimentation were analyzed. The numerical simulations indicated that the UWS significantly altered the flow/current pattern. It presence contributes in reducing the sediment transport that cause siltation problem in port basin.

Peer-review under responsibility of the organizing committee of the Engineering Physics International Conference 2016

Keywords: Sediment transport, Underwater sill (UWS), Method of Characteristics, Particle tracking method, Numerical Simulation;

1. Introduction

The siltation caused by sediment process is commonly found in many harbor and port over the world. Due to siltation, the harbor basins and navigational channels required frequent maintenance dredging to guarantee safe or minimum depth. The costs associated with these maintaining activities are quite high and are qualified as the most expensive item in running costs of harbors. In order to prevent and to reduce such problem, many attempt or solution have been made and proposed. One of them is hard structure prevention such as underwater sill or submerged dike.

Unlike the breakwater structure that was fully hindered the sediment from entering the port basin or navigational channel, underwater sill is an underwater structure that is used to deflect the flow of sediment in bottom section of water depth, whilst the sediment that are transported in the upper section are passing through, and will be deposited or not in the basin depend on the capacity of water flow in carrying sediment. Such structure has been used in Kumamoto port, Japan, and in Port of PT. Semen Gresik (Persero) Tbk Tuban, located at North Coast of Java Island, Indonesia.

The most relevant processes in the deposition and erosion of the channel or basin zone of a port are advection of sediment particles by the longitudinal, transversal and vertical fluid velocities, mixing of sediment particles by turbulent and orbital motions, settling of the particles due to gravity (fall velocity), erosion of particle from bed by current and wave-induced bed-shear stresses [1]. The deposition and erosion in port area where the existence of structure play an important role can be predicted by numerically simulate those relevant process. Various model have been purpose and developed using different type of approaching method.

Tsuruya et al. [2] developed a multi-layered model to predict the mud transport in the area of Kumamoto port by using the finite different method. Multi-layered model is adopted, in aim to reproduce vertical distribution of suspended mud concentration, and to observe the effect of submerged dikes. Based on this research, calculation for the Kumamoto port design were conducted,

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Peer-review under responsibility of the organizing committee of the Engineering Physics International Conference 2016
doi:10.1016/j.proeng.2017.03.048

and the result showed that the amount of decrease in volume deposition caused by the existence of submerged dike was around 30%. It is considered that the submerged dike has a considerable effect on reducing the deposition of sediment.

The research about effect of submerged dike was also done by Chai at. Al [3] by using a 2D numerical modeling of mud transport. The numerical result indicate that submerged dike can reduce the concentration of mud passing the interesting point significantly. The effect of flow velocity, water depth, and dike height on mud transport ware also investigated.

Other the finite different method, particle-based modelling is one of the method that can be used to simulate sediment transport, especially suspended type. In other to solve the equation of suspended particles transport, a number of research has been made using probabilistic or stochastic approaches. Indeed, the suspended particle movement has been regarded as an intrinsically random process. Dimou and Adams[4] describe a two dimensional random walk particle-based model to simulate transport (advection-dispersion) in vertically well-mixes estuaries and coastal waters. Applied to a channel of uniform cross section and spatially variable dispersion coefficient and simulated average longitudinal concentration distribution.

Also using the random walk particle-based model, Argall et.al [5] simulate transport of non-cohesive sediment in rivers and coastal zone where vertical distribution of mean velocity can be inferred under the assumption of a fully developed boundary layer. The prediction of vertical sediment distribution follow the trend of Rouse profile, using roughly 100 particles per unit volume of interest. The model then was applied to predict the settling process in Ballona Creek, a flood protection channels that drains the Los Angeles basin. Using a range of grain size diameter in same time of simulation as an input, the result of this research showed well predicted of the sediment settling. Oh [6] purposed a stochastic modelling using a Wiener process to express the particle diffusion. Latter then he developed the stochastic diffusion jump model of suspended particle for extreme flow by including the effect of buoyancy-type force due to flow acceleration, drag force, and the added mass.

This paper describes a multilayered model based on a particle-based model called particle tracking method for simulation of sediment transport around underwater sill structure. In this study, the effect of UWS on sedimentation pattern, vertical distribution of suspended sediment concentration, as well as the effectiveness of underwater sill structures to control the flow and reduce sedimentation were analyzed.

2. Theoretical approach of suspended sediment transport model

There are a few factors that bring about variations in the motion of sediment particles. To begin with, the variety of particle properties leads to the variations of the particle movement. Thus, particles that are transported in surface flows can vary from i.e. wash load, suspended load, and bed load. Sediment transport concerns the movement of particles by flowing waters. Instead of describing the concentration of the substance at various fixed points it is theoretically possible to track the motion of all the particles of the substance as they are carried out by the fluid. All the particles are tracked continuously, into which the suspended can be discretized, in order to compute the local concentration

2.1. The settling velocity

The settling velocity of sediment (w_s) is the most fundamental property and considered as the primary contributor of particle movement. It determine whether the particle was transported as suspended load or bed load. The settling velocity can be calculated if the characteristic of the particle and fluid are known. It is a function of both density of fluid and sediment, the fluid viscosity, volume and shape of sediment particle.
A convenient equation of estimating w_s is given by Julien [7],

$$w_s = \frac{8\nu}{d}\left[\sqrt{\left(1+0.0139 d_*^{\,3}\right)}-1\right] \tag{1}$$

Where d_* is a dimensionless of particle size given by

$$d_* = \left[\frac{(S_G-1)g}{\nu^2}\right]^{1/3} d \tag{2}$$

2.2. Vertical Sediment Distribution

In a steady, uniform turbulent flow the vertical distribution of suspended sediment is describe by the following equation,

$$\varepsilon_z \frac{dc}{dz} + w_s c = 0 \tag{3}$$

Where the vertical diffusivity ε_z can be derived from logarithmic velocity distribution, as follow