Ocean Modelling 110 (2017) 21–31

Contents lists available at ScienceDirect

Ocean Modelling

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

Depth-integrated modelling on onshore and offshore sandbar migration: Revision of fall velocity

Dae-Hong Kim[a,*], Agustin Sanchez-Arcilla[b], Ivan Caceres[b]

[a] *Associate Professor, Department of Civil Engineering, University of Seoul, Republic of Korea*
[b] *Laboratori d'Enginyeria Maritima, Universitat Politecnica de Catalunya, Barcelona, Spain*

ARTICLE INFO

Article history:
Received 18 April 2016
Revised 14 December 2016
Accepted 26 December 2016
Available online 26 December 2016

Keywords:
Onshore bar migration
Offshore bar migration
Geomorphology
Sediment transport
Boussinesq equation
Suspended load
Bed load

ABSTRACT

This paper presents the results of morphodynamic modelling and analysis of onshore and offshore sandbar migration based on a depth-integrated approach. The coastal flow was modeled using the Boussinesq equation and the morphological evolution was modeled using the suspended sediment transport equation and bed load formulae based on the instantaneous velocity and acceleration. The proposed model was applied to the accretive and erosive conditions and the model reproduced the onshore and offshore sandbar migration and the formation of a berm around the shoreline reasonably. An analysis of the computed results revealed the following. (i) The vertical flow velocity can affect the suspension time of the sediments considerably and the bottom evolution. (ii) The suspended load is the main contributor to the morphological changes in terms of the quantity and quality, regardless of the accretive or erosive conditions. (iii) Regardless of accretive or erosive conditions, in terms of the time-average, the instantaneous flow velocity and acceleration-based bed load models always yielded an offshore and onshore direction sediment flux, respectively, except in the swash zone. On the other hand, the suspended sediment flux calculated by the advection-diffusion equation results in the sediment transport in either direction depending on the flow field.

1. Introduction

The geomorphology in the surf zone is of great scientific and practical importance for ecological and engineering applications. Sediment transport is caused mostly by water flows such as waves, currents, and their interactions. All these coastal flows are affected by weather and climate, and the topography in the surf zone undergoes a range of changes. One of the typical changes with regard to land form evolution is onshore and offshore sandbar migration. The offshore bar migration mechanism under erosive conditions is relatively well understood: High breaking waves on a sandbar crest generate strong undertows that carry sediment particles seaward, resulting in offshore sandbar migration and beach erosion (Thornton et al., 1996). As noted by Elgar et al. (2001) and Fernandez-Mora et al. (2015), however, the process of onshore sandbar migration is not well known compared to offshore sandbar migration and relatively inaccurate predictions have resulted.

One of the reasons for the less accurate predictions under accretive environments originates from the use of phase-averaged sediment transport models based on bottom shear stresses (Roelvink and Stive, 1989; Roelvink, 1991; Wright et al., 1991; Rakha et al., 1997; Gallagher et al., 1998; Elgar et al., 2001). An improvement was made by considering the acceleration skewness in the sediment transport formulation (Elgar et al., 2001). Drake and Calantoni (2001) proposed an acceleration skewness model based on the numerical simulation results. Hoefel and Elgar (2003) adopted the acceleration skewness model and successfully carried out onshore sandbar migration modelling. Recently, Fernandez-Mora et al. (2015) presented a process-based morphodynamic model considering both the velocity skewness (Hsu et al., 2006) and acceleration skewness. Their computed results showed that a joint consideration of both the velocity and acceleration skewness can improve the accuracy of the onshore sandbar migration.

Long et al. (2006) incorporated an instantaneous acceleration model and velocity skewness models into a Boussinesq model. They applied the model to LIP11D experiments (Roelvink and Reniers, 1995) and reported successful computational results on onshore bar migration. On the other hand, less accurate results were obtained for the offshore bar migration test. One of the reasons might be that Long et al. (2006) model does not incorporate the lag of suspended sediment transport, which contributes

---

[*] Corresponding author.
E-mail address: dhkimhyd@uos.ac.kr (D.-H. Kim).

http://dx.doi.org/10.1016/j.ocemod.2016.12.011
1463-5003/

significantly to the morphological changes (Rakha et al., 1997; Soulsby, 1997; Murray, 2004; Wenneker et al., 2011). Rakha et al. (1997) proposed a sediment transport model that can consider the lag effect: A Boussinesq module was used to resolve wave propagation, and it was coupled with a hydrodynamic and sediment transport module considering the suspended and bed loads. This approach was extended similarly by Wenneker et al. (2011) and good results were obtained for onshore and offshore sandbar migration. Xiao et al. (2010) developed a Boussinesq-based morphodynamic model including the lag effect by solving an advection-diffusion equation for the suspended sediments. They validated the model successfully on erosion by breaking solitary waves. Taking the above studies into consideration, an accurate prediction of suspended sediment transport is an important factor for accurate predictions of morphological evolution.

The suspended sediment transport models usually consist of the pick-up, transportation and deposition of sediment particles. To the best of the authors' knowledge, there is some consensus that the erosion (pick-up) and deposition rates are estimated empirically and the transportation by advection-diffusion is calculated physically. One of typical formulae for the deposition rate is $D_e \approx Cw(1-C)^m$ (Cao, 1999; where D_e is the deposition rate, C is the sediment concentration, w is the settling velocity, and m is a constant). D_e is usually estimated empirically instead physically because it is very difficult to estimate accurately the w of sediment particles. In particular, when depth-averaged approaches are adopted, the fluctuating vertical flow velocity by wavy flow is usually ignored, which needs to be revised.

This paper simulated onshore and offshore sandbar migrations using a process based morphodynamic model. Using the computed data some analysis of the sediment transport is provided. Note that the computed results and the related analysis are limited within the long wave scale because the proposed model is based on the scale. A Boussinesq model was coupled with a suspended sediment transport model and bedload models considering the instantaneous acceleration and velocity effects. To make D_e estimation more physical, a revision of the fall velocity estimation is proposed. In addition to the movement of sandbar under water, the morphological evolution of the shoreline zone was modeled in a consistent manner. The remainder of this paper is organized as follow. First, a brief description of the wave-current interaction model considering temporal bottom variations is presented. A morphology evolution model including the suspended and bed loads is then presented. Finally, the sandbar migration under accretive and erosive conditions is simulated and the results are discussed.

2. Morphodynamic model

The proposed morphodynamic model is composed of a flow model and a morphology model. The former is the Boussinesq model considering the temporal bottom variation proposed by Kim (2015). The latter model is also based on Kim's (2015) model with several modifications in the bed load, deposition rate, and avalanche modules. These revisions are described in detail in the following sections. The common parts with Kim's (2015) model are presented briefly in this paper.

2.1. Wave-current interaction model

Boussinesq-type models are essentially well suited for surf zones, where shoaling, diffraction, refraction, nonhydrostatic pressure and dispersion play an important role. Therefore, a fully nonlinear Boussinesq model considering temporal bottom variation was adopted in this study as follows.

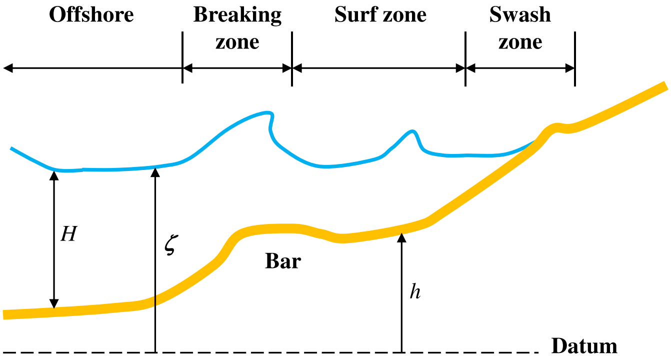

Fig. 1. Schematic of study domain.

$$\frac{\partial H}{\partial t}+\frac{\partial Hu}{\partial x}=-\frac{\rho_b}{\rho_w}\frac{\partial h}{\partial t}+\frac{\rho_s-\rho_w}{\rho_w}(D_e-E_r+\mathcal{H}_T)-\mathcal{H}_c-\frac{1}{\rho_w}\frac{\partial}{\partial x}\left(D_tH\frac{\partial\rho}{\partial x}\right) \qquad (1)$$

$$\frac{\partial Hu}{\partial t}+\frac{\partial Huu}{\partial x}+gH\frac{\partial\zeta}{\partial x}=-g\frac{H^2}{2\rho}\frac{\partial\rho}{\partial x}-H\mathcal{H}_m-u\mathcal{H}_c-\tau^b+u\left\{\left(\frac{E_r-D_e}{1-p_b}\right)+\frac{\rho_s-\rho_w}{\rho_w}\mathcal{H}_T-\frac{1}{\rho_w}\frac{\partial}{\partial x}\left(D_tH\frac{\partial\rho}{\partial x}\right)\right\} \qquad (2)$$

where u is the horizontal velocity, x denotes the spatial axis, and t represents time. $H(=\zeta-h)$ is the water depth, ζ is the water surface elevation and h is the bottom elevation as shown in Fig. 1. ρ is the density of the water flow layer, $\rho_b=\rho_w p_b+\rho_s(1-p_b)$ is the density of the saturated bottom, ρ_w is the water density, ρ_s is the sediment density, and p_b is the porosity of the sediment layer. g is the gravitational acceleration and τ^b is the bottom shear stress. E_r is the erosion rate from the bottom sediment layer and D_e is the deposition rate onto the bed. The high-order terms ($\mathcal{H}_c$, $\mathcal{H}_m$ and $\mathcal{H}_T$) are described in Appendix.

Kim (2015) and Kim et al. (2009) verified various typical benchmark problems of the Boussinesq model were reported by . Although some local differences were observed, the overall performance showed reasonable accuracy for predicting the wave motion and flow velocity.

2.2. Morphology model

The suspended sediment transport was solved by the advection-diffusion equation.

$$\frac{\partial HC}{\partial t}+\frac{\partial HuC}{\partial x}+\mathcal{H}_T=\frac{\partial}{\partial x}\left(D_tH\frac{\partial C}{\partial x}\right)+E_r-D_e \qquad (3)$$

where $D_t=5.93Hu_*$ is the dispersion coefficient and the bottom friction velocity is given by $u_*=(\tau^b/\rho)^{0.5}$. The depth-averaged sediment concentration, C, is related to the densities as follows.

$$C=\frac{\rho-\rho_w}{\rho_s-\rho_w} \qquad (4)$$

D_e was evaluated as follows (Cao et al., 2004).

$$D_e=\gamma Cw_f(1-\gamma C)^{m_o} \qquad (5)$$

where $\gamma=min[2,(1-p_b)/C]$, $m_o=2$, and w_f is the fall velocity. To estimate w_f, the vertical flow velocity (w_z) and the settling velocity of sediment particle (w_s) are considered together, as shown in Eq. (6), because wavy flows fluctuating upward and downward can affect the deposition of sediments.

$$w_f=\begin{cases}w_s-w_z, & w_s>w_z\\ 0, & w_s\le w_z\end{cases} \qquad (6)$$