A Quasi-3D Sediment Transport Modelling for Coastal Morphodynamics

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ABSTRACT

Accurate prediction of sediment transport rates is an important element in morphological studies for the coastal environment. The purpose of this paper is to develop a quasi-three-dimensional (Q-3D) total load sediment transport formula based on the bed load and suspended load transport driven by waves and wave induced nearshore currents for the coastal area. The model consists of a two-dimensional nonlinear wave model, a two-dimensional depth integrated model for wave-driven currents with a model for undertow circulation currents and a coastal sediment transport formula with bed load and suspended load. The bed load sediment transport rate is calculated by the flow velocity coupled with wave and wave driven current near bed, and the suspended load is integrated the sediment concentration calculated by coupled velocity in vertical direction. A comparison has been carried out between the computed sediment transport rates with experimental results. The numerical results obtained are reasonably accurate within a factor of 2.

KEY WORDS: Quasi-3D, Wave, Nearshore Current, Sediment Transport, Modelling.

INTRODUCTION

The numerical simulation of hydrodynamic and sediment transport processes form a powerful tool in the description and prediction of morphological changes and sediment budgets in the coastal zone. One of the key elements in a morphodynamic model is the correct quantification of local sand transport. Most sediment transport models are based on phase-averaged wave models, depth-integrated hydraulic models (currents and wave driven currents) and sediment transport formula. In the hydraulic models, nearshore currents have previously been predicted by using two-dimensional models in the horizontal plane (2DH model). However, in the surf zone, the direction of current vectors near the water surface is different from that at the sea-bottom because of the effect of undertow velocities. Nearshore currents have spiral profiles in the vertical direction. Undertows also play an important role in the morphodynamical changes on a littoral beach such as the cross-shore migration of longshore bars. In order to accurately predict the changes of beach profile, it is very important that the three-dimensional distribution of nearshore currents is determined. Therefore, well predicted vertical current and sediment transport models can be a good tool for coastal area morphological modelling, especially for cases where cross-shore transport mechanisms are important. Considering the accuracy and efficiency, a Quasi-3D model can be applied as a coastal profile model or a coastal area model.

Some models for determining the vertical distribution of nearshore currents have previously been proposed. De Vriend et al. (1987) presented a semi-analytical model and suggested that a 3D model is required when the sediment transport in the cross-shore direction becomes important; and then Svendsen et al. (1989) proposed an analytical model composed of cross-shore and longshore current velocities. In recent years, many Q-3D numerical models have been developed by extending 2DH model with one-dimensional velocity profile model defined in the vertical direction (1DV model), have also been proposed (Sanchez et al., 1992; Briand and Kamphuis, 1993; Okayasu et al., 1994; Elfrink et al., 1996; Rakha, 1998; Kuroiwa et al., 1998; Drønen and Deigaard, 2000; Davis and Thorne, 2002; Fernando and Pan, 2005; Drønen and Deigaard, 2007; Li et al., 2007). In these models, the mean flow is determined by the 2DH model, and the velocity profiles across water column in the vertical direction are resolved by using a 1DV model. While surface wave field and 3D flow field have been analyzed, sediment transport vectors in the horizontal plane can be calculated with the sediment transport profile across water column in the vertical direction.

The aim of this paper is to develop an accurate model for estimation of local sediment transport rate of the nearshore both inside and outside of the surf zone. A two-dimensional 2D fully nonlinear Boussinesq wave module is combined with a Q-3D hydrodynamic module (2DH and extended 1DV module). The 1DV hydrodynamic models similar to those described by Elfrink et al. (1996) with surface-roller concept and a one-equation turbulence model are developed. The calculation of sediment transport rates is based on the formula with wave asymmetric and ripple-bed effects developed by Lin et al. (2009). The Q-3D hydrodynamic modules are validated and compared, for regular waves over fixed beds. The local sediment transport rates is also calculated and validated with experimental data.

2DH WAVE AND NEARSHORE CURRENT MODELS