UNSTEADY EFECTS IN SAND TRANSPORT UNDER NONLINEAR WAVES

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1. Introduction

The phase lag between the orbital velocity and sediment concentration in oscillatory flows near the bed can be an effective process that controls the net sediment transport in the wave direction. The importance of unsteady effects in the sediment transport was observed from the analysis of detailed measurements of flow velocity and sediment concentrations near the bed (e.g., Dohmen-Jansen *et al.*, 2002; Ruessink *et al*., 2012). These experiments have shown that large amounts of sediment are expected to remain in suspension at flow reversal for high orbital velocities and wave nonlinearities, rippled beds and fine sediments.

Different model concepts are presently being used in order to predict sediment transport in coastal zones. These range from the empirical or theoretical transport formulas (e.g., quasi-steady and semi-unsteady models) to more sophisticated bottom boundary layer models. The semi-unsteady models were proposed to tackle the limitations of the quasi-steady models and describe the unsteady effects by involving parameters that quantify the amount of sediment mobilized from the bed during a half-wave cycle and the sediment fall velocity (e.g., Dibajnia and Watanabe, 1992; Dohmen-Jansen *et al*., 2002; Silva *et al*., 2006). The present work aims to present a methodology to evaluate the unsteady effects in net transport rates in non-linear waves.

2. Methodology and Results

Silva *et al*. (2006) have expressed the dimensionless net transport rate for wave and combined wave-current flows (Φ) in sheet flow and rippled bed as a product of two functions:

$$\Phi = G\,\Phi_N \tag{1}$$

where Φ_N represents the value of Φ when the phase lag effects are not considered in the model (quasi-steady approach) and G represents a function that translates the effect of the unsteady processes in sediment transport:

$$G = \left[\frac{Z_c^{\,3} + \alpha_o^{\,6}(1-\beta_o Z_c)^3 - \alpha_0\delta_o\left[\alpha_o^{\,6}(\beta_o Z_c)^3 + (1-Z_c)^3\right]}{1-\alpha_o^{\,7}\delta_o}\right]^{\beta} \tag{2}$$

The quantities α_o, δ_o, Z_c and β_o in Equation (2) are given by:

$$\alpha_o = \frac{u_t}{u_c};\quad \delta_o = \frac{1-t_c}{t_c}\;;\; Z_c = \frac{\omega_{cr}}{\omega_c};\;\; \beta_o = \frac{\omega_c}{\omega_t} \tag{3}$$

and β represents an empirical coefficient. In Equation (3) u_c and u_t represent the equivalent sinusoidal velocity amplitude for each half cycle, t_c the dimensionless value of T_c, and ω_c (ω_t) depends on the ratio between the settling time of the sediment particles and the duration of the wave-crest (trough) half cycle, T_c (T_t). The relation between ω_c (ω_t) to the threshold value ω_{cr} controls the effectiveness of the unsteady correction.

The values of the parameters in Equation (3) can be computed from the analysis of the velocity time series in the wave direction or parameterized as a function of the asymmetry and skewness of the orbital flow velocity according to the analytic formulae of Abreu *et al*. (2010).

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Figure 1 represents values of G for a oscillatory flow with root mean square orbital velocity U_{rms}, period $T = 7$ s, for different values of the velocity skewness index r and $r_0=U_0/U_{rms}$ (U_0 represents the mean current in the wave direction). Clearly, the pattern is strongly modified by the magnitude of U_{rms} and the velocity nonlinearity (skewness) r (r=0 corresponds to sinusoidal waves).

The application of this methodology to different sediment transport models (e.g., Silva *et al*., 2006; Abreu *et al*., 2013) and comparison of the results with the recent experimental data of net transport rates under nonlinear waves (Silva *et al*., 2011; Dong *et al*.,2013) will be further analyzed.

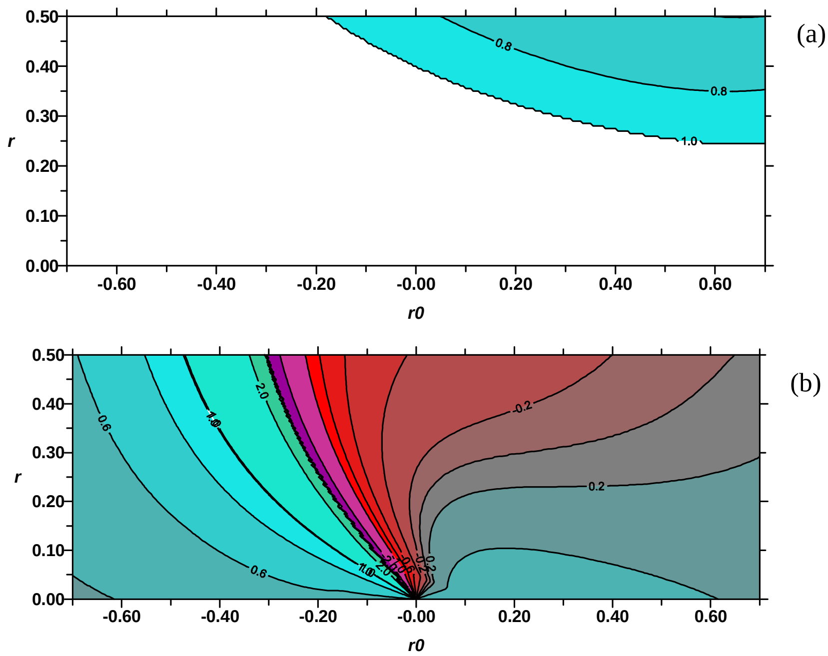

Figure 1. Contours of G for $T = 7$ s; $d_{50} = 0.25$ mm (a) $U_{rms} = 1.0$ m/s , (b) $U_{rms} = 1.5$ m/s as a function of r and r_0.

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