OS21E-1207

Universiteit Utrecht

Gerben Ruessink[1], Hervé Michallet[2], David Hurther[2] and Paulo Silva[3]

1 Utrecht University, Netherlands. g.ruessink@geo.uu.nl
2 University of Grenoble, France
3 Universidade de Aveiro, Portugal

Observations of intra-wave sand flux under acceleration-skewed oscillatory flow

Abstract

We analyze intra-wave velocities and sediment concentrations in the sheet flow and suspension layer under full-scale acceleration-skewed waves. We find that the wave-bottom-boundary-layer is thinner under maximum positive flow than under maximum negative flow, causing the bed shear stress to be positively skewed. The resulting positive net sand flux increases with increasing acceleration-skewness and is always a close balance between a large positive and negative flux.

1. Introduction

Oscillatory flow in the inner surf zone has zero velocity skewness but non-zero acceleration skewness. Acceleration-skewed ('sawtooth') waves produce net transport in the direction of the largest acceleration (i.e., onshore), as demonstrated in various laboratory experiments. However, our current understanding of acceleration effects on sediment transport is poor, mainly because of a lack of detailed intra-wave process measurements.

The aim of our work is to analyze the effect of acceleration skewness, velocity skewness, and net currents on sediment transport processes. Here we analyze a new dataset of intra-wave velocities, concentrations, and sand fluxes under sheet flow conditions generated by full-scale, regular, acceleration- and velocity skewed oscillatory flows with and without opposing currents.

2. Experimental set-up

The experiments were conducted in the Large Oscillating Water Tunnel (LOWT) at Deltares|Delft Hydraulics, the Netherlands (Figure 1a). The experiments involved 4 flows over a quartz sand with a median grain size of 200 μm and a geometric standard deviation of 1.2. The regular horizontal free-stream flow u_∞ was of the following general form

$$u_\infty(t) = U_w\, f\, \frac{\left[\sin(\omega t) + \dfrac{r \sin\Phi}{1+\sqrt{1-r^2}}\right]}{\left[1 - r\cos(\omega t + \Phi)\right]} + \bar{u},$$

where t is time, U_w is the velocity amplitude, $\omega = 2\pi/T$ with T the wave period, Φ is a phase, r is a nonlinearity measure, f is a modification factor to ensure that $u_\infty(t)$ has a standard deviation of $0.5\sqrt{2}\, U_w$, and $\bar{u}$ is the net current velocity. Values of r, Φ and $\bar{u}$ for the 4 flows are given in Table 1. In all cases, U_w = 1.2 m/s and T = 7 s. See also bottom row of Figure 2.

Table 1 Experimental conditions

Code	r	Φ	$\bar{u}$ (m/s)
A1	0.3	0	0
A3	0.5	0	0
C1	0.5	$-\pi/4$	0
B2	0.3	0	-0.4

The present work is based on measurements of (i) time-varying concentrations with a Conductivity Concentration Meter (Figure 1b) and a triple-frequency (1, 2 and 4 MHz) Acoustic Backscatter Sensor (Figure 1c), and (ii) time-varying horizontal and vertical velocities with a 2-MHz Acoustic Doppler Velocimeter Profiler (Figure 1d).

Figure 1a The Large Oscillating Water Tunnel at Deltares|Delft Hydraulics and the instruments used:

Figure 1b Conductivity Concentration Meters

Figure 1c Triple-frequency Acoustic Backscatter Sensor

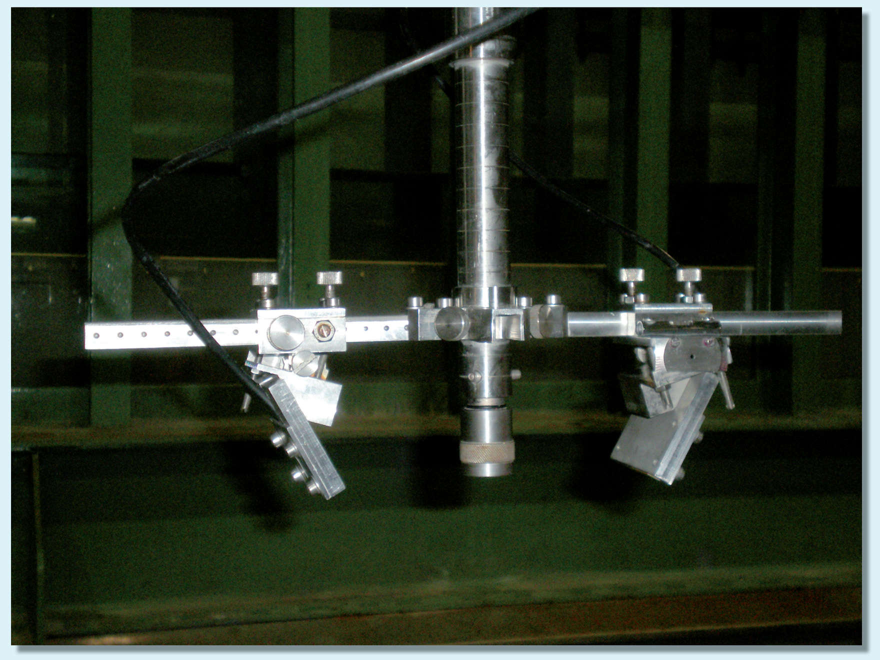


Figure 1d Acoustic Doppler Velocimeter Profiler

3. Data (Figure 2)

Oscillatory flow velocity, $\tilde{u}(t, z) = u(t, z) - \bar{u}$.
The gray line is the top of the wave-bottom-boundary-layer.
The black line is the instantaneous erosion depth δ_e.
The height above the no-flow bed is denoted by z.

Turbulent kinetic energy,
$k = 1.33\, k' = 1.33 * (0.5*(\langle u'^2\rangle + \langle w'^2\rangle))$

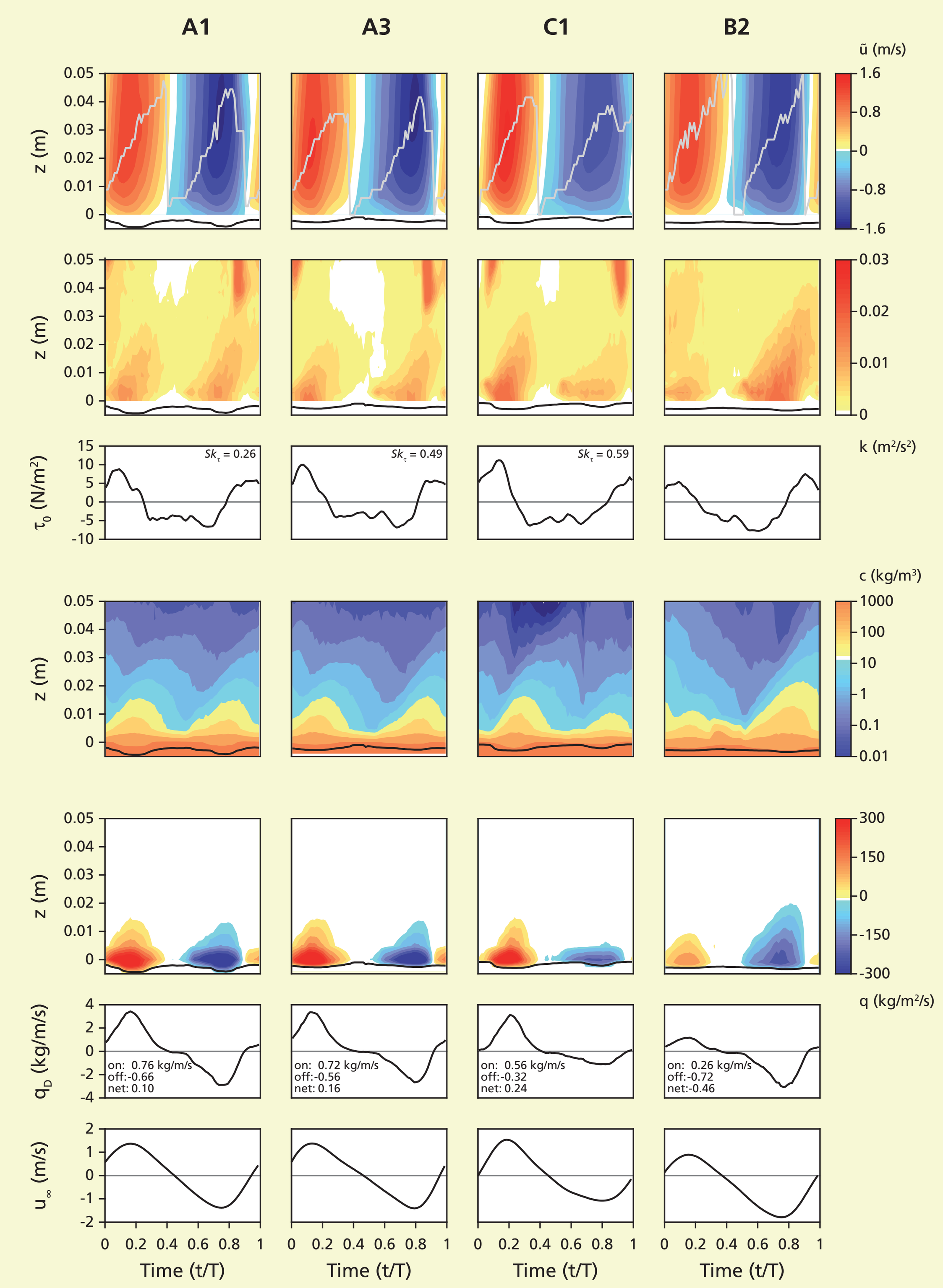
Bed shear stress, estimated from the velocity defect integral method: $\tau_0 = \rho \int_0^{0.03\text{m}} \frac{\partial}{\partial t} (u_\infty - u)\, dz$,
where ρ is the water density.

Sediment concentration, c

Sediment flux, $q = u \times c$

Depth-integrated sediment flux, $q_D = \int_{\delta_e}^{h} q\, dz$,
where h is the total water depth.

Free-stream velocity



4. Findings

Under sawtooth waves (A1 and A3 in Figure 2):

- The wave-bottom-boundary layer (WBBL) is thinner under maximum positive than under maximum negative flow. Accordingly, the bed shear stress is positively skewed, even though the free-stream velocity has zero velocity skewness.
- The skewness in the bed shear stress increases with an increase in acceleration skewness.
- The concentrations and fluxes show two large, almost equal peaks. The net flux is a close balance between the positive and negative flux.
- Some sediment stirred under the negative flow phase remains in suspension into the positive flow phase.
- The depth-integrated flux is approximately in phase with the free stream velocity.
- The net flux increases with an increase in acceleration skewness.

The addition of velocity skewness (C1 versus A1 in Figure 2) results in:

- A smaller difference in WBBL thickness under maximum positive and negative velocity.
- An increase in the skewness of the bed shear stress.
- A decrease in the magnitude of the offshore flux, causing an increase in the net flux.

The strong opposing current (B2 versus A1 in Figure 2):

- Suppresses (enhances) the turbulence kinetic energy under the positive (negative) orbital flow.
- Increases (decreases) the concentration under the negative (positive) flow.
- Produces a net negative flux, which results from the negative current-induced *and* the negative wave-induced flux. Thus, with an opposing current, acceleration-skewed waves produce net transport against the direction of the largest acceleration.

Acknowledgments

Supported by the European Community's Sixth Framework Program as part of the Integrated Infrastructure Initiative HYDRALAB III