High-speed phase-separated PIV over laboratory sand ripples

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Coastal hydrodynamics are intricately coupled with bedform generation and migration, which are important mechanisms for sediment transport and wave energy dissipation. We investigated the transport of sand as bed load and suspended load over ripples in a small-oscillatory flow tunnel and measured the resulting morphological evolution of the bedforms. High-resolution fluid and sediment velocity measurements were made with high-speed phase-separated Particle Image Velocimetry. Coherent structures were identified and determined to play a significant role in the transport of suspended sediments. Bedload transport during ripple migration was quantified within an oscillatory flow cycle using a surface tracking system. The relationship between turbulent kinetic energy dissipation and ripple migration was assessed.

1. INTRODUCTION

Ripples and other bedforms are ubiquitous in shallow water along sandy coastlines. The dynamics of sand ripples are vital to understanding numerous coastal processes such as sediment transport, wave attenuation, boundary layer development, and seafloor acoustic properties. The hydrodynamics above sand ripples are dominated by the coherent vortices formed on the ripple slopes and ejected into the water column at flow reversal. Sediment is entrained from the surface of the ripple and suspended into the water column where it is then advected with the flow (Thorne et al., 2003, van der Werf et al., 2006) and deposited onto the neighboring ripple.

New technology has recently allowed for the measurement of small-scale sediment dynamics in the laboratory. Here, phase-separated Particle Image Velocimetry (PIV) and a laser bed tracking system coupled with a water level sensor and a profiling Acoustic Doppler Velocimeter in a Small-Oscillatory Flow Tunnel (S-OFT) are used to measure fluid and sediment dynamics in the bottom boundary layer. We assess the relationship between sand ripple characteristics, migration rates and turbulent kinetic energy dissipation.

2. LABORATORY EQUIPMENT

The S-OFT is located at the Naval Research Laboratory at Stennis Space Center, Mississippi, USA. The S-OFT has a 2-m long test section and a flow cross-section of 25 cm x 25 cm (Figure 1). Oscillatory flow is generated with a piston flywheel to drive sediment transport and ripple formation. The instruments used to measure the fluid and sediment dynamics are described below.

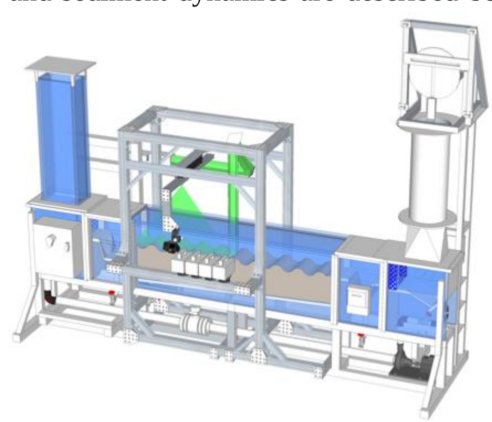

Figure 1: Small-Oscillatory Flow Tunnel.

PIV was used to measure three-dimensional velocities in the bottom boundary layer. However, standard PIV techniques severely limit direct observations of the fluid-sediment interface. Intense reflections at the bed inhibit our ability to separate phase velocities during sediment entrainment. We have implemented phase-separated PIV by adding fluorescent tracer particles to the fluid in order to observe fluid flow and sediment transport simultaneously under oscillatory flows using multiple cameras with varying optical filters. The sediment particles scatter the 532 nm wavelength light. The fluorescent particles absorb the light and re-emit at a higher wavelength. Optical long pass filters were installed on two cameras to capture only the light re-emitted by the fluorescent tracer particles used to determine fluid velocities (Figure 2). A third high-speed camera was used to capture the light scattered by the sand grains allowing for sediment particle tracking. Together, these overlapping, simultaneously recorded images provided sediment particle and fluid velocities at high temporal (100 Hz) and spatial (< 1 mm) resolution.

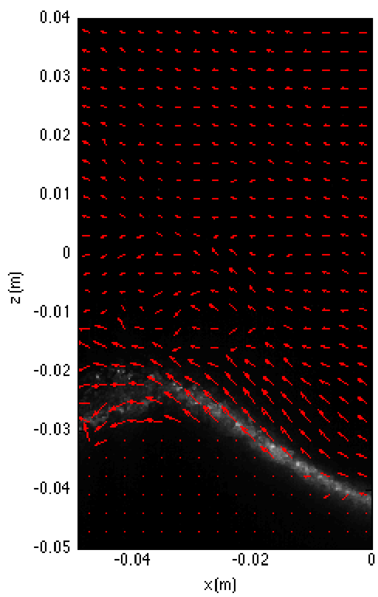

Figure 2: Near-bed fluid velocities over a sand ripple.

A Nortek Vectrino Profiler provided a longer time-series of the three-components of fluid velocity in a one-dimensional vertical profile. The instrument was positioned to measure the velocities within 3 cm of the bed in vertical bins of 1 mm approximately 5 cm upstream of the PIV field of view.

A Bed LAser Surface Tracking (BLAST) system measured the sediment bed elevation. The BLAST system consists of two 520 nm, continuous wave (CW), fan beam lasers that project a ~1-m laser line on the sediment bed in the along-flow direction. Two Canon DSLR cameras capture images and video of each of the laser lines projected on the bed. One CW laser was stepped across the width of the S-OFT with a high precision stepping motor in 0.5-mm increments, while the DSLR camera with a 10-mm fisheye lens captured images of the laser line at every step. Each image size is 5184 x 3456 pixels, resulting in an average of 5-6 pixels/mm resolution. The bed surface elevation was scanned before and after each experiment. The second DSLR camera captured high-definition (HD) video (1080p) at 30 frames per second of sediment bed elevation profiles in the along-flow direction at the center of the test section over several oscillatory flow cycles (Figure 3). The measurements were used to determine the flow phase at which the sand grains were mobilized and estimate sediment transport rates.

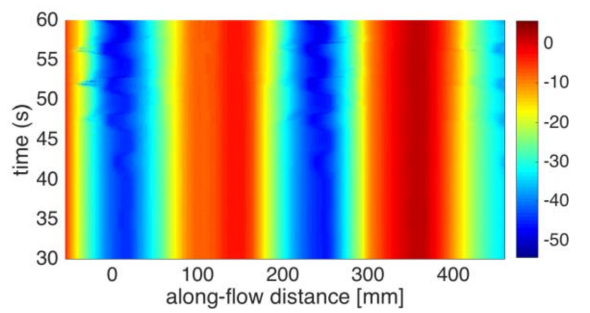

Figure 3. Initial sediment bed elevation after ripple generation in mm.

3. CONCLUSIONS

Measurements were made over a range of periods, orbital excursion amplitudes, symmetric and asymmetric oscillatory flows. Ripple crests were observed to move back and forth at a distance proportional to the orbital excursion amplitude with a migration rate consistent with the estimated bedload transport rate. Additionally, sediment grains were picked up from the flank of one ripple and transported as suspended sediment before being deposited on the flank of the adjacent ripple. Asymmetric oscillatory flows produced a net migration of the ripples proportional to the velocity asymmetry. Pressure gradients were deemed to be an important mechanism for mobilizing the sediment grains. Coherent structures were identified and determined to be a significant mechanism for transporting suspended sediments.

4. ACKNOWLEDGMENT

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5. REFERENCES

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