Near-Bottom Flow Characteristics of Currents at Arbitrary Angle to 2D Ripples

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Motivation and Background

As wind-waves propagate over a sandy bottom from deep to shallow water they interact with the bottom (shoaling and refraction) and the bottom sediments (initiation of sediment motion followed by generation of initially 2D ripples that become increasingly 3D and finally are obliterated, sheet flow, as the water becomes shallower). Co-existing with the waves there will be currents (wind-induced and/or tidal) that are essentially parallel to the adjacent coastline. Thus, a region exists in coastal waters where currents run at a relatively small angle, ~45° or less, to the crests of essentially 2D ripples. Unfortunately, this more physically realistic flow condition is not reflected in the availability of experimental data, most of which have been obtained for co-linear wave-current flows, i.e. with currents perpendicular to the ripple crests. At the 31st ICCE Madsen et al. (2008) presented experimental results on the flow resistance experienced by a current perpendicular to the wave direction, i.e. aligned with the crests of the 2D wave-generated ripples. Their results suggested that a current parallel to experienced virtually the same flow resistance as a current perpendicular to the crests of 2D wave-generated ripples. The apparent absurdity of this result is the motivation for the experimental investigation reported here.

Experimental Set-up and Procedures

The experiments were conducted in the wave basin located in the Hydraulic Laboratory of the Civil Engineering Department at the National University of Singapore. A current entered the wave basin through a 2m-long honeycomb filter inserted in a false sidewall of the wave basin and exited over a 2m-wide tailgate weir placed directly across from the inlet. By adjusting the height of the tailgate, a pump and constant head-tank maintained an average current of U = 14 cm/s for a water depth of h = 40 cm. Experiments were carried out for artificial 2D ripples, formed of aluminum angle profiles of height 1.5 cm spaced at 10 cm intervals, covering the concrete bottom over the 6 by 2 m area of the current channel. Current profiles were obtained with Nortec Vectrino Plus ADVs at several (~8) locations across the central 1m-width of the current channel at distances of 3.0, 4.0, and 5.0 m from the current inlet. In one series the ripples were aligned with the current direction, ($\theta = 0°$), in the other series the angle between ripples and current was $\theta = 30°$. In addition, a limited experimental series was conducted in a flume for a current perpendicular to the same ripple configuration ($\theta = 90°$).

Experimental Results

At each measurement location the horizontal velocity vector (u, v) was obtained as a function of z and the resulting velocity profiles were analyzed using the log-profile method, to determine the flow resistance, represented by the shear velocity, u_*, and the bottom roughness, $z_0 = k_N/30$ where k_N is the equivalent Nikuradse sand grain roughness. For the special case of $\theta = 30°$, the velocity vector was also resolved into the velocity components $u_\perp$ and $u_\parallel$ perpendicular and parallel to the ripple axis, respectively, resulting roughness estimates $z_{0\perp}$ and $z_{0\parallel}$. The results are shown in Table 1. In addition, the angle of the velocity vector relative to the channel axis $\tan\alpha = {}^{v}/_{u}$ was obtained for $\theta = 30°$ and demonstrate (Figure 1) that the flow becomes increasingly aligned with the ripple axis direction as the bottom is approached from above.

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Table 1: Roughness and Shear Velocity Determined from Log-Profile Analyses

θ (degrees)	90	30			0
Vel. Comp	u	$u_{\perp}$	u	$u_{\parallel}$	u
z_0 (cm)	0.62	0.52	0.067	0.023	0.002
u_* (cm/s)	1.82		0.97		0.55

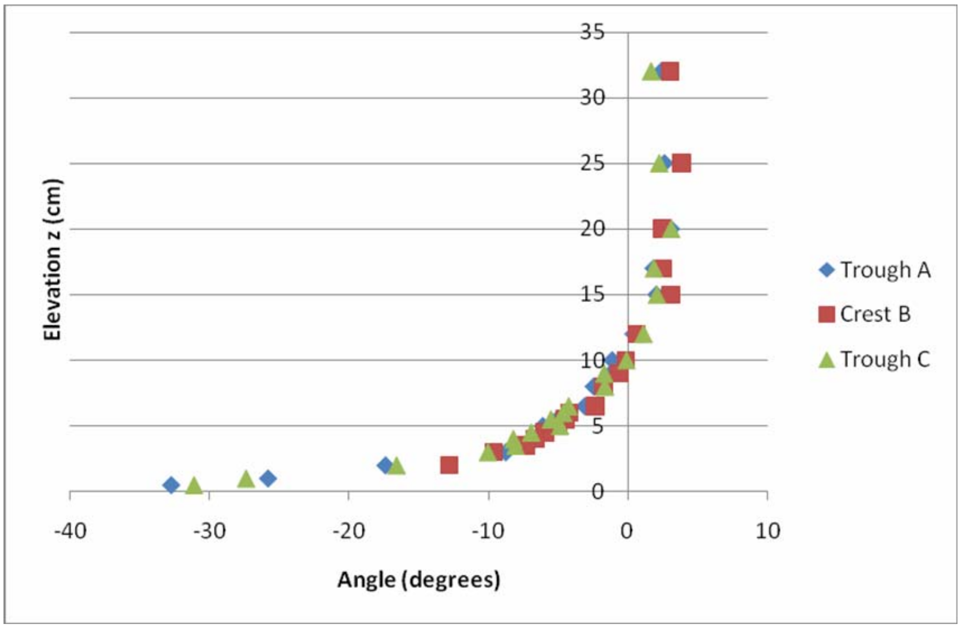

Figure 1: Turning of the velocity vector for ripples at $\theta = 30°$ to channel axis

Conclusions

- The roughness and hence the flow resistance experienced by a current over a 2D rippled bottom depends on current direction relative to the ripple axis, i.e. the bottom roughness of a 2D rippled bed is direction-dependent and decreases, as expected, with decreasing angle of incidence
- The bottom roughness for the velocity component perpendicular to the ripple axis remains essentially constant. This, however, does not appear to be the case for the velocity component parallel to the ripple axis.
- As the bottom is approached from above the current direction becomes increasingly aligned with the ripple axis direction. This conclusion may have serious implications for suspended sediment transport modeling for combined wave-current flows over a wave-rippled movable bed.
- At ICCE2010 results for orthogonal wave-current flows for the case $\theta = 0°$ will be included.

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References

Madsen, O.S., K.A.S.R. Kularatne and H.F. Cheong. 2008. Experiments on bottom roughness experienced by currents perpendicular to waves. *Proceedings 31st ICCE*, ASCE, (1)845-853