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Technical Report

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BOTTOM ROUGHNESS FOR WAVE AND CURRENT BOUNDARY LAYER FLOWS OVER A RIPPLED BED

Paul Peter Mathisen and Ole Secher Madsen, Ph.D.

MITSG 93-27

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MIT Sea Grant College Program

Massachusetts Institute
of Technology
Cambridge, Massachusetts
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ABSTRACT

In coastal regions, the hydrodynamic environment is typically dominated by both slowly varying currents and high frequency wind waves. The near-bottom fluid motion of these wave and current flows is typically characterized by high fluid shear. This high fluid shear leads to bedform development and results in an enhanced energy dissipation experienced by the waves and current. Moreover, this fluid shear can resuspend fine sediments and associated contaminants. Therefore, characterization of the near-bottom wave-current interaction is extremely important. Accordingly, several theoretical models have been advanced for turbulent bottom boundary layers associated with combined wave and current flows over a rough bed. Although these models differ, particularly in the sophistication with which turbulence is modeled, they all share one common feature: the bottom roughness is characterized by a single roughness length scale, k_n. However, no experimental data have been presented which accurately characterize the bottom roughnesses for wave *and* current boundary layers such that this basic assumption can be considered verified.

Therefore, an experimental study of wave-current interaction over a rippled bed is completed using an existing 30-m-long wave flume which was modified to accommodate a uniform current. The flume provides a test section of 17 m and a still-water depth of 60 cm. To simulate ripples, the bed is covered by 1.5-cm-high triangular bars placed at uniform intervals along the length of the flume. Experiments are carried out with bars placed in 10-cm and 20-cm intervals. A 1200-GPM pump is used to generate uniform currents of .12 m/sec and .16 m/sec. A programmable wavemaker is used to generate Stokes waves with wave periods of 2.24, 2.63, and 2.89 seconds and maximum amplitudes of 6 cm. The roughness experienced by the current is determined from velocity profiles obtained using laser doppler velocimetry measurements. The roughness experienced by the waves is determined from the friction factors obtained from measurements of wave attenuation.

Roughness determinations for pure wave motion, pure current flow, and combined wave-current flow over a rippled bed are compared. The roughnesses for pure currents and for pure waves are shown to be the same only if determination of pure wave roughness includes detailed analysis of the phase difference between bottom horizontal orbital velocity and bottom shear stress. The roughnesses for pure waves are also shown to be comparable to the roughnesses for waves in combined wave-current flows. However, apparent roughness predictions of existing wave-current interaction models underestimate the apparent roughness experienced by the current. This difference is shown to be a result of a steady streaming or mass transport which is imposed by the wave motion within the wave boundary layer of the combined wave-current flow. To account for this wave-induced streaming, a conceptual theoretical model is developed which includes the effects of a time-varying eddy viscosity. By applying this model to experimental data, the bottom roughness for pure current, pure wave, and combined wave-current boundary layer flows is shown to be characterized by a single roughness length scale.

Since waves are more realistically represented in terms of a wave spectrum, experiments are also carried out using spectral waves over a rippled bed. Wave spectra with peak periods of 2.24 sec and rms amplitudes of 3 and 5 cm are simulated by generating five wave components. Sidewall friction and wave-wave interactions are measured for spectral experiments over a flat bottom. Using these measurements, the sidewall friction and wave-wave interactions are accounted for when determining wave attenuation due to bottom friction over a rippled bed. Wave attenuation for each component is determined and used to establish a

representative friction factor. Using this friction factor in conjunction with an equivalent monochromatic wave produces a roughness estimate in good agreement with the roughness for strictly monochromatic waves. Thus, the concept of an equivalent monochromatic wave for use in characterization of energy dissipation and friction factor determination (Madsen et al., 1988) is experimentally verified. The concept of an equivalent monochromatic wave is extended to the problem of spectral wave-current interaction (Madsen, 1992) and shown to produce results in agreement with the results for monochromatic wave-current interaction.

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