Numerical investigations of the mechanisms associated with the onshore ripple migration

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INTRODUCTION

Quantification of cross-shore sediment transport is one of most intriguing challenges in shoreline and coastal geomorphology. During the past decades, several key mechanisms associated with onshore/offshore sediment transport have been identified, such as wave skewness/asymmetry, progressive wave streaming and undertow current. However, applying these mechanisms to the migration of wave formed bedforms (ripples) is not straightforward. For example, recent field observations off Fire Island, NY showed that ripples migrated onshore even during periods of offshore directed wave skewness, which is contradictory to the prediction of empirical sediment transport formulations. The physical processes driving ripple vortex formation, ejection and boundary layer streaming associated with rippled bed can further complicate the bedload/suspended load sediment transport over ripples. To fully understand these mechanisms, a comprehensive model that can resolve the ripple dynamics and interactions between free surface wave and rippled bed is examined.

MODELING APPROACH

As a first step, a volume-of-fluid solver interFoam in the OpenFOAM framework is used to understand the hydrodynamics, such as the effect of ripple vortexes and boundary layer streaming. The free surface waves are modeled with a wave generation tool box, waves2Foam (Jacobsen et al. 2011), while the sea-bed boundary layer processes are modeled with a high accuracy $k-\omega$ SST turbulence model (Menter, 1994), in which a rough wall function is implemented (Aupoix, 2015). To examine the effects of free-stream vertical velocities, which are absent in the oscillating water tunnel (OWT), two comparative cases with free surface ('FS') and without free surface ('OWT') were carried out. After understanding the fundamental hydrodynamic processes and their implications to sediment transport mechanisms, a comprehensive model that resolves free surface waves and bedload/suspended load will be used to investigate ripple migration.

PRELIMINARY RESULTS

The wave boundary layer streaming and near-bed velocity skewness are investigated by considering a fixed ripple bed, and the domain setup is shown in Figure 1(a). The waves in the FS case are sinusoidal waves with an amplitude of $a=0.31$ m, a wave period of $T=5$ s, and a water depth of $h=4$ m, thus the nearbed wave orbital velocity is about $u_b=0.39$ m/s. In the middle of the domain (shown as red box in Figure 1a), the bed consisted of 31 ripples with ripple length $\lambda_r=0.46$m and height $\eta_r=0.078$m. The same flow condition and numerical domain are applied to the OWT case, except a smooth-wall top boundary is used to avoid free surfaces. The wave-averaged velocity profiles along the center ripple are shown at three representative locations, $x/\lambda_r=$ -0.25, 0 and 0.25 in Figure 1(b). For a flatbed OWT case, the wave-averaged velocity profile is nearly zero for a sinusoidal wave, however, we observe that both FS and OWT have nonzero streaming velocity at $x/\lambda_r=-0.25$ (onshore-directed) and $x/\lambda_r=0.25$ (offshore-directed). The streaming velocities on either side of the ripple crest are nearly symmetric in OWT, while for the FS case, the onshore streaming velocity at $x/\lambda_r=-0.25$ extends about 5 cm higher than that at $x/\lambda_r=0.25$, even though their magnitudes are similar. Moreover, a non-negligible onshore-directed streaming velocity can be found within 7 cm above the ripple crest, which indicates a possible onshore transport of suspended sediments. In addition, the near-bed time average of velocity cubed ($\langle u_w^3\rangle$, Figure 1c) also shows a much stronger onshore $\langle u_w^3\rangle$ on the stoss side than the lee side. This asymmetry in the nearbed velocity skewness may significantly contribute to the onshore bedload transport. The OWT case shows the opposite behavior with offshore dominated $\langle u_w^3\rangle$ on the lee side resulting in offshore migration. The model results that incorporate both the bedload and suspended load for forcing ripple migration will be discussed in detail as a full paper. The initial modelling results are consistent with the observations that indicate ripples can migrate onshore with less dependence on free stream wave velocity skewness and a greater dependence on $u_{w,rms}^3$ than expected from previous work.

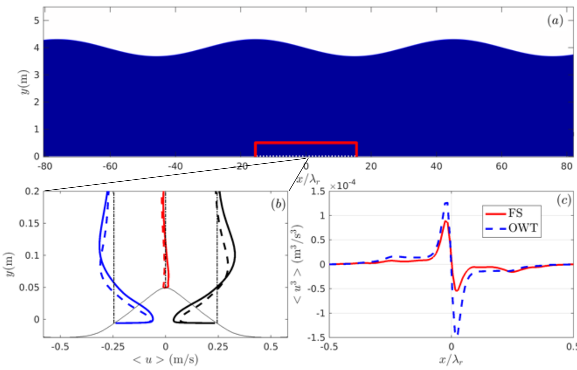

Figure 1 - (a) Central portion of the numerical flume domain (relaxation zones not shown, Air: white; Water: blue). The region signified by the red box consists of 31 ripples. In panel (b), the ripple geometry is shown as thin solid curve. Meanwhile, the wave averaged velocity profiles at x/λ_r=-0.25 (blue), 0 (red) and 0.25 (black) are shown as thick curves for FS (solid) and OWT (dashed). Panel (c) shows the distribution of near-bed <u_w^3> along the center ripple.

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