Evolution of boundary layer flows under a transient long wave

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Abstract:

Similar to many previously recorded historical tsunamis the 2011 Tohoku tsunamis left behind widespread sediment deposits along the Japanese coast. Knowing the relationship between tsunami sediment deposits and tsunami wave characteristics will allow better estimates of times and recurrence intervals of past tsunamis. This will then enhance tsunami data base and improve the assessment of tsunami risk. Therefore, it is important to understand the sediment transport processes under the leading tsunami waves. Since sediment transport is primarily driven by the near-bed flow turbulence and bottom stresses, we need to enhance our knowledge on the evolution of near-bed flows under the leading waves of tsunamis, which can be characterized as transient long waves.
In a recent study (Sumer *et al.* 2010, JFM) U-tube experiments were performed to investigate boundary layer flows driven by a soliton-like pressure gradient. For Reynolds numbers, defined as Re $= aU_{0m}/\nu$, where U_{0m} denotes the maximum free-stream velocity, $2a$ the corresponding maximum fluid particle displacement, and ν the fluid viscosity, ranging between 2 x 10^5 and 2 x 10^6, the boundary layer flow characteristics transform from being simple laminar uni-directional flows to the appearance of 2D laminar vortex tubes, and to the occurrence of turbulence spots.
In this paper, a high resolution and high accuracy 2D pseudo-spectral numerical model (Diamessis *et al.* 2005) is used to simulate the U-tube experiments and to investigate flow instability characteristics in details for higher Reynolds numbers. Furthermore, we also examine the boundary layer flows under asymmetric wave profile: a steep wave front (acceleration phase) with a longer and flatter tail (deceleration phase), which mimic the real tsunami waves better than solitary waves.
Generally speaking, boundary layer flows under a solitary wave can be divided into laminar, disturbed laminar and turbulent flow regimes depending the Reynolds number. In the laminar flow regime (Re $\leq 10^5$) the boundary layer flow is unconditionally stable, in which the growth rate of the shear flow instability is weak, and the time required for a small initial disturbance (say, in order of O(10^{-3} or less) to grow into an O(1) quantity is much longer than the time scale of the event (i.e., wave period). Whereas in the disturbed laminar regime ($10^5 <$Re$< 1.8\times10^6$), the growth rate of the instability is stronger, which enable the shear instability to grow and 2D vortex tubes are shed from the bottom boundary within the time frame of the event. However, this process is constrained by the initial amplitude of the disturbance. For solitary waves with $Re \geq 1.8 \times 10^6$, the growth rate of the shear instability is large enough so that the instability will take place even for an infinitesimal small disturbance. We also discover that for boundary layer flows with $Re \approx 10^7$ a different kind of instability occurs.
For asymmetric waves, the stability conditions can be classified in a similar way as those for the symmetric waves, except that the Reynolds number is defined by using the time scale for the deceleration phase. In other word, the stability characteristics

are not correlated with the acceleration phase. The implications of this feature on the bottom shear stress and sediment transport are investigated.

References:

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