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Theoretical and Experimental study of Nonlinear water waves on uniform current

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The phenomenon of wave-current interaction has been studied extensively since 1970s. Most previous theories dealing with wave-current interactions have employed the Eulerian description. Unlike the Eulerian free surface, which is given as an implicit function, a Lagrangian surface is described through a parametric representation of the position of a particle. The main advantage of such description is to allow better flexibility for describing the actual shape of the ocean surface, which will be demonstrated later in this paper. Based on this reason, it has been shown that the Lagrangian description is more appropriate for the motion of the limiting free surface that cannot be captured by the classical Eulerian solutions. However, reports on this notable improvement using Lagrangian description were rather limited.

In this paper, we present a new third-order trajectory solution in Lagrangian form for the water particles in a wave-current interaction flow. The explicit parametric solution highlights the trajectory of a water particle and the wave kinematics above the mean water level and within a vertical water column, which were calculated previously by an approximation method using Eulerian approach. Mass transport associated with a particle displacement can now be obtained directly in Lagrangian form. The angular frequency and Lagrangian mean level of the particle motion in Lagrangian form differ from those of the Eulerian. The variations in the wave profile and the water particle orbits resulting from the interaction with a steady uniform current of different magnitudes are also investigated. Comparion on the wave profiles given by the Eulerian and Lagrangian solution to a third-order reveals that the latter is more accurate than the former in describing the shape of the wave profile. Moreover, the influence of a following current is found to increase the relative horizontal distance traveled by a water particle, while the converse is true in the case of an opposing current. Finally, a series of laboratory experiments are performed to measure the trajectories of particles under the flow field of wave-current interaction. Comparing the present third-order asymptotic solution with laboratory experiments data, it is found that theoretical results show good agreement with experimental data.