Nonlinear Shallow Water Waves Generated by Submerged Moving Slender Bodies: 
An Experimental Study

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ABSTRACT

In the present study, we examine the consistency and validity of the Boussinesq and KdV equations in describing nonlinear water waves generated by vertical slender bodies moving with near critical speed in a rectangular channel. Our study is focused on investigating the effect of disturbance length \( L \) on wave generation, and whether the two long wave models, which in theory require \( L \) to be much greater than water depth \( H \), can actually be applied to cases where \( L/H = O(1) \). Our numerical results based on the KdV and Boussinesq wave models show that, if \( L \) is sufficiently long, the dominant factor affecting wave amplitude and period will be the ratio of the maximum disturbance width (i.e., beam of a vertical strut) over the channel width, while \( L \) has little effect. This confirms Ertekin’s (1984) and Mei’s (1986) earlier results on the “blockage coefficient”. When \( L \) is of the same order of \( H \), we found that, as \( L \) decreases, it weakens the forcing strength significantly. Results from our towing tank experiments with Froude number ranging from 0.8 to 1.07 revealed that the long wave models give good predictions for resonantly forced long waves even when \( L \) is slightly shorter than water depth.

KEY WORDS: long waves, resonant forcing, Boussinesq and KdV models, hydrodynamics, solitary waves

INTRODUCTION

In 1982, Wu and Wu discovered from numerical simulations based on Wu’s (1981) generalized Boussinesq model that upstream-advancing solitary waves (also called run-away solitons) can be generated periodically by a steadily moving pressure distribution moving with near critical speed on the free surface. Even though there had been earlier observations of run-away solitons in several experimental studies, Wu and Wu’s study provided the first theoretical understanding of the phenomenon. Later, more theoretical analysis based on mass conservation and energy principles was given in Wu (1987). It is known that run-away solitons can be generated by different types of moving disturbances including surface pressure distribution (Wu and Wu 1982, 1987, Akylas 1984, Katsis and Akylas 1987), a bottom topography (Lee, Yates and Wu 1989, Teng and Wu 1990) and vertical slender bodies (Ertekin 1984, Ertekin, Webster and Wehausen 1984, 1986, Mei 1986, Ertekin and Qian 1990, Teng and Wu 1990). For resonantly forced long waves generated by moving disturbances in a rectangular channel that is not excessively wide, the run-away solitons advancing upstream of the disturbances have been observed to have uniform wave crest across the channel. In this case, 2-D models such as the KdV equation and the section-mean Boussinesq equations can be used to predict the wave amplitude and period. For waves generated in a wide channel or an unbounded region, the wave field will be three-dimensional, and 3-D models including the K-P equation (Katis and Akylas 1987, Lee and Grimshaw 1990), the Green-Naghdi equations (Ertekin, Webster and Wehausen 1986) and the generalized Boussinesq equations (Wu and Wu 1982, 1987, Ertekin and Qian 1990) should be applied.

The present study is focused on studying forced long waves generated by moving vertical slender bodies in a uniform rectangular channel where the 2-D models, namely, the KdV equation and the section-mean Boussinesq equations, are applicable. In 1984, Ertekin carried out a series of experiments to study waves generated by moving ship models in a towing tank. His results showed that, the dominant factor that affects the wave amplitude and period is the disturbance blockage coefficient which is defined as the ratio of the strut beam over the channel width. These experimental results were later analyzed by Mei (1986) who derived a forced KdV equation to simulate Ertekin’s experiment. Two specific cases with disturbance length about ten times the water depth were simulated, and the numerical results from Mei’s KdV equation showed good agreement with Ertekin’s experimental results for resonantly forced long waves generated in front of the ship models. (Shorter dispersive waves in the trailing region are three-dimensional and cannot be fully described by 2-D models.) Good agreement between Ertekin’s (1984) experiments and the generalised Boussinesq equations were also found in Ertekin and Qian (1990). It is interesting to note that in both Mei’s (1986) and Ertekin and Qian’s (1990) studies, the detailed geometry of the slender body used in the numerical simulation and the experiments were actually not the same, but it was found that as long as the blockage coefficient was kept equal, the forced long waves predicted by the theory would agree very well with the experiment. In Teng and Wu (1990, 1992), previous study by Mei (1986) was extended to develop section-mean Boussinesq and KdV models for forced waves in arbitrarily shaped...