International Journal of Offshore and Polar Engineering
Vol. 7, No. 4, December 1997 (ISSN 1053-5381)

Effect of Disturbance Length on Resonantly Forced Nonlinear Shallow Water Waves

Michelle H. Teng*
Department of Civil Engineering, University of Hawaii at Manoa, Honolulu, Hawaii, USA

Theodore Y. Wu
Engineering Science, California Institute of Technology, Pasadena, California, USA

ABSTRACT

In the present study, we examine the consistency and validity of the Boussinesq and KdV equations in describing nonlinear water waves generated by submerged disturbances moving with near critical speed in a rectangular channel. The 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 $L/H = O(1)$. The numerical results based on the two wave models show that, if *L* is sufficiently long, the dominant forcing factor affecting wave amplitude and period is the "blockage coeffcient" defined as the ratio of the maximum submerged cross-sectional area of the disturbance over the wetted channel cross-sectional area, while *L* has little effect. This confirms Ertekin's (1984) and Mei's (1986) earlier results. However, when *L* is of the same order as *H*, the present results show that, as *L* decreases, it weakens the forcing strength significantly. This indicates that for short disturbances, both the blockage coefficient and the disturbance shape are important. Results from our towing tank experiments with Froude number ranging from 0.8 to 1.07 showed good agreement with the numerical results even when *L* is slightly shorter than the water depth.

INTRODUCTION

In 1982, Wu and Wu discovered from numerical simulations based on Wu's (1981) generalized Boussinesq equations that upstream-advancing solitary waves (also called runaway solitons) can be generated periodically by a steadily moving pressure distribution moving with near critical speed on the free surface. Despite earlier observations of runaway 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 nonlinear long waves 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 (Ertekin, 1984; Lee, Yates and Wu, 1989; Teng and Wu, 1990; Shen, 1996) and vertical slender bodies (Ertekin, 1984; Ertekin, Webster and Wehausen, 1984, 1986; Mei, 1986; Ertekin and Qian, 1989; Ertekin, Qian and Wehausen, 1990; Teng and Wu, 1990, 1997). For resonantly forced nonlinear long waves generated by moving disturbances in a rectangular channel that is not excessively wide, the runaway 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 (Katsis 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, 1989; Ertekin, Qian and Wehausen, 1990) should be applied.

The present study is focused on studying resonantly 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, aside from the disturbance speed, the dominant factor that affects the wave amplitude and period is the disturbance blockage coefficient, which was defined as the ratio of the maximum cross-sectional area of the ship model over the wetted channel cross-sectional area. For vertical struts whose height extends from the water surface to the channel bottom, the blockage coefficient will be 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 10 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 3-D and cannot be fully described by 2-D models.) Good agreement between Ertekin's (1984) experiments and the generalized Boussinesq equations were also found in Ertekin, Qian and Wehausen (1990). It is interesting to note that in both Mei's (1986) and the Ertekin, Qian and Wehausen (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

---

*ISOPE Member.

Received March 20, 1997: revised manuscript received by the editors September 25, 1997. The original version (prior to the final revised manuscript) was presented at the Seventh International Offshore and Polar Engineering Conference (ISOPE-97), Honolulu, USA, May 25-30, 1997.

KEY WORDS: Free surface, moving disturbance, resonant forcing, KdV and Boussinesq models, soliton.