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Hydrodynamic Resonances in Harbor Engineering

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We summarize the studies of two dynamical problems arising from harbor engineering. The first is on the long-period oscillations in a harbor forced by short and random incident waves. The second is on the unexpected oscillations of the mobile storm barrier designed for the Venice lagoon. In both problems nonlinearity plays a crucial role in the mathematical analysis.

PART I. LONG-PERIOD HARBOR OSCILLATIONS EXCITED BY RANDOM WIND WAVES

INTRODUCTION

Harbors are designed to protect ships from storm-induced sea waves. Long-period oscillations inside a harbor are hazardous to ship operations in general and to loading and unloading of cargos in particular. They can cause excessive straining and breakage of mooring lines as well as collision of ships against piers, etc. During strong oscillations, the swift current at the entrance hammers the passing of small vessels. Early studies of harbor oscillations were focussed on the linear mechanism of synchronous resonance, which is appropriate for treating the effects of long-period tsunamis (Miles and Munk, 1961; Lee, 1971; Chen and Mei, 1974). However, many harbors in the world are troubled more often by the short incident waves generated by storms. An example is the case of Barbers Point Harbor in Hawaii (Okihiro, 1993). The wave gauge at an inside station recorded a sharp peak at the frequency of $f = 0.001$ Hz corresponding to the wave period of $T = 100$ s, which is ten times the typical wind wave period of $O(10)$ s (see Fig. 1).

Hualien Harbor is located on the eastern (Pacific) coast of Taiwan, which is invaded by typhoons several times each year. During Typhoon Longwang on October 2, 2005, a 7000-ton cargo ship broke loose from its dock at the northern end of the basin, drifted southward for 1 km, ran aground outside the harbor, and broke in half. Figure 2 displays the wave height spectra recorded at several stations during Typhoon Tim of 1994. Those spectra at outside stations # 2 and # 5 show high peaks at quite short periods $O(15)$ s. However, at stations #8 and #10 inside the basin, high peaks appear instead at quite long periods $O(140)$ s.

The Port of Long Beach near Los Angeles, California is one of the busiest harbors in the US due to expanding trade with Asia. For a number of years oscillations have been a plague waiting for a solution. Figure 3 shows the wave records both inside the harbor near Pier J and on the Edith platform outside. It is seen that the low-frequency peaks are prominent around Pier J but weak at Platform Edith. The reverse is true for the high-frequency peaks.

Similar experiences in Japan have been reported at a conference held at Port and Harbor Research Institute, Yokohama, Japan (PHRI, 1998). Engineers have tried in the past to use linear ideas of synchronous resonance to cope with this type of problem. Both laboratory tests and computational modeling simulations were based on incident waves of periods comparable to the natural periods of the harbor (see, e.g., Briggs et al., 1994 and Houston, 1976). Engineering remedies based on these studies are clearly not consistent with physics.

As in surf beats (Munk, 1949), infragravity waves are known to be the consequence of quadratic mixing of short waves of nearly equal frequencies (Longuet-Higgins and Stewart, 1962). The relevance of radiation stresses to infragravity waves along coasts has been studied by Elgar et al. (1992), Herbers et al. (1995), Janssen et al. (2003), Okihiro et al. (1992), and Thompson and Briggs (1993), and to harbor oscillations by Bowers (1977), Mei and Agnon (1989), and Wu and Liu (1990). However, these theories are inadequate for treating harbor resonance by random, broad-banded wind-induced waves. Vital to wave forecasting, modeling of broad-banded progressive waves in the open sea is a highly developed branch of oceanography (Komen et al., 1996). However, of greater relevance to coastal engineering is accounting for the effects of diffraction by complex coastlines and refraction by bathymetry. For two-dimensional standing waves in very deep

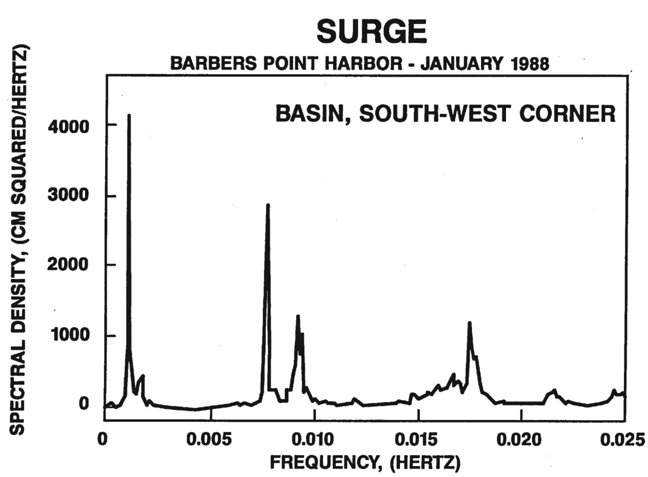

Fig. 1 Sample wave record at Barbers Point Harbor, Hawaii (Okihiro, 1993)

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