FORECASTING THE MOTION OF BERTHED SHIPS IN HARBORS

N. DRIMER, M. GLOZMAN, M. STIASSNIE AND G. ZILMAN [1]

CAMERI - Coastal and Marine Engineering Research Institute, Technion City, Haifa 32000, Israel

1 Introduction

This paper describes a numerical model for forecasting the motion of berthed ships in harbors, excited by waves. The model simulates the whole process, from a deep sea storm, to the motion of a berthed ship. The model together with a complementary module, which draws input data from a weather center, and a graphical user interface, are the main components of a system called Sea-21, which enables to forecast the operability conditions of a marine installation.

2 The physical process and its simulation

In order to simplify the simulation, we decompose the problem into three physical processes: wave shoaling from deep sea to the harbor entrance, wave diffraction and harbor oscillations, and wave-ship interaction in the harbor. Generally, the periods of harbor resonances and of the horizontal modes of motion of a moored ship are in the range of long waves (about one minute). Long waves are better transmitted into a harbor. Thus, the contribution of long waves to the motion of a moored ship becomes considerable and important. Most of the energy in the long waves range, observed at the harbor mouth, is a result of nonlinear wave-wave interaction which takes place in the shoaling zone. The substantial attenuation of wind waves by the breakwaters of the harbor justify the neglecting of nonlinear interaction within the harbor. An illustration of the process is presented in Figure 1.

3 The shoaling model

Agnon *et al*. [1] derived an evolution equation describing the shoaling of unidirectional wide spectra at normal incidence which takes into account second order wave-wave interaction. The present model extends [1] in order to include wave refraction.

While for other components of the process the non linear effects may be neglected, the evolution of the waves from deep into relatively shallow water is an essentially nonlinear process. At open sea the long waves are nearly absent from the spectrum. They are generated through nonlinear interaction among wind waves mostly close to the shore and within a domain of at most several tens of lengths of the short wave.

The near shore wave evolution was described using a nonlinear deterministic model which takes into account the refraction and second order quadratic nonlinear interaction. This model describes the evolution of wide spectra from deep into shallow water and requires the information about spectral density and the modal phases at deep water. Typically the spectral density is known whereas the phases are unknown. The mathematical model generates a set of uniformly distributed random phases which are used in each particular run. The average of 100 - 200 runs gives the mean characteristics of the process.

[1] Permanent address: School of Engineering, Dept. of Fluid Mechanics and Heat Transfer, Tel Aviv University, Ramat Aviv 69978, Israel

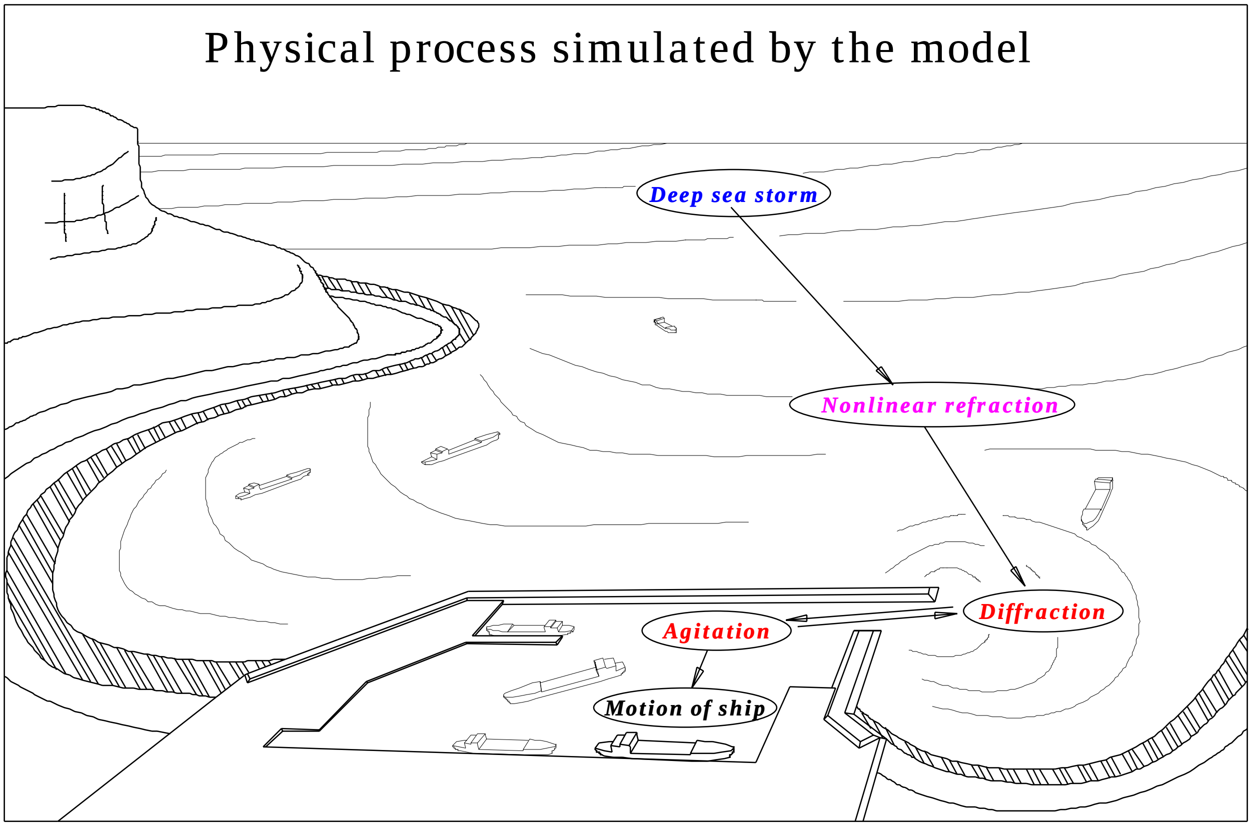

Figure 1: Illustration of the physical process simulated by the model

4 The Agitation Model

To simulate wave diffraction and harbor oscillations, we use the MIKE-21 EMS Model of the Danish Hydraulic Institute. It is a linear model in the frequency domain, which solves the mild-slope equations as described by Madsen & Larsen [2]. The wave spectrum at the harbor entrance obtained by the shoaling model is decomposed into a set of 23 monochromatic waves with periods:

320 seconds / $n, n = 2, 3, 4, 5, 6, 7, 8, 10, ..., 40$.

For each of those periods the mathematical model computes the wave amplification factors, and the components of the particles velocity vectors at the grid points inside the harbor. This information is later used by an interface program, to obtain the boundary conditions for the wave-ship interaction problem.

5 The wave-ship interaction model

This model was developed for the current project and is called the VIP (Vessel In Port) model. Basically, it is a program for solving the linear wave-body interaction problem. The program uses the Boundary Elements Method with the wave source Green's function. In order to solve the diffraction problem for a VIP an interface program reads the binary output file of MIKE 21 EMS and calculates the values of the velocity potential function and its derivatives at the centroids of the boundary elements of the ship's model. Those values are used as an input to evaluate the exciting forces acting on the vessel. The scattering problem, as well as the six radiation problems, are solved with boundary conditions of constant depth and long vertical quay at which the vessel is berthed. In such an approach the re-reflection by the sea-walls which are far from the vessel are neglected.

6 Additional developments

Due to nonlinear reactions of mooring lines and fenders, in many practical situations the linear frequency-domain approach is limited. The linear model can be extended by invoking the time domain simulations. The principle of this approach is first to solve the linear hydrodynamic problem for a set of frequencies, and then using Fourier transform to obtain a set of nonlinear integro-differential equations of ship motion in the time domain. The equations of motion in the time domain may consider nonlinear effects such as nonlinear reactions of mooring lines and fenders, nonlinear roll damping and others. The time domain approach is now under intensive development at CAMERI, and significant progress has already been achieved.

7 Conclusions

We presented a method for numerical simulation of the transformation process of deep sea storms that shoals toward a harbor entrance, propagates into the harbor and excites motion of berthed ships. The mathematical model was used to predict the operability of cargo handling of berthed vessels.

The presented mathematical model is also a practical tool for port designers. It may assist to select among design alternatives which may differ in the layout of breakwaters and quays, bathymetry, and other design parameters.

System Sea-21 has been installed at the ports of Haifa and Ashdod and provides real time forecasting of operability conditions for these installations.

References

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[2] 2. Madsen, P.A. & Larsen, J. An efficient finite-difference approach to the mild-slope equation, *Coastal Engineering*, 1987, **11**, 329–351.