A numerical model for studying the motion of berthed ships in harbours

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Abstract

This paper describes a theoretical - numerical model for the simulation of the motion of berthed ships in harbours, excited by waves. The model simulates the whole process, from a deep sea storm, to the motion of a berthed ship. The model is being developed as a part of a research project, funded by the Israeli Ports and Railways Authority, aimed to assist the design of extensions of the Ports of Haifa and Ashdod in Israel. The numerical model is being run in parallel with physical agitation models for both harbours (Haifa and Ashdod). A verification of the numerical results against the physical model is presented. The movements of the moored ships, calculated by the model, are combined with data of wave statistic, to predict the operability of cargo handling, according to which several alternatives of harbour layout are compared.

The physical process and its simulation

In order to simplify the simulation, we separate the physical process into three stages: wave shoaling from deep sea to the harbour entrance, wave diffraction and harbour oscillations, and wave-ship interaction in the harbour. Since the periods of resonance of the harbour and of the horizontal modes of motion (surge, sway, and yaw) of the moored ship are in the range of long waves (more than about 20 seconds), and since the long waves are better transmitted into the harbour, it is very important to consider the contribution of long waves to the motion of ships in the harbour. Most of the energy in the long waves range, observed at the harbour mouth, is a result of nonlinear wave-wave interaction which takes place in the shoaling zone. The dimensions of the harbour are assumed to be small enough to neglect nonlinear interaction within the harbour.

Following the above simplification of the process, the simulation system is composed of three separate models:

- A nonlinear shoaling model
- A linear agitation model
- A linear wave-ship interaction model

Illustration of the process is presented in Figure 1. Following is a short description of each of the models:

The shoaling model

Agnon et al. [1] derived an evolution equation describing the shoaling of unidirectional wide spectra at normal incidence, accounting for second order wave-wave interaction. The present model extends their work 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, from the point of view of the long waves generation, 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, within a domain of at most several tens of lengths of the short wave.

The near shore wave evolution was described using a unidirectional nonlinear deterministic model, which accounts for the refraction and second order quadratic nonlinear interaction. The model describes the evolution of arbitrary wide spectra from deep into shallow water. The full spectral information, that is, both spectral density and information about the modal phases, is required at the starting point (deep water). As a rule the former is available, however phases are unknown. For any single run the model generates the set of corresponding phases randomly, assuming a uniform distribution. To obtain a statistical picture of the waves evolution, the results of large number of runs are averaged. Experience has shown that the mean results become rather stable and reliable for about 50 to 100 runs.

The Agitation Model

For the simulation of the second stage - wave diffraction and harbour 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 harbour entrance obtained by the shoaling model is decomposed into a set of eleven monochromatic waves with periods:

80 seconds / n , n = 1, 2, ..., 11.

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

The wave-ship interaction model

This model was developed for the current project and is called the VIP (Vessel In Port) model. It is basically a program for the solution of the linear wave-body interaction problem, for a floating body of general geometry. The program uses the Boundary Elements Method with the wave source Green's function. The direct formulation, in which sources and dipoles represent the ship hull is used. In order to solve the diffraction problem for a Vessel In Port 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 for the evaluation of the exciting forces applied on a vessel in port. The scattering problem, as well as the six radiation problems, are solved with boundary conditions which represent the vertical quay at which the vessel is berthed. In this way, the field equation and almost all the boundary conditions are satisfied for a Vessel In Port. The re-reflection by the sea-walls, which are far from the vessel, of waves which were reflected or radiated by the vessel, are neglected.

Verification against Experiments in a wave basin

The first verification case is a container vessel of 30,000 ton dwt., berthed to the Eastern quay at the existing Port of Haifa. Figure 2 presents a comparison of the motion transfer functions. Except for the pitch motion for which the difference between the models is of order of the accuracy of the measuring equipment, all the modes of motion show a satisfactory agreement. The difference between the experimental and the numerical results, composed of the error of the EMS model, the error of the VIP model, the error of measurement and the scale effect of the physical model. For this comparison the physical model was excited by monochromatic waves. Figure 3 presents a comparison of the characteristic surge motion versus the characteristic wave height, here the inputs to both numerical and physical models are wave spectra which represent typical storms. This comparison takes into account the combined error of all the three numerical models, the measurement error and scale effect of the physical model, as well as the error due to nonlinear interactions inside the harbour, which were neglected by the numerical model, however may exist in the physical model as well as in the prototype.

Further confirmation of the model is obtained by comparing the operability of cargo handling as predicted by the numerical and the physical models, for configurations that both have been run. Results of prediction of operability are presented in the next section.

Application for the prediction of operability of cargo handling

Operability of cargo handling for a specific vessel berthed to a particular quay, is predicted through the following stages:

1 For each storm direction:
1.1 Calculating characteristic movements (Xmo) for several typical storms
1.2 Deciding on an operability criteria which define Xmo limits for six D.O.F.
1.3 Interpolating the limit storm (Hmo) which brings the first Xmo to its limit
1.4 Obtaining a statistical distribution of yearly occurrence of Hmo
1.5 Interpolating the yearly percentage of exceeding the limit Hmo which is the down time of cargo handling during storms of the current direction.

2 Executing stage 1 for each of the required directions of storms and calculating the total downtime which is the sum of the contributions of all the directions. The operability is 100% minus the total downtime.

Figure 4 presents the results of prediction of operability, obtained for the Eastern quay of the existing port of Haifa as a reference case, and for three different alternatives of development. The results obtained for the existing port are compared with those obtained by the physical model, it may be observed that the operability is slightly over estimated by the numerical model.

Conclusions

We presented a numerical simulation of the transformation process of deep sea storms that shoal toward a harbour entrance, propagate into the harbour and excite movements of berthed ships. The model was used to predict operability of cargo handling of berthed vessels, and to select from several alternatives of a port development the most promising one.

The presented model is a practical tool to assist port designers in the selection among several design alternatives which may differ in the layout of breakwaters and quay, the type of quay (vertical or sloped), bathimetry, and other parameters.

Reference

1. Agnon, Y. Sheremet, A. Gonsalves, J. & Stiassnie, M. A unidirectional model for shoaling gravity waves, *Coastal Engineering*, 1993, **20**, 29-58.

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

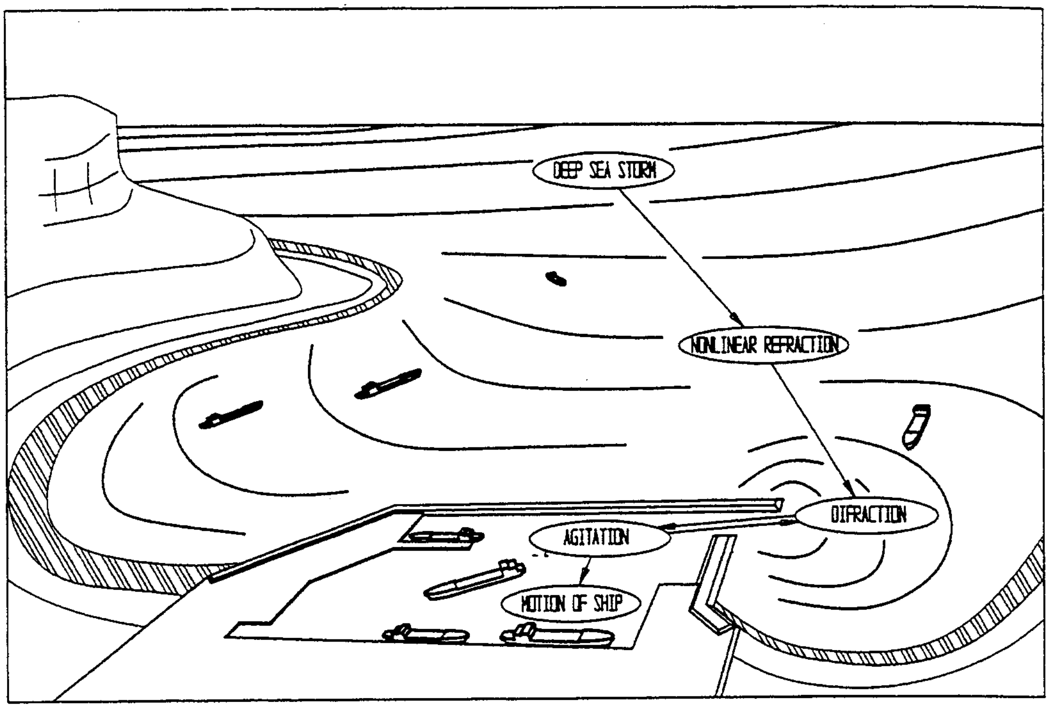


Figure 1 - Illustration of the physical process, simulated by the model.

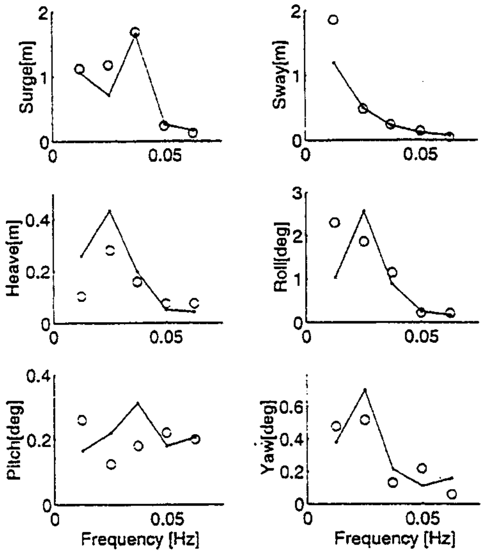


Figure 2 - Transfer functions of movements of a berthed ship. A comparison between

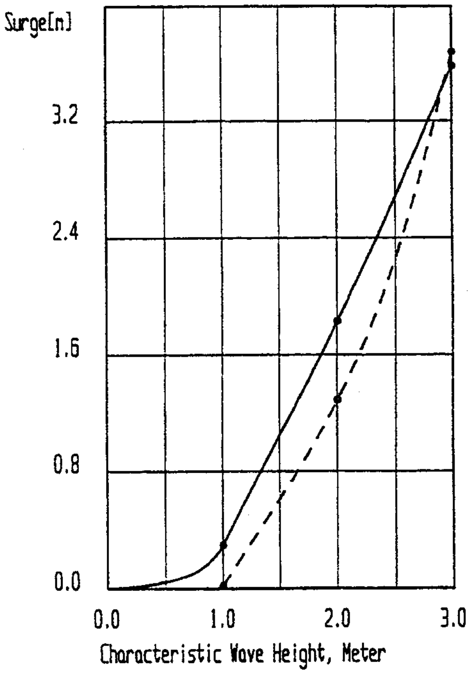
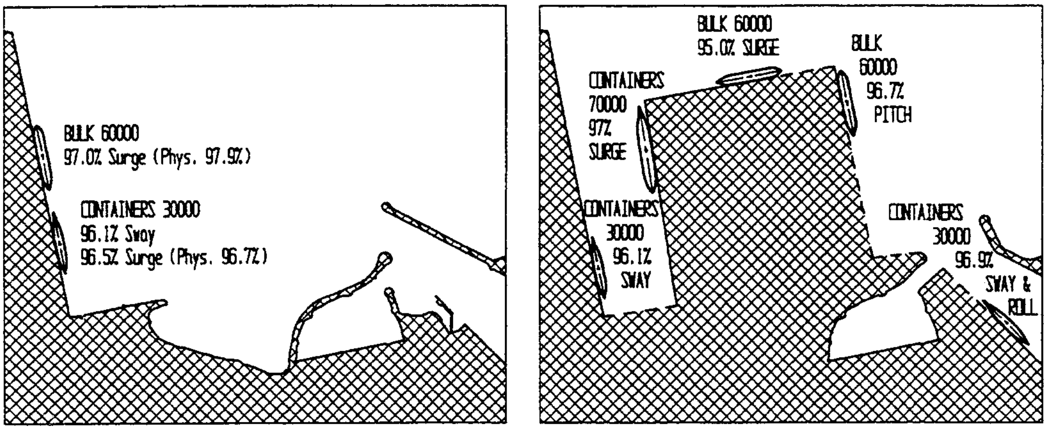
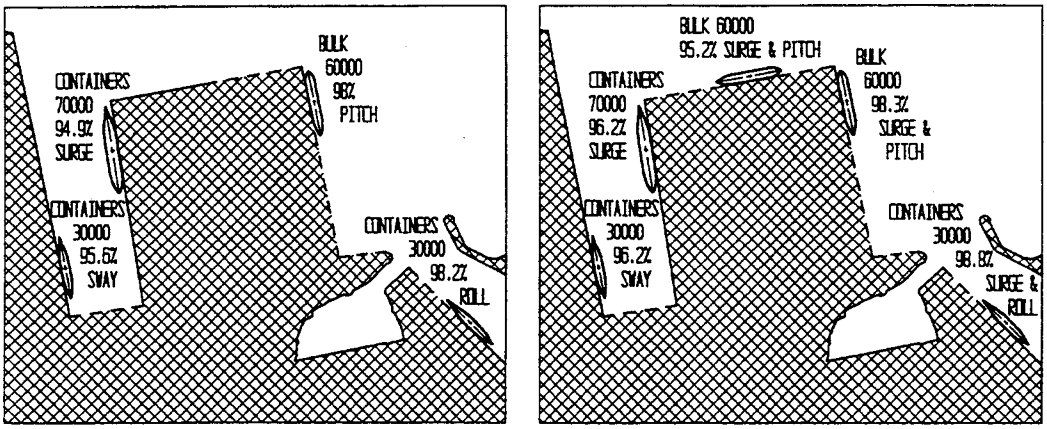


Figure 3 - Characteristic surge of a berthed ship. A comparison



EXISTING PORT

ALTERNATIVE 3a



ALTERNATIVE 3b

ALTERNATIVE 3c5

Figure 4 - Predicted operability for the existing port of Haifa and for alternatives 3a,3b,3c5 of harbour expantion.