MOIA: an Integrated Decision Support Tool for Port Management

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ABSTRACT

This paper describes MOIA, a numerical tool that evaluates sea-wave effects on port operations and broadcasts warning messages whenever the safety of such operations are deemed to be at risk. The evaluation of the sea-wave transformation from offshore - where the results of numerical models for sea-wave forecast at a regional level are available - up to the port area is described. Also, the procedures used to evaluate the sea-wave effects on sailing ships, focusing on the amplitude of the vertical movements of a selected point in the ship, are explained. Such procedures are combined and applied to an example where the average downtime for the navigation at four points along the sailing lane is evaluated for the entrance voyages into the port of Praia da Vitória (Azores) of a given ship.

Keywords

Port operations, warning systems, ships response.

INTRODUCTION

The ability to forecast sea-wave action and its effects on port operations is an advantage for the management activities of any seaport authority. Numerical models for sea-wave forecast at a regional level can produce quite accurate estimates of the sea-state characteristics offshore any given port. Then, by using numerical models for wave propagation, those characteristics can be transferred from offshore up to any point inside a port area. Moreover, numerical modelling can also be used to evaluate the wave effects on port operations.

Santos et al. (2009) presented a set of numerical models whose ultimate goal was contributing to the development of an integrated decision support tool for port management (MOIA) that is able to forecast sea-wave effects on port infrastructure, navigation and operations and to issue warning messages to the relevant members of the port community whenever port safety is at stake.

There is already a preliminary version of the MOIA package that enables the user to define the areas where the forecast of sea-wave characteristics is of relevance as well as the thresholds for such wave parameters whose exceedance leads to the issue of warning messages.

Such thresholds are to be defined according to the port area or activity of interest to the user. In fact, what is usually set is a threshold for the response of a given system to the incident sea waves (for instance the height of the vertical movements of a selected point in the ship) and the sea-wave characteristics at the relevant area are swept to evaluate the system response. This way, the range of sea-state parameters for which the response threshold is not surpassed can be defined. A procedure to implement such range definition is presented in Santos et al. (2010).

This paper gives a brief description of the MOIA package, including the transfer matrix approach implemented

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for the evaluation of the sea-wave transformation from offshore up to the port area, as well as of the procedures used to evaluate the amplitude of the vertical movements of a selected point in the ship. There is also an example of the application of these procedures to the definition of the average downtime for the navigation at four points along the sailing lane for entrance voyages into the port of Praia da Vitória (Azores) of a selected ship. The paper closes with some conclusions and directions for future work.

THE MOIA PACKAGE

The basic idea behind the MOIA package is the possibility of knowing one or two days in advance the sea-wave characteristics offshore the port area and to transfer those characteristics into the port thus anticipating the occurrence of hazardous events and issuing in due time warning messages, which will lead to a reduction of the occurrence of emergency situations in port activities.

The functionalities of the MOIA system, which are described in more detail in the next sections, are:

- Sea-wave characterization inside the port area from offshore estimates obtained with regional models;
- Characterization of sea-wave effects on port infrastructure, navigation and operations;
- Issue of warning messages to the relevant members of the port community.

Sea-wave characterization inside the port area

The first issue to be addressed was sea-wave propagation. The sea-wave characteristics predicted offshore by WAVEWATCH III (WWIII), a third generation wave model developed at NOAA/NCEP (Tolman, 1999), are propagated onshore, first with the SWAN model (Booij et al., 1999) up to the port entrance and from there into the port with the DREAMS model (Fortes, 2002).

In order to be of use to support management decisions, the forecasts of sea-wave characteristics at the selected points inside the port have to be available on a regular basis for the relevant members of the port community. For this, once the coupling procedure for the numerical models for wave propagation was established and tested, an interface to such a procedure was implemented.

Every hour, the files containing the WWIII forecasts of the offshore sea-wave characteristics are downloaded from the University of the Azores site. The key point in the whole procedure is the assignment of the date and hour of the WWIII run to the wave characteristics inside the port area computed with a transfer matrix approach.

This means that every forecast instant of the usual 36-hour set of values produced by one run of the WWIII model is stamped with the same WWIII run time. So, every MOIA wave forecast has two characteristic times: the WWIII run time and the forecast time. This enables the evaluation of the MOIA forecast age and to decide on the need to update the set of most recent wave forecasts at the port.

Since the set of wave forecasts at the port may trigger the issue of warning messages according to the pre-defined threshold values of each port community member, the possible forecast update does not imply the removal of the previous one but rather the addition of one set of records to the database that stores the MOIA information. This is so to enable tracing management decisions to the information that lead to them.

Characterization of sea-wave effects

Although port activities may be conditioned by damages in the harbour protection works or by flooding of the terminal areas, all caused by sea-wave action, one of the major concerns in naval and port engineering is the navigation safety within a port. When there is an obvious lack of security, the consequences might be devastating. Losses of human lives, cargo disturbances and environmental impacts can heavily penalize the maritime industries. This work so far has focused on sea-wave effects on the vertical movements of sailing ships entering or leaving ports. If these vertical movements exceed pre-defined threshold values, they may result in the occurrence of ship grounding or even shipwreck.

Once the sea-wave characteristics at the ship position are known it should be possible to assess the ship's response in terms of the amplitudes of her motion when she is sailing inside the port. The evaluation of the amplitude of the vertical motions of selected points in the ship can be made by using frequency domain results. This is so because no significant second-order forces appear when the ship is sailing in the port or at the port entrance. This means that one may compute the response spectrum for the movement of one of such points from the incident sea-state spectrum and the response transfer function for the motion amplitude of that point oscillation.

The response transfer function can be obtained from the solution of the motion equation of the free floating ship, which is usually written for the ship's centre of gravity. The numerical model used for this is the WAMIT model, Newman & Sclavounos (1988), developed at the Massachusetts Institute of Technology. It must be pointed out that such response depends on the incident wave height as well as on the wave period and direction.

Issue of warning messages

The user interface (Figure 1) handles the user registration, the selection of the available prediction points that are of interest for the user and the definition of the warning messages that the relevant members of the port community wish to receive as well as the media through which such message will be broadcast (for the time being, Email or SMS).

Such messages are to be issued whenever, for a given phenomenon, the observed variable (the phenomenon response) is deemed to reach a value that can be considered dangerous for a port activity - in the case study presented here, the observed variable is the vertical motion of a point in the ship.

Since the response of the relevant phenomena depend on the sea-wave characteristics at a given point the decision support tool only has to look at the sea-state parameters and at the function that relates those parameters to the dangerous values of the observed variable. Santos et al. (2010) presents the implementation of a set of procedures to assess the vertical motions of a point in a ship that is manoeuvring at a port entrance once the sea-state characteristics along the entrance lane are known.

a)

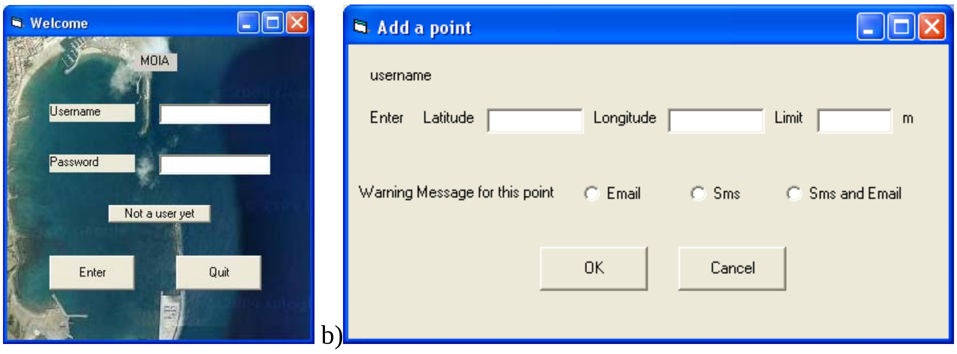

Figure 1. The MOIA interface: a) user identification; b) selection of an available prediction point

CASE STUDY

An example of the application of the procedures used in the decision support tool is given with the assessment of the vertical movements of a ship at the entrance of the Praia da Vitória port (Figure 2). The tested ship was the "N/M Fernão Gomes" whose length is 114 m, beam is 19 m and draft is 7 m. Instead of looking at all the points along the ship trajectory, the strip that can be occupied by the ship was divided into stretches and the vertical motions of a point, whose coordinates in the ship reference frame are (45.5 m, 5.4 m, 0.0 m), were observed in the centroids of such stretches. These are the points P1 to P4 in Figure 2 and are the points where incident sea-wave characteristics were evaluated.

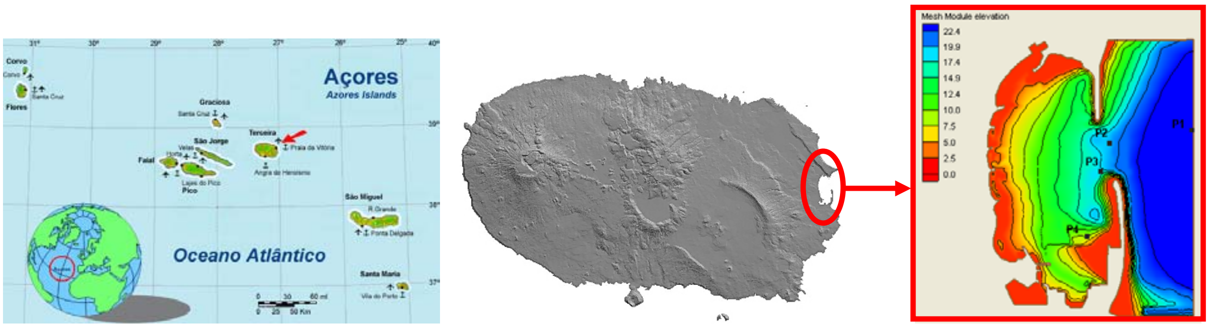

Figure 2. Praia da Vitória port and the location of points P1 to P4.

In this exercise the ship advance velocity was not taken into account. The ship heading varied from 270º at point P1 to 180º at point P4, being 255º and 225º at points P2 and P3, respectively. Four different response transfer functions had to be defined – one for each point – the main cause for that being the variation in the water depth at the selected points: P1 = 37.90 m, P2 = 19.72 m, P3 = 17.93 m and P4 = 8.89 m.

Praia da Vitória wave regime

Starting with the sea-wave characteristics predicted offshore by WAVEWATCH III (WWIII) and using the numerical models SWAN and DREAMS in sequence, the 8760 offshore data records from January 1, 2009 to January 1, 2010 (one year) were transferred to each point at the entrance and inside the port, thus enabling the establishment of the wave regime at each of these points.

Figure 3 presents the time series of significant wave height (HS) for the points P1 to P4 in the study period, whereas Table 1 presents, for the same period, the values of the statistical parameters (maximum, average, minimum, standard deviation and most frequent range) for the sea-wave characteristics at the same points and at a point offshore the port.

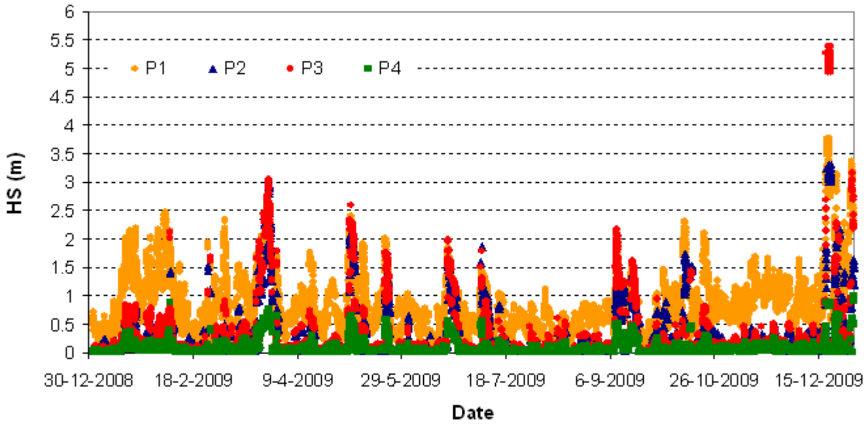

Figure 3. Time series of significant wave height (HS) for the points P1 to P4, for the period from January 1, 2009 to January 1, 2010.

HS values show that point P4 is more protected from the incident waves than the other points, never exceeding the value of 1 m. As for points P1, P2 and P3, they are located close to the harbour entrance and so they are subjected to most of the incident waves. As can been seen on December 20, 2009, HS at points P1, P2 and P3 reached its maximum value of 3.8 m, 3.3 m and 5.4 m, respectively.

In what concerns wave directions (DIR), the results show a decrease from the port entrance to the points inside the port. As expected, at the port entrance (point P2) there is no significant variation between the wave direction computed for that point and the wave direction predicted offshore the port.

Points \ Statistical Parameters		Maximum	Average	Minimum	Standard Dev.	Most Frequent Range
Offshore	HS (m)	3.77	0.84	0.06	0.54	[0.0 - 1.0] (70.00%)
	TP (s)	16.69	9.21	2.21	2.47	[11.0 - 12.0] (13.93%)
	DIR (º)	352.5	47.0	7.5	53.6	[20.0 - 30.0] (49.03%)
SWAN P1	HS (m)	3.77	0.84	0.07	0.54	[0.0 - 1.0] (69.77%)
	TP (s)	16.69	9.21	2.21	2.47	[11.0 - 12.0] (13.93%)
	DIR (º)	352.5	47.0	7.5	53.59	[20.0 - 30.0] (49.03%)
DREAMS P2	HS (m)	3.29	0.22	0.01	0.38	[0.0-1.0] (94.50%)
	TP (s)	16.69	8.98	4.06	2.98	[10.0-11.0] (17.11%)
	DIR (º)	346.7	280.5	191.7	68.19	[310 - 320] (26.80%)
DREAMS P3	HS (m)	5.37	0.26	0.01	0.47	[0.0-1.0] (93.44%)
	TP (s)	16.69	8.98	4.06	2.98	[10.0-11.0] (17.11%)
	DIR (º)	256.69	212.2	163.01	50.7	[220- 230] (33.24%)
DREAMS P4	HS (m)	0.99	0.08	0.01	0.12	[0.0-1.0] (100%)
	TP (s)	16.69	8.98	4.06	2.98	[10.0-11.0] (17.27%)
	DIR (º)	297.3	210.8	50.2	67.9	[20.0 - 30.0] (49.02%)

Table 1. Sea-wave parameters for the offshore location and for points P1 to P4 for the period from January 1, 2009 to January 1, 2010, based upon WAVEWATCH III forecasts.

Vertical movements at the entrance voyages

Assuming that the sea waves incident at points P1 to P4 can be described by a JONSWAP spectrum then it is not difficult to compute the spectrum of the vertical movements of the selected point in the ship based on the incident wave spectrum and on the ship's response transfer function and from there to get the significant height of that vertical movement.

Although it would be reasonable to use different threshold values for the height of the vertical movement of the selected point in the ship according to the stretch of the entrance voyage, for this application example the same value, 0.5 m, was considered for the points P1 to P4. To make the analysis easier, that threshold is set for the significant value of the vertical movement of the selected point.

So considering the predicted values of HS, peak period (TP) and DIR at points P1 to P4 on October 12, 2009 at 5:00 AM, namely (2.3 m, 8.2 s, 143º), (1.7 m, 8.2 s, 274º), (0.4 m, 8.2 s, 205º) and (0.1 m, 8.2 s, 210º), one gets for the significant height of the ship´s vertical movement at those points, respectively, 2.9 m, 1.6 m, 0.3 m and 0.1 m. This means that a warning message should be issued for points P1 and P2 (the most exposed points) whereas for points P3 and P4 such a message would not be needed.

Repeating the procedure for the whole time series of significant wave heights and directions at points P1 to P4 in the period from January 1, 2009 to January 1, 2010, and using a frequency approach - taking into account that the total number of sea-wave forecast data is not the same for every point (8760 values for P1, 8314 for P2 and P3 and 8124 for P4) - one gets the expected fraction of time when the significant height of point (45.5, 5.4, 0.0) vertical movement exceeds 0.50 m, or the expected value of the probability for the same event. As expected, they decrease from 82% outside the port, at point P1, to 0% at point P4, inside the port, being 13% at points P2 and P3.

CONCLUSIONS AND FUTURE WORK

This paper shows how the estimation of the incident waves along the ship's entrance trajectory into a port can lead to the issue of warning messages due to excessive vertical movement of the same ship. The significant height value of the vertical movements of a selected point in the "N/M Fernão Gomes" ship in her entrance voyage into the Praia da Vitória port was investigated. Assuming that a JONSWAP spectrum could describe the incident waves, such a significant height was derived from zero-th order moment of the response spectrum.

Future work includes taking into account the ship advance speed and the definition of the vertical movement height distribution for a given incident sea state. In addition, other shapes for the incident wave spectrum will be investigated.

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