Numerical software package SWAMS – Simulation of Wave Action on Moored Ships

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ABSTRACT

Container ships traffic has increased significantly in recent years as well as the ship dimensions, therefore the need for port expansion and construction of new ports. Portugal is no exception to this global phenomenon and there are plans to expand some of the major Portuguese ports (eg Sines and Leixões). These large ships require depths and widths of the entrance channels relatively large and it is inevitable that waves enter the ports. These waves can cause serious problems in port operation as a result of excessive movement of the ship. The costs associated with berth downtime are enormous. For container ships, horizontal movements must be very small due to crane operation constraints. Excessive movements can also cause ship collisions with berth or with other ships or the breakage of mooring lines, all with serious economic losses. From the above it becomes clear how important it is the ability to know the sea conditions that lead to excessive movement of ships. This knowledge would bring a huge asset to the port operational management and it could point out ways of mitigating these problems.

This paper describes the development of an integrated tool made of several numerical models able to characterize the wave climate and its effects in ports, particularly in terms of movements of ships moored to a port terminal. The validation of this tool is presented in the form of some simple test cases. Additionally an application to a real harbour situation is also presented. The information obtained from this tool is a major help in port management and it can significantly increase the competitiveness of our ports.

1. INTRODUCTION

Maritime transportation is of great economic importance in Portugal: almost 80% of the total Portuguese goods transportation is carried out by sea, namely 64% of the Portuguese exports and 85% of the imports. This mean of transportation clearly overpasses other types, such as rail, air or others. For instance, rail transportation is used in only about 19% of the cases. In addition, the significant growth observed in water sports, recreation and tourism does emphasize the significant role of port activities in the Portuguese economy.

Most ports in mainland Portugal are located in estuaries although two of the most important ports are open coast ports: Sines and Leixões. In the Azores and Madeira archipelagos, where the maritime transportation plays an even more important role, given the lack of land connections, the situation is reversed: all ports are located in the open coast.

The recent increase in the foreign trade, as well as in the recreational boating and tourism, does necessarily lead to the development of port areas, both new and existing ones through the expansion, improvement and maintenance of the existing ports, and the mitigation of environmental problems. Moreover, the harsh conditions experienced on the coast of mainland Portugal, due to the severe wave climate, the wide range of tidal amplitudes and the intense coastal drift, do lead to a number of coastal and port protection problems whose solutions in most cases are very complex and costly, both in terms of initial investment and maintenance. Some of the current concerns related to port activities are:

- Construction of new commercial, fishing or pleasure ports or the improvement of existing ones;
- Repairing / maintenance of harbour protection structures, especially in the west coast of mainland Portugal and in the Azores;
- Improving navigation conditions both at port entrances and inside the port areas;
- Increasing the operational time in port terminals by avoiding excessive movements of the moored ships.

In this context, and to better cope with these challenges, Portugal has seriously invested in the collection and processing of sea wave data, as well as in the characterization of sea wave regimes, in the planning and design of coastal structures (breakwaters, training walls, coastal protection, entrance channels), in the simulation of the behaviour of manoeuvring and moored ships and in the evaluation of port operational conditions.

Sea waves inside a sheltered basin can cause excessive motions on moored ships which can lead not only to interruption of loading and unloading operations but also to collisions with other ships or port infrastructures with significant economic losses. Coupling a numerical model for wave propagation with a numerical model for moored ship behaviour subjected to the wave action can identify potentially adverse sea states and help planning safe harbour activities.

A numerical tool called SWAMS (Simulating Wave action on Moored Ships) has been developed to tackle this problem. The great advantage of such a tool is the ability to provide time series of ship's movements, as well as of forces and extensions in the mooring elements once the offshore sea-wave characteristics are known. This information can be derived from buoy measurements or prediction models, making this a very useful tool, both for design of port infrastructures and for planning of port activities.

For sea-wave propagation SWAMS may use a linear model based upon the mild slope equation, DREAMS [6], that is able to simulate the propagation of monochromatic waves into sheltered areas taking into account refraction, diffraction and reflection or a more complex model, BOUSS-WMH, that is capable of a more accurate description of sea states evolution along varying-depth sheltered regions by taking into account also nonlinear interactions and energy dissipation due to bottom friction and wave breaking.

To simulate moored ship behaviour, SWAMS uses the numerical package MOORNAV [13] which resorts to the frequency domain results of the WAMIT model [8] for the radiation and diffraction problems of a free floating body to get the hydrodynamic forces necessary to BAS model [9]. This model assembles and solves, in the time domain, the moored ship motion equations taking into account incident sea waves, wind, currents and the geometry and constitutive relations of mooring system elements.

WAMIT was initially developed to evaluate the wave-induced stresses on floating structures deployed offshore. Within a harbour basin, waves are diffracted by the harbour structures which invalidates the use of WAMIT model to solve the diffraction problem unless one considers several floating bodies, some of them immobile and occupying the whole of the liquid column. However, this implies the solution of a huge system of linear equations. A possible alternative is to use the so-called Haskind relations [7] involving the potential flow associated with the waves radiated by the ship and the potential of incident waves at the position where the ship is to be placed.

Figure 1. Main azards of excessive ship movements.

In this paper we describe: the basic equations of moored ship behaviour, the SWAMS package, the application of this package to evaluate moored ship motions in a very special condition in which the model can be used directly with WAMIT; the new implemented procedures based on Haskind relations and the first test results obtained with these procedures. The paper ends with the presentation of final remarks on the work.

2. SWAMS NUMERICAL TOOL

2.1. General description

SWAMS - Simulation of Wave Action on Moored Ships - is an integrated tool for numerical modeling of wave propagation and of moored ship behaviour inside ports to help in the decision making process for planning port operations.

It consists of a graphical user interface and a set of modules for running numerical models. The user interface enables data storage and manipulation, numerical model execution and enables graphical visualization of results. Each model corresponds to a module to which are attached the databases that bring together all the project information. With this application one may conduct studies in a more efficient way since the work related with the construction of the data files for each model, the model calculations and results visualization are easier.

SWAMS was developed in Microsoft Access™ and Microsoft Excel™, which has the advantage of including the event-driven object programming language Visual Basic for Applications (VBA). An advantage of this language is the possibility to use and handle different Microsoft Windows applications.

SWAMS is accompanied by a Graphical User Interface that enables users to use numerical models in a friendly manner.

SWAMS databases are MS Access ™ databases, corresponding to the numerical models modules, which contain all the project information together with several folders where all the created files are stored.

The graphical representation of data and results in SWAMS is made with Tecplot™ (for DREAMS and BOUSS-WMH modules) and with MS Excel ™ (for WAMIT and BAS modules) and with Autocad (for WAMIT module). All these graphical visualization programs are run by event-driven macros that automate the entire process of creating maps and graphs.

The SWAMS ensemble includes 2 main modules:

- WAVEPROP module. This module is the wave propagation module and includes 3 numerical models and a mesh generator:
    - SWAN is a spectral model, Booij et al. [3], which is based on the equation of conservation of wave action and it is capable of modeling the non-linear propagation of sea waves;
    - DREAMS is a linear finite element model,[6], which is based on the mild-slope equation for monochromatic wave propagation;
    - BOUSS-WMH is a nonlinear finite element model, [11], which solves the extended nonlinear Boussinesq equations;
    - GMALHA is a mesh generator, [12], for triangular finite elements non-structured meshes.
- MOORNAV module, [13], that assembles and solves the moored ship motion equations assuming the linearity of the floating body / waves system, proposed in [3]. This module is made of two numerical models:
    - WAMIT, [8], that solves, in the frequency domain, the radiation and diffraction problems associated to the interaction between incident waves and a free-floating body;
    - BAS, [9], that assembles and solves, in the time domain, the motion equations of a moored ship at berth taking into account the time series of the wave, wind and current forces on the ship, the impulse response functions of the ship and the constitutive relations of the mooring system elements (mooring lines and fenders).

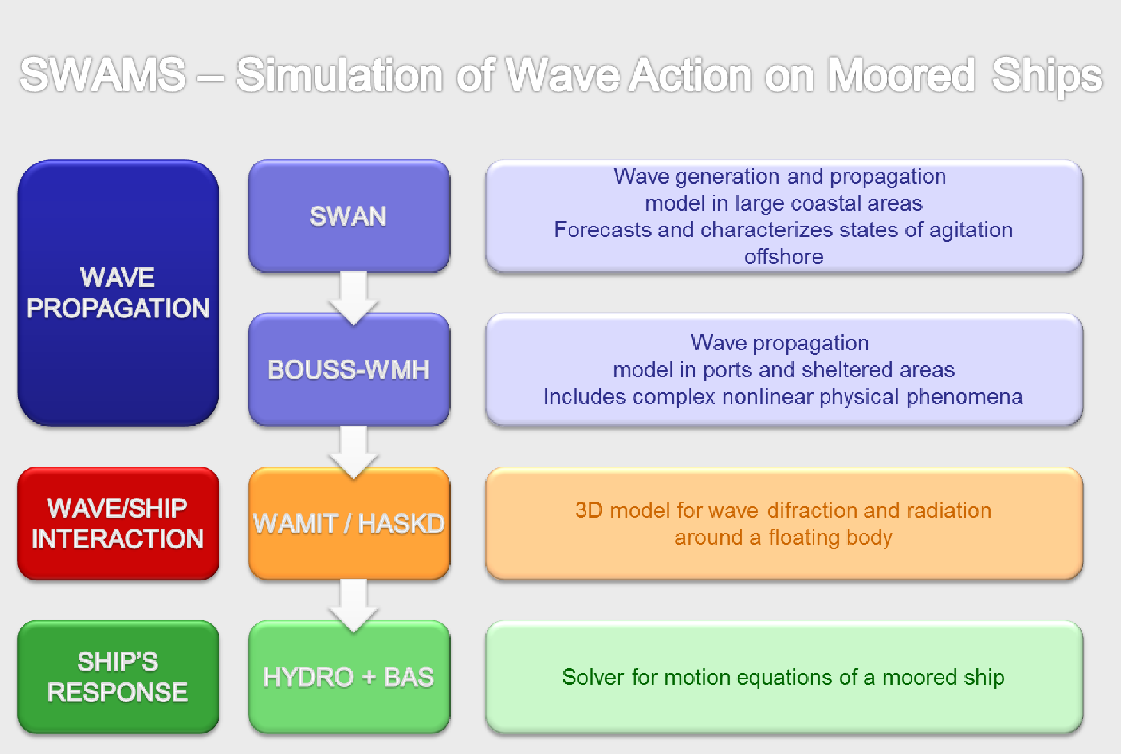


Figure 2: Structure of SWAMS numerical software package.

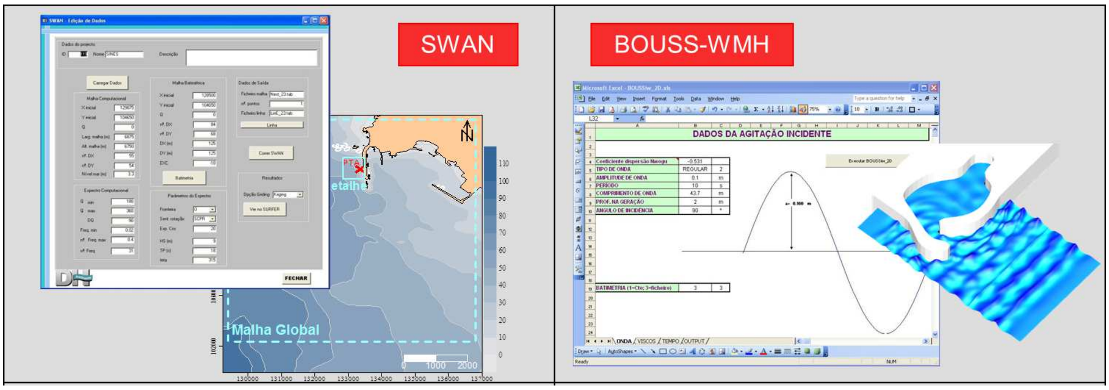


Figure 3: GUIs of WAVEPROP module.

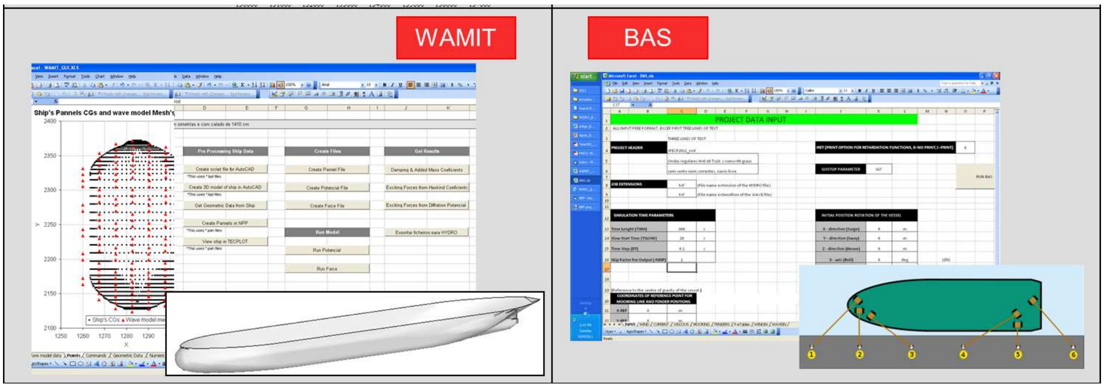


Figure 4: GUIs of MOORNAV module.

2.2. WAVE PROPAGATION MODULE

2.2.1. SWAN

The SWAN module of the SWAMS package takes care of the input data for the SWAN numerical model, the model run and results visualization.

The numerical model SWAN, BOOIJ et al. [3], simulates the generation, propagation and dissipation of sea waves. It is based on the conservation of wave action and it is a freeware model that is being developed by the Delft University of Technology, from The Netherlands. This constant development of the model is one of its major advantages, since improved versions do appear quite often and their inclusion in the SWAMS package is not difficult. This model propagates sea-waves from offshore up to the coast and takes into account refraction, diffraction and shoaling due to bottom depth variation and currents, sea-wave growth due to local wind, wave breaking induced by bottom variation and by whitecapping, energy dissipation by bottom friction, current-induced wave blocking and reflection and wave transmission through obstacles.

The wave field at the study region is characterized by a bidimensional spectrum at the nodes of the rectangular grid used to discretize that region. This kind of discretization enables the application of the model to areas where wind induced wave growth is important or where previous sea states or swell are present. The wave propagation either in the stationary or non stationary modes in the geographic and spectral spaces is carried out using implicit numerical schemes. The study region can be described in either cartesian or spherical coordinates.

The input data needed for the SWAN model are: the bathymetry of the study region and the boundary conditions at the domain entrance, in addition to the computation options. The SWAN results that are currently available through the SWAMS package are the significant wave height, the average and peak periods, the average and peak wave directions, the directional spreading, the bandwidth parameter and the water level at any point of the computational grid.

2.2.2. GMALHA

The mesh generator GMALHA [12], was developed for the construction of triangular non-structured finite element meshes used for wave propagation models. For a given coastal zone, including a boundary line and bathymetry information within it, GMALHA generates an optimized mesh. The boundary line can be very complex, since it comprises the shoreline with port infrastructures, beaches, marinas, islands, etc.

GMALHA was developed especially for the numerical finite element models, DREAMS and BOUSS-WMH.

GMALHA first generates a coarse mesh that fills domain. The method used for the generation of the initial mesh is the Advancing Front Method. The mesh is then subjected to some post-processing algorithms in order to obtain the optimized mesh. These algorithms are: local refinement conditioned by the bathymetry, control of element uniformity, Laplace smoothing [5] and edge swap to correct valence and internal angles.

The refinement algorithm assures that, according to local bathymetric conditions and wave period, there must be a minimum number of points per wave length (never less than 8). The wave length at each node (L) depends on the period (T) and local depth (h) and is obtained iteratively: (L_0 is the offshore wave length)

$$L = L_0 \tanh\left(\frac{2 \cdot \pi \cdot h}{L}\right) \qquad L_0 = \frac{g \cdot T^2}{2 \cdot \pi}$$

With this local refinement it is guaranteed that the model will adequately produce accurate results with the least number of nodes (elements) possible, minimizing CPU times and increasing the spatial area of applicability of the numerical models.

GMALHA is coupled with a user interface developed in Microsoft Excel™.

2.2.3. DREAMS

The DREAMS module deals with the input data for the DREAMS numerical model, the model run and results visualization.

The numerical model DREAMS evaluates the propagation and deformation of monochromatic sea waves in coastal regions. The model can be used to study the short wave penetration into a harbour or the resonance of a sheltered region excited by long waves. It is based on the elliptic form of the mild slope equation, which describes the combined effects of refraction and diffraction of monochromatic waves that propagate over mild sloping bottoms such as those that occur at ports, harbours and coastal regions. To solve the mild slope equation the model uses the Finite Element Method. The boundary conditions implemented in the model are the generation-radiation condition at the open boundaries and reflection conditions (be it total or partial reflection), which are adequate for the solid boundaries of the study region, namely beaches, cliffs and breakwaters.

Input data for DREAMS are the characteristics of the incident wave (wave period and direction, as well as the tide level) and the characteristics of the finite element mesh used to discretize the study domain as well as of that domain boundary. SOPRO permits the input/edition of all the referred data needed for the DREAMS numerical model.

DREAMS results are the wave height indexes (H/Ho) - i.e. the ratio between the wave height at a point of the computational domain, H, and the incident wave height, i.e. at the domain boundary, Ho - the amplification coefficients (for wave resonance studies) and the wave directions. Optional results of the model are horizontal velocity field and the wave crests (phase zero contour lines). Most of those results can be visualized with the Tecplot™ software.

2.2.4. BOUSS-WMH

The nonlinear wave phenomena in the nearshore zone can be described by Boussinesq-type equations. One example of this class of equations was introduced by Nwogu [10]. These equations describe the nonlinear evolution of waves over a sloping impermeable bottom without considering wave breaking. The effects considered include refraction, diffraction, reflection, shoaling and non linear interactions. The range of validity of those equations extends from shallow up to intermediate water depths. Therefore, they seem adequate to describe the wave field outside and inside harbours and sheltered zones.

Walkley[14] developed a finite element model, BOUSS, based upon the extended Boussinesq equations derived by Nwogu [10]. The Finite Element Method is used for the spatial discretisation while the time integration is carried out by using SPRINT package (Berzins [1]). The problem is formulated for the free surface water elevation, the velocity and the pressure. The boundary conditions included in the model are of three types: generation, radiation and reflection condition. BOUSS-WMH (Boussinesq with irregular internal wave generation), is a new version in which wave generation is made inside the domain using a source function instead of generating waves at a boundary. Monochromatic or random waves can be simulated. Several applications to literature cases were already performed, Pinheiro et al. [11], and showed the ability of the model to simulate correctly the wave propagation for regular or irregular waves.

For a user friendly use of the numerical model BOUSS-WMH a Graphical User Interface (GUI) was developed in Microsoft Excel™ Environment using Visual Basic for Applications™ (VBA) as the programming language. This GUI builds all the data files and executes the model. The inputs needed for a correct use of the model are: 1 - Wave characteristics (Monochromatic: Period, wave height and tide level or irregular: Time series of surface elevation); 2 - Mesh characteristics (Nodes, elements, depths and boundary conditions), 3 - Time integration parameters.

The finite element mesh is created using the mesh generator, GMALHA, Pinheiro et al. [12]. This mesh generator produces unstructured triangular finite element meshes with optimized node density according to local wavelength, optimized element geometry and minimized bandwidth. The model produces several types of outputs, such as: a) Plots of surface elevation; b) Plots of Velocities; c) Plots of Wave height indices; d) Time series of surface elevation at given points.

3. MOORNAV MODULE

The evaluation of moored ship motions due to incident sea waves can be made using the numerical package MOORNAV (Santos [13]). This package is made of two numerical models:

- WAMIT (Korsemeyer et al., [8]) that solves in the frequency domain the radiation and diffraction problems of the sea-wave interaction with free-floating bodies;

- BAS (Mynett et al. [9]) that assembles and solves in the time domain the motion equations of a moored ship taking into account the time series of wave forces on the ship, the impulse response functions of the ship and the constitutive relations and geometry of the mooring system elements (mooring lines and fenders)

to which an interface between the two models was added because the WAMIT results are not the quantities needed for the BAS model to operate. They have to be transformed from the frequency domain to the time domain.

3.1. Moored Ship Equations

Assuming small amplitude of the ship movements along each of its six degrees of freedom, it is easy to define the part corresponding to the quasi-static variation of submerged hull form. This leads to the hydrostatic restoring matrix C_{kj} whose coefficients are the force along degree of freedom k due to a unit change, in still water, of the ship position along degree of freedom j.

The same assumption on ship movement amplitude leads to the linearity of the interaction between the hull and the incident waves. Such linearity allows the decomposition of that problem into two simple problems,[7]: The radiation problem in which one determines the forces along each degree of freedom that are needed for an arbitrary hull movement in otherwise calm water, and the diffraction problem in which one determines the force along each degree of freedom k that is exerted by incident sea waves on the motionless ship hull.

As to the arbitrary hull movement in otherwise calm water – the radiation problem – this can be considered the superposition of impulsive motions each of them generates a free-surface elevation that moves away from the hull as a wave. So, in the forces associated to the radiation problem there is the so-called infinite frequency added mass, m_{kj} – the reason for this designation to be clarified later – which is the force along the k degree of freedom needed for a unit acceleration along the j degree of freedom and $K_{kj}(\tau)$, the impulse response function (also known as retardation function), which is the force along the k degree of freedom, τ seconds after a motion with impulsive velocity along the j degree of freedom.

From the above, the motion equation for the moored ship can then be written as

$$\sum_{j=1}^{6}\left[(M_{kj}+m_{kj})\ddot{x}_j(t)+\int_{-\infty}^{t}K_{kj}(t-\tau)\,\dot{x}_j(\tau)\,d\tau+C_{kj}x_j(t)\right]=F_k^d(t)+F_k^m(t)+F_k^f(t) \tag{1}$$

where M_{kj} is the mass matrix of the ship and $F_k^m(t)$ and $F_k^f(t)$ are the instantaneous values of the forces due to mooring lines and fenders. Strictly speaking, this is a set of six equations whose solutions are the time series of the ship movements along each of her six degrees of freedom as well as of the efforts in mooring lines and fenders.

3.2. WAMIT

In the above equation the mass matrix and the hydrostatic restoring matrix depend only on the ship geometry and on the mass distribution therein. The forces due to mooring lines and fenders can be determined from the constitutive relations of these elements of the mooring system and from the changes in the distance between their ends (for fenders one has account for the no-length variation associated to absence of contact between the ship and the fender).

In turn, the impulse response functions, the infinite-frequency added mass matrix and the excitation forces due to waves, F_k^d, depend on the hull shape and on the disturbance caused in wave propagation flow by the motionless hull or on the flow generated by the hull motion in otherwise calm water.

Assuming that any sea state that acts on the ship can be decomposed into sine waves of known period and direction, the diffraction force associated with this sea state can be obtained from the superposition of the stationary diffraction forces due to each of these sinusoidal components. That is, results from the diffraction problem in the frequency domain may be used to produce a time domain result.

Also the impulse response functions and the infinite-frequency added masses can be determined from results obtained for the radiation problem in frequency domain:

$$K_{kj}(t)=\frac{2}{\pi}\int_{0}^{\infty}b_{kj}(\omega)\cos(\omega t)d\omega \tag{2}$$

$$m_{kj}=a_{kj}(\omega)+\frac{1}{\omega}\int_{0}^{\infty}K_{kj}(t)\sin(\omega t)d\omega \tag{3}$$

where $b_{kj}(\omega)$ is the damping coefficient for frequency ω and $a_{kj}(\omega)$ the added mass coefficient for the same frequency. The added mass and damping coefficients result from decomposing the stationary force associated to the radiation problem for a sinusoidal movement of frequency ω into a part that is in phase with the body velocity (the damping coefficient) and a part in phase with the body acceleration (the added mass coefficient).

The use of frequency-domain results to generate data for a problem in the time domain is due to the large availability of numerical models to solve, in the frequency domain, the interaction problem of a floating body with sea waves.

WAMIT [8] is one of these models. It was developed at the former Department of Oceanic Engineering of the Massachusetts Institute of Technology and it uses a panel method to solve in the frequency domain the diffraction and radiation problems of a free floating body. This model uses Green's second identity to determine the intensity of source and dipole distributions over the panels used in discretization of the hull wetted surface. With such distributions it is possible to generate the harmonic flow potentials of the radiation and diffraction problems of a free ship placed in a constant-depth zone not limited horizontally.

Input data for this model are, the panel discretization of the wetted ship hull and of other floating or immobile bodies as well as the frequencies and directions of the incident monochromatic waves. Model results are the frequency dependent added mass and damping coefficients as well as the diffraction forces and the motion amplitudes of the free-floating ship when subjected to the incident waves, the so-called response amplitude operators.

3.3.BAS

The BAS model was developed at Delft Hydraulics and it uses the above mentioned matrix and functions, together with the body mass and the hydrostatic restoring matrices, the constitutive relations of the mooring system elements and the time series of the diffraction forces due to incident sea waves to assemble and solve the motion equations of the moored ship.

A theta method is employed to discretize the second order differential equations producing a set of algebraic non-linear equations that is solved by the Newton-Raphson method with a first estimate obtained by the first order Adams-Bashforth method. The model results are the time series of the motions along the six degrees of freedom of the centre of gravity of the ship as well as of the forces on the mooring lines and fenders.

Using the damping coefficients, $b_{kj}(\omega)$, obtained for a set of frequencies of the ship motion in otherwise calm water and an high frequency approximation for this variable, with equation (2) one may compute the corresponding impulse response function, $K_{kj}(\tau)$.

Infinite frequency added mass coefficients for a given kj pair can be computed for each ω frequency of the radiation problem with equation (3). A m_{kj} value almost independent from frequency is a good indicator of the impulse response function definition. The selection of the best m_{kj} value depends on the frequency ranges of the expected excitation and of the moored ship response in the case study.

4. SWAMS APPLICATION

This section presents one application of the numerical package for the evaluation of the behaviour of a ship moored inside a schematic harbour basin under a sea state whose characteristics outside that basin are known. This numerical application illustrates SWAMS functioning, ie, of the set of models DREAMS, BOUSS-WMH, WAMIT, and BAS and draws attention to the modifications needed for a widespread application. It must be pointed out that Haskind relations produced diffraction forces in the frequency domain. For this the monochromatic incident wave field at the ship location was evaluated with numerical model DREAMS.

The methodology is as follows:

1. Using model DREAMS the characteristics of the wave field for a set of periods within the wave spectrum are determined and from this the wave velocity potentials are obtained.
2. Using the model BOUSS-WMH the wave time series in the position to be occupied by the ship within the harbour basin are determined.
3. Using the model WAMIT, radiation and diffraction forces are obtained for the same set of periods.
4. After that, the impulse response functions and time series of the forces exerted by the incident waves on the ship are determined.
5. Finally, using the BAS model, the equations of motion of the moored ship are solved in the time domain, taking into account the time series of forces due to waves, the impulse response functions of the ship and the constitutive relations of the elements of the mooring system.

The wave propagation calculations were performed on a LINUX CORVUS workstation with four AMD Opteron ™ 265, 2GHz and 8GB of RAM, while the calculations of the behaviour of the ship are made on a personal computer Intel Quad Core ™ Q6600 2.4Ghz and with 1.97GB of RAM.

4.1. Incident waves

The computational domain is 2000 m wide and 4000 m long. The schematic port located on the right hand side of the domain consists of two breakwaters: the North breakwater with two stretches, one horizontal and the other vertical of 750 meters and 1000 meters in length, respectively and the South Breakwater with one horizontal stretch, 400 m long, defining a quadrangular basin whose side length is approximately 700m, Figure 5.

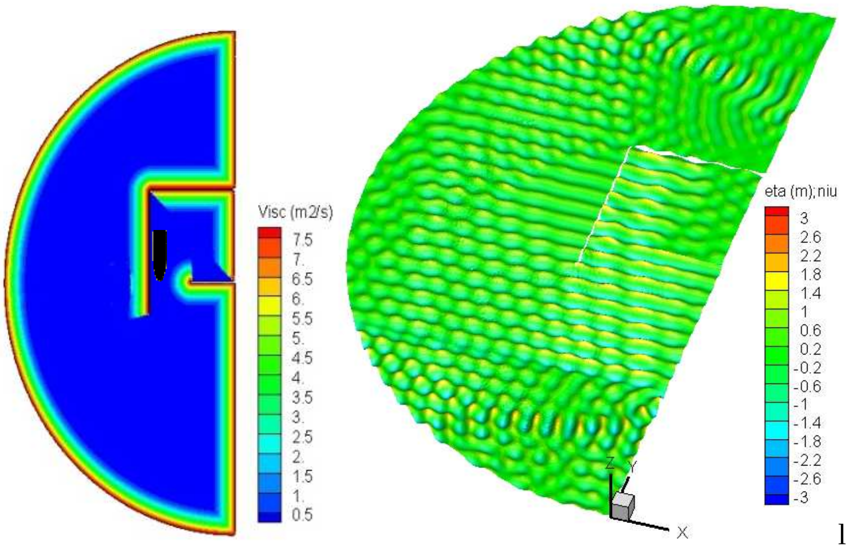


Figure 5: Calculation domain. Regular waves with a period of 10 s and amplitude 0.6 m from South (North coincides with the direction of the y axis).

The finite element mesh of the harbour domain was generated having a minimum of 8 points per wavelength, the depth in the whole area is 17 m and the incident regular waves had a period of 10 s and an amplitude of 0.6 m, resulting in a mesh with 185 599 elements, 93 616 points, 1 631 boundary points and a bandwidth of 322.

Figure 6 shows the time series of free surface elevation at a point within the port, where the ship is to be moored 600 s after the start of the calculation with the BOUSS-WMH module with regular waves from South (propagating in the positive direction of the y-axis) with 10 s period and 0.6 m amplitude.

4.2. Moored ship response

The ship has a volume of 108 416 m^3, a waterline length of 243 m, a maximum beam of 42 m and a draft of 14 m. Since it is intended to illustrate the operation of the numerical model for moored ship behaviour only, the adopted mooring scheme was very simple, with only two breast lines (l1 and l4), two spring lines (l2 and l3) and two fenders (f1 and f2) as shown in Figure 8. The ship's longitudinal axis is parallel to the jetty, her bow being 98 away from the south end of that jetty. All mooring lines were made of polyethylene with the same maximum traction force of 1274 kN and had the same length (hence the same constitutive relations). The constitutive relation of one of these mooring lines is shown in Figure 8a). The pneumatic fenders had a maximum compression force of 3034 kN, the constitutive relations shown in Figure 8b) and the hull´s friction coefficient is 0.35. In this study, it is assumed that the wave hitting the ship propagates with straight crests perpendicular to the jetty where the ship is moored. This assumption makes the analysis simpler and allows one to use directly the results of the numerical model WAMIT for the free ship diffraction problem.

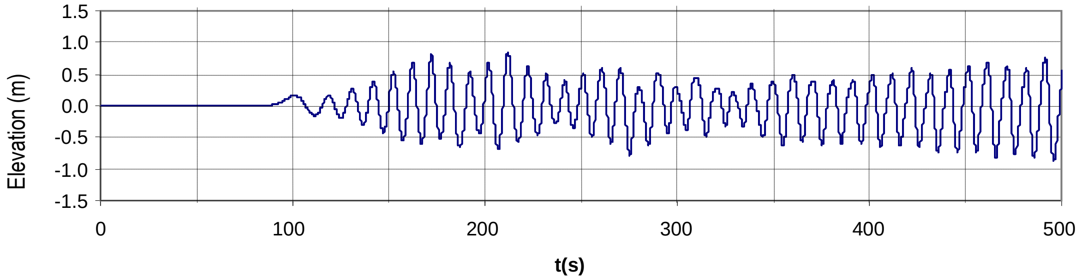


Figure 6: Free surface elevation in the area where the ship is moored.

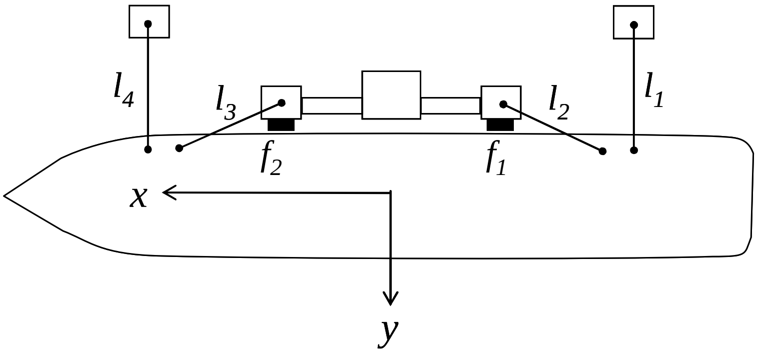


Figure 7: Mooring scheme.

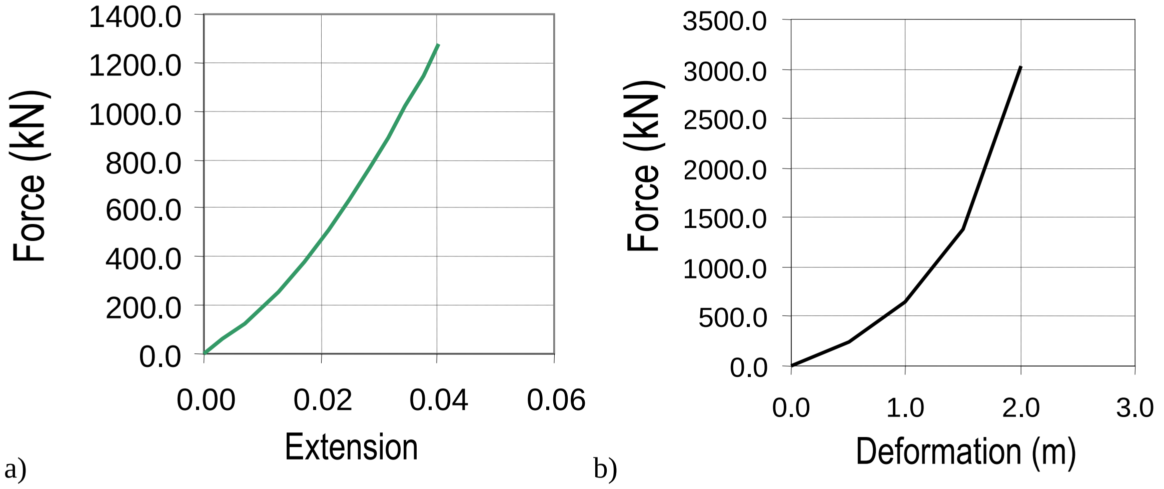


Figure 8: Constitutive relations: a) lines; b) fenders.)

For the interaction between the free ship and the incident waves (in the frequency domain), it was considered that only the pier wall close to the ship has some influence in this interaction. Thus it was modelled the ship near a vertical wall 750 m long, 50 m wide that occupied the whole of the water column, that is, with a height of 17 m. The ship’s side close to the wall was 30 m apart from the wall and the ship's bow was 98 m away from the end wall.

The wet surface for the ship hull was divided into 3732 panels whereas the wall surface was divided into 1284 panels. Figure 9 shows a perspective of those panel distributions. The numerical model WAMIT was used to solve the radiation problem of the ship for 76 frequencies evenly spaced between 0.0125 rad / s and 0.95 rad / s.

Forces due to incident monochromatic waves were calculated using the Haskind relations with the incident wave field given by the DREAMS numerical model. As expected, the proximity of the vertical wall destroys the symmetry of the flow around the ship that existed when there was no wall. An example of this is the transverse force and the yaw torque on the ship that appear for head waves when there is a wall near the ship, Figure 10.

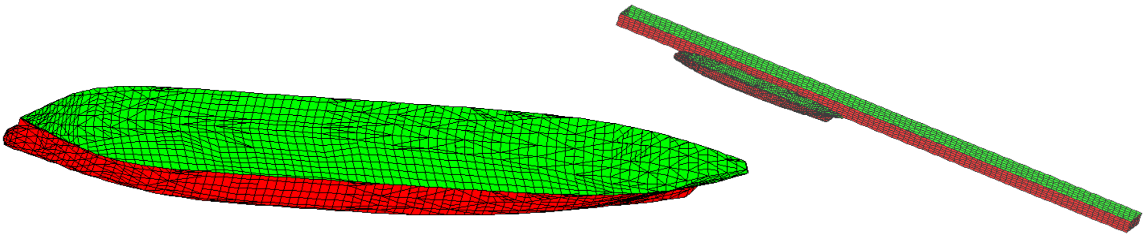


Figure 9: Panel discretization of the ship and the wall.

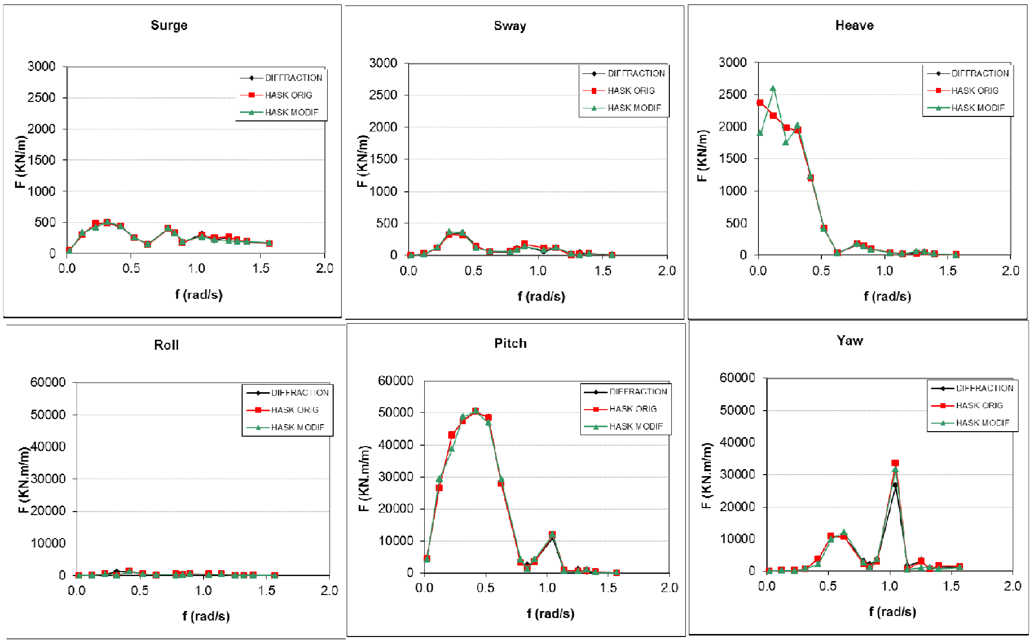
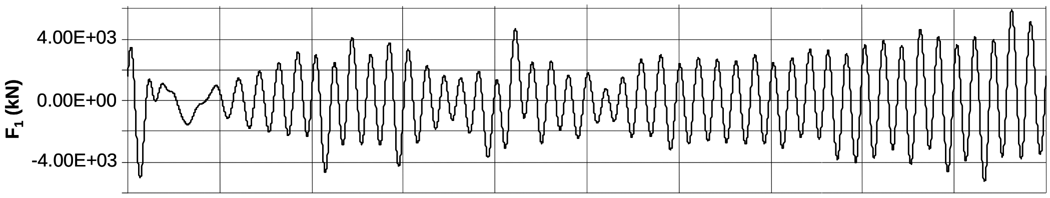


Figure 10: Forces due to incident head waves along the six degrees of freedom of the ship.

With the results from the frequency-domain radiation and diffraction problems, it was possible to determine impulse response functions and the infinite-frequency added mass coefficients that are needed to mount the moored ship motion equations. All impulse response functions were calculated with a time interval of 0.1 s and a maximum duration of 200 s.

Starting from the impulse response functions for the 36 possible pairs (force along k coordinate due to motion with impulsive velocity along j coordinate) and the corresponding added mass coefficients for the several frequencies for which the radiation problem was solved in the frequency domain and using equation (3) several estimates for the infinite-frequency added mass added were obtained. The most suitable value for this quantity was assumed to be the most frequent of those values.

The time series of the forces due to incident waves on the ship were determined by using the time series of the free wave elevation estimated for a point in the area where the ship is to be moored together with the results from the frequency-domain diffraction problem for bow waves. Given the limitations of the procedure for obtaining the force time series, which is based on the Fast Fourier Transform, one might only consider the first 500 s of the free-surface elevation time series. Figure 11a) shows the time series of longitudinal force exerted by the incident waves on the ship. In the figure it can be seen another limitation of the procedure implemented to calculate time series: oscillations in the force time series do occur before the incident wave arrival to the location where the ship is moored (around t = 90 s) something which is not physically possible.



a)

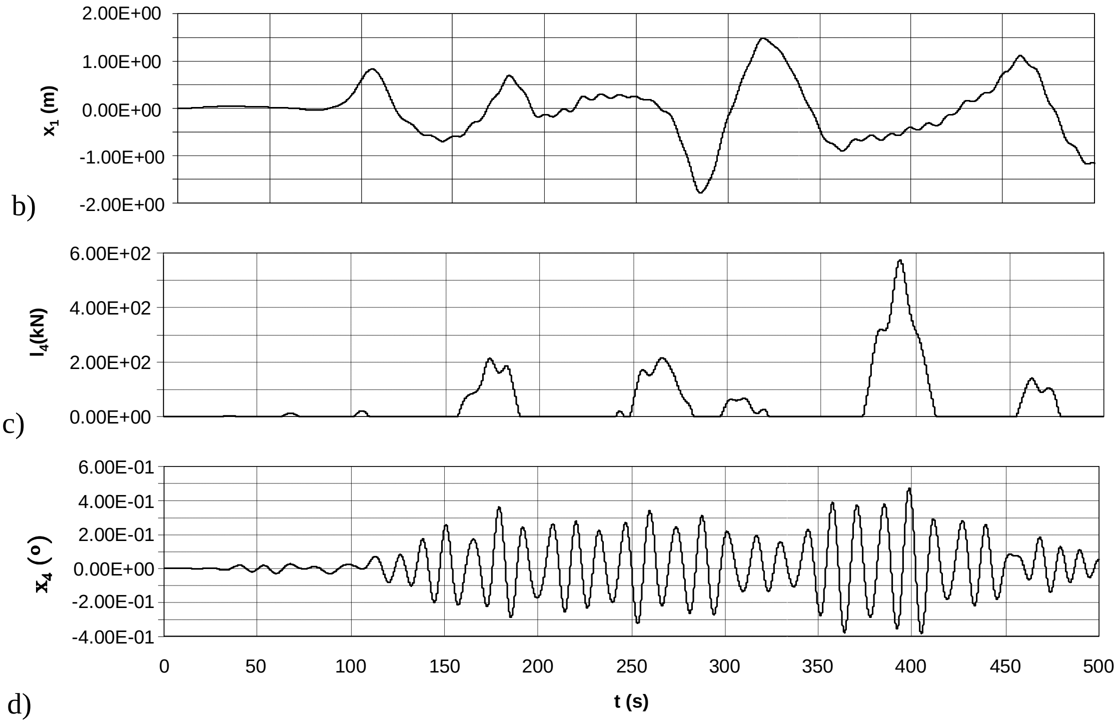


Figure 11: Moored ship time series: a) Longitudinal forces; b) Longitudinal motion; c) Tension on mooring line l1; d) Roll motion.

The time series of the movements along the longitudinal axis of the moored ship shown in Figure 11b), illustrates the non-linear response of the ensemble ship + mooring system. In fact, for oscillations in the free-surface elevation whose period is about 10 s, there are moored ship oscillations with a much higher period. The period of these oscillations is controlled by the existence of mooring lines and fenders, as can be confirmed in Figure 11c) with the time series of the forces in the bow breast line. Since the mooring system elements produce forces acting on the ship in the horizontal plane only, it is for the movements in this plane that the non-linear behaviour is most evident. This can be confirmed with the time series shown in Figure 11d) with the roll motion where it is observed that the oscillation period is similar to the period of the incident wave on the ship.

5. FINAL REMARKS

This paper presents a new integrated numerical tool for simulating wave action on moored ships named SWAMS. It comprises a set of 2 main modules (WAVEPROP and MOORNAV) and 7 numerical models (SWAN, GMALHA, DREAMS, BOUSS-WMH, HASKD, WAMIT, HYDRO and BAS).

Completely "user-friendly" graphical user interfaces were developed for each module and transfer of information between them is automatic as well as graphical representation of data and results using commercial visualization software such as Tecplot™ and Surfer8™ and AutoCAD™.

Results obtained with the numerical package SWAMS in modelling the behaviour of a moored ship inside a schematic harbour are presented. The time series of the ship's movements and tensions in the mooring system clearly illustrate the nonlinear behaviour of the system ship-moorings-fenders.

A Boussinesq-type model was used to determine the time series of the incident waves. Results were obtained for a wave whose propagation direction coincided with the breakwater's length, which facilitated the determination of the diffraction forces. To solve more complex problems, where the incident waves are significantly diffracted by the harbour's infrastructures or other obstacles, a new procedure was tested based on so-called Haskind relations. So far, the velocity potentials of incident waves needed for this were obtained with a linear wave propagation model. The initial results presented here are very promising and the wave propagation model will soon be replaced by a more complex Boussinesq-type model.

SWAMS can assist decision makers in the planning phase of port infrastructures since it is possible to test several layouts for the construction of new ports or even expansion of existing ports and also determine which of the berths with greater problems within the port are.

In port operation stages SWAMS can assist port activities managers using wave forecasts to predict the behaviour of a specific moored ship hence planning activities of loading and unloading, assigning more favourable berths for vessels or even decide on a more appropriate and efficient mooring system.

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