IMPLEMENTATION AND VALIDATION OF SAFEPORT SYSTEM AT SINES HARBOUR

Andreia Helena Gomes[1] – ahgomes@lnec.pt
Liliana Viana Pinheiro[1] – lpinheiro@lnec.pt
Conceição Juana Fortes[1] – jfortes@lnec.pt
João Alfredo Dos Santos[2,3] – jasantos@dec.isel.ipl.pt
[1] Ports and Maritime Structures Unit, National Laboratory of Civil Engineering – Lisbon, Portugal
[2] Polytechnic Institute of Lisbon – Portugal
[3] Centre for Marine Technology and Ocean Engineering – Lisbon, Portugal

Abstract. SAFEPORT safety system aims to daily reports to Sines harbour administration, potencial emergency situations regarding ships operation in port areas caused by extreme weather-oceanographic conditions, that may occur in the next three. It consists of a set of numerical models and a qualitative risk assessment and forecasting. It uses forecasts provided offshore of the area under study of sea agitation, wind and tide. The characterization of the response of the free and moored ships at a berth is performed using the numerical models which deals with formulations in the frequency and time domain. The system issue alerts, through danger levels associated with risk levels of exceedance of recommended values for movements and forces imposed on ship mooring systems. SAFEPORT can be adapted to any port. So far, it has been developed and adapted to three terminals of the port of Sines, where three different ships were simulated. This paper presents the developments made to date of the safety system, in terms of its implementation and validation. The numerical models run every day, in real-time mode, in a computer cluster and the system provide forecast results for the next 72 hours. The results are disseminated on a web page and a mobile application in a variety of formats.

Keywords: *SAFEPORT, SWAMS, Wave propagation, Moored ships, MOORNAV, Risk analysis*

1. INTRODUCTION

The growth of the maritime-port sector has triggered an increase in the size of ships and consequently the construction of port terminals in areas more exposed to the actions of the maritime-port environment to accommodate such ships. Indeed, a ship moored in such conditions may be subject to excessive movement that may lead to extreme loads on its mooring system elements, jeopardizing the safety and the operability of both the ship and the terminal. Thus, keeping ship movements within established limits plays an important role when dealing with the intensification of maritime transport.

A ship can move in six modes of oscillation: surge, sway, heave, roll, pitch and yaw. The introduction of mooring lines in the process of berthing ships allows the restriction of oscillations in the horizontal plane, namely surge, sway and yaw (Santos, 2010), preventing that the amplitude of these movements does not exceed the limits considered admissible. However, in extreme situations (e.g. storms and long waves), the effectiveness of the mooring lines is compromised and breakage of these elements is frequent. The breakage of a mooring line during a storm is sudden and violent, putting people, the ship and even the berthing structure at risk if the ship's energy is not absorbed by the fenders.

The movements of ships depend on a diversity of factors and a complex interaction of phenomena which make certain situations, where the safety of the ship is affected, seem impossible to predict. Nevertheless, practicable and sufficiently accurate numerical models represent a valuable tool to assess the behavior of a moored ship. Although not as accurate as physical models due to the difficulty in representing some physical phenomena, the use of numerical models presents advantages such as reduced cost and the ability to simulate a large number of alternatives in a short period of time.

This paper presents a safety system comprising a set of numerical models able to anticipate the effects on ships of potentially hazardous sea state and weather conditions. The so-called SAFEPORT system, was developed in the scope of the BlueSafePort project, which consists of adapting the pre-existent HIDRALERTA system (Fortes *et al.*, 2015 and Poseiro *et al.*, 2017) to Sines harbour, adding to it the capability of forecasting risks for maneuvering (entering or leaving the port) and docking ships, and a mobile application.

SAFEPORT is a forecasting and alert system, which provides, once a day, 3-day advance forecasts of sea waves, wind and tide conditions, and their consequences on ships. The system issues alerts, based on risk levels associated with safety and operability criteria, to ship movements and forces applied on mooring elements. The main beneficiaries of this system are the bulk liquid terminal (TGL), the multipurpose terminal (TMS) and the container terminal (TXXI). Three ships were moored in these terminals; an oil tanker, a general cargo ship and a container ship. Figure 1 shows the location of the SAFEPORT system operational prototype and the selected ships.

Figure 1 – Location of the Sines harbour, its target terminal and selected ships.

2. SINES HARBOUR SAFEPORT SYSTEM

Based on the HIDRALERTA system platform, the prototype of the SAFEPORT system was also developed in a python framework and its architecture was structured in four generic modules with early warning capabilities (Figure 2), namely: I – Sea-waves characteristics; II – Navigation in port areas; III – Monitoring; IV – Risk assessment and forecasting.

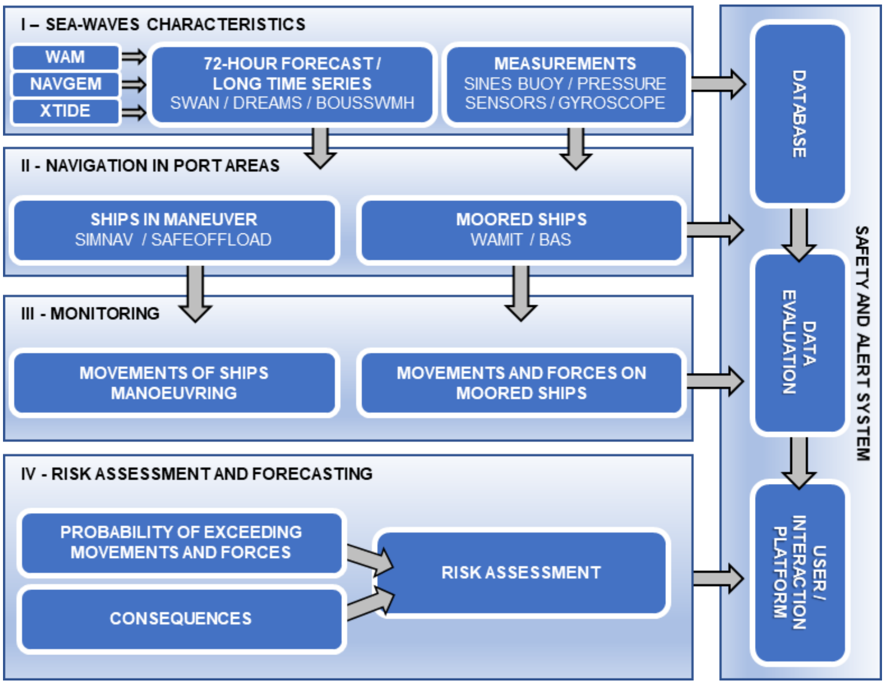


Figure 2 - SAFEPORT system architecture.

The numerical models associated with the behavior of maneuvering ships are not included in this work and are carried out by the Centre for Marine Technology and Ocean Engineering. Numerical simulations run on the Central Node for Grid Computing of the Portuguese Infrastructure for Distributed Computing, a 64-node high performance computing facility. SAFEPORT needs approximately 1 hour to generate new forecast results. The system is currently in testing and validation phase therefore, forecasts should be interpreted as indicative.

The objective of the first module is to determine, once a day, 72-hours in advance and every 3 hours, the sea-state characteristics inside a given port or at a terminal. This type of system is only possible due to the accuracy achieved by weather-oceanographic forecasting models at regional and local level.

The second module aims to characterize the response of free and moored ships inside a port subject to the action of sea-waves and wind. Given the non-linear behavior of the ship – moorings – fenders system, the numerical models implemented in the system are the ones from the MOORNAV module (Santos, 1994), which deals with formulations in the time domain, relating instantaneous values of movements and forces. The MOORNAV module uses the WAMIT model (Korsemeyer *et al.*, 1988) to study the interaction of the free ship with the incident waves and the BAS model (Mynett *et al.*, 1985) to solve the equations of motion of a moored ship and compute the time series of the ship's motion in its six degrees of freedom and the forces exerted on its mooring system (moorings and fenders).

The Monitoring module is dedicated to real-time monitoring of the safety system's performance. The SAFEPORT system daily compare the sea-waves characteristics measured with the Sines 1D wave buoy with the SWAN and WAM results. This activity lacks the collection of data at terminals, acquired in situ, which was not possible due to the restrictions imposed by the pandemic. These data allows a validation of the characteristics of sea waves inside the Sines harbour, as well as the behaviour of the simulated ships. To accomplish this task, it is intended to install pressure sensors in the terminals and a gyroscope on a moored ship.

Based on the 72-hour forecast and its consequences on moored ships, a qualitative risk assessment and forecasting (probability x consequences) was implemented in the SAFEPORT system, associated with the probability of exceeding pre-established thresholds for the amplitude of ships' motions and for the forces on their mooring system. Based on the risk levels, the system issues alerts, through the definition of danger levels related to the difficulty of loading and unloading operations and the probability of breakage of an element of the mooring system, due to excessive ship motions

In the safety system development the following main actions were considered:

- Collection and processing of data from the harbour;
- Development and adaptation of numerical models for ships moored in the harbour;
- Development and adaptation of numerical models for ships maneuvering in the harbour;
- Development of the risk methodologies associated to moored ships;
- Development of the web platform and mobile application to disseminate the results.

3. SAFEPORT SYSTEM IMPLEMENTATION

3.1 WAM, NAVGEM and XTide models

Sea-waves data are supplied by European Centre for Medium-Range Weather Forecasts, ECMWF (Persson, 2001), through WAM model (WAMDI Group, 1988), which implementation in the safety system enables accurate forecasts, 72 hours in advance (with results every 3 hours), of the significant height (H_s), the peak period (T_p) and the average direction (θ_m) of the sea waves.

Before being incorporated into the system, the WAM model was validated with Sines1D wave buoy data (Figure 3). Simulations were performed for, and compared with the buoy data acquired for the same 40 years.

Sea levels of astronomical tide and wind fields from x and y directions are provided by XTide (Flater, 1998) and NAVGEM (Whitcomb, 2012) models, respectively. An automatic download procedure of this parameters were established and points were selected to extract their results everyday, for the next 3 days. All these models were coupled with the SWAN model (Booij *et al.*, 1999). XTide and NAVGEM models were also coupled with BAS model.

3.2 SWAN model

Nearshore wave transformation models require bathymetric data with relatively high spatial resolution to model the complex processes in the nearshore region (Poseiro *et al.*, 2017). Thus, three bathymetric meshes were created using a triangulation method with linear interpolation and equal spacing between points (Figure 4). To achieve a better numerical performance, the model calculation domain, as well as the bathymetric meshes, was discretized into three nested rectangular meshes (Table 1).

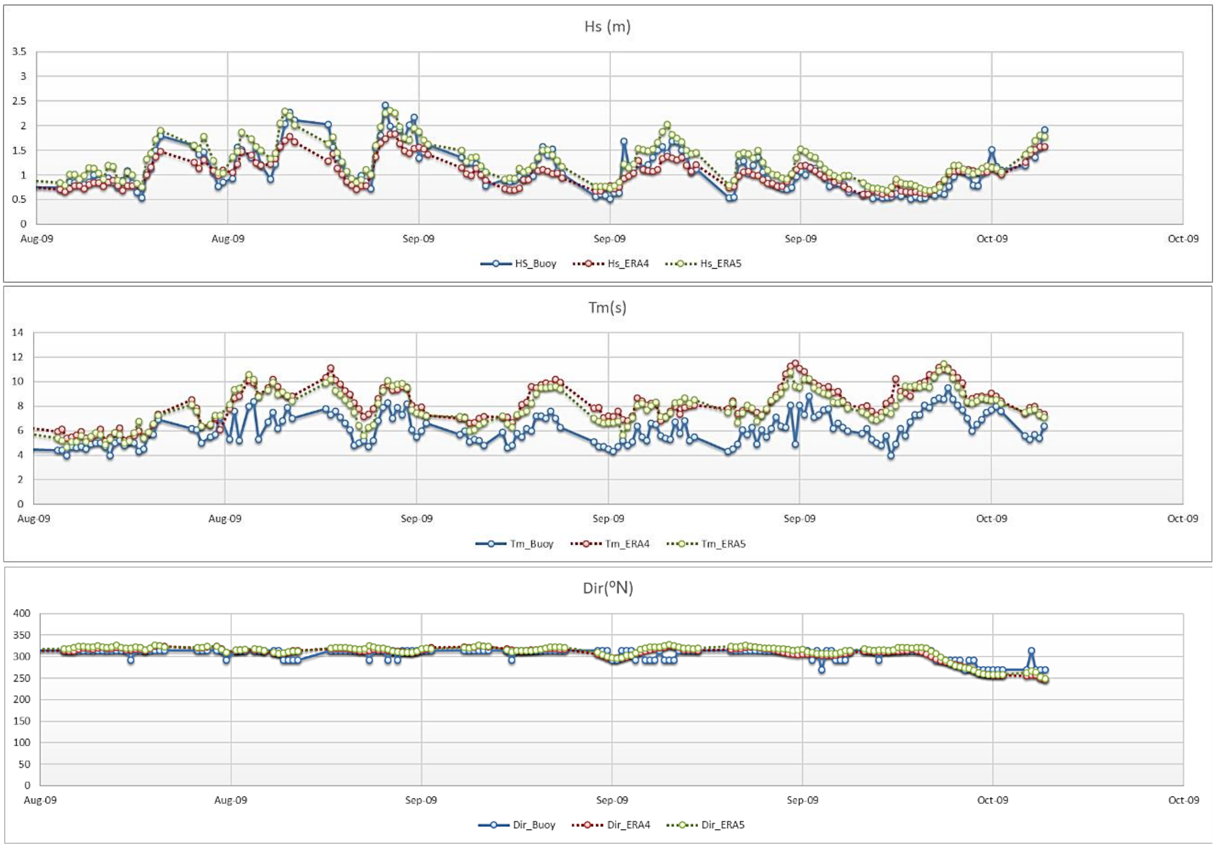


Figure 3 - Comparison of the Sines1D wave buoy records (significant height, Hs; mean period, Tm; direction, Dir) with the forecasts obtained at the nearest ECMWF point, using two datasets: Era4 and Era5.

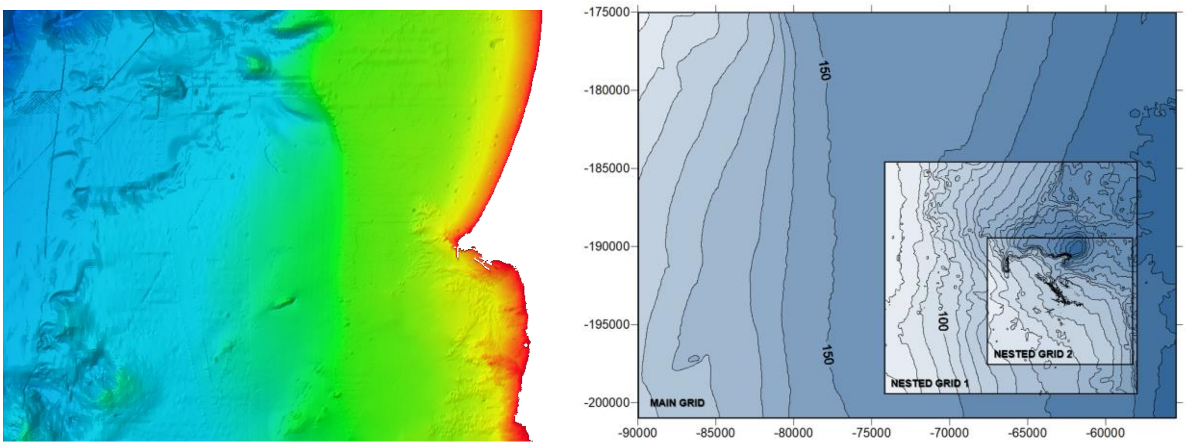


Figure 4 - Bathymetry of the surrounding area of the Port of Sines and the bathymetric meshes used in the SWAN numerical model.

Table 1 - SWAN model computational grids.

Grid	Area (mxm)	Resolution	
		Δx (m)	Δy (m)
Main	71400 x 53600	200	200
Nested 1	34700 x 26200	100	100
Nested 2	16105 x 14805	25	25

JONSWAP spectrum was assumed to represent the real spectrum of waves approaching the port and, diffraction and dissipation by bottom friction were the physical phenomena accounted for SWAN model. As boundary conditions, SWAN uses WAM, XTide and NAVGEM forecasts.

The same procedures applied in the validation of the WAM model were used to validate and calibrate the SWAN model (Figure 5).

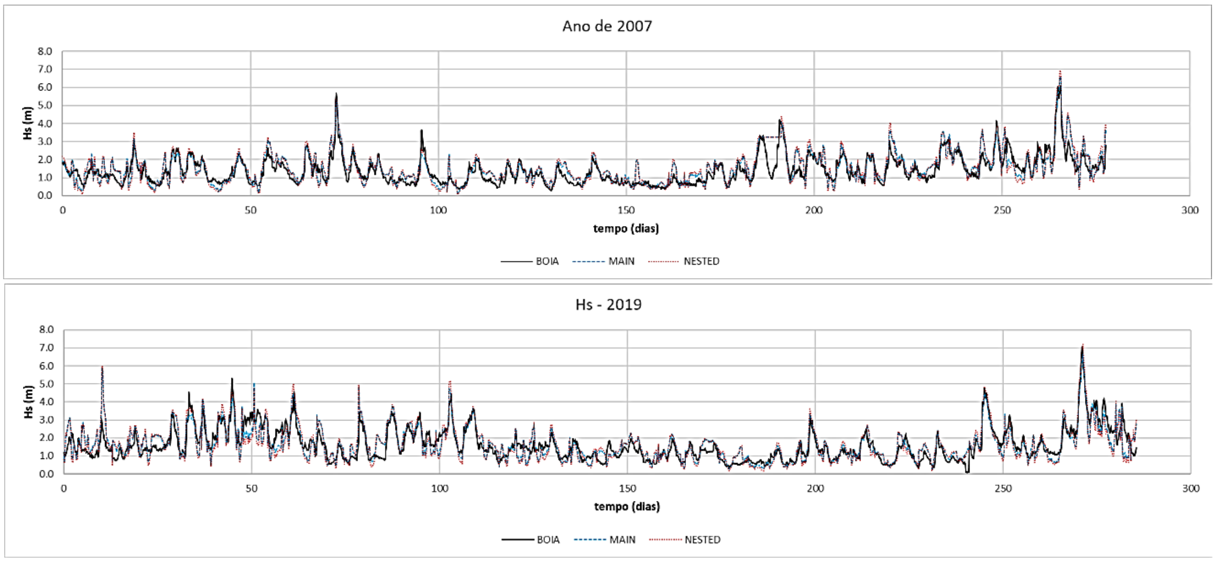


Figure 5 - Comparison of Sines 1D buoy records with SWAN numerical model results (extracted from main and nested grids)

3.3 DREAMS model

For the DREAMS model, a finite element mesh was created, with the GMALHA numerical tool (Pinheiro, 2008), to characterizes the port area of Sines, in terms of its bottom morphology and its solid boundary (Figure 6). The finite element mesh was created with the same dimensions as the bathymetric meshes, 7 nodes/wavelength and a minimum period of the wave of 14s, resulting in a mesh with 234861 points.

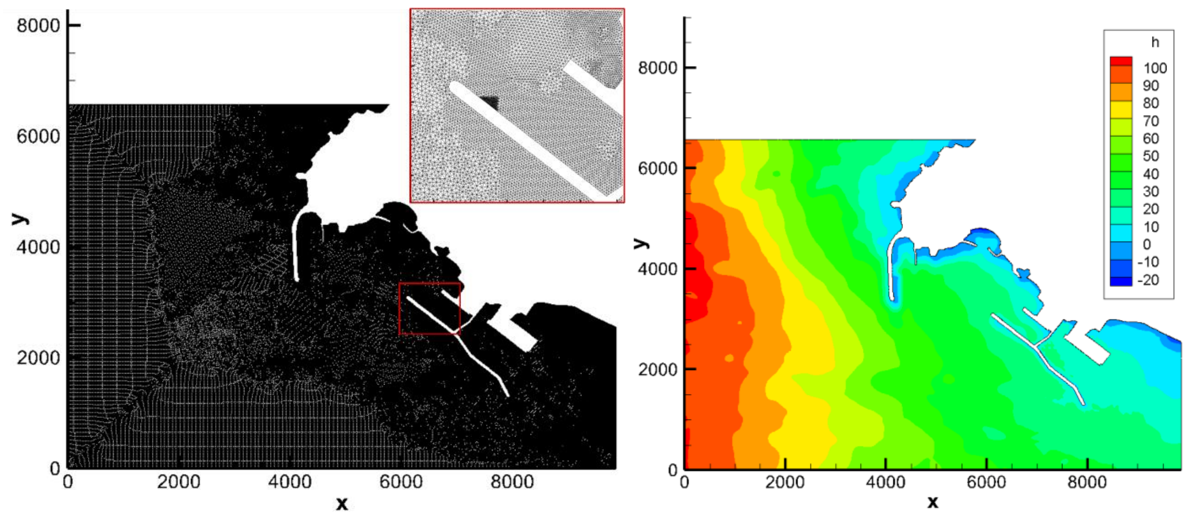


Figure 6 - Finite elements mesh of the Sines port basin.

As input data GMALHA uses the coordinates of the solid port boundary and two bathymetric meshes with the same area and different spacing between points, one large bathymetry and other finer (thin bathymetry) (Table 2).

Table 2 - DREAMS model computational bathymetry meshes

Bathymetric Mesh	Area (m^2)	Resolution	
		Δx (m)	Δy (m)
Large	9867 x 6576	100	100
Thin		20	20

Different reflection coefficients are defined for different boundaries and addressed as input data on the DREAMS model. The empirical formulas proposed by Seeling & Ahrens (1995) were used to determine the reflection coefficients associated with porous breakwaters and slopes. For non-porous slopes the formulas proposed by Neelamani *et al.* (1999) were used.

The boundary conditions of the model domain were defined from H_s, T_p and θ_m parameters, obtained by applying the SWAN model. The DREAMS model simulation provides the characteristics of the sea agitation within the port, required to evaluate the behavior of moored ships.

3.4 WAMIT model

To apply the WAMIT model, three different ships were selected to represent as comprehensively as possible the ships operating in the TGL, TXXI and TMS, namely an oil tanker, a general cargo ship, and a container ship, respectively (Table 3).

Table 3 - General geometric characteristics of the simulated ships.

Ship	Draft (m)	Beam (m)	Lenght Overall (m)
Oil Tanker	22.0	26.5	340
General Cargo	10.5	30.0	220
Container	8.0	19.0	120

The wetted boundary of the ships' hulls was dicretized into triangular and quadrangular panels (Figure 8) with the Nautical Pre-Processor tool (Santos, 1994) and their geometric properties were extracted. The submerged hull of the oil tanker was discretized with 1004 panels, the general cargo ship with 1992 panels and the container ship with 3464 panels.

Figure 7 - Simulated ships' hull discretized into panels.

To run the models, others input data are required, such as the water depth at each terminal and the range of periods and incident wave angles to be simulated. The water depth at TGL was set at 28 meters, at TXXI at 17 meters and at TMS at 18 meters. For all models a range of 89 frequencies and 5 angles of atack were considered.

The WAMIT results consist of the impulse response functions, the added inertia coefficients for infinite frequency and the transfer functions associated with the forces that the waves exert on the ship evaluated either from the Haskind relations, in terms of the radiation solution, or from pressure integration based on the diffraction solution.

The script routine procedures established to couple the numerical models do not include the WAMIT model, due to the need to manually edit the damping coefficients to avoid instabilities in the model. Thus, the system input files with all the WAMIT results are created by the numerical model HYDRO (Hurdle, 1987 and Schuurmans, 1991), which puts the WAMIT information in the convenient format to be used by the numerical model BAS.

3.5 BAS model

The BAS numerical model was applied to solve, in the time domain, the equation that describes the motions of the moored ships. The model prepares the time series of the excitation forces and computes the time series of the motions and mooring line and fender forces. BAS model provide the ultimate outputs to trigger the alert system.

As input data the ships' BAS models use the computed results by the DREAMS and WAMIT models. For the oil tanker and the general cargo ship, 8 mooring lines (equivalent to 16 moorings) grouped in two and 5 fenders were defined (

Figure *8*). For the container ship model, a total of 10 mooring lines (equivalent to 20 moorings) and 5 fenders were defined (

Figure *8*).

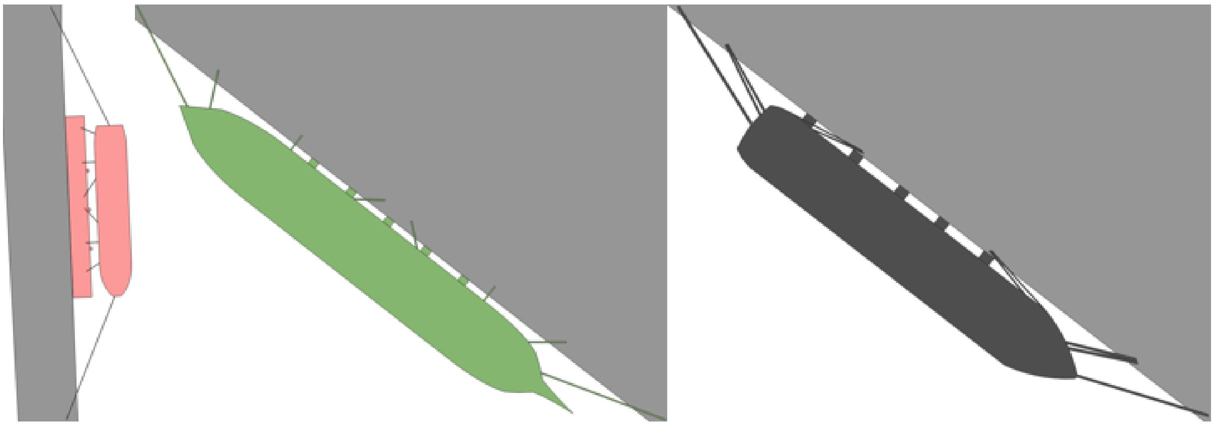


Figure 8 - Mooring lines and fenders arrangements

The constitutive relations for all the mooring lines are linear. For an elongation of 4%, the maximum load on mooring lines of the oil tanker is 2100 kN, on the general cargo ship is 1900 kN and, on the container is 1860 kN. The same constitutive relations were considered for all ships’ fenders, a linear compression with a maximum force of 8900 kN for a deflection of 1 m.

3.6 Risk Assessment

A qualitative risk methodology associated with the probability of exceeding pre-established thresholds for the amplitude of ships' motions and for the forces on their mooring system was developed. The SAFEPORT system also issue alerts to sea-wave and wind conditions. The threshold values are the ones recommended by organizations concerned with maritime and port activities and by the Sines harbour administration. Figure 12, Figure 14 and Figure 15 of the Appendix A presents the threshold values considered in the SAFEPORT system and the symbol that represents their exceedance.

4 RESULTS DISSEMINATION

The dissemination of the results of the SAFEPORT system for the port of Sines is done through a website (Figure 9) and a mobile application (Figure 10) developed under the BlueSafePort project. The user interface allows the presentation of results in an interactive and friendly way. For that, procedures to generate and disseminate alerts and to create layouts generated by the numerical models and warning data were developed.

Figure 9 – SAFEPORT System current web page.

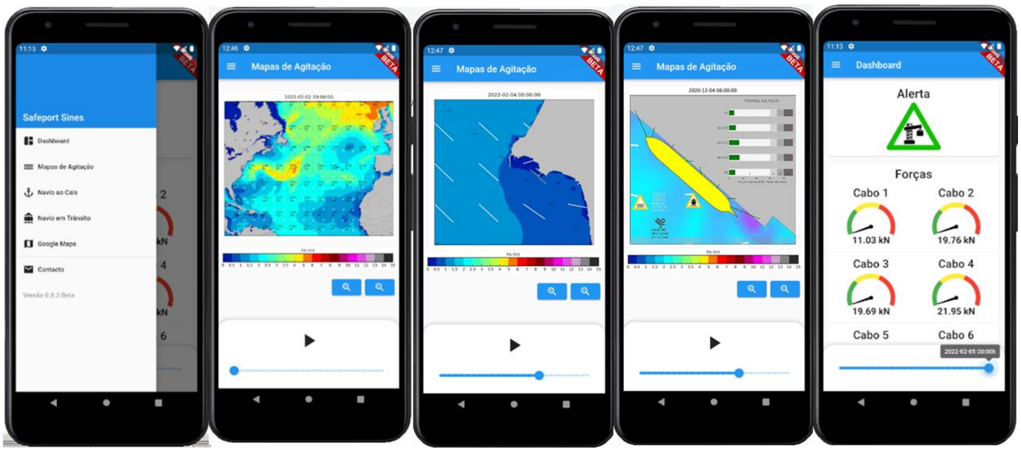


Figure 10 - SAFEPORT System mobile application.

The system, daily reports are built with the 3-day forecasts of the system results in terms of waves and navigation (Figure 11 to Figure 13 of the Appendix A). These reports are automatically sent by email daily to a pre-established list of email addresses of the responsible entities. The email contains a summary of the alerts issued for the next three days.

5 FINAL CONSIDERATIONS

Based on offshore forecasts computed by accurate weather-oceanographic forecasting models, the SAFEPORT system estimates the relevant wave parameters for the assessment of the behavior of ships moored within port basins, using a set of numerical models.

The SAFEPORT system are user-friendly and sufficiently flexible and scalable to other national and/or international ports. To register a new case study, the system requires new bathymetry and shapefiles with the geographic characterisation of the harbour area and its vicinity, a new harbour solid boundary and the refletion of its structures, new results extraction points, the hull of the ships operating in the new harbour, the ships' mooring system arrangement and characteristics and a new list of email addresses.

Acknowledgements

The authors would like to thank the BlueSafePort project (ref: FA_04_2017_016), the National Infrastructure for Distributed Computing (INCD) for granting access to the digital infrastructure to support research and the Sines and Algarve Ports Administration.

REFERENCES

Booij, N. R. R. C.; Ris, R. C.; Holthuijsen, L. H. (1999) - A third-generation wave model for coastal regions: 1. Model description and validation. Journal of geophysical research: Oceans, 104(C4):7649-7666. https://doi.org/10.1029/98JC02622

Flater, D. (1998) - XTide Manual: Harmonic Tide Clock and Tide Predictor. Technical Report, USA. Available on-line at https://flaterco.com/xtide

Fortes, C.J.E.M. (2002) - Transformações não lineares de ondas em portos. Análise pelo método dos elementos finitos. Tese de doutoramento em Engenharia Mecânica, Instituto Superior Técnico, Lisboa, Portugal. Available at http://repositorio.lnec.pt:8080/jspui/handle/123456789/8712

Fortes, C.J.E.M.; Reis, M.T.; Poseiro, P.; Santos, J.A.; Garcia, T.; Capitão, R.; Pinheiro, L.; Reis, R.; Craveiro, J.; Lourenço, I.; Lopes, P.; Rodrigues, A.; Sabino, A.; Araújo, J.P.; Ferreira, J.C.; Silva, S.F.; Raposeiro, P.; Simões, A.; Azevedo, E.B.; Reis, F.V.; Silva, M.C.; Silva, C.P. (2015) - Ferramenta de Apoio à Gestão Costeira e Portuária: o Sistema HIDRALERTA. VIII Congresso sobre Planeamento e Gestão das Zonas Costeiras dos Países de Expressão Portuguesa. Aveiro, outubro 2015.

Hurdle, D. (1987) - HYDRO Program Package. Transformation of hydrodynamic characteristics to time domain. Delft Hydraulics.

Schuurmans, S. TH. (1991) - HYDRO Program Package, Version 2.00. Transformation of hydrodynamic characteristics to time domain. Delft Hydraulics.

Korsemeyer, F.T.; Lee, C.H.; Newman, J.N.; Sclavounos, P.D. (1988) - The analysis of wave effects on tension-leg platforms. Proc. 7th International Conference on Offshore Mechanics and Arctic Engineering, 1-14. Texas, Houston.

Mynett, A.E.; Keunig, P.J.; Vis, F.C. (1985) - The dynamic behaviour of moored vessels inside a harbour configuration. Int. Conf. on Numerical Modelling of Ports and Harbour, 23-25. Cranfield: BHRA. The Fluid Engineering Centre, April 1985. England: Birmingham.

Persson, A. (2001). User Guide to ECMWF Forecast Products. Meteorological Bulletin M3.2. ECMWF: 115.

Pinheiro, L.V.; Fortes, C.J.; Fernandes J.L. (2008) - Gerador de Malhas de Elementos Finitos para a Simulação Numérica de Propagação de Ondas Marítimas. Revista Internacional de Métodos Numéricos para Cálculo y Diseño en Ingeniería (RIMNI), 24(4).

Poseiro, P.; Gonçalves, A.B.; Reis, M.T.; Fortes, C.J.E.M. (2017) - Early warning systems for coastal risk assessment associated with wave overtopping and flooding. *Journal of Waterway, Port, Coastal, and Ocean Engineering*.

Santos, J.A. (1994) - Final report, Projecto NATO PO-Waves (3/94-B) "MOORNAV – Numerical model for the behaviour of moored ships". Lisbon.

Santos, P. (2010). Análise da Interacção de Navios com Dispositivos de Acostagem e Amarração. Estudo em Modelo Físico do Posto" A" do Terminal de Petroleiros do Porto de Leixões. Available at https://hdl.handle.net/10216/58347

Seelig, W.N. and J.P. Ahrens, 1981. Estimation of wave reflection and energy dissipation coefficients for beaches, revetments and breakwaters. CERC Technical paper 81-1, Fort Belvoir, U.S.A.C.E., Vicksburg, MS.

WAMDI Group (1988) - The WAM Model - A third generation ocean wave prediction model. J. Physical Oceanography (18): 1775-1810.

Whitcomb, T. (2012) - Navy global forecast system, NAVGEM: Distribution and user support. 2nd Scientific Workshop on ONR DRI: Unified Parameterization for Extended Range Prediction.

APPENDIX A

In this section, an example of the daily report and the recommended threshold values for metocean conditions and navigation are presented.

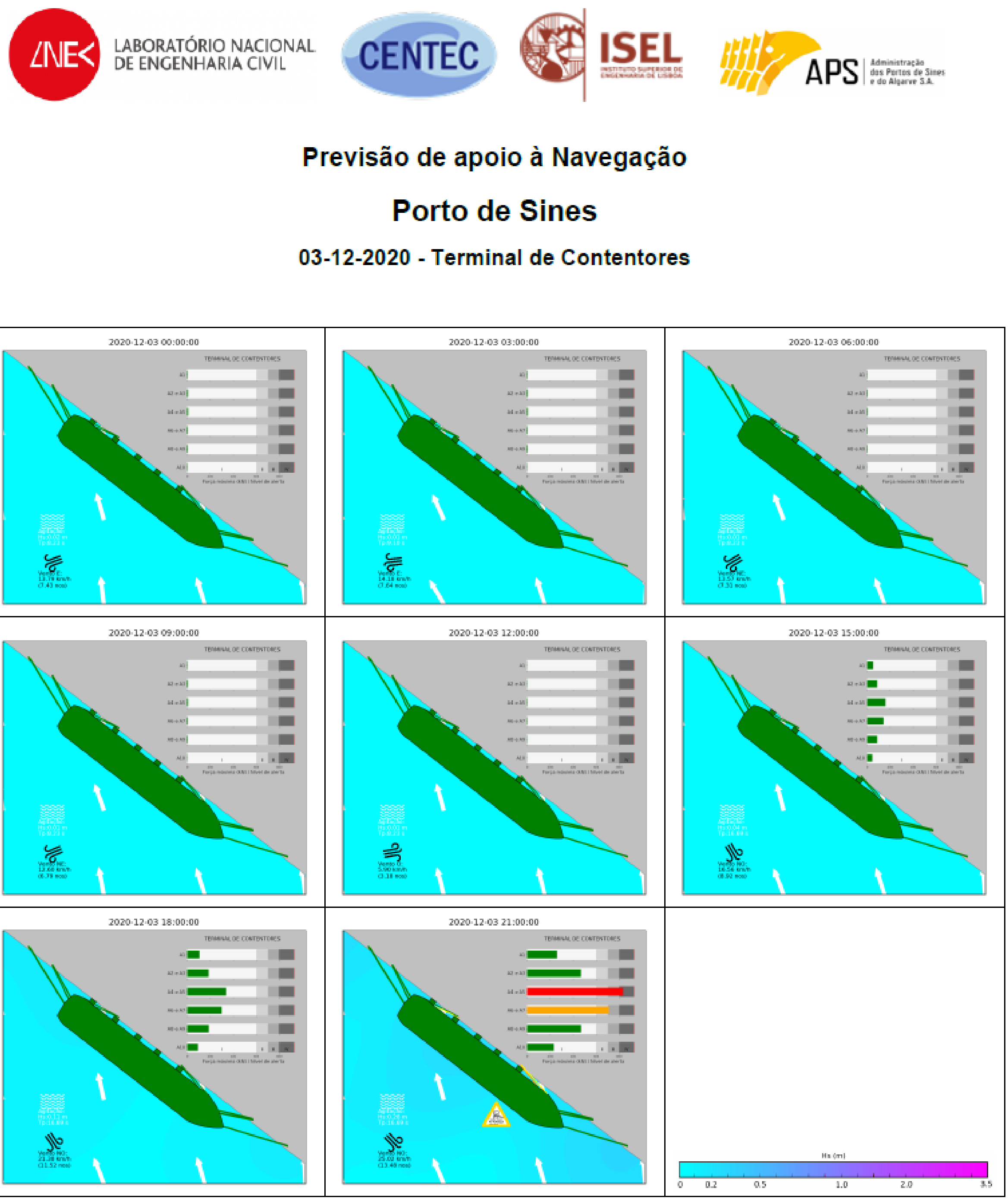
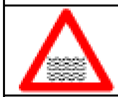
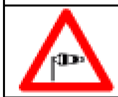


Figure 11 - Ship layout and alerts

Limiares de condições meteorológicas, movimentos dos navios amarrados e forças nas amarras para os níveis de risco de 0 a 3.

Símbolo	Descrição	Nível de Alerta			
		0 H_s (m)	1 H_s (m)	2 H_s (m)	3 H_s (m)
	Altura de onda no interior do porto[1]	< 0,5	[0,5 – 0,8[	[0,8 – 1,0[	≥1,0

Símbolo	Descrição	Nível de Alerta			
		0 V (km/h)	1 V (km/h)	2 V (km/h)	3 V (km/h)
	Velocidade média do vento no interior do porto[2]	< 65	[65 – 75[	[75 – 87[	≥87

Símbolo	Descrição	Nível de Alerta			
		0 Mov (m)	1 Mov (m)	2 Mov (m)	3 Mov (m)
	Movimento em x (avanço) do navio porta-contentores[3]	< 0,25	[0,25 – 0,4[	[0,4 – 0,5[	≥0,5
	Movimento em y (deriva) do navio porta-contentores[3]	< 0,15	[0,15 – 0,24[	[0,24 – 0,3[	≥0,3
	Movimento em z (abatimento) do navio porta-contentores[3]	< 0,2	[0,2 – 0,32[	[0,32 – 0,4[	≥0,4

Símbolo	Descrição	Nível de Alerta			
		0 Rot (°)	1 Rot (°)	2 Rot (°)	3 Rot (°)
	Rotação em x (rolo/balaço) do navio porta-contentores[3]	< 0,75	[0,75 – 1,2[	[1,2 – 1,5[	≥1,5
	Rotação em z (guinada) do navio porta-contentores[3]	< 0,25	[0,25 – 0,4[	[0,4 – 0,5[	≥0,5

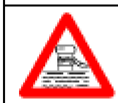
Símbolo	Descrição	Nível de Alerta			
		0 $F_{máx}$ (kN)	1 $F_{máx}$ (kN)	2 $F_{máx}$ (kN)	3 $F_{máx}$ (kN)
	Força nos cabos de amarração do navio porta-contentores[4,5]	< 800	[800 – 1200[	[1200 – 1862[	≥1862

Figure 12 - Thresholds for weather conditions, movements of the moored container ship and forces on moorings for risk levels 0 to 3.

CONSEQUÊNCIAS	MEDIDAS
Insignificantes	Sem alterações nas atividades portuárias.
Reduzidas	Algumas alterações nas atividades portuárias. Operações de carga e descarga com medidas de segurança reforçadas. Possibilidade de reforço nas amarrações.
Sérias	Operações de carga e descarga condicionadas. Necessário reforço das amarrações e seleção do posto de acostagem mais favorável.
Extremas	Operações de carga e descarga interditas. Possibilidade de ocorrência de roturas de amarras. As infraestruturas podem ficar seriamente danificadas. Manobras de atracação, entrada e saída do porto desaconselhadas.

[1] Foram considerados os valores limite estipulados pela autoridade portuária.

[2] Foram considerados os valores limite estipulados pelo Instituto Português do Mar e da Atmosfera.

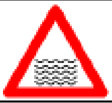
[3] Foram considerados os valores limite estipulados pela Associação Mundial para a Infraestrutura de Transportes Aquaviários (PIANC, 2005).

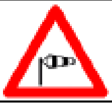
[4] Foram considerados os valores limite estipulados pelo Fórum Marítimo Internacional das Empresas Petrolíferas (OCIMF, 1992).

[5] Foram considerados os valores limite estipulados por Pinheiro *et al*. (2018) (OMAE2018).

Figure 13 - Consequences and related mitigation measures and reference to threshold values.

Limiares de condições meteorológicas, movimentos dos navios amarrados e forças nas amarras para os níveis de risco de 0 a 3.

Símbolo	Descrição	Nível de Alerta			
		0 H_s (m)	1 H_s (m)	2 H_s (m)	3 H_s (m)
	Altura de onda no interior do porto[1]	< 0,5	[0,5 – 0,8[	[0,8 – 1,0[	≥ 1,0

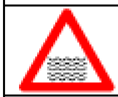
Símbolo	Descrição	Nível de Alerta			
		0 V (km/h)	1 V (km/h)	2 V (km/h)	3 V (km/h)
	Velocidade média do vento no interior do porto[2]	< 65	[65 – 75[	[75 – 87[	≥ 87

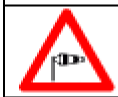
Símbolo	Descrição	Nível de Alerta			
		0 Mov (m)	1 Mov (m)	2 Mov (m)	3 Mov (m)
	Movimento em x (avanço) do navio de carga geral[3]	< 0,15	[0,15 – 0.24[	[0,24 – 0,3[	≥ 0,3
	Movimento em y (deriva) do navio de carga geral[3]	< 0,1	[0,1 – 0,16[	[0,16 – 0,2[	≥ 0,2
	Movimento em z (abatimento) do navio de carga geral[3]	< 0,75	[0,75 – 1,2[	[1,2 – 1,5[	≥ 1,5

Símbolo	Descrição	Nível de Alerta			
		0 $F_{máx}$ (kN)	1 $F_{máx}$ (kN)	2 $F_{máx}$ (kN)	3 $F_{máx}$ (kN)
	Força nos cabos de amarração do navio de carga geral[4,5]	< 950	[950–1520[	[1520–1900[	≥ 1900

Figure 14 - Thresholds for weather conditions, movements of the moored general cargo ship and forces on moorings for risk levels 0 to 3.

Limiares de condições meteorológicas, movimentos dos navios amarrados e forças nas amarras para os níveis de risco de 0 a 3.

Símbolo	Descrição	Nível de Alerta			
		0 H_s (m)	1 H_s (m)	2 H_s (m)	3 H_s (m)
	Altura de onda no interior do porto[1]	< 0,5	[0,5 – 0,8[	[0,8 – 1,0[	≥ 1,0

Símbolo	Descrição	Nível de Alerta			
		0 V (km/h)	1 V (km/h)	2 V (km/h)	3 V (km/h)
	Velocidade média do vento no interior do porto[2]	< 65	[65 – 75[	[75 – 87[	≥ 87

Símbolo	Descrição	Nível de Alerta			
		0 Mov (m)	1 Mov (m)	2 Mov (m)	3 Mov (m)
	Movimento em x (avanço) do navio petroleiro[3]	< 1,25	[1,25 – 2[	[2 – 2,5[	≥ 2,5
	Movimento em y (deriva) do navio petroleiro[3]	< 1	[1 – 1,6[	[1,6 – 2[	≥ 2
	Movimento em z (abatimento) do navio petroleiro[3]	< 0,75	[0,75 – 1,2[	[1,2 – 1,5[	≥ 1,5

Símbolo	Descrição	Nível de Alerta			
		0 Rot (°)	1 Rot (°)	2 Rot (°)	3 Rot (°)
	Rotação em x (rolo/balaço) do navio petroleiro[3]	< 2	[2 – 3,2[	[3,2 – 4[	≥ 4
	Rotação em z (guinada) do navio petroleiro[3]	< 1	[1 – 1,6[	[1,6 – 2[	≥ 2

Símbolo	Descrição	Nível de Alerta			
		0 $F_{máx}$ (kN)	1 $F_{máx}$ (kN)	2 $F_{máx}$ (kN)	3 $F_{máx}$ (kN)
	Força nos cabos de amarração do navio petroleiro[4,5]	< 1050	[1050 – 1680[	[1680 – 2100[	≥ 2100

Figure 15 - Thresholds for weather conditions, movements of the moored oil tanker and forces on moorings for risk levels 0 to 3.