EARLY WARNING SYSTEM TO SUPPORT CONSTRUCTION & MANAGEMENT OF PORT INFRASTRUCTURES: THE CASE OF TX-1 AÇU PORT CONSTRUCTION

by

Antonio Tomás[1], Manuel Simancas[2], Gabriel Díaz-Hernández[1], Javier L. Lara[1], Inigo J. Losada[1] and Francisco Esteban[2]

[1] Environmental Hydraulics Institute (IHCantabria), Universidad de Cantabria, Spain. antonio.tomas@unican.es
[2] FCC Citizen Services, Spain.

ABSTRACT

This study presents an integrated early-warning system to support construction and manage the harbor infrastructures exposed at different construction stages. The system is designed as a flexible tool, with a user-friendly interface, to be relocatable in any location. It is oriented to obtain the short and mid-term (within 180-hour prediction) characteristics of met-ocean conditions (waves, water level and wind) at the harbor surroundings in the site, as well as, wave-structure interaction characteristics for any construction phase. The system goes beyond the classical met-ocean alert system, because integrates the use and coupling of different numerical models, downscaling techniques, met-ocean databases and validation and/or calibration procedures with in-situ measurements. It is fully coupled with construction protocols related with any specific activities at any location along the harbor. One of the main objectives is to help the construction managers to improve and establish human safety threshold, related with the different tasks along the harbor, exposed to the met-ocean variables, and interacting with the unfinished harbor structures. On the other hand, the system also allow to optimize exploitation and construction costs and to achieve the individual deadlines of every task or activity.

1. INTRODUCTION

Harbors construction and management in highly exposed locations (i.e. severe met-ocean conditions) is a challenging issue. Met-ocean conditions highly affect the normal development of construction activities, seriously jeopardizing every task at the surroundings of the water-land threshold. Construction managers demand, not only the information about wave and wind conditions during construction, but also their influence and interference with daily construction activities, first, to reduce accidents, and second, to improve the management of the construction agenda along different stages. It is necessary to optimize construction costs and to achieve the individual deadlines of every task or activity. Note that some construction operations are very expensive, because use resources very specialized, and they could be used only during specific met-ocean time-windows.

Once the construction of the port has been completed, it is necessary to manage the exploitation and planning of port activities through a reliable met-ocean forecasts, in order to optimize the available resources.

Aware of this problem, in the last few years IHCantabria has been working on the development of a new methodology to solve these problems and to generate a new set of tools to aid the constructors and managers of ports infrastructures. The new methodology has been applied to several ports around the world, improving and optimizing the tools.

The first IHCantabria implementations of early warning system to support port constructions were in Sancti-Petri in Spain and Langosteira harbor in Spain (Díaz-Hernández et al., 2010 and Díaz-Hernández et al., 2017). Then, new developments of these tools were implemented in the TX-1 Açu port construction in Brazil (the example explained in this study) and the ongoing Aberdeen port construction (United Kingdom). These systems were developed thanks to the support and confidence of companies such as DRAGADOS and FCC Citizen Services, and the methodological principles came from Spanish R&D&i projects (SAYOM and CLIOMAR).

On the other hand, a lot of examples of IHCantabria early warning systems to support the management of ports are now operating in Spain. Eleven systems (Gijón, Málaga, Almería, Carboneras, Santa Cruz de La Palma, Santa Cruz de La Gomera, Santa Cruz de Tenerife, Las Palmas, Arrecife, Puerto del Rosario and Barcelona) are installed in the framework of SAMOA Project (Rodriguez et al., 2017). And new developments are implemented in the Port of Algeciras in the framework of SAFEPORT Project (De los Santos et al., 2016). All these systems are installed in "Puertos del Estado" (Spanish Ministry of Civil Works) and accessible via http://www.puertos.es and https://cma.puertos.es. Other IHCantabria operational systems for port management are in operation at the ports of Langosteira and Santander; and Huelva, Tenerife and Algeciras in the framework of ATHENEA Project (Castanedo et al., 2012).

The new early warning system methodology contains different modules, and it is design as a flexible tool that can be adapted according to the harbor location, the construction procedures and the met-ocean complexity. The system is oriented to obtain the short and mid-term (within 180-hour prediction) characteristics of met-ocean conditions (waves, water level and wind) at the harbor surroundings in the site, as well as, wave-structure interaction characteristics for any construction phase. The system goes beyond the classical met-ocean alert system, because it use the best "solution" for each "problem". Each module integrate and couple the best numerical models, downscaling techniques, met-ocean databases, and/or calibration procedures with in-situ measurements. The modules are fully coupled with construction protocols related with any specific activities at any location along the harbor.

One of the main objectives is to help the construction managers to improve and establish human safety threshold, related with the different tasks along the harbor, exposed to the met-ocean variables, and interacting with the unfinished harbor structures. On the other hand, the tools allow to optimize exploitation and construction costs and to achieve the individual deadlines of every task or activity.

2. METHODOLOGY

The new early warning system methodology contains different modules, and is design as a flexible tool that can be adapted according to the harbor location, the construction procedures and the met-ocean complexity.

First, deep water a met-ocean module (as the main core of the system) should be defined, covering two main tasks: a) the wind, wave and sea-level hindcast analysis, based on high-accurate and validated global datasets; and b) the 7-days hourly prediction for wind, wave and sea-level forecasting system, such as NOMADS system (provided by NOAA).

Second, the downscaling module designed to propagate the met-ocean variables from deep to coastal zone and to any location near, in front and/or inside the harbor.

Third, the met-ocean-structure interaction module that contains high-resolution analysis for one or more of the following processes: harbor agitation and resonance due infragravity waves (mild slope and Boussinesq modelling); wave run-up and overtopping (laboratory data, analytical formulations and CFD modelling); scour and silting (analytical approximations and CDF modelling); moored ship response (CFD, Boussinesq and potential theory approximation); dredging (measurements and dredge protocols); and wake waves (Boussinesq modelling), considering any construction stage for any bathymetric characteristics and any unfinished harbor structure geometries.

It is important to note that the information provided by this third module is relevant because is combined with the construction activities, recommendations and protocols along the breakwaters, basins, and berthing zones, as well as, the crucial importance in the use of CFD numerical modelling to cover the lack of semi-empirical formulations in literature for unfinished breakwater cross-sections. In particular wave overtopping information (i.e.: mean discharge, maximum volume) is considered as a crucial product to be crossed with secure thresholds related with the different construction works to determine its viability and safety.

Finally, the system can include a fourth module dedicated for the assimilation of real-time measurements provided by met-ocean data (nowcast), as a quick quality control module for each variable predicted.

The robustness of the early warning system makes it suitable for the construction stages, as well as for the optimization of the operation of these infrastructures once the works are finished.

3. APPLICATION & RESULTS

3.1 Introduction

To illustrate the application of the new early warning system, and to better understand the methodology, the tools and the results, one example is presented: the early warning system for the construction of Açu TX-1 terminal in Brazil.

In 2013, the company FCC Citizen Services within the Joint Venture FCC Tarrio TX-1 Construção LTDA started the construction of the TX-1 terminal of Açu Superport in São João da Barra, 315 kilometers north of Rio de Janeiro (Brazil). The works include the construction of a breakwater, composed by a 600 m long rubble-mound breakwater 600 m long (Core-loc 10T) and a 2.100 m long vertical breakwater (47 reinforced concrete caissons), with a crest at +10 m elevation.

To support the construction of Açu Port, a high-resolution operational system in the port was developed, ad-hoc for the FCC constructive resources and techniques.

This operational system allows planning the operations in advance (more than a week forecast) and realistic (assimilating in-situ instrumental information), from the numerical prediction of wind, sea level, waves, long-waves, agitation and overtopping, taking into account the geometric evolution of the works in each construction stage. The system produces daily safe working conditions

(1) to transport the caissons from Río de Janeiro to the port of Açu,

(2) to construct the caissons,

(3) to anchor the caissons and

(4) to construct the crest.

All the modules are integrated in a friendly web-based interface, available 24/7 service for the managers. The web gives a quick understanding about the daily activities at the different areas of the port. Information is daily updated and sent also by e-mail to the managers.

3.2 Methodology

In figure 1, it is presented the general methodology and the modules used in the early warning system application for the construction of the Port of Açu and the general methodology:

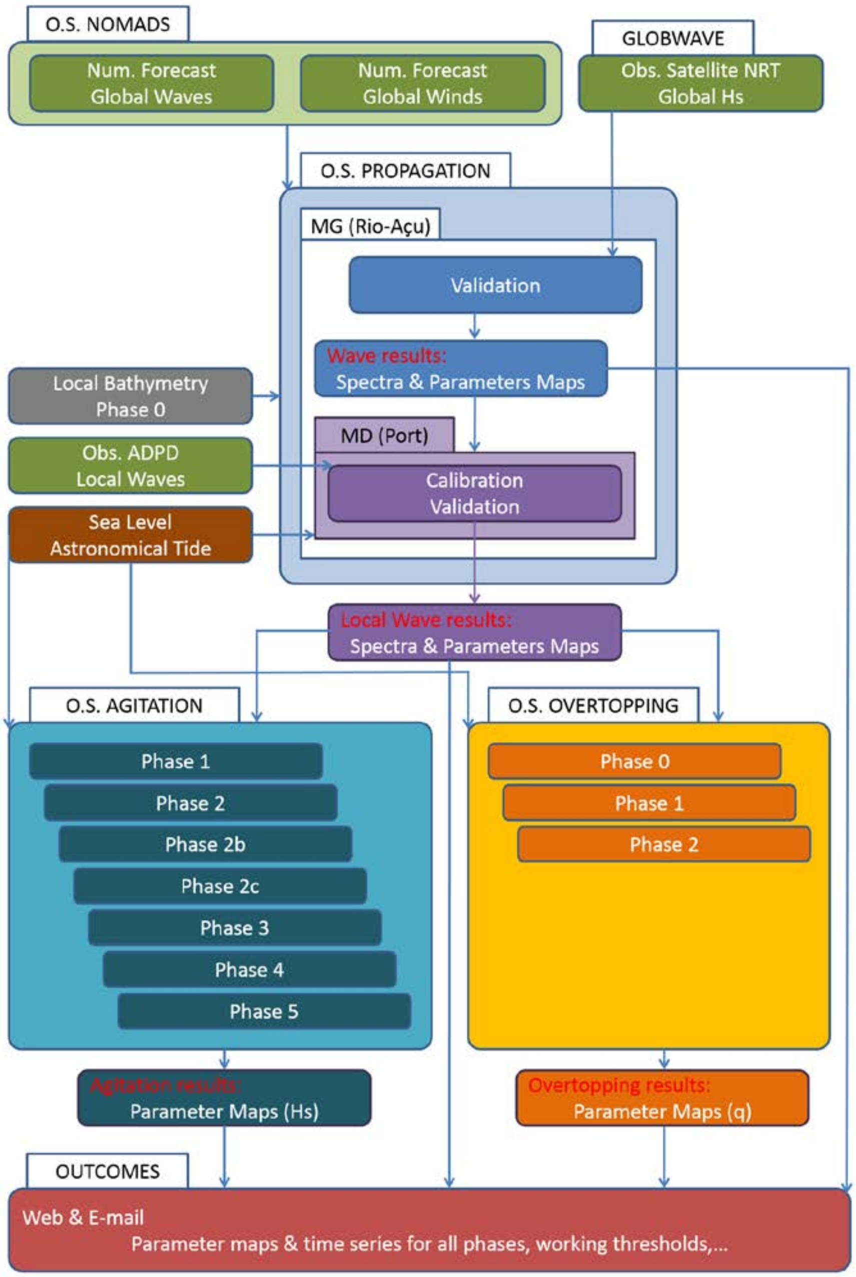

Figure 1: Overall methodology of the early warning system for the construction of Açu TX-1 terminal in Brazil

The operational system of propagation (O.S. PROPAGATION), based on the global wave and wind conditions of the NOMADS operational system, performs dynamic downscaling or propagation to determine the local wave conditions in the surroundings of the port. The system solves the processes of coastal propagation (refraction, diffraction, shoaling, bottom friction, wind generation and wave breaking) with the SWAN (Booij et al., 1999) numerical model based on the energy balance equation. As a result, all wave results have hourly temporal resolution with a prediction horizon of 7.5 days and are updated several times a day.

The SWAN model is carried out by means of several nested meshes that increase the spatial resolution as it gets closer to the port of Açu. The General Mesh (MG Rio-Açu) covers the entire study area from Rio de Janeiro to the port of Açu with a spatial resolution between 1 and 5 km. The results of this General Mesh are validated with the data measured by the Jason-2 satellite in real time (Near Real Time), see figure 2. MG results are wave spectra and parameters, providing the wave and wind conditions on the navigation route from Rio de Janeiro to the Port of Açu and also the forcings for its different nested meshes.

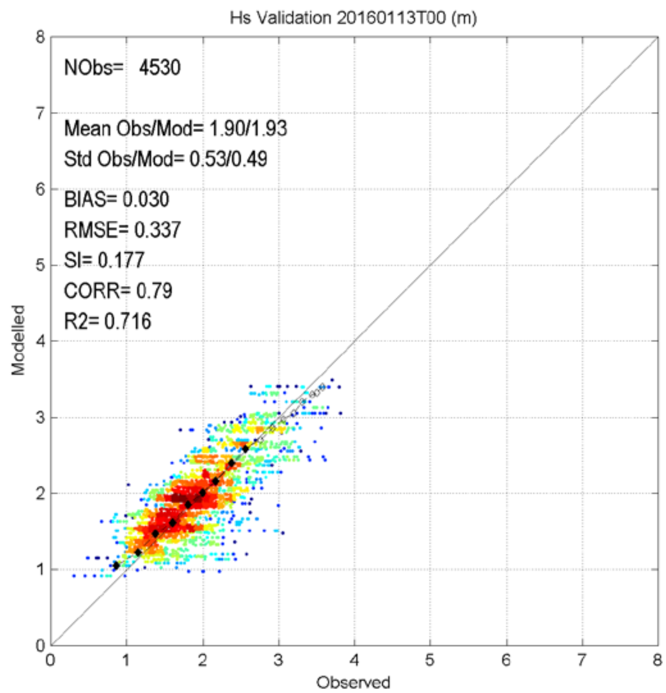

Figure 2: Example of validation of the OS PROPAGATION, General Mesh, with the significant wave height data observed by Jason-2 satellite up to January 13, 2016.

The Detail Mesh (MD Port) reaches a spatial resolution of about 50 meters and uses the detailed bathymetry of the study area and the local sea level to propagate the waves to the port. As a result, the incident waves in the port are obtained, without taking into account their interaction with the breakwaters, which is why it is called construction Phase 0 (without port). These results are validated, every month, with measurements taken in-situ by an ADCP located outside the area of influence of the breakwaters under construction. The biases or systematic errors obtained from these comparisons are assimilated by the system, so the results finally obtained by the system in the following predictions are corrected or calibrated, improving their quality (see figure 3). Finally, the results in the Detail Mesh provide incident wave conditions (wave spectra and parameters) at the port of Açu (Phase 0, without breakwaters) and also the forcings for the operational systems of agitation and overtopping over the vertical breakwater.

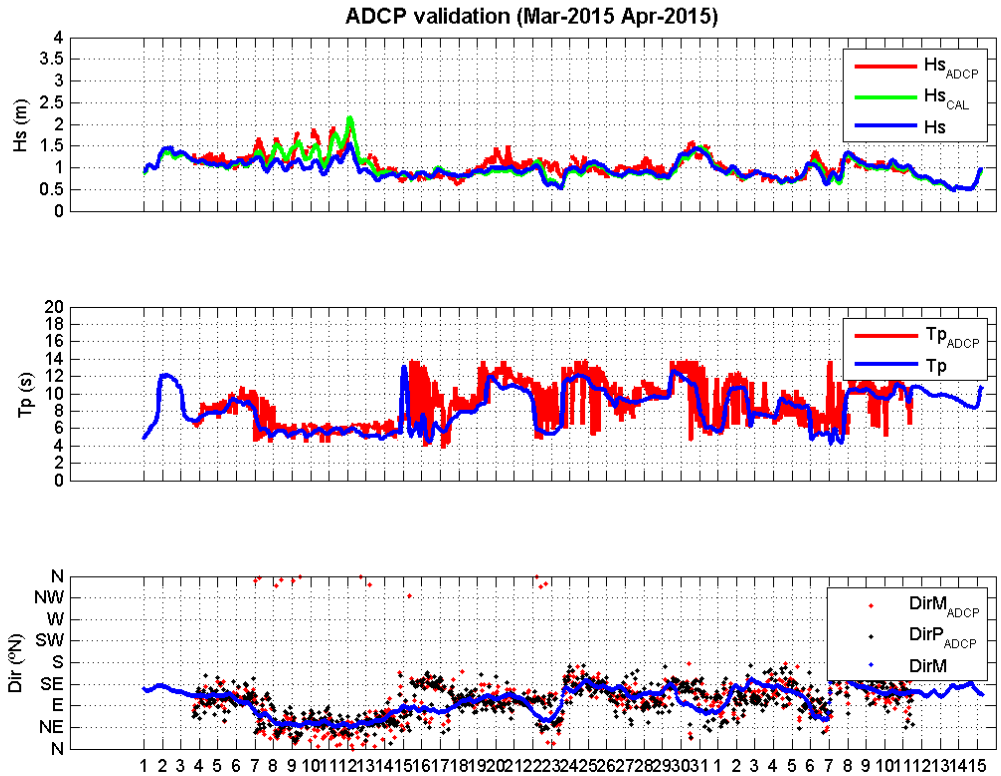

Figure 3: Example of time series validation of the significant wave height (Hs), peak period (Tp), and mean wave direction (DirM) of the original Operational System (blue), the Calibrated Operational System (green) and ADCP measurements in the Port of Açu (red), from March 3, 2015 to April 11, 2015.

The operational system of agitation or internal disturbance (O.S. AGITATION) takes into account the interaction of waves with the contours, breakwaters or quays in the port of Açu (both vertical and rubble mount breakwaters). The MSP model (based on the elliptic Mild SloPe equations) is used to solve the agitation (the linear processes of refraction, diffraction, shoaling, total or partial reflection, bottom friction and wave breaking. For this reason, the computational grids of this model are specifically defined for each construction phases of the port. Each construction phase (1, 2, 2b, 2c, 3, 4 & 5) take into account the time-variation in its layout, either by advancing the rubble mounds layers or by the anchoring of the caissons for the vertical breakwater (see example of 4 different phases in figure 4). Note that wave results change drastically for each phase construction.

The MSP model uses, as a forcing, for each construction phase, the sea level and wave spectra of Phase 0 (SWAN model Detail Mesh) and generates the significant wave height maps with a spatial resolution in the order of 10 m; taking into account the geometric and reflection characteristics of the different elements of the port phase construction. The results are updated several times a day and have 7.5 day prediction horizons with hourly time resolution.

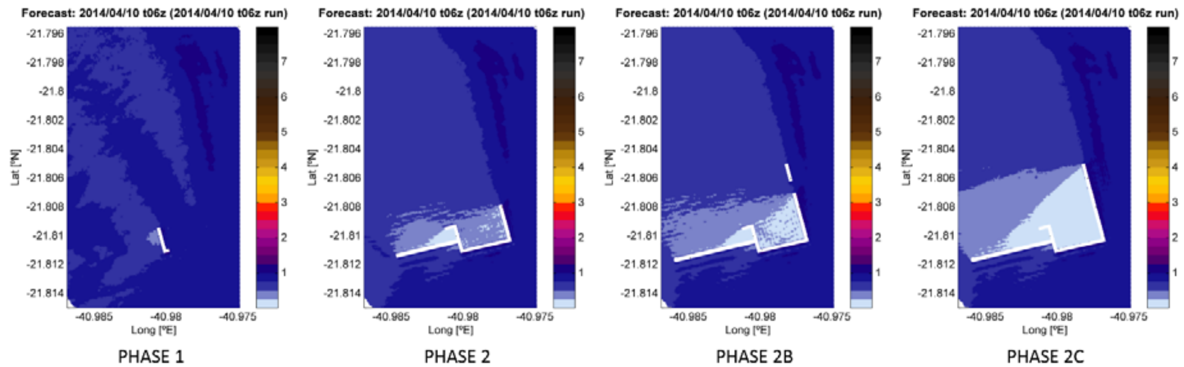

Figure 4: Example of significant wave height (Hs) prediction inside the Port of Açu for four different agitation phases (1, 2, 2B and 2C). White areas indicate the progress of works.

The operational system of overtopping (O.S. OVERTOPPING) also uses the sea level and wave spectra predictions from Phase 0 (SWAN Model Detail Mesh) as forcing. Based on these predictions, it calculates the hourly mean overtopping rate (q) over the 7.5 day forecast horizon, for each of the three construction phases of the crest (see figure 5), taking into account the different caisson typologies used in the Port of Açu.

The overtopping calculation is carried out using formulae previously adjusted for each type of section and construction phase of the crest, using the sea level and wave values specific to each caisson of the port of Açu. These formulae have been determined from a catalogue of numerical simulations carried out ad-hoc, with the numerical model IH2VOF, for the specific characteristics of the vertical breakwater of the port of Açu; covering its complete range of geometries, waves and sea levels. The model called IH2VOF (Losada et al. 2008, Lara et al. 2008) is an advanced numerical tool that solves the two-dimensional RANS (Reynolds Average Navier-Stokes) equations and includes small-scale physical processes such it solves the flow in porous media, the realistic wave breaking and the consequent phenomenon of run-up, the overtopping on the structure, forces on monolithic parts of the structure (ie caissons); taking into account non-linear and turbulent effects resulting from the temporal interaction between individual waves and the structural elements of the port.

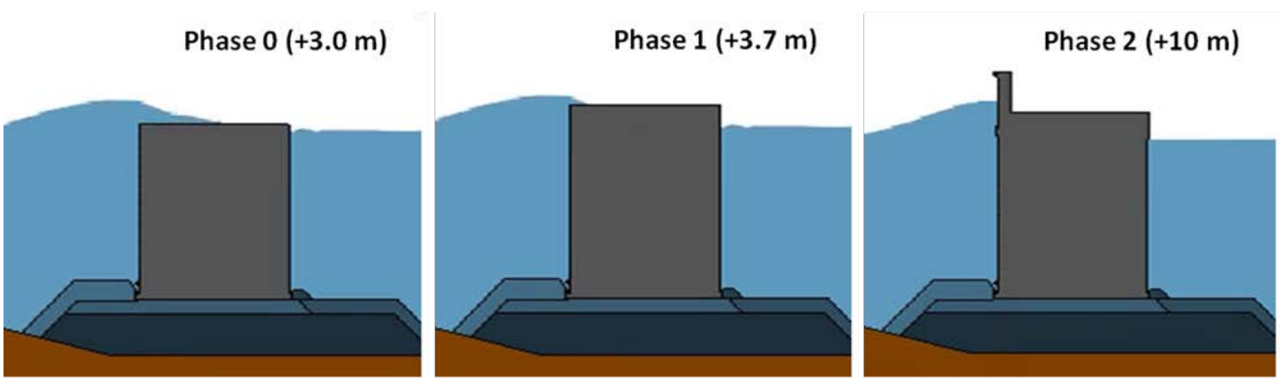

Figure 5: Example of overtopping results simulated by IH2VOF for three different crest construction phases (0, 1 and 2) in the caisson vertical breakwater.

Finally, all the results obtained (OUTCOMES) are displayed in a web page, which represents in a friendly way, the maps and time series of the last forecast of the operational system. Results for the following 7.5 days, of the different parameters of wind, waves, sea level, agitation and overtopping on the vertical breakwater, for each of the constructive phases of the port, are shown. Also, the different results are interpreted and crossed with different work thresholds defined by FCC for the transport and anchoring of caissons and the construction of the crest. Excel® sheets with the most relevant results of each operational system update are also automatically sent by e-mail to the managers of the works, for the construction phase that is currently in progress.

3.3 Results

In figure 6 is shown the initial view of the web page where all results are displayed. There are 12 panels to access the different modules results:

RIO-AÇU: O.S PROPAGATION, General Mesh (Operational System to the transport of caissons from Río de Janeiro to the port of Açu).

PHASE 0: O.S PROPAGATION, Detailed Mesh (Operational System to anchor the caissons)

PHASE 1: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 2: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 2B: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 2C: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 3: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 4: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 5: O.S AGITATION (Operational System to construct and anchor the caissons).

PHASE 0 OVERTOPPING (Operational System to construct the crest of the caissons).

PHASE 1 OVERTOPPING (Operational System to construct the crest of the caissons).

PHASE 2 OVERTOPPING (Operational System to construct the crest of the caissons).

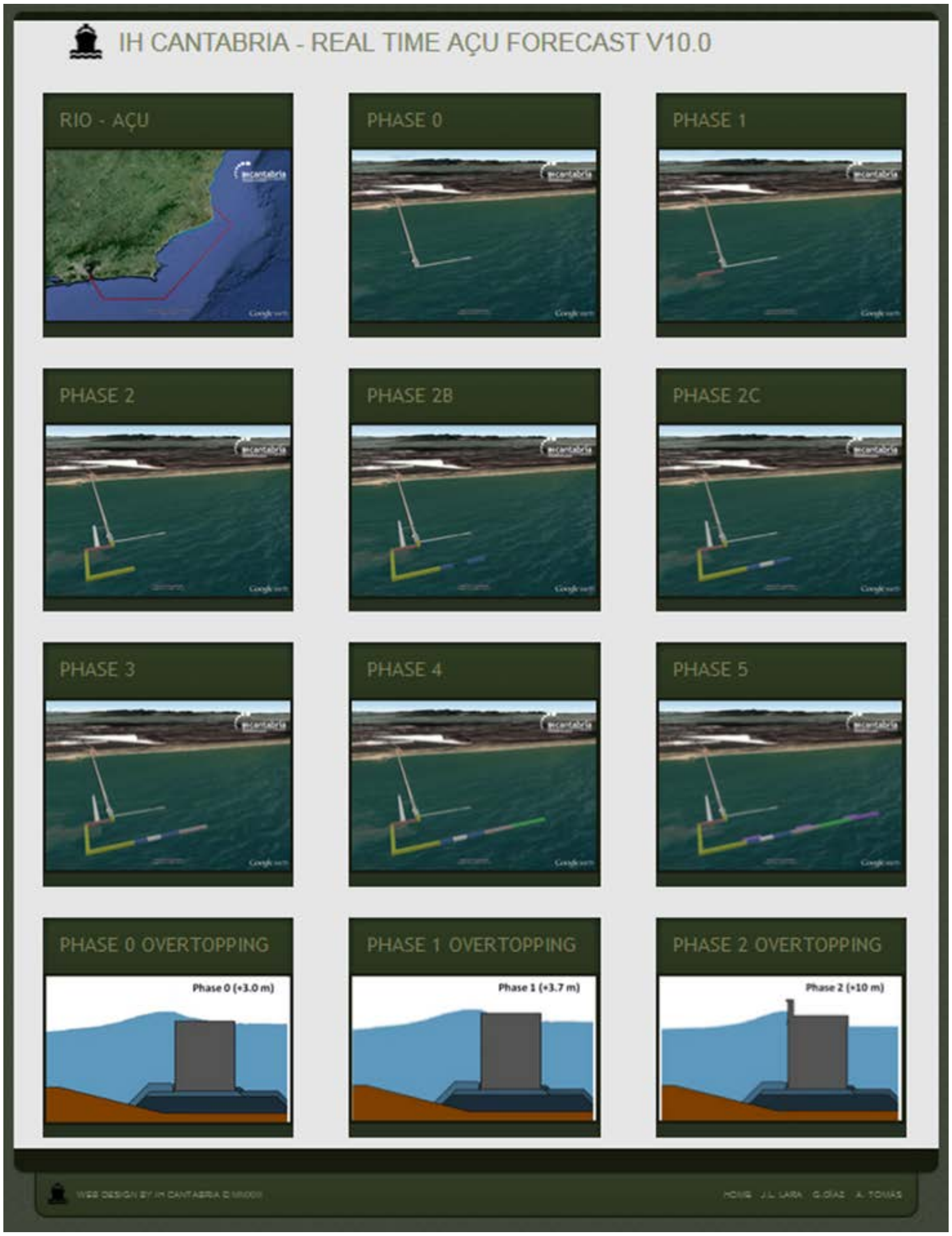

Figure 6: Initial view of the web page of the early warning system for the construction of Açu TX-1 terminal in Brazil

Figure 7 shows an example of the results that can be obtained from the system (RIO-AÇU) for a safety development of the marine transportation of the caissons from Rio de Janeiro to Port of Açu. In the upper part (1), several options are available: i) downloading an excel with the numerical information of the last prediction; ii) downloading png images with the hourly spatial fields of the significant wave height, peak period and wind; iii) downloading the validation of operational system with satellite data. Next in (2) there is an animation with the 180 hours of wave and wind predictions. Hs is represented in a color scale, with black arrows representing wave direction and grey arrows representing wind direction. The navigation route from Río Janeiro to Açu port is represented in grey. Next in (3), access to the Hs and W predictions and navigation thresholds (green, red) in the prediction horizon (X axis) along the location of the navigation route (Y axis) are included. Finally, at the bottom (4), for the selected prediction instant, locations where the navigation threshold is exceeded are represented in red, and represented in green when navigation is permitted.

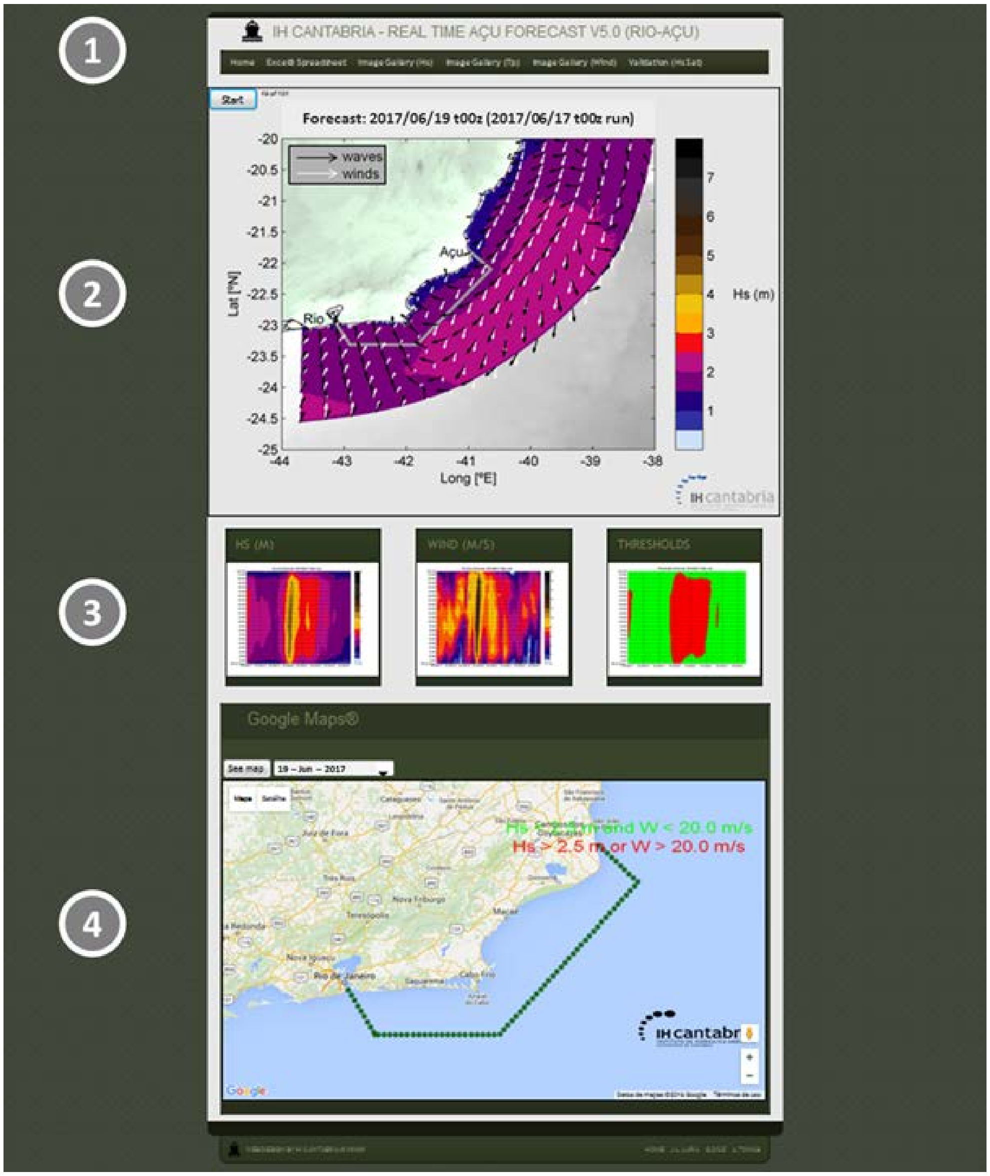

Figure 7. General view of the web page of the RIO-AÇU module. (1) Access to the Excel sheet with all the data from the last prediction. (2) Animation with 180-hourly the spatial Hs prediction. (3) Time series of the Hs and W prediction and the thresholds in all the locations of the navigation route. (4) Geo-spatial representation of the threshold along the navigation route (Hs and W) for each prediction horizon.

Figures 8 and 9 shows, similar to figure 6, examples of the results that can be obtained from the O. S. AGITATIONS module to construct and anchor the caissons (PHASE 4 in figure 8) and O.S. OVERTOPPING to construct the crest of the caissons (PHASE 1 OVERTOPPING in figure 9).

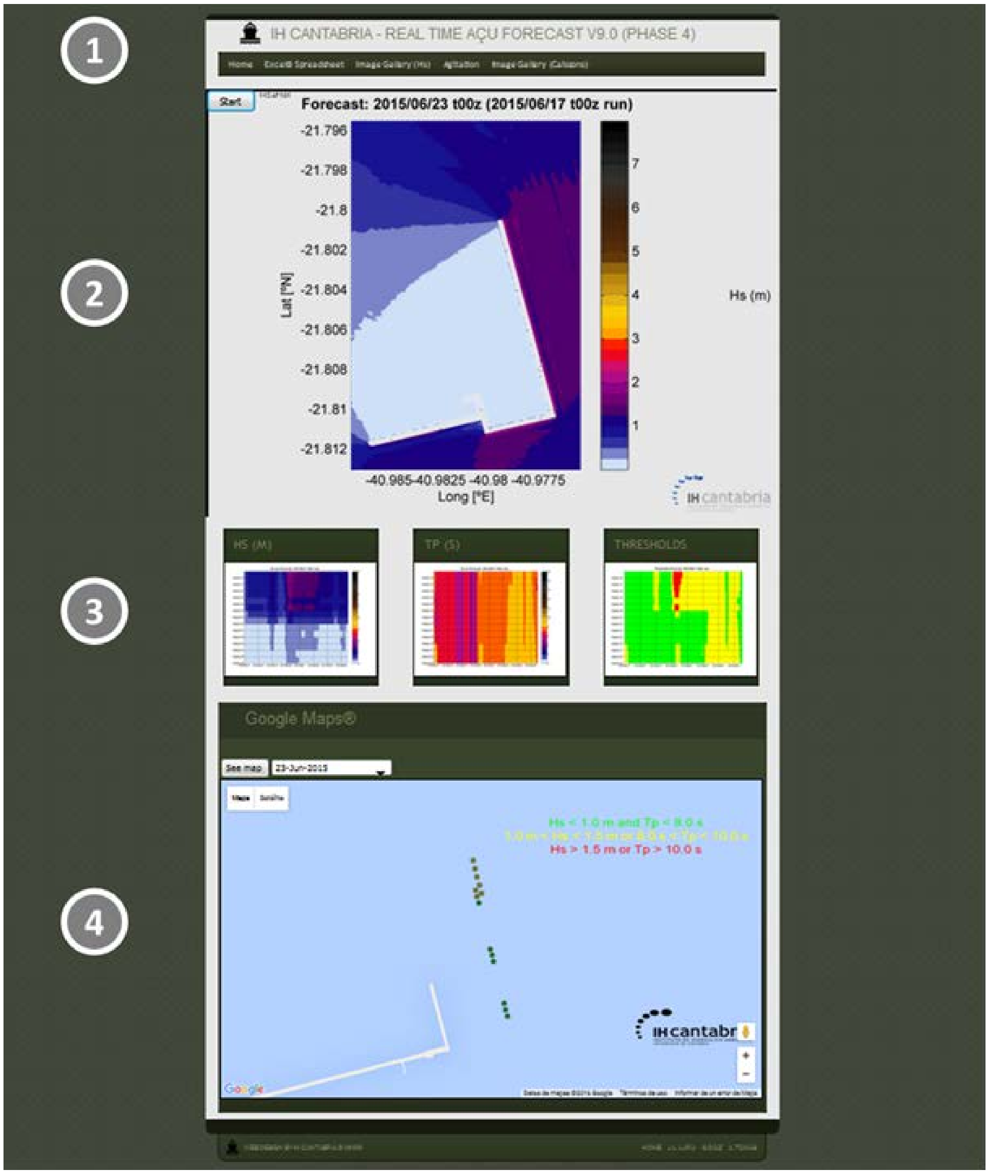

Figure 8. General view of the web page of the PHASE 4 module. (1) Access to the Excel sheet with all the data from the last prediction. (2) Animation with 180-hourly the spatial Hs prediction. (3) Time series of the Hs and Tp prediction and the thresholds in all the locations of caissons for anchoring. (4) Geo-spatial representation of the threshold for each caisson for anchoring (Hs and Tp) for each prediction horizon.

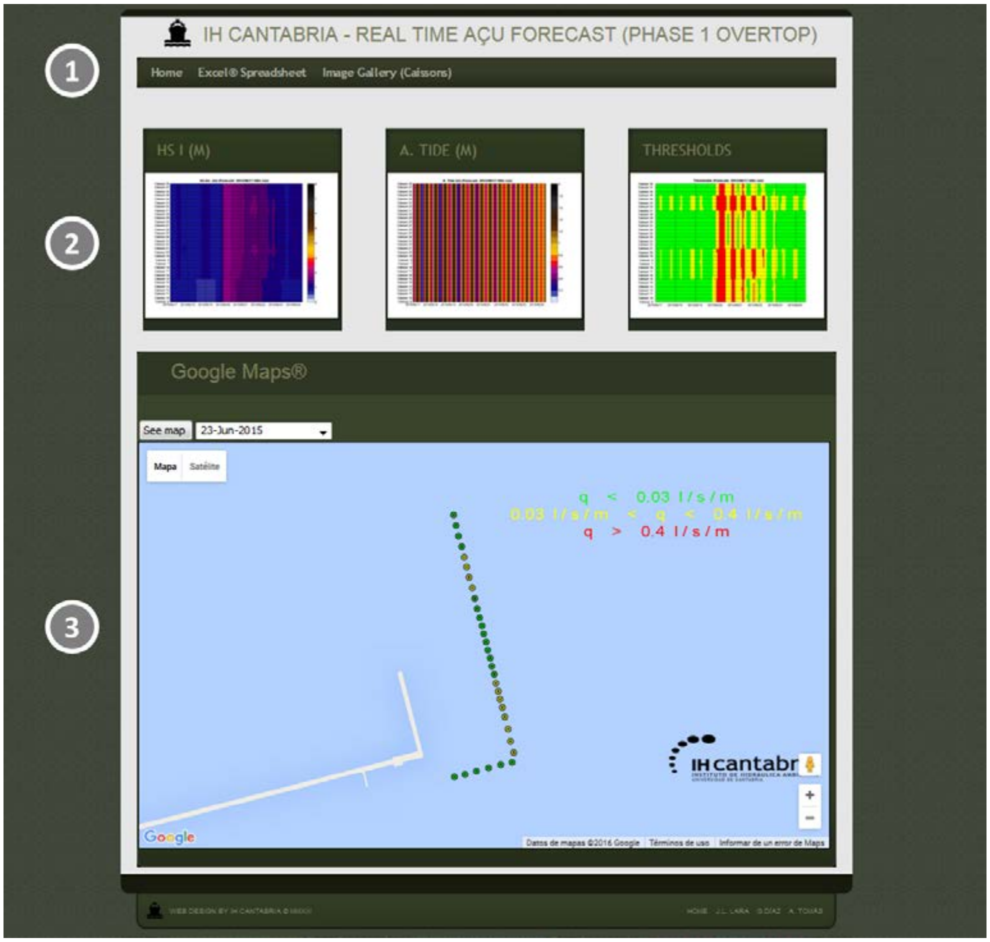

Figure 9. General view of the web page of the PHASE 1 OVERTOPPING module. (1) Access to the Excel sheet with all the data from the last prediction. (2) Time series of the Hs and Sea Level prediction and the thresholds in all the locations of caissons for working on the crest. (3) Geo-spatial representation of the threshold for each caisson for working on the crest (q) for each prediction horizon.

4. CONCLUSIONS

This study presents an integrated methodology of early-warning system to support construction and manage the harbor infrastructures exposed at different construction stages. The system is designed as a flexible tool, with a user-friendly interface, to be relocatable in any location. Results of the early warning system for the construction of Açu TX-1 terminal in Brazil, are presented.

An operational system of very high spatial resolution and specific for the construction processes of the Port of Açu has been implemented. This system offers results with a prediction horizon of one week (180 hours), hourly time resolution and is updated at least 3 times a day.

The prediction of all the climatic information in open waters (waves, sea level and wind) provided by the NOMADS system has been integrated, confirming the need to increase the spatial-temporal resolution of the dynamics and, at the same time, to adequately resolve the processes that condition the safety of the different works in the Port of Açu:

Maritime transport from Rio de Janeiro

Construction of caissons

Anchoring of caissons

Construction of the crest

The operational system has been successfully structured in several modules that numerically model, with the latest generation tools, the different processes at the most appropriate scale: operational system of propagation (SWAN model), operational system of agitation (MSP model) and operational system of overtopping (IH2VOF model).

The numerical runs have been carried out for each configuration and phase of works, updating the results according to the constructive and realistic progress of the works.

The system is validated and verified the benefits of the forecasts by comparing the expected values with the real ones measured by the in-situ ADCP. Results of the system were improving by assimilation of real data measured by the ADCP.

Specific working thresholds have been defined and validated on site (for transporting the caissons, anchoring the caissons and work on the crest) which are automatically crossed with weather forecasts. With this procedure, working parts (red, yellow and green) are generated daily and distributed via web and e-mail. This make possible to plan the different working conditions on site quickly, truthfully, reliably and safely.

A friendly and easily accessible web page has been implemented to distribute all results of the latest update of the predictions (geo-spatial representation, animations, figures, numerical data...). Results can be shows by different users. The system allows to the end user to trace the flow of all the information generated.

The robustness of Açu's operational system allows it to be adapted for the construction of other maritime works, as well as for the optimization of the operation of these infrastructures once the works are completed.

The close collaboration between IHCantabria-FCC has improved the quality of the results obtained by the operational system.

The system help the construction managers to improve and establish human safety threshold, related with the different tasks along the harbor, exposed to the met-ocean variables, and interacting with the unfinished harbor structures. And the system results also allow to optimize exploitation and construction costs and to achieve the individual deadlines of every task or activity.

5. REFERENCES

Booij, N.; Ris, R.C.; Holthuijsen, L.H. (1999). A third-generation wave model for coastal regions, Part I: Model description and validation. Journal of Geophysical Research, 104(C4). pp 7649-7666. doi: 10.1029/98JC026222.

Castanedo, S., Abascal, A.J., Camus, P., Tomás, A., Cárdenas, M., Medina, R., (2012) High resolution oil spill forecasting using hybrid downscalling techniques. 33th International Conference on Coastal Engineering. Santander (Spain).

De los Santos, F.J.; Rodriguez-Rubio, P.; Terrés, J.M.; Mans, C.; Molina, R.; Díaz-Hernández, G.; Tomás, A.; Lara, J.L.; Álvarez, E. (2016) Proyecto Algeciras-Safeport para la gestión de riesgos océano-meteorológicos en entornos portuarios: oleaje, viento, agitación, rebase y oleaje generado por el paso de embarcaciones. VI Congreso Nacional de la Asociación Técnica de Puertos y Costas. (ATPYC) Palma de Mallorca (Spain). pp 257-269. ISBN 978-84-88975-91-1 (in spanish)

Díaz-Hernández, G., Losada, I.J., Mendez, F.J., Guanche, R., Reguero, B., Camus, P. (2010). An early-alert system to support construction of port infrastructures. 32th International Conference on Coastal Engineering. Shangai, (China)

Díaz-Hernández, G., Losada, I.J., Mendez, F.J (2017). Improving construction management of port infrastructures using an advanced computer-based system. Automation in Construction, 81, pp 122-133. doi: 10.1016/j.autcon.2017.06.020

Lara, J.L.; Losada, I.J.; Guanche, R. (2008). Wave interaction with low mound breakwaters using a RANS model. Ocean Engineering, ELSEVIER. Vol. 35(13), pp. 1388-1400

Losada, I.J.; Lara, J.L.; Guanche, R.; Gonzalez-Ondina, J.M (2008). Numerical analysis of wave overtopping of rubble mound breakwaters. Coastal Engineering, ELSEVIER. Vol. 55(1), pp. 47-62

Rodríguez, B., Díaz-Hernández, G., García-Valdecasas, J. M., Álvarez-Fanjul, E., Lara, J. L., Medina, R., Tomás, A. (2017) Validación pre-operativa y puesta en marcha del sistema operacional de agitación portuaria del proyecto SAMOA. XIV Jornadas Españolas de Ingeniería de Costas y Puertos. Alicante (Spain). pp. 85-86. (in spanish)