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Improving construction management of port infrastructures using an advanced computer-based system

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ABSTRACT

This study presents the design, development, scheme and field validation of an early-alert ocean wave system. It is designed to automate, improve, analyse, design and manage the daily construction activities of any harbour at construction stage. The objective is threefold: a) maximise construction safety, with regards to well-known hazards which occur during construction, especially breakwaters that interact with high-energy sea states, b) optimise the transport, by means of specialised vessels, of the refill material, and c) to minimise the construction delay and disruption on a daily basis, thanks to short-term construction forecasting (96 h). The system, known as PATO, offers short-term sea states characteristics, at any point near harbour structures, and relevant wave-structure interaction parameters at any harbour construction stage. The system is able to assist harbour project managers by providing accurate ocean wave data through a user-friendly interface.

1. Introduction

New ports have been recently built and several harbour structures, such as basins and breakwaters, have been enlarged in Spain, e.g. the enlargement of the main breakwater and basin of Gijon Port in Asturias, or the construction of a new deep water port in Punta Langosteira in Galicia, Spain. These construction projects have meant an important improvement of maritime transport of goods and oil, having a high impact on the local and national economy of the area. The continuous growth of the port operation market requires harbour projects to be improved with very large dimensions and deeper waters (due to the larger size of the ships, the greater amount of goods movement, wider warehousing, and broader navigability needs, as well as docking dimensions inside the basins). Consequently, the new construction sites are located further offshore and highly exposed to ocean wave action, commonly related to high-energy sea state episodes with individual ocean waves easily reaching 10 m of significant wave height (e.g. coastal zones at the North of Spain/Portugal, Northern coast of Europe, tropical hurricane/typhoon zones, etc.). These high-energy sea states interact with port infrastructures such as breakwaters, platforms and dikes at different construction stages. This interaction yields different effects and impacts depending on the specific location, the incident ocean wave characteristics, and the construction stage of each structure. Two of the most important effects deriving from the wave-structure interaction are the overtopping of waves above the crest and exceptional basin agitation conditions, especially under high energy sea-states if the projected port shelter is not fully completed. In the last years, unfortunately several human casualties have been registered in harbour facilities under construction in Spain, mainly because of accidents linked to unexpected overtopping events over incomplete structures.

Additionally, we need to account for economic impact due to both direct damage on machinery and materials plus construction downtimes due to high basin agitation. These safety and efficiency loss problems during construction phase can be solved or minimised through the implementation of an automated operational system, that is able to forecast undesirable overtopping events and basin agitation while the port is being built, in sufficient advance to take the necessary actions. It is to be noticed that in many locations worldwide, such as the North of Spain, due to the severe marine conditions, construction is only possible during 6 months a year or less, which results in the extension of port construction times to several years.

This can be achieved by means of a precise, early, daily and hourly prediction of the ocean characteristics (significant wave height H_s, peak period T_p, and mean direction θ), reaching the construction area, combined with the use of advanced numerical modelling, considering all the different stages of construction, for every structure designed, and for any location inside or outside the harbour facilities. Based on these

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forecasts, the project manager can automate the daily construction agenda, materials, components, tools, equipment, and workforce, setting safety thresholds, through an automatic decision-making system, designed to assess and minimise the adverse impact on safety, project scheduling and costs. Hence, the purpose of this study is to develop and validate a decision support system for the construction of port infrastructures that is able to deliver the relevant management and safety information at different construction stages and under the continuous action of time-dependent ocean wave and water level characteristics.

It is important to mention that some progress has been recently made on early-alert systems incorporating oceanic and atmospheric forecast of wave run-up on coastal structures using offshore wave data. Previous analyses of safety and hazards related to wave overtopping processes and tolerable limits on overtopping responses [1], and analyses for wave run-up over rubble-mound breakwater are based on multiple linear regression equations relating wave run-up and offshore wind and wave parameters [2]. However, all of these only take into account already built breakwater sections and are based on the use of semi-empirical formulations of extensive laboratory data, not accounting for the actual under-construction geometry and materials or even out of range of the actual dynamics and processes on-site. It adds a forecast system specialising in Lagrangian particle trajectory tracking models. These models are used for maritime safety purposes and in aid of combating oil and chemical marine pollution events [3,4], on the coast and harbours. Consequently, to the best of the author's knowledge, there are no formal studies on *ad hoc* forecast systems for harbour construction projects, dealing with overtopping and harbour agitation. Standard deep water wave and weather forecast systems (waves, wind, pressure, currents, water level, etc.) have been recently downscaled to coastal regions. These systems are provided by a few national and international agencies (National Oceanic and Atmospheric Administration NOAA, MetOcean Agency in Spain, European MetOcean Centre, MetOcean UK, etc.), but they only provide ocean wave data near beaches, breakwaters or coastal structures, with some additional weather information. None of them link predicted wave data with subsequent processes such wave-structure interaction (run-up and overtopping) or/and harbour agitation of surf zone hydrodynamics. The lack of these kinds of systems is, presumably, due to different limitations such as:

- High-resolution information on the site characteristics and dynamics is required.
- Adequate modelling can only be based on high fidelity models considering all relevant processes.
- From wave generation to wave agitation or overtopping, there is no single model that is able to solve all the processes involved.
- There are no empirical wave overtopping formulations for breakwater geometries taking into account geometries at construction phases (all of them are obtained in laboratory for final/complete sections).
- Harbour agitation numerical modelling does require high CPU-time calculations, which are not practical for standard forecast system response (model runs could delay more than the desired forecast prediction time frame).
- Workforce and machine safety threshold information relating to different construction jobs over the breakwater is not collected in any formal publication and/or report.
- There is limited standardised information for construction thresholds and safety limits under extreme conditions.

Therefore, the early-alert system presented overcomes most of the limitations described above through the combination of advanced modelling for wave-structure interaction for any breakwater geometry (for any construction stage), and the safety limits for construction jobs provided by the client (DRAGADOS construction company).

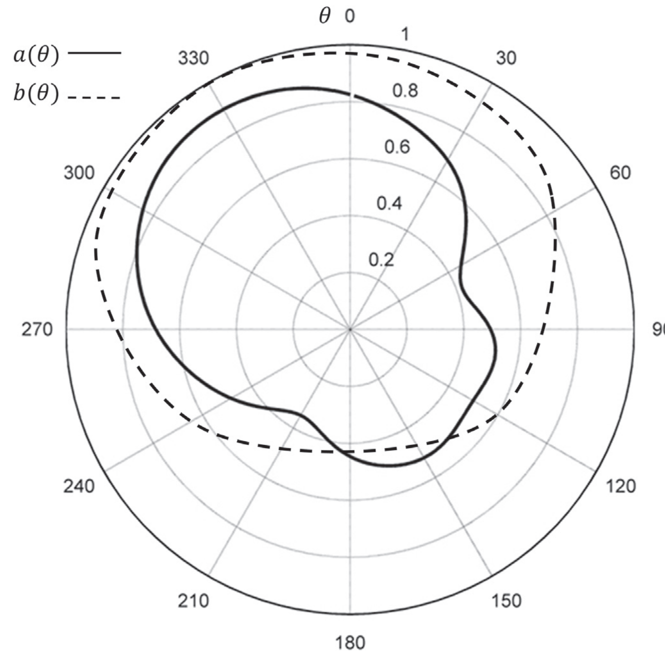

Fig. 1. Calibration coefficients $a(\theta)$ and $b(\theta)$ for H_s, obtained for SIMAR-44 database at Villano Buoy.

2. Scope of the research

The PATO system (acronym in Spanish for Early Alert System for Waves) is presented as one of the main products of the SAYOM project (acronym in Spanish for Aid System for Maritime Construction and Management) as an innovative system developed to improve, assist and manage marine constructions in Spain, developed by DRAGADOS, a construction company, and the Environmental Hydraulics Institute, (IHCantabria or IH), from 2008 to 2010 through the combination of an automatic clustering technique optimising the modelling of the relevant marine dynamics, the advanced numerical modelling of wave and structure interaction processes, considering the actual geometry and materials at the different construction phases, the safety and operation limits provided by a construction company with experience under extreme conditions and a user-interface that is tailor-made for the needs of construction-site managers. The system is designed under the scope of the information technique (IT) philosophy, with the aim of achieving a positive impact by the improvement of the construction schedule, minimisation of the labour hazards and work disruption, the improvement in construction productivity, at the same time as maintaining the cost within the budget for any harbour construction. The construction manager should have access to the use of IT on construction jobsites though the design of daily, accurate and first-hand ocean wave data at the surroundings of the construction site, and be able to ascertain how this data interacts with harbour structures and the possible effects on the development of the coordination system, construction schedule system, tasks and agenda. One of the main goals in the development of this study is to set an automated, integrated and fully-independent-location system, which could be easily extended and implemented to any harbour under construction around the world. The system has been tested and validated with a pilot test applied to the construction of a new harbour at Punta Langosteira, Galicia, Spain, one of the most high-energy sea-state exposed harbours in Spain with maximum individual waves of over 16 m.

3. Data processing methodology

The first part of the development of this wave prediction system deals with the integration of various kinds of data analysis, acquisition,