Port infrastructure monitoring (Madeira Island, Portugal) through GNSS, inertial systems and physical and numeric models.

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Abstract

Port infrastructures as breakwaters, are specially designed to be exposed to the most adverse and extreme conditions. Actions such as wind, waves, tides, sediment dynamics and ships anchoring are factors that can weaken these infrastructures over time. The present work focuses on the control of the stability of Funchal Port breakwater (Madeira Island-Portugal).

Several approaches have been reported in the literature regarding breakwater stability monitoring. The methodologies employed in these studies, include several methods such as classic surveying techniques, Global Navigation Satellite System (GNSS), remote sensing and underwater video inspections (Pilarczyk and Zeidler, 1996). Control systems with alert emission alarms using the carrier phase of GPS signal through single frequency receivers have been used for monitoring different types of infrastructures and allowed to determine displacements with a sub-centimeter accuracy (Knecht and Maneti, 2001). Physical modeling using reduced model have been used in different applications. Coastline hydraulic models and hydraulic efficiency models are some examples of common applications of the physical models applied to large scale engineering hydraulic infrastructures (Silva, 2010). Breakwaters two-dimensional or three-dimensional modeling is common practice, targeting a variety of studies through the structural stability, overtopping, behavior plans to house water, sediment dynamics in the design phase and after the prototype construction. However, there are several strengths and limitations of the studies conducted with reduced physical models. Is essential added complementary information in order to understand the type of infrastructure, promoting the creation of real scenarios and consequent responses to the several boundary conditions that are expected to be simulated. Mathematical modeling is also of great applicability several areas, such as hydraulics dams and breakwaters and embankments studies (Pereira, 2008).

Safety control of structures is based on the comparison of the observed results (from measurements made in a monitoring system) with results of physical models and numerical models. These two groups of results allow to: i) understand the observed behavior; and ii) predict future behavior for normal conditions but also for extreme conditions.

When there are differences between the measured and the predicted values is necessary to understand the causes of these differences, only way to make the right decisions on

the maintenance/rehabilitation of the structure, a fundamental step for a good management of port infrastructures.

This paper describes the observation system and the surveying and inertial methods applied in the monitoring of the breakwater as well as the main results obtained. Concerning the monitoring techniques it were used spatial surveying techniques (GNSS), classical surveying techniques and inertial methods to control: i) displacements of the breakwater superstructure and of the tetrapods: ii) displacements and vibration of the superstructure during cruise ships docking/undocking at the port.

The measurements of vibrations, a very unusual monitoring method in breakwaters, can be the only fast method capable of detect underminings, an erosion of the foundation. When it is large it can be responsible by variations of the geometry of the structure (usually by a settlement of the crest) and therefore can be detected, and the displacements measured by applying surveying measuring devices. When the undermining doesn't cause deformations of the breakwater, and therefore there are no displacements of the superstructure, other techniques have to be used. Measuring vibrations of the superstructure, either in discrete campaigns or continuously, using accelerometers, is a solution since variations of the foundation can be responsible by changes of its vibration.

In ship cruise docking/undocking campaigns, it was found that the infrastructure shows several sensitivity points. The ship cruise docking/undocking causes an oscillation of the infrastructure that range between 1 to 5 mm. Then the structure returns to the equilibrium position. In scenarios that combine extreme conditions of wind, sea waves, large ship cruise and difficult docking manoeuvres conditions, the oscillations values found were up to 2 cm (Pereira et al., 2011). Despite this finding, through the superstructure absolute positional campaigns performed, the infrastructure presents a very low degree of variation, less than 10 mm. In the tetrapod control campaigns, it was found movements ranging between a few cm to 3 m, switching between the equilibrium positions, depending on the sea wave conditions. Considering the obtained results regarding the ship cruise docking/undocking control campaigns, we conclude that the structure is very sensitive to these processes (Pereira et al., 2012).

In this paper it will be made also a reference to the models, the physical and the numerical, of the breakwater. These models were build to access the behavior of the breakwater, especially the layers under the superstructure (by both physical and numerical models) and the tetrapodes (only by the physical model) as result of the impact of large, stormy waves, and large cruise ships.

Regarding the physical model, the wave generation system, the data collected for processing, as well the test conditions discussed for the different scenarios that were considered are discussed considering the change in the return periods (20, 50 and 100 years). It was found that for return periods of 20 years, the behavior of the infrastructure as a whole was stable. For return periods of 50 years, the overtopping become more frequent and more intense and began to blow on the superstructure, but not the tetrapods. In the 100 years return period tests, it was found that the behavior of the infrastructure has been quite unstable, with constant overtopping and the morphology of its submerged layers changed.

The main objectives regarding the numerical model approach were:

i) Estimate numerically the main natural frequencies of vibration of the infrastructure from the calibrated parameters of deformability of the model to fit the calculated frequencies by change the materials and the layers identified in the physical model;

ii) Calculate the expected displacements corresponding to the cruise ships docking processes (agitation protected area) and the associated maritime agitation (agitation exposed area) maximum forces.

The calibrated model (which is assumed to adequately represent the existing conditions of the breakwater Funchal port) were considered to study the expected maximum displacement due to cruise ships docking, and consider the equivalent force to the wave pressure propagation in a storm episodes. The possibility of occurrence of deterioration of the foundation of the submerged layers, particularly in the tetrapods mantle and detritus tetrapods, the stool and submerged riprap mantle as well as the innermost layers under the superstructure (this is assumed earlier) were also taken into account. The maximum displacements obtained for the two cases are 0.0311 m and 0.0297 for cruise ship docking and wave pressure, respectively.

Considering the results obtained with this work, the Port authorities decided to maintain the monitoring program and hold an underwater video in order to pre-plan the needed corrective actions.

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