DAMAGE EVOLUTION OF RUBBLE-MOUND BREAKWATERS BASED ON AEROPHOTOGRAMMETRIC SURVEYS

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1. INTRODUCTION

Due to its extensive coastal zone, Portugal owns many related maritime structures, the most common of which are breakwaters that usually protect man-made harbours.

These maritime structures, especially rubble-mound breakwaters, are assumed to be at risk in the design process, due to the load they can withstand. Therefore, at some point in the life of the marine structure, repairs will be required, and monitoring programs are deemed of paramount importance in assessing damage evolution of such structures.

The use of an UAV (Unmanned Aerial Vehicle), or drone, has enriched ongoing LNEC's Systematic Observation of Maritime Works program (OSOM+) (Capitão *et al.*, 2018). Since 2018, this methodology has been applied to all breakwaters of the Port of Sines (Fortes *et al.*, 2019), as well as Portimão and Faro-Olhão inlet breakwaters (Lemos *et al.*, 2020). More recently, in early 2022, under the scope of To-SeAlert and BSafe4Sea projects, an aerial survey of the breakwater of Ericeira harbor has been conducted. Using previous aerial surveys of that breakwater, carried out in 2013, 2018 and 2022 it is now possible to make a study on the evolution of this protection structure.

The purpose of this paper is to present the results on this evolution and to clarify the additional capabilities of the surveys obtained by drone, in addition to the conventional information of terrestrial visual observations.

2. THE ERICEIRA CASE STUDY

The Ericeira harbour is located on the west coast of Portugal, between Cabo da Roca and Cabo Carvoeiro. This harbour is primarily intended to shelter a small fleet of artisanal fishing boats and consists of a single breakwater that also functions as a mooring berth.

By the year of 1987, having suffered the action of several storms, the Ericeira breakwater was severely damaged. Reconstruction work did not begin until 2009. However, this reconstruction was delayed because of winter storms and was only completed in 2010. Since then, several monitoring campaigns have been undertaken, revealing some armour units' displacements, mainly in the armour layer of the breakwater's head, demonstrating the need for a careful monitoring of this breakwater. In 2019 repairing works were carried out to reconstruct the breakwater's head. Nevertheless, a severe subsequent storm has again destroyed it.

3. DRONE SURVEYS

3.1. Methodology

To test the feasibility of the monitoring of the Ericeira breakwater by using aerial monitoring, a trial flight was carried out in 2013 by a team composed by LNEC and the SINFIC company using a fixed-wing SenseFly Swinglet CAM drone, carrying a Canon IXUS 220 HS camera (Henriques *et al.*, 2014 and 2016). During the flight, conducted at an altitude of 185 m, 72 photos were taken with an overlapping area of about 80% between consecutive photos. The photos were processed by considering two procedures; one using the Lisa Foto and Bluh softwares (Fonseca *et al.*, 2013), that produced a point cloud and an orthomosaic with a pixel resolution of 6.1 cm, the other using Pix4D (Henriques *et al.*, 2014, 2017) that produced a point cloud and an orthomosaic with a pixel resolution of 4.0 cm.

In April of 2018, under the project OSOM+ (Capitão *et al*., 2018), another survey of the same breakwater was undertaken. It comprised the use of a quadcopter DJI Inspire V1 Pro drone with a ZENMUSE X3 camera. During the flight, conducted at an altitude of 40 m, 221 photos were taken with an overlapping area of around 80% between consecutive photos, according to a pre-defined flight plan. The MicMac software was used to obtain a point cloud and an orthomosaic with a pixel resolution of 1.6 cm. Later, the original data were re-processed with Metashape software to obtain corresponding updated products.

In January 2022, a third survey was conducted within the scope of the SIARL (Coastal Resource Administration System) Project, that was carried out using a quadcopter DJI Matrice 300 RTK drone. During the flight, which was conducted at an altitude of 120 m, 1485 photos were taken with a longitudinal overlapping area of approximately 85% between consecutive photos. The point cloud was obtained using Pix4D software, and the resulting orthomosaic had a pixel resolution of 1.5 cm.

From these point clouds, it was possible to extract profiles and compare eroded depths between surveys. Regarding the damage evolution analysis and considering the repair works of the breakwater's head in 2019, and its subsequent ruin events of 2020, only the comparison between 2013 and 2018 was possible at the head zone. On the other hand, for the trunk zone we were able to draw conclusions on the progress of damages from 2013 to 2022.

3.2. Results and discussion

Due to the different equipment and software used to obtain the different point clouds by the three work teams, some inconsistencies between them rose apparent that were mainly caused by the different characteristics of the obtained clouds of points, namely its point densities. Actually, the point cloud obtained from the 2013 survey has 267 741 points and a density of 47 points/m^2; the point cloud from the 2018 survey has 3 519 912 points and a density of 250 points/m^2 and the point cloud obtained from the 2022 survey has 4 789 043 points and a density of 340 points/m^2. Different flight altitudes, the light conditions and the water levels, amongst others, can explain these differences.

The clouds of points were post-processed using CloudCompare's algorithms (Girardeau-Montaut, 2006). The *Volume* algorithm enabled to compute the eroded volume and distances by comparing the clouds of points. This eroded volume computation relies on the gridding process of the cloud(s) and the grid step defines the size of the elementary cells used in the volume computation. In the present work, the grid step was set to 0.1 m.

Between 2013 and 2018, an erosion depth of approximately 5 m at the breakwater's head can be considered (in some areas, the erosion depth corresponds to the complete displacement of the armor layer, a designated pre-ruin stage).

From 2018 to 2022, the breakwater´s trunk was eroded to depths ranging between 1 and 3 m (which is approximately the characteristic dimension of an armour's unit), which represents a serious damage.

Despite the different characteristics of the point clouds used, the comparison of the breakwater's surfaces obtained on the different instances allowed a very enlightening diagnosis to be taken using this methodology, which was confirmed by the visual inspection of this breakwater that is carried out annually under OSOM+ LNEC's Systematic Observation of Maritime Works program.

4. CONCLUSIONS

This paper describes three aero-photogrammetric surveys conducted on the Ericeira harbour breakwater. As a result of the measurements taken on these surveys, three-dimensional surface models and point clouds were obtained. By comparing the latter, it became possible to extract and compare profiles and eroded depths for the three conditions.

As point clouds were obtained using different equipment, methodologies, and software, point cloud densities were found different, and therefore inconsistencies were also found between them.

Nevertheless, the drone survey methodology described made it possible to clearly diagnose a pre-ruin stage at the breakwater´s head for the 2018 condition. Regarding the trunk zone, the comparison between 2013 and 2022 campaigns allowed one to diagnose important damages of the armour layer in most sectors of the breakwater.

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