Photo surveys with drones. The improvement of OSOM+, the systematic monitoring of maritime works

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ABSTRACT

OSOM - SYSTEMATIC MONITORING OF MARITIME WORKS - is a monitoring programme developed by the Portuguese National Laboratory for Civil Engineering (LNEC) to support the decision-making process relative to the maintenance schedule, or even repairing time, of maritime works. The main goal of this programme is the monitoring of the structure's behaviour, through the analysis of the data collected during monitoring campaigns performed by LNEC. In recent years, the programme has been enhanced with new functionalities, being one of the most important contributions the integration of photogrammetric surveys, with drones, to improve visual inspections. The stage of testing this new source of information has already been completed and, for this reason, drones and photogrammetric methods are fully incorporated in the now-called OSOM+ programme. Nevertheless, there is still place for new studies that will help, in the near future, to make the drone surveys more efficient. This paper presents an ongoing study and some conclusions that are emerging.

I. INTRODUCTION

Breakwaters are built to promote sheltered areas, for people, ships and harbour activities. In the design of rubble-mound breakwaters, a common type of breakwater in many countries, it is assumed that, during their lifetime, damage may occur in certain stretches of the structures and therefore maintenance and repair works will be quite certainly needed. However, to successfully carry out these interventions, in a timely and cost-effective manner, it is imperative that the structures are observed and monitored in a systematic way. This enables one to follow their structural behaviour and, through diagnosis analysis, to specify the most suitable (and preferably the less expensive) timespan to undertake any necessary intervention.

In Portugal, the National Laboratory for Civil Engineering (LNEC) has developed, since 1986, a programme for Systematic Observation of Maritime Works (OSOM) for a large number of breakwaters along its coastline (Santos *et al*., 2003). The objective of this programme is to monitor the behaviour of the structures and recommend timely interventions for their maintenance and/or repair. The OSOM methodology is based on a series of systematic visual observation campaigns (Figure 1) that provide the necessary information to feed the ANOSOM database (Reis and Silva, 1995; Lemos and Santos, 2007), which is meant to characterize the Present Condition, the Evolution Condition and the Risk Condition of the observed maritime structures. Based on this information, it is then possible to establish when, where and under what circumstances maintenance or repair works should be carried out.

Since 2015, the OSOM methodology has been improved and updated so that it is now termed the OSOM+ methodology (Fortes *et al*., 2019). Those improvements include the use of different survey methodologies (Figure 2), the enhancement of the ANOSOM database and the development of a mobile app to employ during the observation campaigns.

Figure 1 – Photograph taken during a visual observation campaign of a breakwater

Figure 2 – Detail of the orthomosaic of the area presented in Figure 1

Figure 3 – Photograph taken in 2013

Figure 4 – Photograph taken in 2018

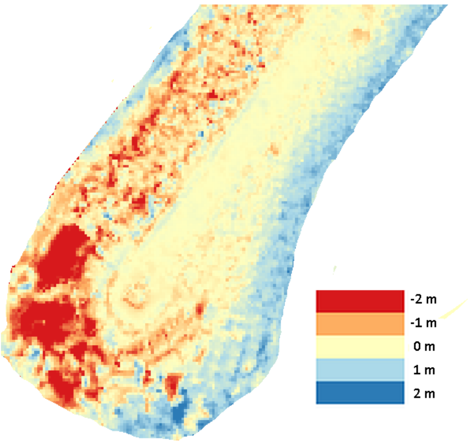

Figure 5 – Height changes of a breakwater head between 2013 and 2018

The use of drones (Henriques *et al*., 2014, 2016, 2017) provides more detailed and accurate information on the condition of the structures. It also allows a better assessment of the evolution of structures' envelopes as it produces more relevant information on the most problematic areas.

Photographs can, by themselves, provide much information about the structures (Figures 3 and 4). However, the products generated with these photos - orthomosaics, point clouds, numerical models of the surfaces, profiles - are more valuable to the institutions responsible for structural safety and security. They easily allow studies of temporal evolution and can generate quantitative information, important for those who have to calculate distances and/or volumes. As an example, Figure 5 presents a comparison of two numerical models of a breakwater, generated from two photographic surveys performed in 2013 and 2018 (Figures 3 and 4). One can easily detect several changes at the breakwater's head.

II. Motivation of the Research

The photogrammetric software used to produce orthomosaics, point clouds, etc., needs to calculate the position and orientation of each aerial photograph. In a first step, these data are determined using a referential established by the software. To transform these data to the referential chosen by the user, points that can be identified in the aerial photographs are coordinated in the chosen referential. These points, known as ground control points (GCP), should be already marked on the structure surface when the survey is carried out. If there are points that, due to shape and colour, can be recognized in the photographs, these can be used too. As an example, Figure 6 shows two GCP: an artificial GCP, since it is the result of painting a triangle with orange ink, and a natural GCP, which is the corner of the cover of an electricity box. The points are coordinated by surveying methods (usually using a total station or a GNSS receiver) either before or after the aerial survey. To assess the quality of the surveys, check points (CP) are also used. These have the same characteristics of materialization and coordination as the GCP. The difference is that they are not used during processing.

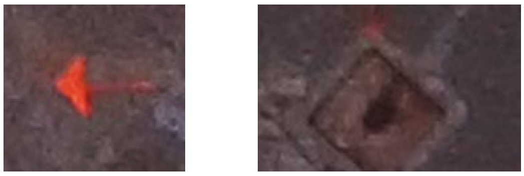

Figure 6 – Two GCP seen in an aerial photograph: an artificial GCP, painted with orange ink, and a natural GCP, the corner of the cover of an electricity box

Figure 7 – Surface of a breakwater with an accessible area (painted orange points are perceivable) surrounded by an area covered with rock and Dolos blocks (these ones at the bottom of the photo)

Figure 8 – The armour layer of a breakwater with two different kinds of blocks: tetrapods and Antifers

Theoretically, GCP should be spaced strategically throughout de surveyed area. However, due to the physical characteristics of the majority of the rubble-mound breakwaters, with the armour slopes made of big inaccessible blocks of concrete or rock. See as an example the Dolos blocks in Figure 7, or the tetrapods and Antifers in Figure 8 (from Silva et *al*., 2012). For this reason, the surveyors only have an easy and safe access to the structure crest and, sometimes, to a small area around it. For this reason, most of the time, GCP and CP are concentrated in a narrow strip along the crest, leaving large areas without GCP or CP.

Very few rubble-mound breakwaters have the armour layer made with parallelepiped blocks placed with the top faces horizontal or sub-horizontal, like the ones presented in Figures 9 to 12. Although one could think that in this kind of armour layer it is possible to mark GCP throughout the whole surface, the reality is quite different. Not only, in some areas, the distance between blocks does not allow the passage between them, but also, quite often, the surface of the blocks is covered with a thin layer of slime, which makes them slippery.

The time spent to mark and coordinate the points is always much longer than the time needed to make the photographic survey. Take the example of the breakwater presented in Figures 9 to 12 (breakwater C in Table 1). The photographic survey, carried out with four flights, took 45 min (including the preparation of the flights and battery changes). The GCP marking and coordination took five hours. Usually, the time spent in these last operations is shorter (two to three hours in long breakwaters and less in shorter ones), because points are located only at the breakwater crest, a place easily accessed.

Nevertheless, if one has to undertake, for example, the photographic survey of the seven breakwaters required to protect the port of Sines, the time spent in the field is very relevant, especially the one required for marking and coordinating points. On the other hand, if in the photogrammetric processing less GCP are used, the products (point cloud, digital surface model, orthomosaics, profiles) may be generated with less quality, i.e., the description of reality may have larger errors than when more GCP are used. Hence, why not asking the following questions:

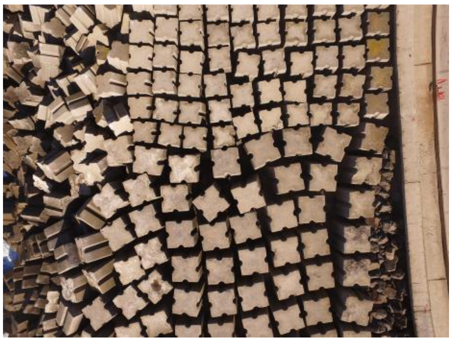

Figure 9 – Aerial photograph of a breakwater made of Antifer blocks, regularly placed

Figure 10 – Head of the breakwater presented in Figure 6

Figure 11 – Coordinating a GCP

Figure 12 – Coordinating a GCP. The greenish colour of the surface of the blocks is due to slime

- Would it be possible to use fewer GCP if the product errors are constant or smaller than the required accuracy?
- Can one use these products to analyze the changes on the breakwaters surface, including to undertake measurements with sufficient accuracy?
- Would it be possible to avoid placing GCP on the slippery armour block surfaces?

To answer all these questions, a set of tests is being performed. This paper presents the first achieved results.

III. The tests

To derive some conclusions, the team used photographs of aerial surveys of sections of three different breakwaters, all taken during low tides. Table 1 presents information concerning these breakwater sections: length, height and widths. The locations where these measurements were taken are shown in Figure 13.

In the photographic surveys, a DJI Zenmuse X3 camera was used, attached to an Inspire V1 Pro drone. The flight plans were made using the DJI GS Pro software. An overlap of 80% between photographs was chosen. Table 2 presents some characteristics of the flights: date, height, duration (time span between the first and the last pictures taken) and number of photographs. The table also includes information about the different type of tests undergone, which involve processing with a different number of GCP and CP. Finally, the table shows the label provided to each test.

Table 1. Characteristics of breakwater sections A, B and C

	Length (m)	Width1 (m)	Height (m)	Width2 (m)
A	260	37	8	9
B	440	65	10	13
C	900	80	17	20

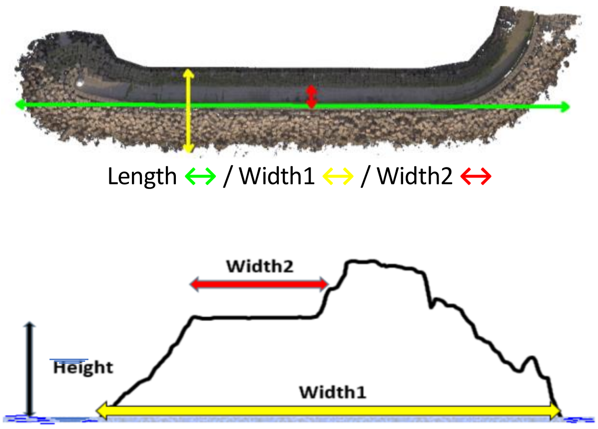

Figure 13 – Locations where the measurements presented in Table 1 were taken

Table 2. Flight characteristics and number of GCP and CP

Date	Height (m)	Duration (min)	Nº photos	Nº GCP	Nº CP	Test label
1st week Nov. 2018	40	4	72	16	-	A1
				4	13	A2
3rd week Nov. 2018	40	5	71	4	13	A3
1st week Nov. 2018	30	5	161	7	-	B1
				4	-	B2
March 2019	30	5	282	4	-	B3
1st week Nov. 2018	30	22	386	54	-	C1
				31	23	C2

Since between November 2018 and March 2019 there were no sea storms, breakwater surface changes were not expected. The difference between the number of photographs taken for the same structure (see B1 and B3) is related with their orientation.

The photographs of the surveys were processed with the open source software MicMac. Point clouds were generated using the technique Structure from Motion (SfM) and, from these, numerical models of the breakwater surfaces were generated with the software Cloudcompare. The software QGIS and these heightmaps were used to extract data along cross-sectional profiles and to calculate differences between the surfaces.

When four GCP were used, these were located near the limits of each section (see the red circles in Figure 14). A larger number of GCP means that more points (green circles in Figure 14) were added to the set.

Breakwater C (Figures 10 to 13 and 16) has different characteristics. It has not a concrete superstructure at the crest. On the inner side, there are two parallel roads at different heights (5 m and 10 m). Between the roads and the concrete blocks (top at 15 m), there is a concrete wall (top at 16.5 m). These elevations are average values.

The location of the 54 GCP is as follows (Figure 15): 23 on the surface of the blocks (green circles); 31 on the surface of the roads or at the top of the wall (red circles). The roads and the top of the wall (see Figure 16) are easily accessed and, for this reason, it is simple to mark and coordinate points on these two areas. The drawback is that they are located on one side of the breakwater.

Cross-sectional profiles of the three breakwaters are presented in Figures 16 to 18. These profiles were extracted at the center of the breakwaters. The profiles of breakwaters A and C include, each, a CP.

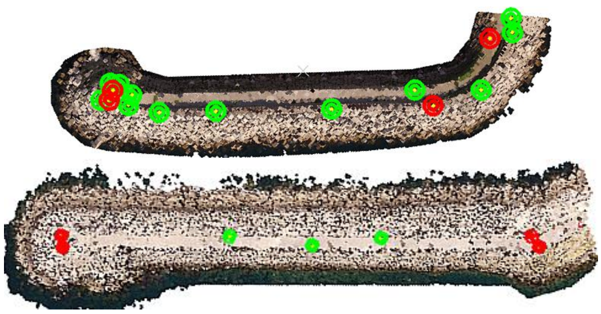

Figure 14 – Location of the GCP in breakwaters A and B

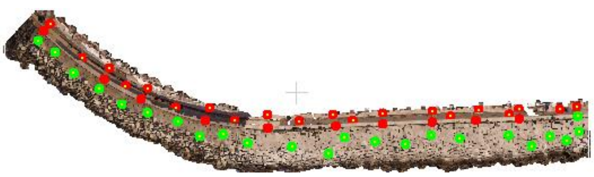

Figure 15 – Location of the GCP in breakwater C

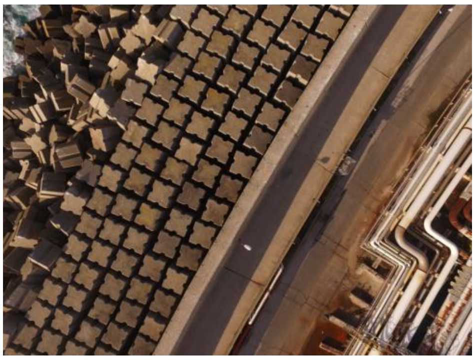

Figure 16 – Aerial photograph of breakwater C. Antifer blocks on the left side, the superstructure in the center, two roads and pipes on the right side

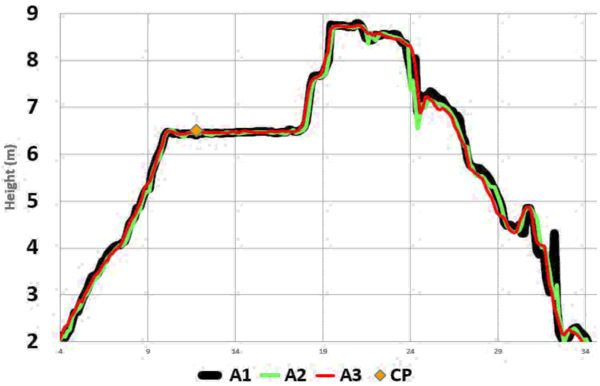

Figure 17 – Cross-sectional profiles of breakwater A

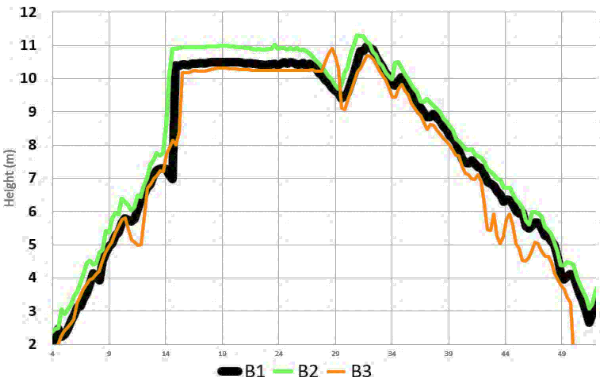

Figure 18 – Cross-sectional profiles of breakwater B

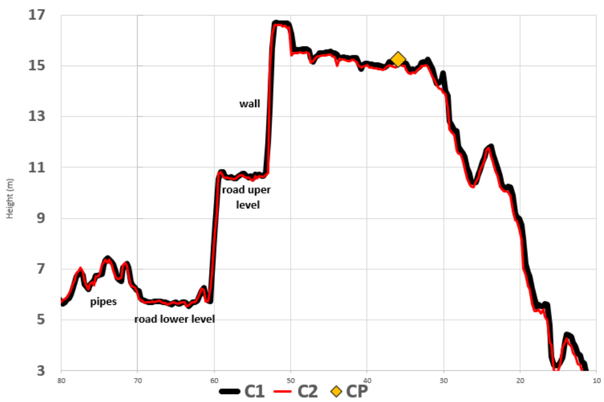

Figure 19 – Cross-sectional profiles of breakwater C

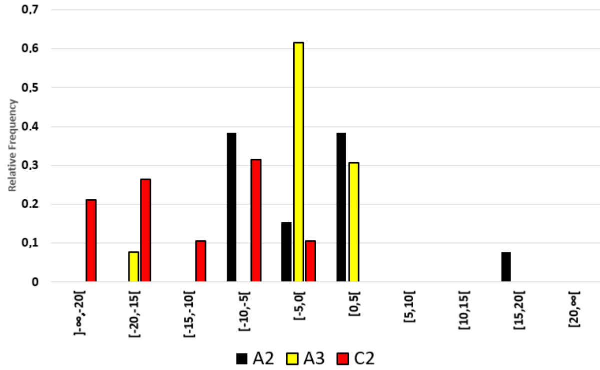

Figure 20 – Distribution of vertical distances between clouds and CP

In some versions of the performed tests, points clouds were generated with a small number of GCP (clouds A2, A3 and C2, see Table 2) and a large number of CP. In each of these three clouds, the vertical distance between each CP and the nearest point of the cloud was determined by the tool “Closest point set” of the software Cloudcompare. These vertical distances were grouped according to the ten intervals presented in the X-axis of Figure 20. Then, the relative frequency was determined and presented as the Y-axis in the chart in the same Figure. By comparing the results of point clouds A2 and A3, one can notice that cloud A3 is the closest to the CP (90% of the points analyzed are at a distance from a CP shorter than 5 cm). On the other hand, the points analyzed in point cloud C2 are the furthest away from their respective CP, being almost all lower than the CP (negative differences).

IV. CONCLUSIONS

This paper presents the first studies performed to generate recommendations on the quantity of GCP and CP needed in photographic surveys of breakwaters, which are carried out for monitoring purposes only. The first results seem to suggest that it is possible to mark less points than those marked so far.

The next steps of this study will include the use of different software for data processing and the accomplishment of more flights, always with the marking of many GCP and CP for a correct evaluation of the quality of the generated products. At that stage, an assessment will be made not only with vertical differences, like those presented in this paper, but also with horizontal differences. Furthermore, the analysis presented was limited to areas with easy accesses, like the breakwater crests. It is planned to expand the analysis to the entire breakwater surface.

V. ACKNOWLEDGEMENTS

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