The monitoring of rubble mound breakwaters. An assessment of UAV technology

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Abstract

Breakwaters are protective and sheltering structures which aim to provide either protection from waves and currents for people and goods at the coast or sheltering conditions for ships and boats moored at the port, thus ensuring that port operations are performed in safe conditions. For that reason, occurrence of damages on such structures usually implies significant economic losses, such as harbour inoperability.

In Portugal where severe sea states due occur, rubble mound breakwaters (RMB) are the most common type of these breakwater structures. The most conventional structure of a RMB consists in a core of a mix of fine and coarse material covered by one or two layers of natural rock or/and artificial concrete blocks that forms the so-called armour layer.

In order to predict damages that may occur in RMB's and evaluate its importance in terms of structural safety and functionality, it is of utmost importance to follow a monitoring program on such structures. The main goal of such monitoring is to detect changes, movements and instabilities in the position of the armour layer blocks, since those mechanisms may lead to a weakening or even a breakage of the structure. Results on the monitoring will enable authorities to plan and prioritize repairs and minimize future short and long-term costs.

Traditionally, the monitoring of the RMB is made with visual, systematic, observations, but this technique is both time-consuming and depends heavily on the experience of the observer and, additionally, a limited amount of quantitative information is obtained, although a relevant qualitative evaluation is achieved.

Photogrammetric techniques, using photos acquired by cameras mounted in UAV (drones) have already proved to be the most suitable technique to complement traditional monitoring, as they provide quantitative, with required accuracy, measurements on the surveyed area, they enable observation of specific areas and new perspectives difficult for human observers, and at present they are not too expensive to implement.

This paper joins, as authors, two groups of experts: one with experience in flights with different UAV models and another one with experience in systematic monitoring surveys of breakwaters and maritime structures. This paper includes, as example, the results of studies conducted in three rubble mound breakwaters and presents conclusions according to the views of each group of experts.

Key words: breakwater, monitoring, photogrammetry, orthomosaic, point cloud, UAV

1 INTRODUCTION

A RMB, the most common type of breakwaters, is a breakwater with a form of a hill made of stones and covered with blocks of concrete and/or stone (see Fig. 1). RMB are civil engineering structures that present a significant difference from other large structures such as dams, bridges, buildings or even other types of breakwaters. While these are built to last, i. e., under normal conditions there are no need significant repair works and usually only small maintenance interventions are necessary, it is expected that RMB need to be repaired during their lifetime. As usually is easy to repair a RMB when the damages are small, it is important to perform inspections to early detect the areas that need reconstruction.

Fig. 1 Two rubble mound breakwaters in Alvor

Usually in RMB the only area with good accessibility is the superstructure, a solid structure generally made of concrete that surmounts many of these breakwaters (Fig. 2). The walking inspection is done here, an area where the visibility to the areas near the water is frequently limited due to the low point a view of the observer. Due to the shape, size and position of the blocks placed in the sea side (Fig. 3 and 4), is difficult, when not impossible, to reach this area, usually the most damage one. The inspection can be completed with observations from a boat, which is expensive and demands a flat sea, a sea state not so usual in many areas.

Fig. 2 Superstructure of Ericeira RMB

But there is a point a view where one can get complete information from the outermost layer: over the breakwater, from the air. From the photos in Fig. 6 and 7 is easy to see the

distribution of the blocks, and detect the weaken areas of the breakwater due to the lack of protection (see also Fig. 12). Having into account price and quality of the images, the best solution to get the aerial photos is to use an unmanned aerial vehicle (UAV) with a camera, apply photogrammetric rules during the aerial survey and process the photos using photogrammetric software to produce maps and numerical surface models, two products from one can derive lengths, areas or volumes due to their metric quality.
This paper presents the experience that the National Laboratory from Civil Engineering (LNEC), with the support of private enterprises (Geosense and SINFIC), has acquired in the use of UAV to support the inspection of RMB.

Povoa do Varzim north breakwater

Fig. 4 Seen from the superstructure

Fig. 6 Seen from the air (UAV photo)

Ericeira north breakwater

Fig. 5 Seen from the top of a tetrapod

Fig. 7 Seen from the air (UAV photo)

2 THE AERIAL PLATFORM AND THE FLIGHT

Fixed wing SenseFly Swinglet and multi-rotor DJI Inspire 1 were used in the aerial surveys presented in this paper. In all the flights the plans were established previously and automatically by computer programs and the flights were autonomous. As the GNSS receivers of the UAV don't have high precision, it was necessary to coordinate ground control points, i.e., points on the surface of the RMB easily seen in the photographs (Fig. 8 to 10, Ericeira RMB), used to geo-reference the surveys, A full description of the first flight, performed with the Swinglet over Ericeira RMB, as well as information on accuracy and the problems faced, can be found in Henriques *et al.* (2014).

Fig. 8 Manhole as seen on a photo

Fig. 9 Corner of a manhole being coordinated

Fig.10 Coordinating a point by GNSS

Being more aerodynamic, the fixed wing is more stable when it flies with strong winds, common in areas near the sea. It also flies higher, faster and silently, which makes it a better platform to avoid the attack of seagulls. However, the weaknesses are many. It demands a soft platform to land, which is difficult to find in some coastal areas (landing on the sand of the beaches is no solution), a problem not faced by multi-rotor UAV which can land on concrete or stone areas with no damages. Due to the shape of the breakwaters (long and narrow) is more difficult to a fixed wing UAV to perform a good flight path, which needs cross strips to ensure a better acquisition geometry.
In addition to perform flights to get photos for cartographic applications, multi-rotors can also be used to perform inspections, i.e., they may be conducted manually to inspect special areas. They are also more versatile since is possible to easily acquire oblique photographs (Fig. 6).
The best hour of the day to perform the flights is near the solar noon, when the sun is higher and therefore the shadows are shorter. To maximize the areas exposed, the flights should be done during the low tides.

3 ORTHOS AND POINT CLOUDS

The photogrammetric software used to process the photos can generate two products useful to the analysis of the breakwater: an orthomosaic (known usually as ortho, a raster file) and a point cloud.
An orthomosaic is an orthogonal projection of the object (Fig. 11). From the ortho is possibly to get, only, planimetric coordinates (X,Y). The ortho results from the combination of two photogrammetric processing tools: first the ortho-rectification of each photo (correcting each from distortions induced by the camera optical errors, its orientation and height), and after the mosaicking (process of "stitching" the images into a single image). It is suitable to apply digital image processing techniques, a technique that demands raster files.

Fig. 11 Orthomosaic of Portimao east RMB

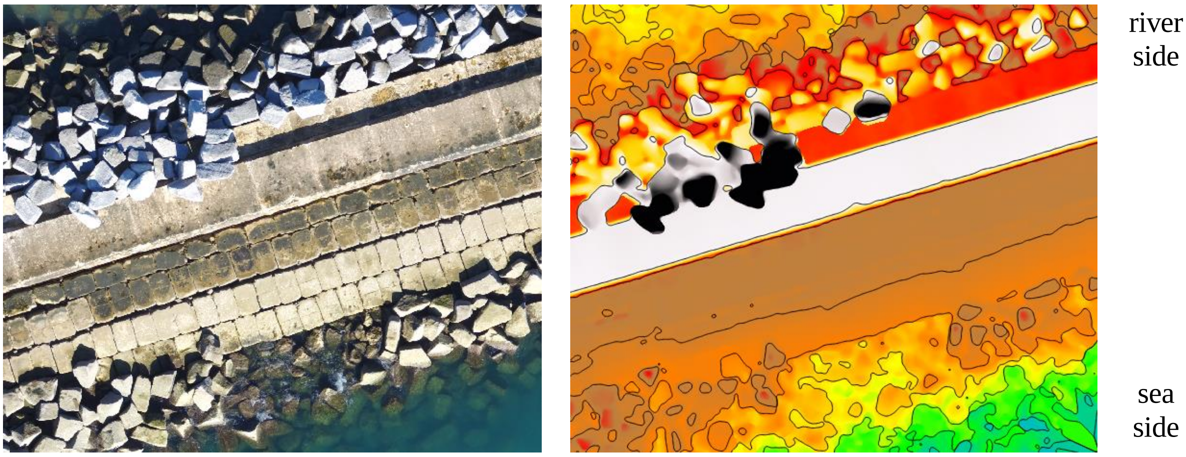
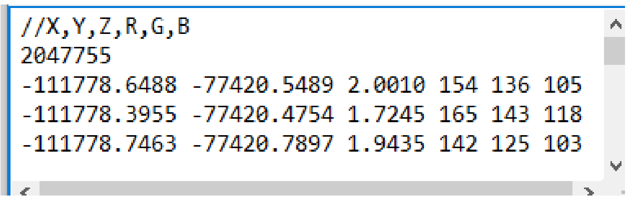


Fig. 12 Detail of Portimao east breakwater: orthomosaic and colored DSM with contour lines

The point cloud is a set of points with 3D coordinates (X, Y, Z). These points are used to represent surfaces. The point cloud is calculated during the creation of the orthos since it is needed for the ortho-rectification. Photogrammetric software can give the attribute "color" to each point by using the colors of the ortho, possible because both (ortho and the point cloud) have the same coordinate system: knowing the planimetric coordinates (X, Y) of a point of the cloud is possible to extract, from the ortho, the color that is in the position (X, Y) and assign it to the point. Fig. 13 presents the beginning of the ASCII file with the point cloud of the RMB of Ericeira. The first two lines give information of the data that is registered and the total of points in the file. To each point is included its cartographic coordinates (X, Y; reference system PT-TM06/ETRS89), elevation (Z; altimetric datum Cascais) and the color (RGB; 8bit mode).



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//X,Y,Z,R,G,B
2047755
-111778.6488 -77420.5489 2.0010 154 136 105
-111778.3955 -77420.4754 1.7245 165 143 118
-111778.7463 -77420.7897 1.9435 142 125 103
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Fig. 13 Information included in a point cloud file (coordinates and color)

4 EXPLORING THE POINT CLOUDS AND THE ORTHOS

From the point cloud is possible to build a digital surface model (DSM) or even work directly with the point cloud. Differences between point clouds or between DSM allow the detection of differences, a clear evidence of the movement of blocks of the surface layer of the breakwater. Other way of exploring the data is by drawing vertical profiles or contour lines.

Fig. 13 presents profiles of the two breakwaters of Portimão. It was done only one survey. The east breakwater presents several problems (see Fig. 12): areas on the sea side no protected by blocks; blocks moved from the sea side to the river side; blocks on the superstructure. Because the two breakwaters are similar one can compare both. Fig. 14 presents a chart with three profiles: one of the west breakwater (W), two of the east breakwater (E-1 and E-2), being the profile E-1 in the area with lack of stones, area that can be noticed in Fig. 12.

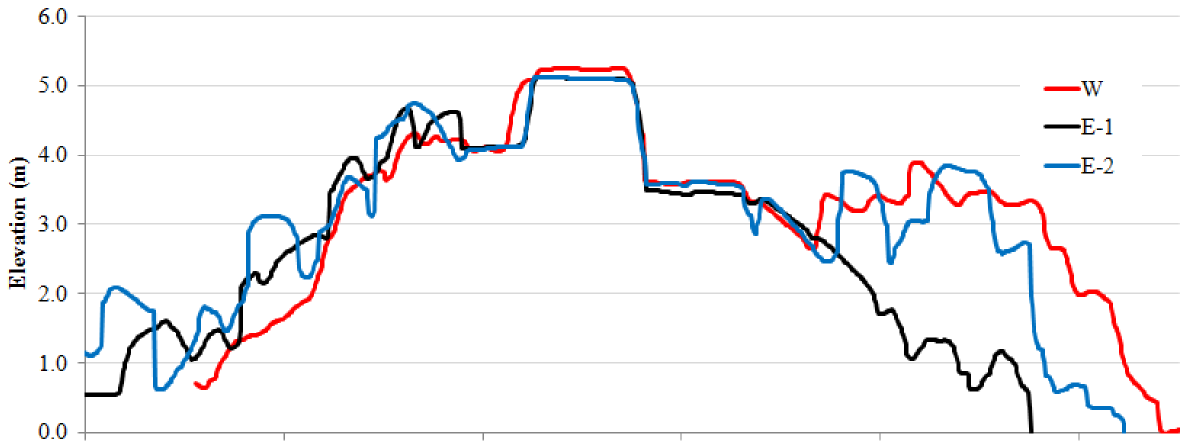
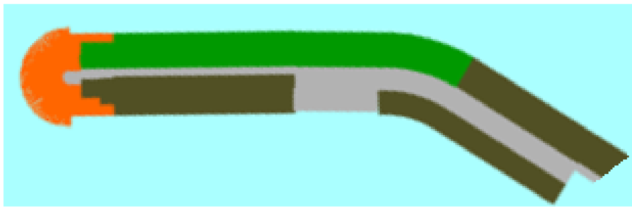


Fig. 13 Portimão breakwaters: one profile of the west (W) breakwater and two profiles of east (E) breakwaters

Another source of information to evaluate these structures it's their project. Fig. 14 presents an image of the breakwater of Ericeira and Fig.15 presents a dense point cloud build from the data included in the project (the profiles, Fig. 19) and colored accordingly with the type of blocks/surface. From both point clouds is possible to draw the profiles (Fig. 16) or compute the differences (Fig. 17).

A B C

Fig. 14 Ericeira breakwater. Division related with the types of blocks of the armour layer (from Henriques et. al 2016)



A: tetrapods (green area)
B: Antifer cubes (orange area)
C: stone blocks (brown area)
Q: concrete (grey area: quay and superstructure)

Fig. 15 Ericeira breakwater. Point cloud designed from the project

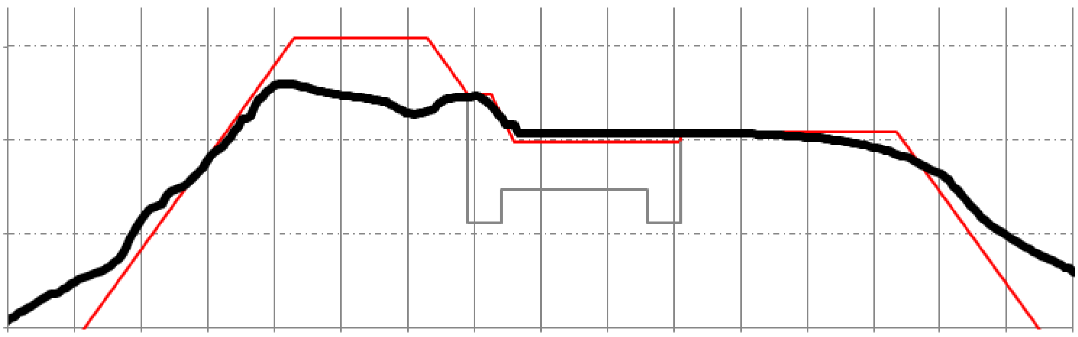


Fig. 16 Ericeira RMB profiles: red – project; black –aerial survey (DSM)

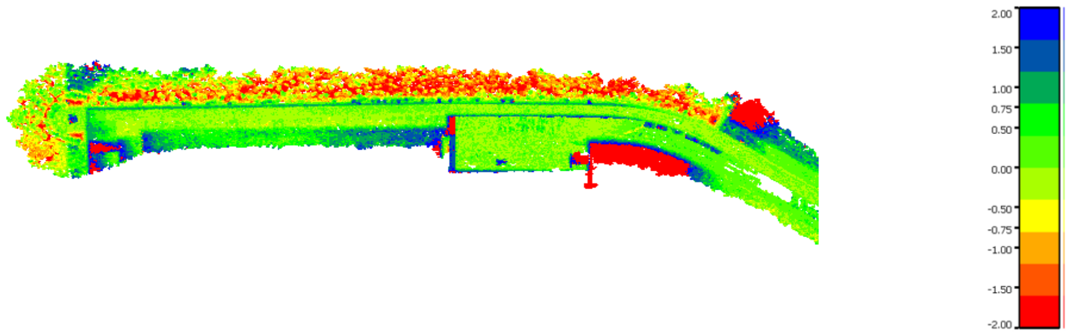


Fig. 17 Differences between two point clouds: project and photo survey. Scale unit: meter

In Fig. 17 one can notice that some areas are limited by straight lines like the one presented in Fig. 18. The line is a border between tetrapods and blocks of stone (areas A and C in Fig. 14). In the point cloud of the project it was not made transition between the two areas which have profiles slightly different, with equal slopes but with different elevations as one can see in Fig.19 that present three consecutive profiles: i) red: profile +140m, stone area; b) blue: profile +150m, transition area; iii) green: profile +160m, tetrapods area. Naturally, the best solution to analyse the evolution of the breakwater would have been to have an aerial survey made right after the conclusion of the construction works.

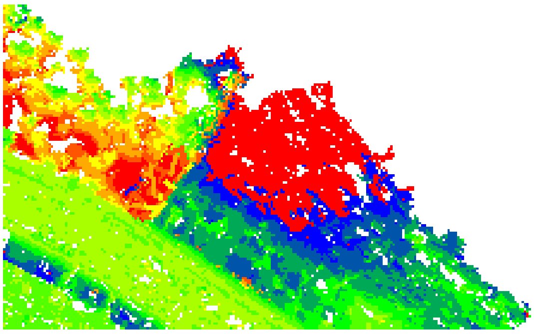


Fig. 18 A detail of the differences between point clouds in a transition area: left tetrapods; right stone

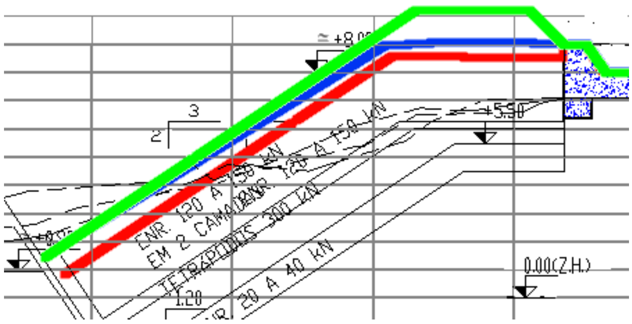


Fig. 19 Three profiles of the project. See text for explanation of the colors used. In the graph each rectangle has 1 meter height

Although points clouds have advantage over the orthos because they have 3D information, one can apply digital image processing tools to the orthos and extract data to analyze the breakwater behavior. For instance, Fig. 20 presents the result of applying a software (Henriques *et al.*, 2016), under development, to an ortho to detected each block and to acquire data of its position (Soares *et al.*, 2016 and 2017) to feed a GIS.

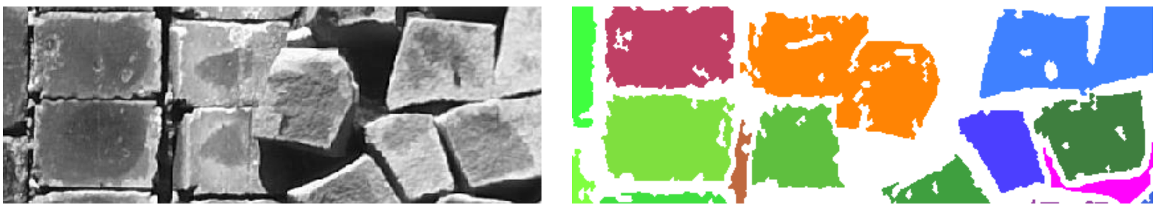


Fig. 20 An ortho and the result of applying a software to detected continuous areas

5 CONCLUSIONS

UAV to perform a photographic survey and photogrammetric software to generate orthomosaics and point clouds, allows that one can get data about the most exterior protection layer of rubble mound breakwaters, at a reduced cost. The accuracy of the generated products allows to detect and to quantify changes in the surfaces of the RMB being, therefore, a valuable tool in the monitoring not only of breakwaters but also from other maritime structures.

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