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

Maria João HENRIQUES, Rute LEMOS, Rui CAPITÃO, Conceição Juana FORTES, Portugal

Laboratório Nacional de Engenharia Civil, LNEC
Lisboa, Portugal,
E-mail: mjoao@lnec.pt, rlemos@lnec.pt, rcapitao@lnec.pt, jfortes@lnec.pt

Abstract

Breakwaters are protecting and sheltering structures which aim is 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 do 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 shows how UAV aerial photos can be useful in assisting systematic monitoring surveys of RMB, namely for Portimão and Ericeira RMB.

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

1 INTRODUCTION

RMB are the most common type of breakwaters in Portugal. They are usually used in exposed locations, being designed to withstand severe waves. They are made up of a core of quarry-run material, including fine to coarse material, and covered by one or more layers of armour natural stones or by artificial concrete blocks (see Fig. 1). RMB are 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, meaning that 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. For this reason RMB should be inspected frequently to early detect the areas that need reconstruction and, if these are detected, to alert the responsible authorities so they promote the reconstruction of those areas. The sooner the problems on the RMB are detected and repaired, less costs, longer lifetime and higher performance can be expected.

Fig. 1 Two RMB in Alvor estuary entrance

Usually, the monitoring of the RMB is made by visual, systematic observations (Lemos et al., 2007 and Silva et al., 2015). The visual inspection is done mostly along the breakwater crest (many times a concrete superstructure, as in Fig. 2) but also in some selected points on the armour units, along the armour layer, which implies that in more exposed areas, the inspection may be conditioned by the safety of the observer in case of severe wave conditions.

Fig. 2 Superstructure of Ericeira north breakwater

Actually, due to the shape, size and position of the blocks placed in the armour layer, mainly on the sea side (Fig. 3 and 4), it is difficult, when not impossible, to reach this area, usually the most prone to the occurrence of damages. Also, the visibility of areas near the water is often limited due to the low point a view of the observer. The inspection can be completed with observations by boat, requiring good wave conditions, sometimes rare, due to the geographic location and/or the meteorological conditions at the time of the observation.

However, there is a view where one can get supplementary information from the outermost layer: over the breakwater, from the air, as shown in Fig 5 and 6. In those photos it is easy to have a global view of the breakwater and its blocks distribution, and detect important areas of the breakwater that might be hidden from the traditional walking observer point of view (see also Fig. 11).

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, applying photogrammetric rules during the aerial survey and to 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. 3 Seen from the superstructure

Fig. 5 Seen from the air (UAV photo)

Ericeira north breakwater

Fig. 4 Seen from the top of a tetrapod

Fig. 6 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 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 (GCP), points on the surface of the RMB easily seen in the aerial photographs (Fig. 7 to 9), used to geo-reference the surveys (Henriques et al. 2014).

Being more aerodynamic, the fixed-wing vehicle is more stable when flying with strong winds, a common condition in areas near the sea. It also flies higher, faster and silently, which makes it a better platform to avoid the unwanted attack of seagulls. However, there are many weaknesses: a) it demands a soft platform to land, which is difficult to find in some coastal areas (landing on the sand of the beaches is not a solution), a problem not faced by multi-rotor UAV which can land on concrete or stone areas with no damages; b) due to the shape of the breakwaters (usually long and narrow), it 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 manually-operated inspections of special areas. They are also more versatile since is possible to easily acquire oblique photographs (Fig. 5).

Whatever the UAV used, 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.

Fig. 7 Manhole as seen on a photo

Fig. 8 Coordinating the corner of a manhole

Fig.9 Coordinating a GCP using GNSS

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 (Figs. 10 and 11 left). From the ortho it is possible 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, second, 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. 10 Orthomosaic of Portimão east RMB

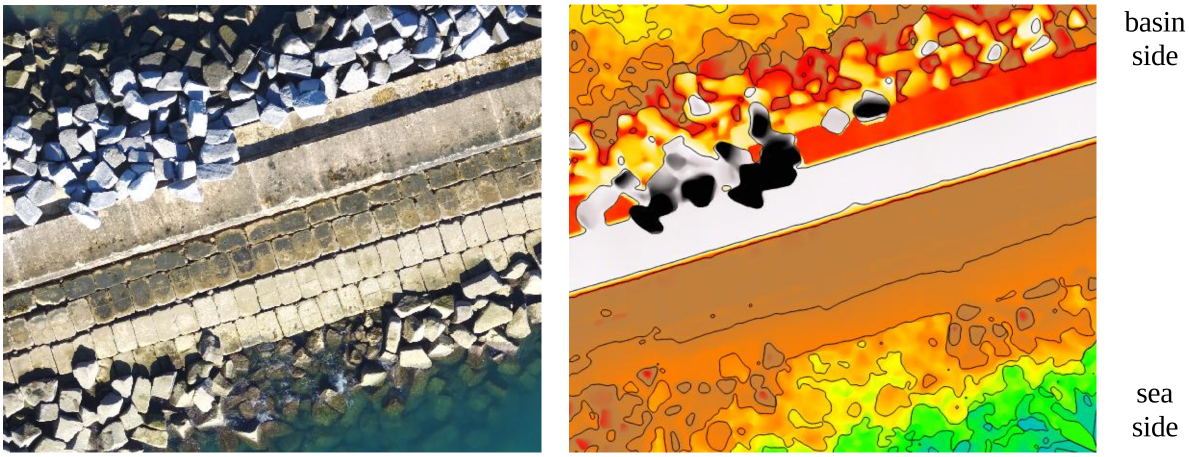
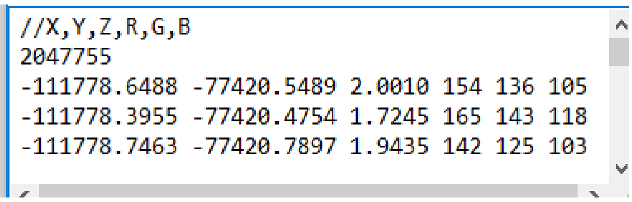


Fig. 11 Detail of Portimão east breakwater: orthomosaic (left) and colored digital surface model (DSM) with contour lines (right)

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. 12 presents the beginning of the ASCII file with the point cloud of the RMB of Ericeira. The first two lines give information of the recorded data and the total of points in the file. To each point is included its cartographic coordinates (X, Y), elevation (Z) and the color (RGB; 8-bit mode).



```
//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
```

Fig. 12 Information included in a point cloud file (coordinates and color)

4 EXPLORING THE POINT CLOUDS AND THE ORTHOS

From the point cloud it is possible to build a digital surface model (DSM, Fig. 11 right) 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 shows three profiles of the two RMB of Portimão (east and west) using only one survey: 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. 11.

The east RMB exhibits several anomalies (see also Fig. 11): areas of armour layer, mainly on the sea side, not protected by stones; stones moved away from the sea side to the basin side; stones placed on the superstructure. Because the two breakwaters have a similar structure – the cross sections are almost equal, with both RMB having two rows of rectangular concrete blocks on the sea side - one can compare both profiles. In area E-1 the concrete rectangular blocks are no longer protected by the stones.

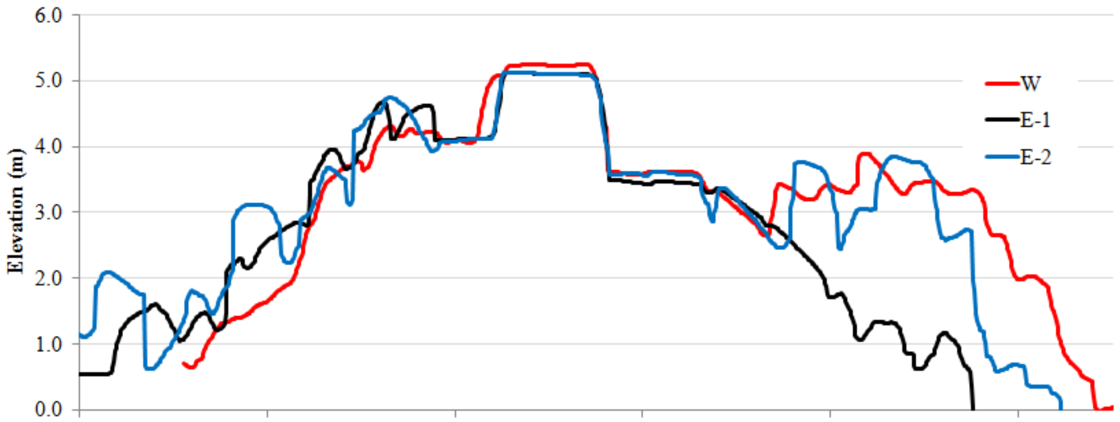
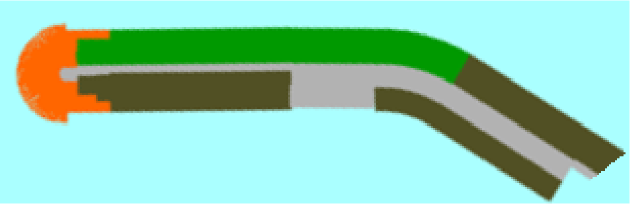


Fig. 13 Portimão breakwaters: one profile of the west (W) breakwater and two profiles of east (E) breakwater

Another source of information to analyse the evolution of these structures it's on the details of their design project. Fig. 14 shows an aerial image of the breakwater of Ericeira and Fig.15 presents a dense point cloud build from the data retrieved from its design project (some profiles are shown in Fig. 19) and coloured according with the type of blocks/surface. From both point clouds, it is possible to draw profiles of design and survey (Fig. 16) and compute the differences between the DSM generated from point clouds of design and survey (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

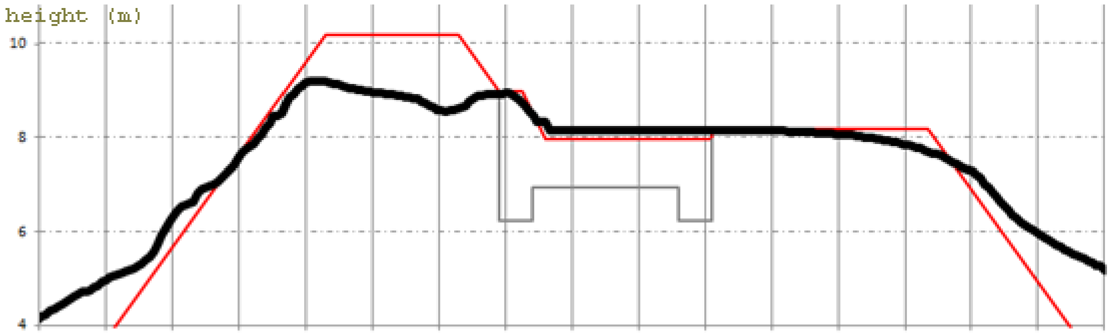


Fig. 16 Ericeira RMB profiles: red – project; black –aerial survey (DSM)

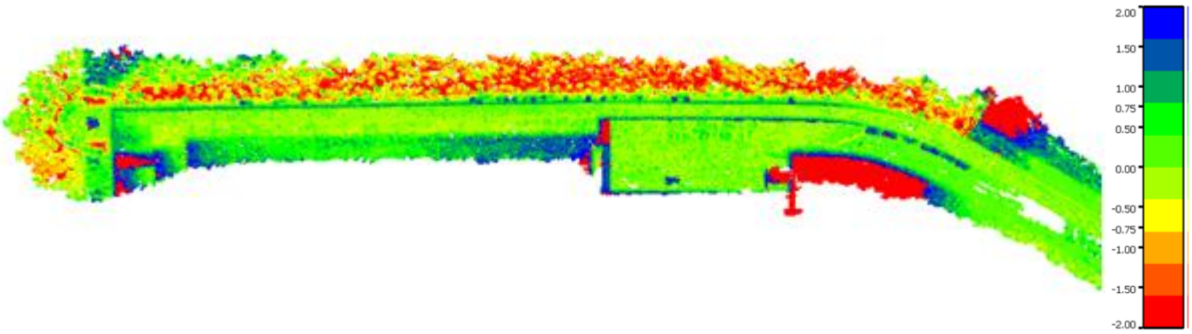


Fig. 17 Differences between two point clouds: project and photo survey. Scale unit: meter

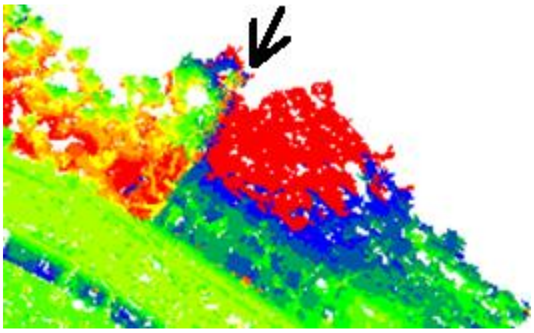


Fig. 18 A detail of the differences between point clouds in a transition area. Left area: tetrapods; right: stone

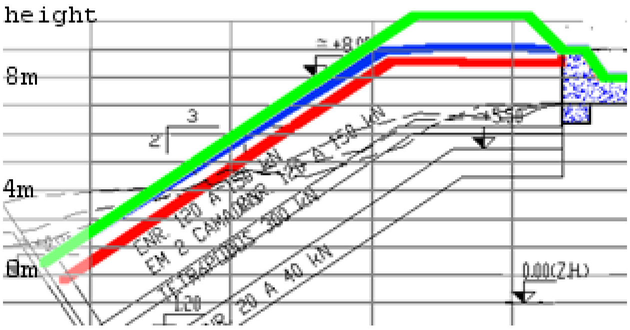


Fig. 19 Three profiles of the project. See text for explanation of the colors used

In Fig. 17 one can notice that some areas are limited by straight lines like the one presented in Fig. 18, the border between tetrapods and blocks of stone (areas A and C in Fig. 14). The point cloud build with data from the project has no transition between these two areas. These areas have profiles slightly different: equal slopes but different elevations as seen in Fig.19, which presents three consecutive profiles of this area: i) red: profile +140 m, stone area; b) blue: profile +150 m, transition area; iii) green: profile +160 m, tetrapods area. In civil engineering works such like RMB, design project may often depart from what is being constructed, due to the construction difficulties associated with such challenged environmental locations where RMB are built. 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 (named as reference survey) and later aerial survey inspections of the RMB should be compared with this reference survey.

Although point 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 continuous areas associated to each block and to acquire data of its position (Soares et al. 2016 and 2017) to feed a GIS.

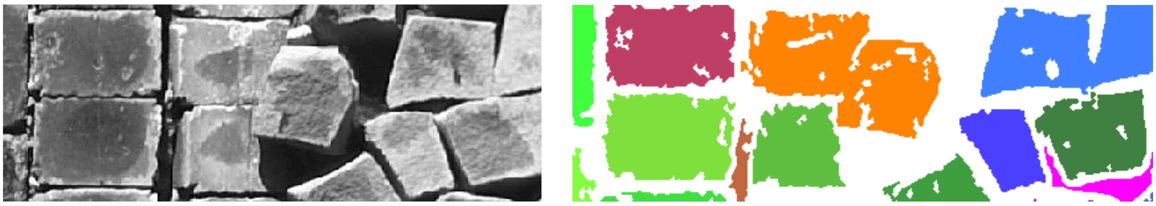


Fig. 20 An ortho and the result of applying a software to detected continuous areas

5 CONCLUSIONS

The use of UAV to perform photographic survey and the use of photogrammetric software to generate orthomosaics and point clouds, allows one to obtain additional, yet important, data about the most exterior protection layer of RMB, at a reduced cost. The accuracy of the generated products allows one to detect and to quantify changes in the surfaces of the RMB being, therefore, a valuable tool in the monitoring breakwaters and other maritime structures. However, the flights in coastal areas are difficult to perform since there is a need to combine the best flight hours, considering the height of the sun and the tide, with an adverse environment where strong winds or fog are common.

ACKNOWLEDGEMENT

The authors would like to thank to Geosense (http://www.geosense.pt) and SINFIC (http://www.sinfic.pt/saas) for carrying out the flights and processing the photos.

6 REFERENCES

Henriques,M.J. – Fonseca,A. – Roque,D. – Lima,J.N. – Marnoto,J. . 2014. Assessing the Quality of an UAV-based Orthomosaic and Surface Model of a Breakwater, In *FIG Congress 2014, Kuala Lumpur, Malasia*, ISBN 978-87-92853-21-9, 16pp.

Henriques,M.J. – Roque,D. – Santos,A.V. 2016. Monitorização de quebra-mares com veículos aéreos não tripulados, In *Atas do I Seminário Internacional UAV, Lisbon, Portugal*, 10pp.

Henriques,M.J. – Braz,N. – Roque,D. – Lemos,R. – Fortes,C.J.E.M. 2016. Controlling the damages of physical models of rubble-mound breakwaters by photogrammetric products - Orthomosaics and point clouds, In Proceedings of the 3rd Joint International Symposium on Deformation Monitoring, Vienna, Austria, 8pp.

Lemos, R. – Santos, J.A. 2007. ANOSOM - Análise da observação sistemática de obras marítimas, In 5^{as} *Jornadas de Engenharia Costeira e Portuária, Lisbon, Portugal.*

Silva, L.G. – Capitão, R. 2015. Observação Sistemática de Obras Marítimas. Estruturas marítimas da costa oeste de Portugal continental. Campanhas de observação visual efetuadas em 2015. *LNEC, Report 369/2015 – DHA/NPE, Lisbon, Portugal*

Soares,F. – Henriques,M.J. – Braz,N. 2016. Integration of image processing tools for monitoring breakwaters models, In *ESA Living Planet Symposium 2016 Proceedings, Praga, Czech Republic*, poster.

Soares,F. – Henriques,M.J. – Rocha,C. 2017. Concrete Block Tracking in Breakwater Models, In *FIG Working Week 2017, Helsinki, Finland*.