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OBSERVAÇÃO E MONITORIZAÇÃO DE OBRAS MARÍTIMAS COM A NOVA METODOLOGIA OSOM+

OBSERVING AND MONITORING MARITIME WORKS THROUGH THE USE OF THE NEW OSOM+ METHODOLOGY

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Resumo: Neste artigo descreve-se o novo programa OSOM+, sob a responsabilidade do Laboratório Nacional de Engenharia Civil (LNEC), Portugal, para a observação e monitorização sistemática de obras marítimas, o qual tem vindo a ser aplicado a um grande número de estruturas marítimas na costa continental portuguesa e no estrangeiro. O programa OSOM+ compreende quatro componentes principais a realizar em cada estrutura marítima: a) Inspeções visuais periódicas por técnico experiente; b) Inspeções aéreas periódicas com utilização de UAV/drone; c) A base de dados ANOSOM-GIS, para armazenar e/ou consultar as informações obtidas, bem como para avaliar os estados atuais, de evolução e de risco das estruturas; e d) Uma aplicação móvel, portátil, para preenchimento em tempo real e visualização das informações da base de dados ANOSOM-GIS.
Esta metodologia, recentemente atualizada, engloba uma série de ferramentas cujas funcionalidades são ilustradas neste trabalho pela sua aplicação a um estudo de caso: o quebra-mar da Ericeira, em Portugal.

Palavras-chave: Obras marítimas, Observação, Monitorização, Levantamento aéreo, UAV, quebra-mar da Ericeira.

Abstract: This paper describes a programme under the responsibility of the National Laboratory for Civil Engineering (LNEC), Portugal for the systematic observation and monitoring of maritime works, termed OSOM+, which has been applied to an extensive number of maritime structures on the Portuguese mainland coast and abroad. The OSOM+ programme comprises the following four main components for each structure: a) Periodic visual inspections by a

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trained technician; b) Periodic aerial inspections using a UAV/drone; c) The ANOSOM-GIS database, to store and/or query obtained information, as well as to diagnose present, evolution and risk conditions; and d) A mobile, portable, application, for real-time input and visualization of the ANOSOM-GIS database information.

This recently updated methodology encompasses a number of tools whose functionalities are illustrated in this paper with an application to a case study: the Ericeira's breakwater, in Portugal.

Keywords: Maritime Structures, Observation, Monitoring, Aerial Surveys, Drones, Ericeira's breakwater.

1 INTRODUCTION

Breakwaters are common port and coastal protection structures available worldwide, in particular in the Portuguese coasts. Their main goal is to reduce the wave action, promoting sheltered areas, so that safety conditions for people, ships and harbour activities are guaranteed during the lifetime of the structure.

In the design of some of those maritime structures, specifically for rubble-mound breakwaters, it is assumed that during its lifetime damage may occur in certain stretches of the structure 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 throughout their lifetime. This enables one to follow up 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 (SILVA, 1995; 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 that provide the necessary information to feed the ANOSOM database (REIS and SILVA, 1995; LEMOS and SANTOS, 2007) 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.

Besides the structures along the Portuguese mainland coast, the OSOM programme (and the ANOSOM application) has been applied to the Azores archipelago (SILVA, 1996), to the Macau’s airport maritime structures (REIS et al., 2001) and to several structures on Moroccan ports (LEMOS et al., 2014). Similar monitoring programs were developed by Tulsi and Phelp (2009) and Marujo (2017). The first is based upon aerial photos while the second uses visual observations and a multi-criteria methodology to prioritise the interventions on the breakwater. However, both monitoring programs were implemented for just one specific breakwater and were applied for a few years only.

Since 2015, the OSOM methodology has been improved and updated so that it is now termed OSOM+ methodology (CAPITÃO et al., 2018). Those improvements include the use of different survey methodologies, the enhancement of the ANOSOM database and the development of a mobile app to employ during the observation campaigns.

The use of an Unmanned Aerial Vehicle (UAV), or drone (HENRIQUES et al., 2014, 2016), provides more detailed and accurate information on the condition of the structures, but it also allows a better assessment of the evolution of structures' envelopes as it produces more relevant representative profiles of the most problematic zones of the structures.

The migration of the existing ANOSOM database to a GIS-based online platform (LEMOS et al., 2016) enables a more intuitive and comprehensive interface with the final user.

The development of a mobile app (MAIA, 2016; MAIA et al., 2017) assists the observer in the visual campaigns by providing an immediate tool to fill relevant information onsite while giving online access to selected information related to each maritime structure stored in the ANOSOM database.

Following the work of Capitão et al. (2018), the present paper describes the main features of the OSOM+ methodology. The port of Ericeira is used to illustrate the new tools and functionalities of OSOM+ to this real case scenario, see Figure 1.

Figure 1 - Ericeira's breakwater

Source: GOOGLE EARTH and LNEC

2 THE OSOM+ PROGRAMME

The OSOM+ programme comprises four main components for each maritime structure, namely:

a) Periodic visual inspections by a trained technician, supported by systematic photos and video taking, all GPS-tagged;
b) Periodic aerial inspections, through vertical-oriented photographs with a UAV/drone;
c) The ANOSOM-GIS database, to store and/or query all information obtained during the visual and aerial inspections and to perform a diagnosis analysis of each section of the structures, namely its present, evolution and risk conditions;

d) A mobile, portable, application, for real-time input and visualization of the database information obtained during visual and aerial inspections.

The OSOM+ allows the evaluation of the structure´s risk condition during its monitoring time and, based on it, enables adequate planning of the maintenance and/or repair works. This is extremely important from the management and planning standpoints. In fact, the timely identification of an anomalous behaviour of a maritime structure (e.g., an excessive movement of the armour layer) may allow for immediate or planned actions, which, in turn, avoid further degradation of the structure. This degradation could make a later repair much costlier, if not impossible, or even cause the collapse of the structure.

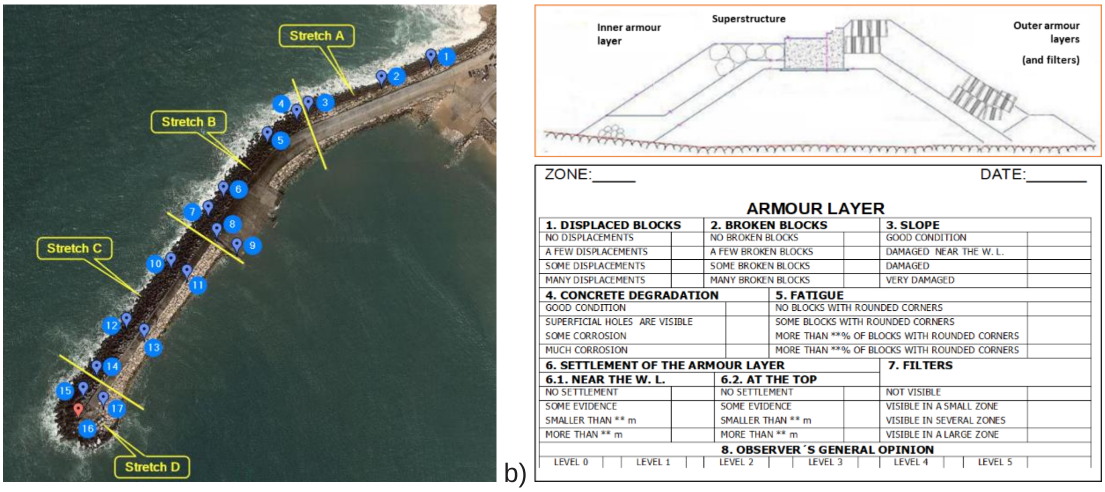
2.1 Visual inspection

The visual inspection allows, in a fast and intuitive way, to follow the behaviour of the structures. It also allows, through subsequent analysis and data diagnosis, to infer on the evolution of damage on the observed structure and on the likely need of interventions, thus preventing future structural problems.

The visual inspection of the structure (SANTOS et al., 2003) is made usually every year and/or whenever a strong storm/typhoon hits the structure. The main objective is to better characterize the present condition of the structure.

For that purpose, the structure is firstly divided into several stretches, according to their different physical and functional characteristics. In general, each stretch corresponds to a different cross-section along the breakwater, with the head of the breakwater always considered as a stretch, Figure 2a.

Figure 2 - Ericeira’s breakwater: a) Division into stretches; b) Field campaign form for the armour layer



ZONE:_____ DATE:_______

ARMOUR LAYER

1. DISPLACED BLOCKS		**2. BROKEN BLOCKS**		**3. SLOPE**	
NO DISPLACEMENTS		NO BROKEN BLOCKS		GOOD CONDITION	
A FEW DISPLACEMENTS		A FEW BROKEN BLOCKS		DAMAGED NEAR THE W. L.	
SOME DISPLACEMENTS		SOME BROKEN BLOCKS		DAMAGED	
MANY DISPLACEMENTS		MANY BROKEN BLOCKS		VERY DAMAGED	

4. CONCRETE DEGRADATION		**5. FATIGUE**	
GOOD CONDITION		NO BLOCKS WITH ROUNDED CORNERS	
SUPERFICIAL HOLES ARE VISIBLE		SOME BLOCKS WITH ROUNDED CORNERS	
SOME CORROSION		MORE THAN **% OF BLOCKS WITH ROUNDED CORNERS	
MUCH CORROSION		MORE THAN **% OF BLOCKS WITH ROUNDED CORNERS	

6. SETTLEMENT OF THE ARMOUR LAYER				**7. FILTERS**	
6.1. NEAR THE W. L.		**6.2. AT THE TOP**			
NO SETTLEMENT		NO SETTLEMENT		NOT VISIBLE	
SOME EVIDENCE		SOME EVIDENCE		VISIBLE IN A SMALL ZONE	
SMALLER THAN ** m		SMALLER THAN ** m		VISIBLE IN SEVERAL ZONES	
MORE THAN ** m		MORE THAN ** m		VISIBLE IN A LARGE ZONE	

8. OBSERVER´S GENERAL OPINION											
LEVEL 0		LEVEL 1		LEVEL 2		LEVEL 3		LEVEL 4		LEVEL 5	

Source: GOOGLE EARTH and LNEC

Then, for each stretch, visual observations are made by a trained technician walking along the crest of the breakwater and looking at, at least, the following three main components of the breakwater: the outer armour layer, the superstructure and the inner armour (including filters, if possible). For each of these components, the observer is able to detect possible changes in the breakwater and its armour units, namely broken elements, changes in their placement, their relative location within the armour layers, etc. The technician is also able to characterize the deterioration of the breakwater elements due to the natural physical and chemical processes that are likely to occur in the harsh sea environment where these structures reside. All this information is then filled into a paper or electronic (using the app) form, whose structure template is shown in Figure 2b for the armour layer only. Each form usually corresponds to a single stretch of the structure and enables characterization of all its main components.

The visual inspection is always complemented with photos and videos. In fact, for each stretch, a set of notable waypoints is established where photos and/or videos will be taken in every campaign, with the same photo view parameters (notably the same camera focal length and view angle and the same photo framing), Figure 3a. Those photos should be taken systematically, at exactly the same predefined locations and directions, through use of GPS-tagging provided by the GPS equipment, Figure 3a. Moreover, the observer compares, in situ, the current state of the stretch at that location/direction with previous photos taken in the last campaign, if available.

In addition, 360° handheld videos are made for selected points that, during the course of the campaign, are somewhat considered relevant to better illustrate and characterize the present condition of the observed component, stretch or even the whole structure. Figure 3b and Figure 3c show photographs taken at predefined points of Ericeira’s breakwater, according to the southwest and the northeast predefined directions, respectively.

In general, in order to have the maximum depth of the armour slope visible to the observer, the visual inspections should be carried out during low tide. Also, to guarantee the security of the observer, the inspections should be performed under good weather conditions and, preferably, under calm sea-wave conditions.

Figure 3 - a) Systematic photographs taken at predefined points. Case of Ericeira's breakwater, according to two predefined directions: b) southwest; c) northeast

GPS Data

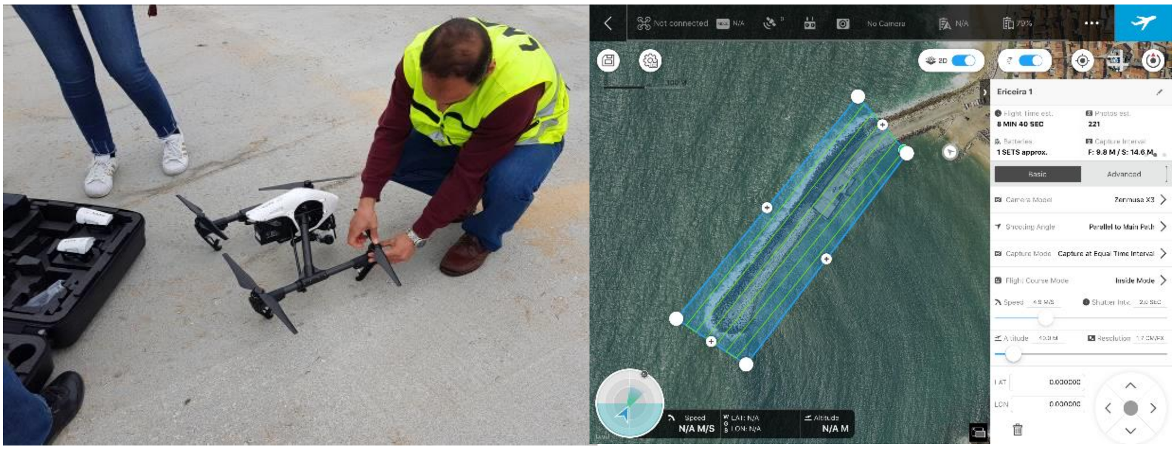
	Decimal	Sexagesimal
Latitude:	38.96458577	N38°57'52.51"
Longitude:	-9.42237068	W9°25'20.53"
Image Direction [°]:	215.50	Geographic North
Dest. Latitude:		

Source: LNEC and GOOGLE EARTH

2.2 Aerial inspection with UAV

At present, the OSOM+ methodology also includes the use of a professional UAV, operated by LNEC´s pilot, thus allowing aerial photographic surveys of the maritime structures (Figure 4). This complements the information obtained in visual observation campaigns and provides substantially more detailed information on the structure, since it covers hidden perspectives from a human observer walking on the structure.

Figure 4 - UAV flight of Ericeira’s breakwater. LNEC´s UAV (left) and flight plan (right)



Ericeira 1

Flight Time est.: 8 MIN 40 SEC

Photos est.: 221

Batteries: 1 SETS approx.

Capture Interval: F: 9.8 M / S: 14.6 M

Camera Model: Zenmuse X3

Shooting Angle: Parallel to Main Path

Capture Mode: Capture at Equal Time Interval

Flight Course Mode: Inside Mode

LAT: 0.000000

LON: 0.000000

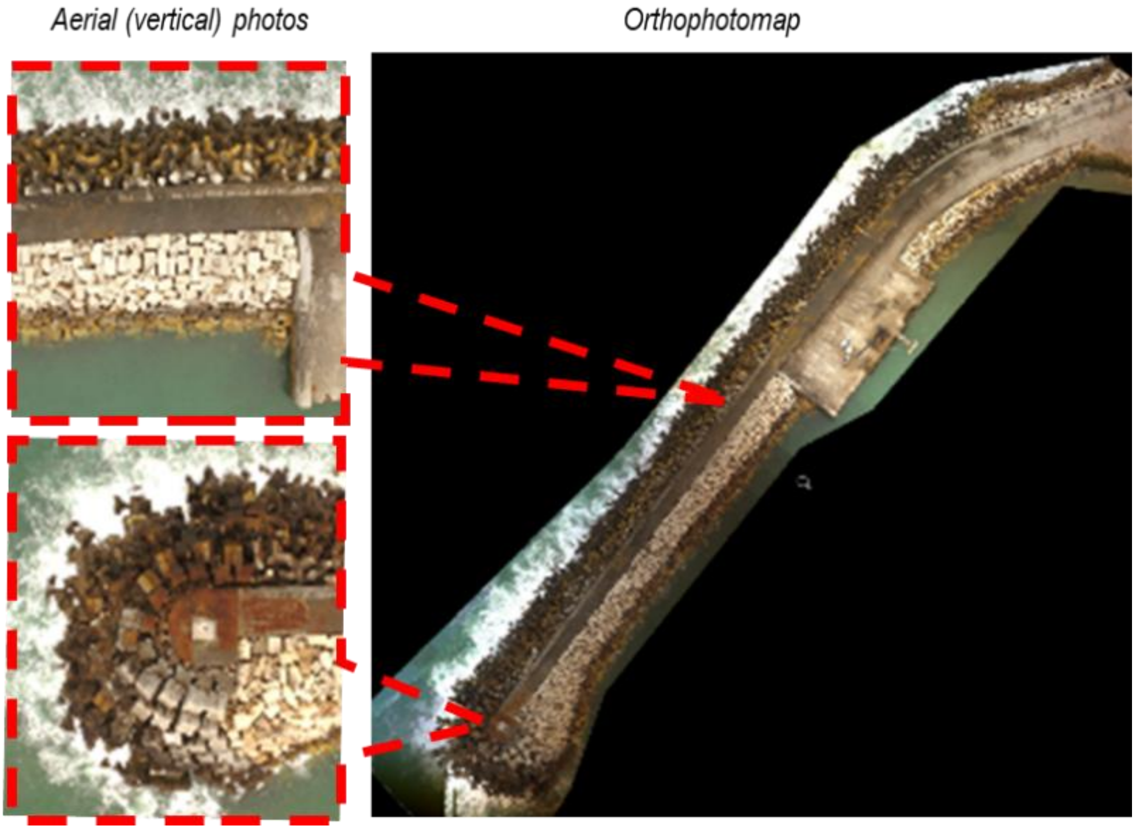
Source: LNEC and DJI GO APP

The results of these observation campaigns are the individual aerial photographs, captured in a regular pattern and in the vertical direction (zenith), as well as the respective orthophotos (i.e., geometrically corrected, or orthorectified, images) and numerical surface models of the structure.

Recently, during a campaign on April 24, 2018, an aerial photographic survey of the Ericeira’s breakwater was performed at a height of 40 m (Figure 5), which produced the orthophoto shown in Figure 5 and the point cloud shown in Figure 6.

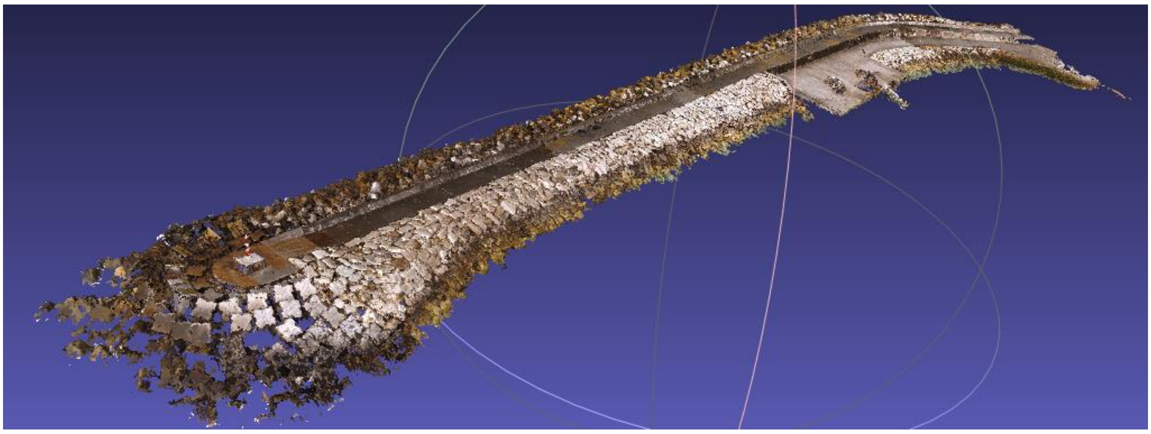
In order to georeference the obtained models and to allow comparisons between surveys or models taken in different dates, it is always necessary to obtain data pertaining to specific positions on the structure, by using high-resolution positioning equipment (a pair of GNSS receivers and/or a total station, with centimetre precision). In this case, the selected points were located in the superstructure (a crown wall).

Figure 5 - Aerial photos (left) and orthophotomap (right) of Ericeira's breakwater. Drone campaign in April 2018



Source: LNEC

Figure 6 - Point cloud of Ericeira's breakwater. Drone campaign in April 2018



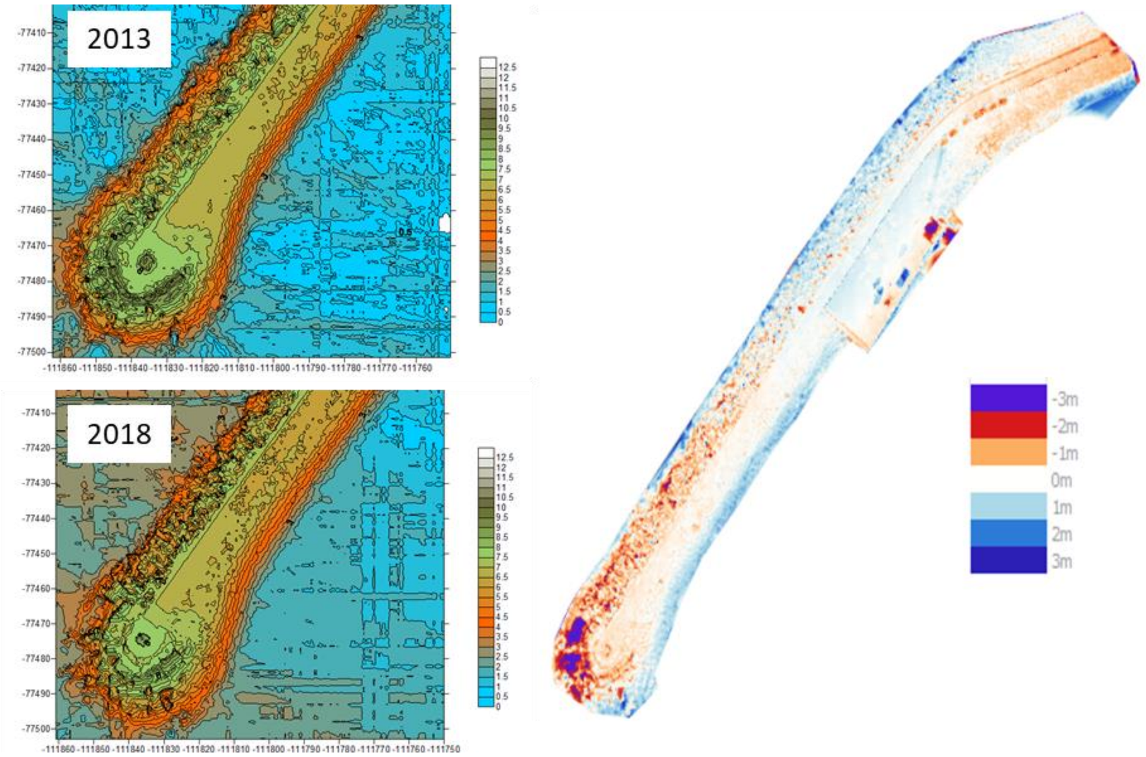
Source: LNEC

Once the models are georeferenced, it is possible to compare the data and models resulting from aerial surveys of different campaigns (different dates). Figure 7 shows a comparison of aerial photos of the Ericeira’s breakwater taken during a trial campaign conducted on February 9, 2013 and the more recent campaign on April 24, 2018. Figure 8 presents the corresponding point clouds and the differences between them, where changes become apparent. Also, one can get profiles from the two campaigns, at more vulnerable points of the structure, rendering it possible to accurately quantify the areas and volumes of the differences. Figure 9 illustrates the depth differences between 2013 and 2018 surveys.

Figure 7 - Aerial photos of Ericeira’s breakwater: February 2013 (left) and April 2018 (right)

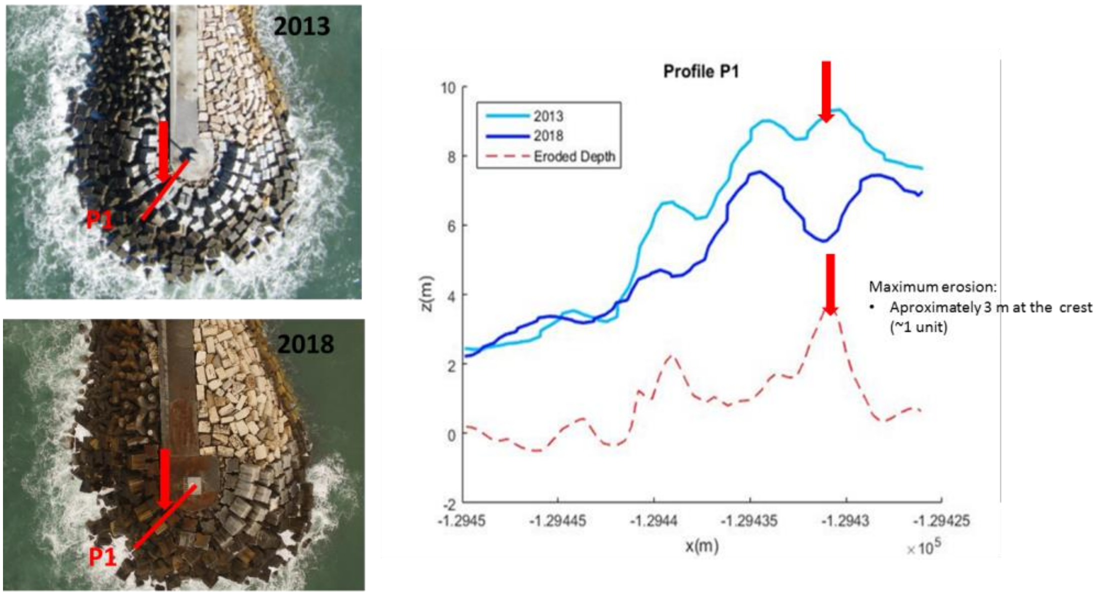
Source: LNEC

Figure 8 - Contour maps (left) and differences of point clouds (right) of Ericeira's breakwater between 2013 and 2018



Source: LNEC

Figure 9 - Comparative profiles of a vulnerable section of Ericeira's breakwater



Maximum erosion:
- Aproximately 3 m at the crest (~1 unit)

Source: LNEC

2.3 ANOSOM_GIS database

The new ANOSOM_GIS database, which is based on the previous ANOSOM database (REIS and SILVA, 1995; SANTOS et al., 2003, LEMOS and SANTOS, 2007), is now enhanced with a GIS interface and is currently an online tool for querying information on each section of the breakwater (LEMOS et al., 2016). It allows:

a) the storage, query and analysis of the information collected on the already observed breakwaters, in particular the data from the visual and drone observation campaigns or other information (e.g. surveys of the emerged and submerged parts of the structure);
b) the diagnosis of the structure, i.e., it processes the present condition, the evolution condition (corresponding to the degree of evolution for a certain period of time) and the risk condition (associated to the lack of intervention) for each breakwater section. This is done through the application of properly calibrated pre-specified criteria, being therefore a fully developed methodology, duly consolidated since 1986.

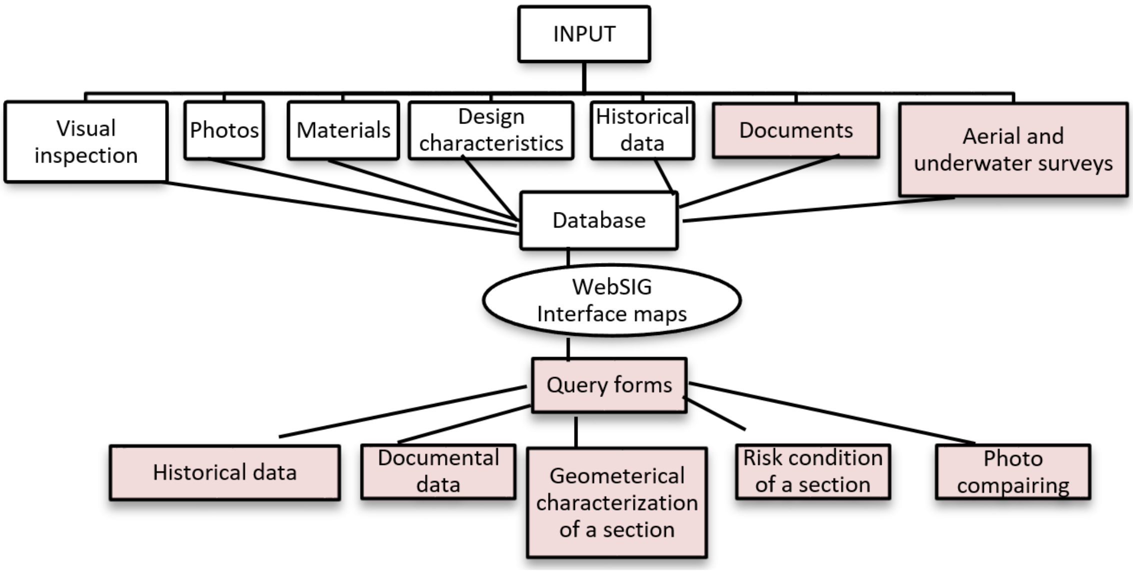
The recent update of the ANOSOM_GIS database (LEMOS et al., 2016) makes use of geographical information systems (GIS), allowing the assessment of the information stored in the database projected on a base map, making use of information layers.

Figure 10 illustrates a flow chart representing the currently implemented modules (with white foreground), as well as the modules to be implemented in the future (with pink foreground).

In the interface base map, by selecting a layer and a corresponding section, it is now possible to check the information related to each section.

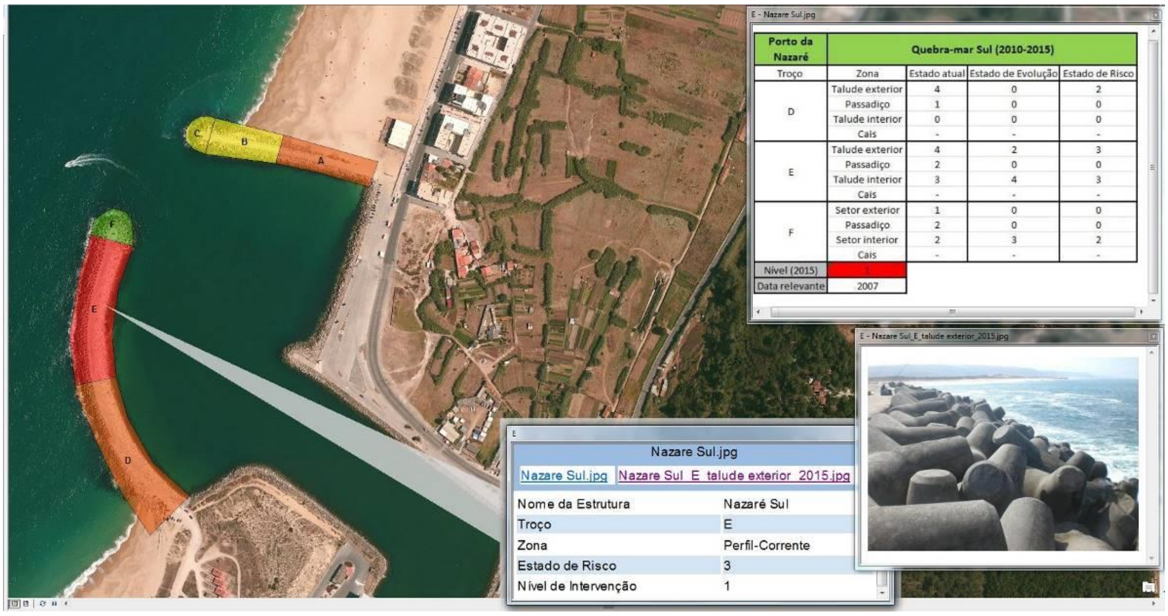
Figure 11 to Figure 13 illustrate some search operations regarding risk condition, design information, materials and historical data.

Figure 10 - Flow chart of the ANOSOM_GIS database



Fonte: LNEC

Figure 11 - A search operation in the ANOSOM_GIS interface for risk condition of Nazaré's breakwaters



Porto da Nazaré	Quebra-mar Sul (2010-2015)			
Troço	Zona	Estado atual	Estado de Evolução	Estado de Risco
D	Talude exterior	4	0	2
	Passadiço	1	0	0
	Talude interior	0	0	0
	Cais	-	-	-
E	Talude exterior	4	2	3
	Passadiço	2	0	0
	Talude interior	3	4	3
	Cais	-	-	-
F	Setor exterior	1	0	0
	Passadiço	2	0	0
	Setor interior	2	3	2
	Cais	-	-	-
Nível (2015)	1			
Data relevante	2007			

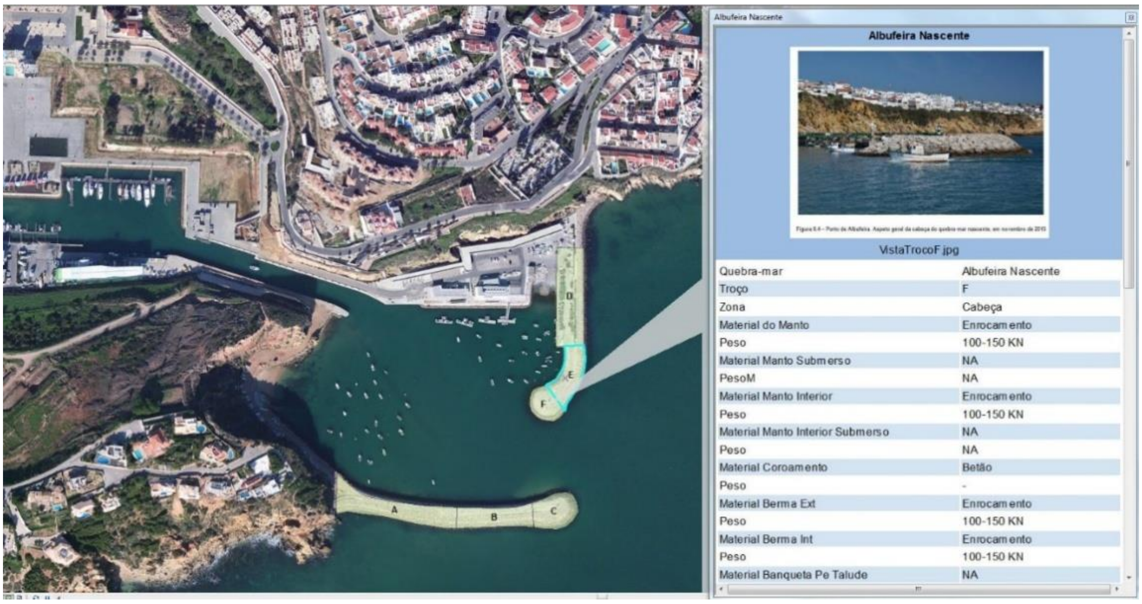
Nazare Sul.jpg

Nazare Sul.jpg | Nazare Sul_E_talude exterior_2015.jpg

Nome da Estrutura	Nazaré Sul
Troço	E
Zona	Perfil-Corrente
Estado de Risco	3
Nível de Intervenção	1

Source: LNEC

Figure 12 - A search operation in the ANOSOM_GIS interface for construction materials of Albufeira's breakwaters

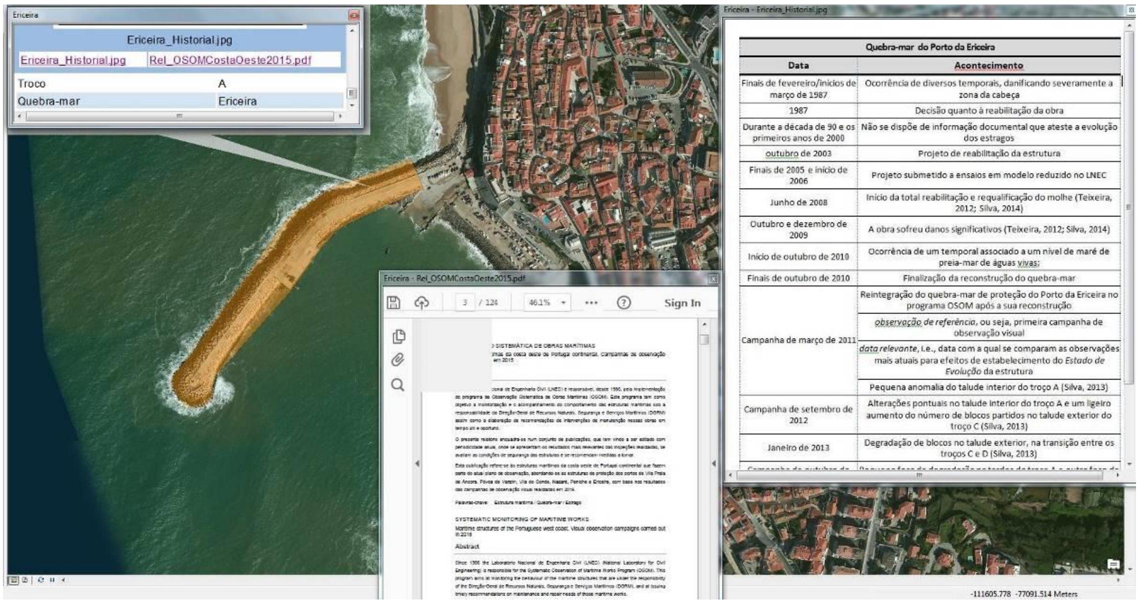


Albufeira Nascente

Quebra-mar	Albufeira Nascente
Troço	F
Zona	Cabeça
Material do Manto	Enrocamento
Peso	100-150 KN
Material Manto Submerso	NA
PesoM	NA
Material Manto Interior	Enrocamento
Peso	100-150 KN
Material Manto Interior Submerso	NA
Peso	NA
Material Coroamento	Betão
Peso	-
Material Berma Ext	Enrocamento
Peso	100-150 KN
Material Berma Int	Enrocamento
Peso	100-150 KN
Material Banqueta Pe Talude	NA

Source: LNEC

Figure 13 - A search operation in the ANOSOM_GIS interface for historical data of Ericeira's breakwaters



Ericeira_Historial.jpg	Rel_OSOMCostaOeste2015.pdf
Troco	A
Quebra-mar	Ericeira

Quebra-mar do Porto da Ericeira

Data	Acontecimento
Finais de fevereiro/inícios de março de 1987	Ocorrência de diversos temporais, danificando severamente a zona da cabeça
1987	Decisão quanto à reabilitação da obra
Durante a década de 90 e os primeiros anos de 2000	Não se dispõe de informação documental que ateste a evolução dos estragos
outubro de 2003	Projeto de reabilitação da estrutura
Finais de 2005 e início de 2006	Projeto submetido a ensaios em modelo reduzido no LNEC
Junho de 2008	Início da total reabilitação e requalificação do molhe (Teixeira, 2012; Silva, 2014)
Outubro e dezembro de 2009	A obra sofreu danos significativos (Teixeira, 2012; Silva, 2014)
Início de outubro de 2010	Ocorrência de um temporal associado a um nível de maré de preia-mar de águas vivas;
Finais de outubro de 2010	Finalização da reconstrução do quebra-mar
Campanha de março de 2011	Reintegração do quebra-mar de proteção do Porto da Ericeira no programa OSOM após a sua reconstrução
	observação de referência, ou seja, primeira campanha de observação visual
	data relevante, i.e., data com a qual se comparam as observações mais atuais para efeitos de estabelecimento do *Estado de Evolução* da estrutura
	Pequena anomalia do talude interior do troço A (Silva, 2013)
Campanha de setembro de 2012	Alterações pontuais no talude interior do troço A e um ligeiro aumento do número de blocos partidos no talude exterior do troço C (Silva, 2013)
Janeiro de 2013	Degradação de blocos no talude exterior, na transição entre os troços C e D (Silva, 2013)

Source: LNEC

The database, which was initially fed with information related only to the structure's project design (project drawings, existing hydrographic surveys, underwater inspections, aerial photographs, historical data, etc.), was subsequently fed with information collected in the different observation campaigns and whenever changes resulting from relevant interventions on the structure were identified.

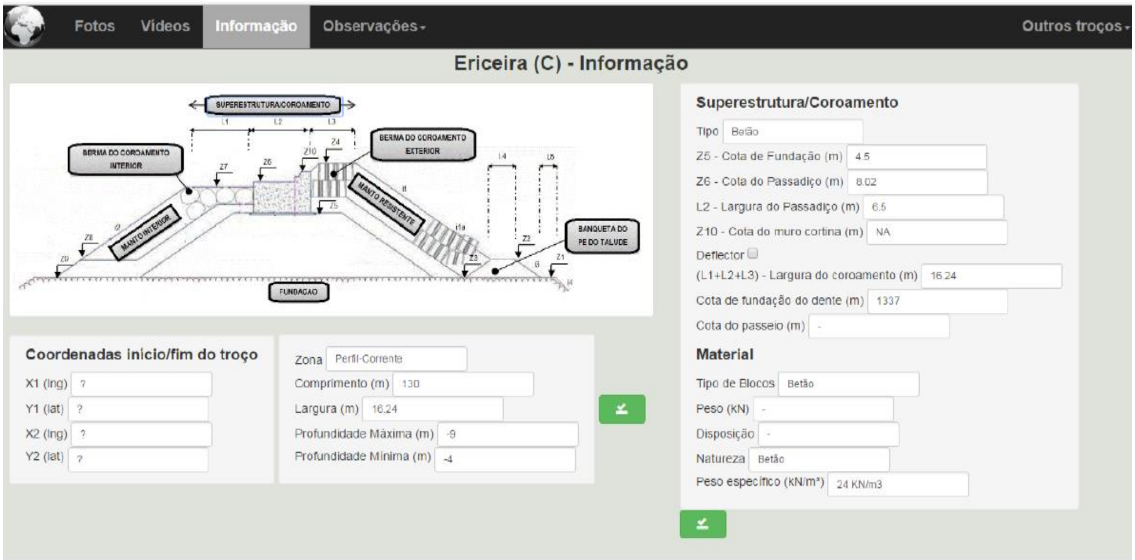
2.4 Mobile application for data entry and visualization

A computer tool (MAIA, 2016; MAIA et al., 2017) was also developed for being used in mobile device platforms (smartphones and tablets) during and after observation campaigns. This is a Web-GIS (multiplatform) mobile application that allows:

- The filling-in and real-time (during campaigns) uploading of the observational information;
- The online checking, during campaigns, of the structure's information from previous campaigns, namely:
  - The location of the observational points and characteristics of the associated photos and videos (framing and direction);
  - The related photos and videos;
  - The information on the physical characteristics of the breakwater stretches and their components;
  - The present, evolution and risk conditions, if existing.

To ease information viewing and analysis, the stretch interface page (Figure 14) includes an interactive drawing of a breakwater, making it possible to view a particular part of the information by clicking on the structure's relevant component. The interface has also been designed with several tabs and a navigation bar (at the top of the page) allowing the user to navigate to other pages to see the photos and videos pertaining to the selected stretch, to access stretch observations (according to the selected date) and to analyse the characteristics of other stretches belonging to the same structure.

Figure 14 - Information about stretch C of Ericeira's rubble-mound breakwater



Ericeira (C) - Informação

Coordenadas início/fim do troço

X1 (lng)	?
Y1 (lat)	?
X2 (lng)	?
Y2 (lat)	?

Zona	Perfil-Corrente
Comprimento (m)	130
Largura (m)	16.24
Profundidade Máxima (m)	-9
Profundidade Mínima (m)	-4

Superestrutura/Coroamento

Tipo	Betão
Z5 - Cota de Fundação (m)	4.5
Z6 - Cota do Passadiço (m)	8.02
L2 - Largura do Passadiço (m)	6.5
Z10 - Cota do muro cortina (m)	NA
Deflector	☐
(L1+L2+L3) - Largura do coroamento (m)	16.24
Cota de fundação do dente (m)	1337
Cota do passeio (m)	-

Material

Tipo de Blocos	Betão
Peso (kN)	-
Disposição	-
Natureza	Betão
Peso específico (kN/m^3)	24 KN/m3

Source: LNEC

The information collected during the visual campaigns (photographs, videos, and other data, such as damage information) is immediately uploaded to the server and viewed on the device on the spot (Figure 15).

The application allows the calculation of the present, evolution and risk conditions of the structure in real time (if existing) and the assessment of whether the structure needs repair or immediate maintenance works. The developed tool has clearly increased productivity and efficiency of the inspections. However, this system should only able to be operated when good meteorological conditions exist, as the wind and waves may harm these mobile devices. Furthermore, they should be operated only when the safety of the observer is not at stake, as their manoeuvring may, for example, hinder equilibrium on top of armour blocks.

Figure 15 - Photographs of stretch A of Ericeira’s rubble-mound breakwater

Source: LNEC

3 FINAL REMARKS

Since 1986, LNEC has been responsible for a programme of systematic observation and monitoring of an extensive number of maritime structures in Portugal and abroad. Since then, several resources have been added to this programme, culminating to the recently implemented OSOM+ methodology/programme, whose main features are described in this paper.

Now, visual (traditional) observation campaigns are complemented with aerial photogrammetric surveys using a drone, allowing a sounder and better determination of the present, evolution and risk conditions of the structures (and of its components), and a more complete information to feed the also improved ANOSOM_GIS database. In particular, the information from the drone surveys enables the comparison between point clouds resulting from aerial surveys of different campaigns, thus allowing visualization of changes, by getting comparative profiles at more vulnerable points of the structure, and by rendering it possible to accurately quantify the areas and volumes of the differences.

The continued application of the OSOM+ program will allow us to calibrate the evaluation criteria for interventions in breakwater. Those criteria are now being developed based on the quantitative information provided by the drones.

During field campaigns, the use of the Web-GIS mobile application also streamlines the programme processes. This tool has clearly increased productivity and efficiency of the inspections.

In the end, both the provider of this information (LNEC) and the end-users (e.g., port and harbour administrations) benefit from a more accurate information on the structural conditions in a predominantly quantitative nature, which complements the already existing detailed qualitative information obtained during the visual observation campaigns.

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