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Application of the OSOM+ Systematic Observation Methodology to Maritime Structures at the Port of Sines

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ABSTRACT: The current OSOM+ methodology developed at LNEC - National Laboratory for Civil Engineering has been applied to the maritime and port infrastructure at the Port of Sines with the objective of monitoring structural performance and, when necessary, recommending timely maintenance interventions.

During monitoring campaigns, systematic photographic records were collected at georeferenced locations along each structure, and observed anomalies were identified. In addition, drone-based photogrammetric surveys were carried out, providing more detailed and accurate information on the condition of the structures. The integrated cloud-based GIS platform offers an intuitive and comprehensive online interface for data visualization, as well as a mobile interface that enables efficient on-site data input and real-time access to information stored in the maritime structures database.

This methodology has enabled the assessment of the current condition, evolution, and risk status of the port structures at Sines. Based on these evaluations, maintenance and repair actions can be planned in a timely and informed manner.

This paper compares the results of inspection campaigns conducted in 2018, 2020, 2022, and 2023 on the west breakwater, based on visual inspections and drone surveys, and supported by a critical analysis of georeferenced photographs, orthomosaics, point clouds, digital surface models, and cross-sectional profiles.

The results indicate that only minor displacements of armour units have been observed along the Sines west breakwater, which, to date, have been classified as non-significant anomalies.

KEYWORDS: Maritime structures, monitoring, visual inspection, drone survey, photogrammetry

1 INTRODUCTION

Since 1986, the National Laboratory for Civil Engineering (LNEC) has been developing the *Systematic Observation of Maritime Works* (OSOM) programme, aimed at monitoring the structural behaviour of rubble-mound breakwaters along the Portuguese continental coastline—namely the west and south coasts—as well as the island coastlines. The primary objective of the programme is the early identification of structural anomalies in maritime structures, thereby enabling timely maintenance and/or repair interventions while affected areas remain limited and remediation is simpler and more cost-effective.

The OSOM methodology was initially based on systematic visual inspection campaigns, which provided data for the former ANOSOM database (Reis et al., 1995; Lemos et al., 2007). This database supports the assessment of the current condition, condition evolution, and risk level of the monitored maritime structures. Since the 2010s, the OSOM programme has undergone significant developments. In 2017, with the integration of drone-based monitoring techniques, the programme evolved into OSOM+ (Capitão et al., 2018).

The use of unmanned aerial vehicles (UAVs) has substantially improved the accuracy and level of detail in structural condition assessments, allowing more reliable quantification of settlements, volume losses, and other structural changes affecting the monitored structures.

This paper presents LNEC's experience in visual inspection and drone-assisted monitoring of rubble-mound breakwaters and demonstrates the application of the OSOM+ methodology through a specific case study: the Port of Sines, where inspection activities began in 2018 (Fortes et al., 2019) under a contract established with the Port of Sines Authority (APS). Particular emphasis is placed on the port's main protective maritime structure, the west breakwater.

THE PORT OF SINES

The Port of Sines is the largest artificial harbour in Portugal, operating as a deep-water port with natural bathymetries reaching depths of up to −28 m CD (Chart Datum), as shown in Fig. 1. Owing to its strategic geophysical characteristics, it serves as Portugal's main maritime gateway for energy supply, handling the import and export of containers, liquefied natural gas, coal, crude oil, and petroleum derivatives.


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Figure 1. The Port of Sines

The port is equipped with specialised terminals designed for the efficient handling of various cargo types, all of which are protected by extensive rubble-mound breakwaters.

All breakwaters at Sines are monitored under the OSOM+ programme, including the west breakwater, the east breakwater, the marina breakwater, the fishing harbour breakwater, and the service port breakwater (see Fig. 2).

Among these, the west breakwater is the case study presented in this paper (outlined in yellow in the figure, while the remaining structures are shown in red). This breakwater suffered severe storm damage during 1978 and 1979, with progressive failure episodes that fractured and displaced large dolos armour units and undermined the superstructure, ultimately leading to extensive reconstruction works (Reis et al., 2011). Subsequent repair interventions included the use of heavy Antifer-type cubes on widened sections and gentler slopes, followed by a final redesign to meet updated 100-year return-period sea states. These interventions highlighted the importance of armour unit mechanical strength limits, placement density, and the risks associated with storm climate underestimation. Such lessons are consistent with broader assessments of concrete armour integrity, which emphasise size-effect fragility and the need for structural and hydraulic verification beyond notional stability numbers (Scaravaglione et al., 2022; Leone et al., 2024). These considerations strongly motivate the implementation of systematic monitoring approaches, such as the one described in this study.

Figure 2. Rubble-mound breakwaters at the port of Sines

The breakwaters protect a wide range of critical infrastructures, including five specialised terminals (liquid bulk, petrochemical, dry bulk, liquefied natural gas, and container terminals), a logistics activity zone, the fishing harbour, and the leisure marina.

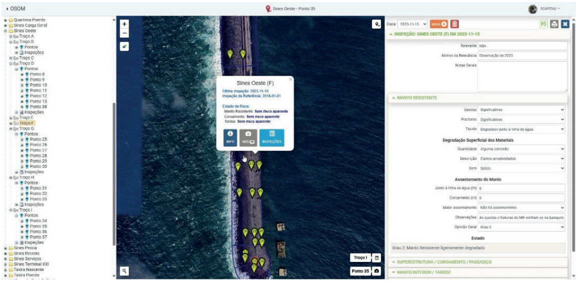
From a structural perspective, each breakwater consists of a core of finer material overlain by an armour layer composed of large units. In the more exposed sections, the armour layer comprises concrete units of various geometries—such as tetrapods, Antifer cubes, or parallelepipeds—to enhance stability and wave energy dissipation. The superstructures of the breakwaters are constructed in reinforced concrete. Access conditions vary across the structures: while some breakwaters are publicly accessible, others are located within restricted operational areas with limited or prohibited public access.

OSOM+ METHODOLOGY

Introduction

The OSOM+ methodology was developed to support infrastructure owners in the systematic monitoring of breakwaters and other maritime structures, enabling the timely recommendation of maintenance and/or repair interventions. It integrates systematic visual inspection campaigns with drone-based photogrammetric surveys, providing comprehensive and up-to-date information on structural behaviour and evolution. All collected data are stored in the ANOSOM database (Maia et al., 2017), which supports the characterization of each structure's *Present Condition*, *Evolution Condition*, and *Risk Condition*. This diagnostic framework enables informed decision-making regarding the timing, location, and urgency of required maintenance or repair works.

More recently, the development of the ANOSOM-WEB interface has introduced a web-based GIS platform accessible from any internet-connected device (smartphone, tablet, or computer). During field campaigns, inspectors can use this platform to review data from previous inspections, access real-time condition assessments, and determine whether immediate intervention is required (Fig. 3).



Sines Oeste (F)

Última inspeção: 2023-11-15

Inspeção de Referência: 2018-01-01

Estado de Risco:

Manto Resistente: Sem risco aparente

Coroamento: Sem risco aparente

Tardoz: Sem risco aparente

Data: 2023-11-15

INSPEÇÃO: SINES OESTE (F) EM 2023-11-15

Relevante: Não

Motivo da Relevância: Observação de 2023

Notas Gerais:

Quedas: Significativas

Fracturas: Significativas

Talude: Degradado junto à linha de água

Quantidade: Alguma corrosão

Descrição: Cantos arredondados

Som: Sólido

Junto à linha de água (m): 0

Coroamento (m): 0

Maior assentamento: Não há assentamento

Observações: As quedas e fraturas do MR verifiam-se na banquet

Opinião Geral: Grau 2

Grau 2: Manto Resistente ligeiramente degradado

Figure 3. ANOSOM-WEB interface showing the west breakwater of the Port of Sines

Currently, OSOM+ comprises four main components:

- Periodic **visual inspections** conducted by trained personnel, including systematic GPS-tagged photographic and video documentation;
- Periodic **UAV-based aerial surveys** using vertically oriented imagery;
- The **ANOSOM-WEB database**, which stores all inspection data and supports condition assessment and diagnostic analyses;
- A **mobile application** that enables *in situ* data entry and real-time access to inspection results.

OSOM+ visual and UAV inspection campaigns systematically observe the emerged parts of the breakwaters, with surveys deliberately scheduled during low-tide conditions to maximise armour exposure and reduce surf-zone interference in geospatial products. It should be noted, however, that the absence of routine submerged monitoring may bias diagnostic assessments by failing to capture toe scour, filter exposure, or settlement patterns—mechanisms that have historically contributed to significant damage in concrete-armoured structures, including the west breakwater at Sines, as discussed previously. Nevertheless, ANOSOM-WEB already supports the integration of “surveys of emerged and submerged zones,” enabling the future incorporation of multibeam bathymetry, side-scan sonar, ROV or diver inspections, and subsea photogrammetry to address this limitation (Reis et al., 2011).

Visual inspection

Visual inspections provide a rapid and intuitive means of monitoring the structural behaviour of rubble-mound breakwaters over time. These inspections, following the methodology outlined by Santos et al. (2003), are typically conducted on an annual basis and additionally after the occurrence of severe storm events that may have affected the structural integrity of the structure as a whole or of individual components.

To enhance the reliability and consistency of observations, each breakwater is subdivided into distinct sections defined according to their specific physical and functional characteristics. In general, each section corresponds to a unique structural cross-section, with the breakwater head always defined as an individual section. For each section, a set of observation points is established and marked directly on the structure. During each inspection campaign, photographs and/or videos are acquired from these predefined locations using consistent photographic parameters—including camera focal length, viewing direction and angle, and framing—to allow direct comparison over time.

To ensure optimal visibility of the armour layers and filters (where present), visual inspections are preferably carried out at low tide. In addition, for safety reasons, inspections are conducted only under favourable weather conditions, ideally when the sea state is calm, thereby reducing the risk of accidents to inspection personnel.

Aerial inspection

The use of Unmanned Aerial Vehicles (UAVs), or drones, as demonstrated by Henriques et al. (2024), has significantly enhanced the accuracy and level of detail of structural condition assessments of rubble-mound breakwaters. UAV-based surveys enable the acquisition of comprehensive data on the evolution of the structural envelope and facilitate the extraction of representative profiles in critical areas. Each UAV campaign produces high-resolution nadir aerial images captured along regular flight patterns. These images are processed to generate point clouds, digital surface models (DSMs), and orthomosaics, which complement ground-based visual inspections by providing additional perspectives, particularly in areas not readily accessible to inspectors walking on the structure.

At LNEC, the initial UAV surveys conducted in 2017 employed a DJI Inspire V1 platform. Subsequent campaigns adopted the DJI Matrice 300 RTK, significantly improving flight stability and operational safety, particularly under moderate to strong wind conditions (up to 54 km h^{-1}). From 2020 onwards, the integration of Real-Time Kinematic (RTK) positioning further enhanced positional accuracy and overall survey reliability.

Prior to 2020, UAV flights typically covered the full length of each breakwater, from head to root, while avoiding sensitive infrastructure (e.g. gas and petrochemical pipelines). Following 2020, compliance with updated European regulations required maintaining a minimum distance of 150 m from buildings, which in some cases reduced survey coverage. To compensate for these restrictions, oblique image acquisition from flight paths over the sea was implemented to ensure adequate coverage of the structures.

Typical flight parameters include altitudes of 30–40 m and approximately 80% longitudinal and transverse image overlap. Flights are autonomous (pre-programmed) and are conducted during low-tide conditions to maximise exposure of the armour layer.

All necessary authorisations were obtained in advance from the relevant national authorities, including the National Aeronautical Authority (ANA), local Port Authorities, aerodrome and heliport authorities, and, where applicable, the Institute for Nature and Forest Conservation (ICNF).

Weather conditions were closely monitored in the five days preceding each flight using official meteorological forecasts, with particular attention given to wind speed and gusts.

The ANOSOM-WEB database

The ANOSOM-WEB database, derived from the earlier ANOSOM system (Reis & Silva, 1995; Santos et al., 2003; Lemos & Santos, 2007), has undergone substantial development through the integration of a GIS-based interface aimed at improving the efficiency of querying and analysing information for each breakwater section. It is now implemented as a web-based Geographic Information System (GIS) platform that enables the centralised management, access, and analysis of all observational data. The platform is accessible from any internet-connected device (smartphone, tablet, or personal computer) and was developed using modern web technologies, including PHP/Laravel for backend development, JavaScript with Bootstrap and jQuery for frontend interactivity, and Leaflet for spatial data visualisation and map integration (Maia et al., 2017). The GIS functionalities are supported by MySQL spatial extensions, which enable efficient storage, querying, and manipulation of georeferenced datasets.

The system supports the import and visualisation of standard geospatial formats, such as shapefiles, and integrates cartographic layers from third-party services, including ESRI/ArcGIS. This allows users to visualise inspection data directly over accurate basemaps and customised site plans. Key functionalities include interactive spatial mapping, attribute querying, and retrieval of historical records, which together facilitate spatio-temporal analysis of structural condition. In addition, the platform provides structured input forms for both visual inspection and UAV survey data, which are georeferenced and linked to individual structural components or sections. This enables a seamless workflow from field data acquisition to analytical diagnosis, ensuring that maintenance decisions are based on comprehensive and up-to-date information.

The ANOSOM-WEB platform provides the following core functionalities:

a) Storage and analysis of visual inspection and UAV survey data, as well as other structural inspection inputs (e.g. surveys of emerged and submerged zones);

b) Diagnostic assessment of each breakwater section, including *Present Condition*, *Evolution Condition*, and *Risk Condition*, based on predefined and calibrated evaluation criteria (Santos et al., 2003);

c) Consultation of historical records, including design documentation, past interventions, hydrographic and aerial surveys, and underwater inspections;

d) Physical characterisation of each section, including geometry, construction materials, and standard cross-sectional configurations.

The platform enables real-time diagnosis of structural condition, allowing on-site users to assess whether immediate maintenance or repair actions are required. Figure 4 illustrates the interface's capability to retrieve photographs and related information linked to specific locations and inspection events. Initially populated with design-phase data, the database has since been continuously updated with results from systematic inspection campaigns and records of structural modifications following major interventions.

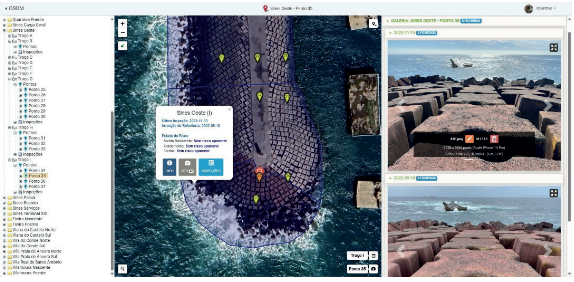


Figure 4. ANOSOM-WEB interface showing photographs and related information for the west breakwater at the Port of Sines (point 35, section I, head)

APPLICATION TO THE SINES WEST BREAKWATER

Integrated visual and UAV monitoring

This section presents the application of the OSOM+ methodology to the monitoring of the west breakwater at the Port of Sines. The analysis integrates inspection data obtained from four monitoring campaigns conducted in 2018, 2020, 2022, and 2023. These campaigns combined traditional systematic visual inspections with drone-based (UAV) surveys.

The comparative assessment is based on a comprehensive set of geospatial products, including georeferenced photographs, orthomosaics, dense point clouds, digital surface models (DSMs), as well as longitudinal and transversal profiles. Together, these products enable a detailed and multi-dimensional interpretation of the structural evolution of the breakwater over time.

This integrated monitoring approach allows the detection of subtle morphological changes, the quantification of structural displacements, and the evaluation of the overall condition of the armour layer with increased accuracy. The combination of UAV-derived data with systematic visual inspections ensures a robust and cross-validated interpretation of physical changes, thereby supporting more reliable decision-making for maintenance planning and risk management at the Port of Sines.

Visual inspection

For the visual inspection campaigns, the west breakwater was subdivided into nine sections (A to I), according to the distinct physical and functional characteristics of the structure. Within each section, several georeferenced observation points were defined, with their number varying according to the extent of the section and the presence or clarity of identified anomalies (Fig. 5).

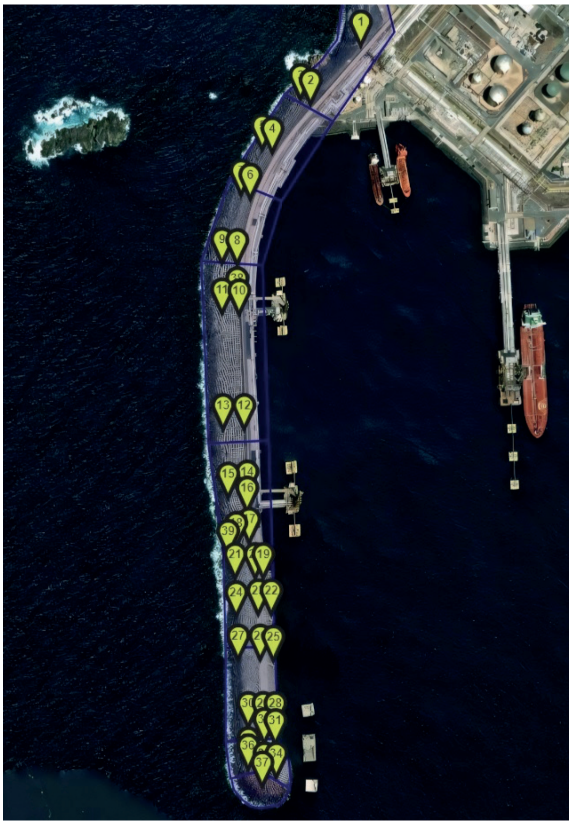


Figure 5. Sines west breakwater showing the division into sections (A to I) and visual reference points (1 to 37)

For each section, a qualitative assessment of the current structural condition was carried out, focusing on the state of the armour layer, the superstructure, and the inner filter layers. Observations included aspects such as armour unit displacement, block fractures, and material degradation, which were recorded using predefined qualitative scales (e.g., for unit displacement: none, few, some, many).

Figures 6, 7, and 8 present photographs taken during the 2018, 2020, and 2022 inspection campaigns, respectively, at predefined observation points on the Sines west breakwater. These include point 27 on the seaward side of section G, point 28 on the harbour-side of section G, and point 37 at the breakwater head (section I). Comparisons between the 2018, 2020, and 2022 campaigns revealed some localized structural changes, which are illustrated in Figures 9 and 10. These figures show photographs from the locations where the most relevant changes were detected, namely section F at point 24 (Fig. 9) and section F at point 27 (Fig. 10). In both cases, block breakage was observed between successive inspection campaigns.

Figure 6. 2018 visual observation at point 27F (F – front direction) of the Sines west breakwater (outer armour layer)

Figure 7. 2020 visual observation at point 28F of the Sines west breakwater (inner armour layer)

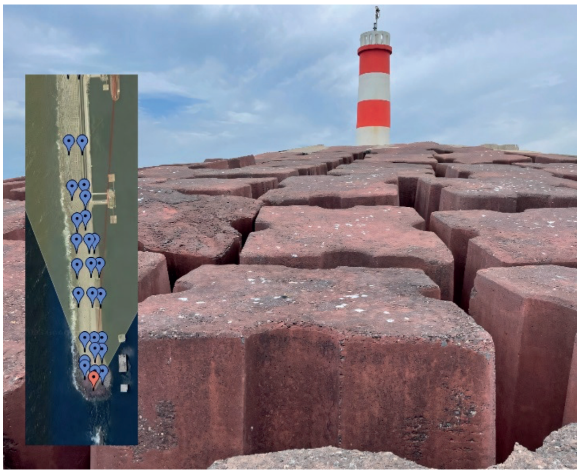


Figure 8. 2022 visual observation at point 37T (T – back direction) of the Sines west breakwater (head, section I)

Overall, based on the in situ visual inspections conducted in 2022, no significant changes in the general condition of the breakwater were identified when compared with the 2018 and 2020 surveys. Some localized alterations, such as isolated broken blocks and minor armour unit displacements, were observed; however, these were classified as non-significant and do not compromise the overall structural integrity of the breakwater.

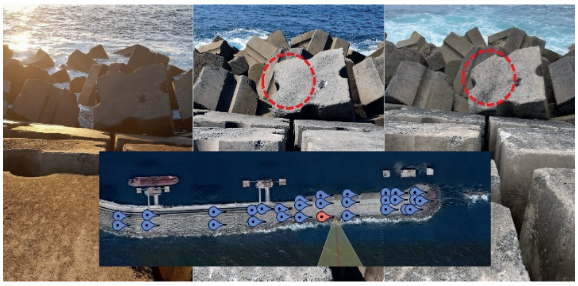


Figure 9. Visual observation at point 24L (L – lateral direction) of the Sines west breakwater (2018–2020–2022). Broken Antifer block observed between 2020 and 2022

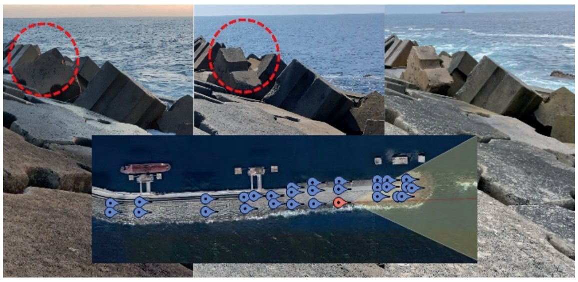


Figure 10. Visual observation at point 27F of the Sines west breakwater (2018–2020–2022). Broken Antifer block observed between 2018 and 2020

Aerial inspection

For the aerial inspection of the structure, the required equipment consisted of an Unmanned Aerial Vehicle (UAV) system operated in conjunction with dedicated flight control and mission-planning software. The initial survey campaign, conducted in 2018, employed a DJI Inspire V1 platform equipped with a Zenmuse X3 camera (12 MP). In the subsequent campaigns of 2020 and 2022, the system was upgraded to a DJI Matrice 300 RTK fitted with a Zenmuse H20 payload (wide-angle and 20 MP zoom cameras with integrated laser rangefinder). This upgrade significantly improved flight stability, positional accuracy, and operational safety, particularly under moderate to strong wind conditions (Fig. 11).

Figure 11. LNEC DJI Matrice 300 RTK UAV

To ensure accurate photogrammetric processing, Ground Control Points (GCPs) were established and surveyed using GNSS technology. These points were clearly marked to ensure visibility in the UAV imagery. In addition, a set of independent Check Points (CPs) was defined to assess the geometric accuracy of the resulting models (Fig. 12).

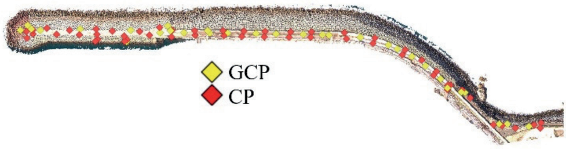


Figure 12. Location of GCPs and CPs on the Sines west breakwater

Flight operations were managed using the DJI Pilot application, which was employed for mission planning, system configuration, and sensor calibration to ensure optimal image acquisition. During flight execution, the software also provided real-time UAV control, obstacle-proximity warnings, and automated collision-avoidance functions (Figs. 13 and 14).

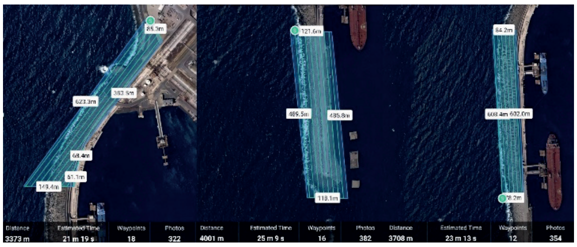


Figure 13. Flight plans over the Sines west breakwater

Figure 14. UAV operator preparing a flight on the Sines west breakwater; the RTK GNSS base antenna is visible at the top of the image

Following each survey, the acquired imagery was processed using Agisoft Metashape (Agisoft LLC), a photogrammetric software package used to generate dense point clouds and Digital Surface Models (DSMs). The resulting DSMs were subsequently analysed in QGIS (GPL licence), which provided the tools required for spatial comparison and change detection.

To identify localised structural changes between the 2018, 2020, and 2022 campaigns, successive DSM comparisons were performed by generating differential DSMs (d-DSMs). These products revealed areas of material loss and deposition. To enhance visual interpretation, the colour scale of the d-DSMs was adjusted to highlight zones exhibiting significant changes.

All dense point clouds, DSMs, and orthomosaics were referenced in the ETRS89 / PT-TM06 coordinate system to ensure spatial consistency across survey epochs. An example of the comparison results is shown in Fig. 15, illustrating DSM differences after outlier filtering. Most excluded points were associated with the waterline, where noise and reflection effects are more pronounced.

Figure 15. Results of DSM differencing between 2018–2020 and 2020–2022 after outlier removal

The processing workflow followed a sequential procedure applied to each breakwater section and survey campaign: (i) generation of the dense point cloud; (ii) computation of the DSM and storage in matrix format (Fig. 16); and (iii) production of the orthomosaic (Fig. 17).

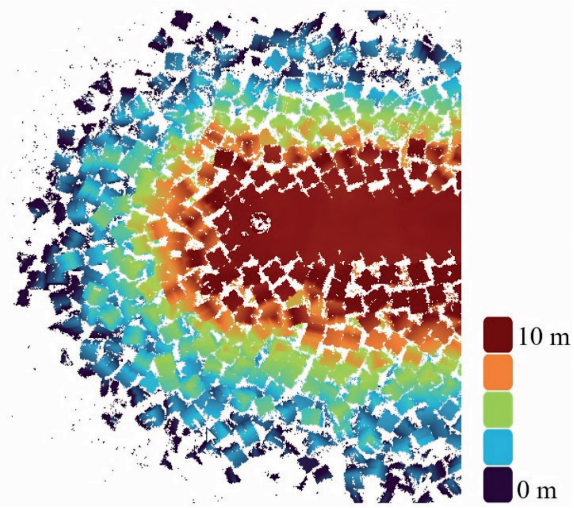


Figure 16. DSM (matrix representation) of the head section of the Sines west breakwater

Figure 17. Detail of the orthomosaic of the Sines west breakwater (head section)

For reporting purposes and to facilitate visual interpretation, the dense point clouds were also converted into three-dimensional meshes (see Fig. 18).

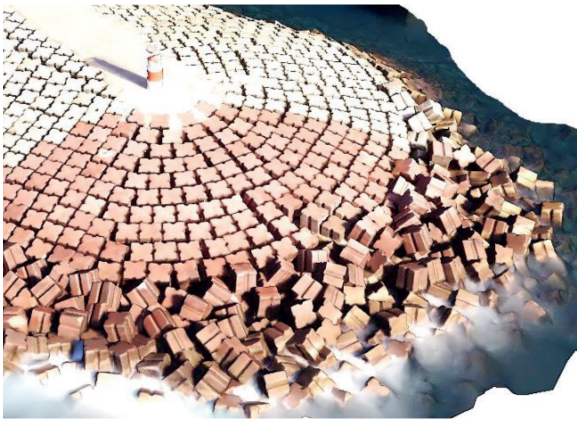


Figure 18. Mesh representation of the head section of the Sines west breakwater

Figures 19 and 20 present, as examples, the maps of detected changes and the corresponding orthomosaics for 2020 and 2022 in sections where relevant modifications were identified. In the adopted colour scale, red indicates material loss, while blue represents material deposition. These analyses were carried out in QGIS, which also served as the primary platform for visualising orthomosaics and DSMs, owing to its robust capabilities for handling and displaying georeferenced raster data and for enhancing topographic features through colour manipulation.

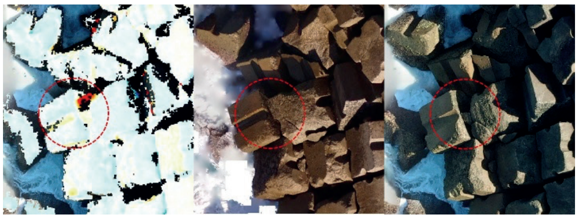


Figure 19. West breakwater. Changes detected between 2020 and 2022 – Occurrence 2 – Section E

Figure 20. West breakwater. Changes detected between 2020 and 2022 – Occurrence 3 – Section G

As previously noted, changes in the armour layer geometry were identified through DSM differencing: subtracting one DSM from another highlights spatial variations, enabling both qualitative interpretation and quantitative assessment of structural evolution. This analysis was performed entirely within the QGIS environment.

Figures 21 to 23 show selected orthomosaic excerpts illustrating specific types of detected changes. The associated DSM differences are represented using colour maps, allowing clear visualisation of localised morphological evolution.

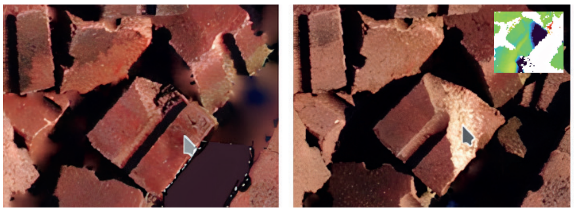


Figure 21. Armour unit exhibiting increased erosion between 2020 and 2022

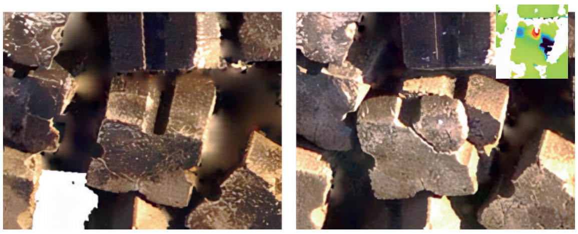


Figure 22. Armour unit failure observed between 2020 and 2022

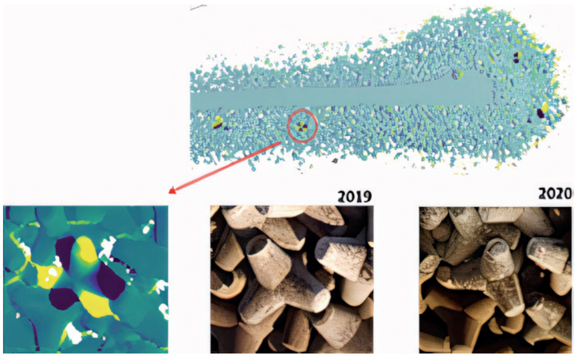


Figure 23. Tetrapod rotation observed between 2019 and 2020

Profiles

Point clouds, supported by orthomosaics, were used to extract accurate cross-sectional profiles of the structure. Transversal profiles were generated along predefined cross-shore sections, oriented perpendicular to the longitudinal axis of the breakwater.

The location and spacing of these sections were selected to cover representative areas of the structure and were kept consistent across survey campaigns to enable reliable temporal comparison. Profile planes were defined by first establishing a baseline polyline along the crest of the breakwater, using the orthomosaic as a spatial reference. Subsequently, a set of normal vectors was defined at regular intervals along this baseline, indicating the direction of each transversal cut (see Fig. 24). An example of the extracted profiles is shown in Fig. 25.

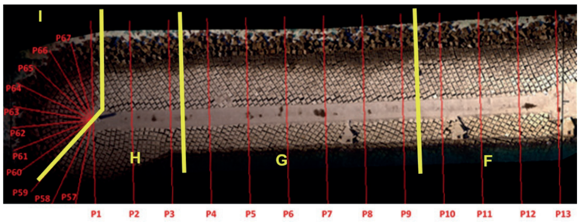


Figure 24. Sines west breakwater: location and details of the extracted profiles, sections F to I (head)

Profile comparison allows the detection of geometric changes in the most vulnerable sections of the structure between consecutive survey campaigns. For the Sines west breakwater, only negligible or no changes were observed between successive profiles.

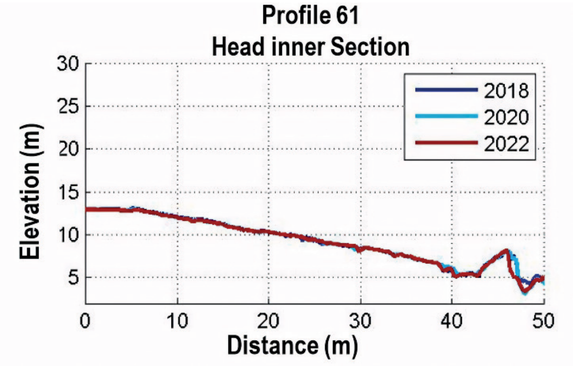


Figure 25. Example of extracted profiles (Profile 61 at the head of the breakwater)

When analysing the profiles, particular attention should be paid to the following factors, as they may contribute to discrepancies between surveys:

- higher quality of image acquisition and point clouds in the 2020 and 2022 surveys compared to 2018;
- slight differences in tidal levels between inspection campaigns;
- potential misalignment of point clouds due to inherent uncertainties in photogrammetric processing;
- increased uncertainty in surf-zone areas that are partially or fully submerged;
- local limitations in image acquisition caused by the presence of vessels, pipelines, mooring equipment, or other obstructions.

In summary, since 2018, only minor and non-significant displacements of armour units have been observed along the Sines west breakwater. As with all maritime structures of this type, it remains essential to monitor such minor anomalies and, whenever feasible, restore the structure to its original as-built condition.

CONCLUSIONS

Overall, the OSOM+ framework, enhanced by the integration of UAV-based survey capabilities and the development of new digital tools, represents a significant improvement in both the operational efficiency and analytical depth of systematic coastal infrastructure monitoring. Periodic visual inspections, when combined with UAV-derived datasets, enable a more robust assessment of present conditions, structural evolution, and risk indicators. In addition, the deployment of a mobile, field-ready application during inspection campaigns streamlines data acquisition and improves workflow integration.

For the Port of Sines, this study highlights the substantial contribution of visual inspections and aerial photogrammetric surveys to the monitoring of rubble-mound breakwaters. The imagery acquired during visual inspection campaigns and the data products derived from UAV surveys—particularly digital surface models (DSMs), point clouds, and orthomosaics—significantly enhance the capacity to quantify structural evolution within the OSOM+ programme.

Originally grounded in qualitative assessments, the methodology has evolved to incorporate higher-resolution data and increasingly quantitative analyses. With the current level of precision achievable through drone-based surveys, structural changes on the order of a few centimetres can now be detected with confidence. This represents a critical step forward in the early identification of potential risks and supports more reliable long-term management of coastal infrastructure.

Although this study focused on the monitoring of existing maritime structures, the applicability of the methodology extends beyond this scope. The same survey techniques can support verification of as-built geometry during construction or repair phases, which is essential for quality control and contractual validation.

This enhanced monitoring approach benefits both the data provider (LNEC) and the primary end users, namely Port Authority Administrations—specifically, in this case, the Port of Sines Authority (APS). The transition towards a predominantly quantitative monitoring framework yields more precise, objective, and actionable insights into the condition and performance of maritime structures.

ACKNOWLEDGEMENTS

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