A NEW METHODOLOGY FOR BREAKWATER DAMAGE ASSESSMENT AND ITS IMPLEMENTATION ON A WEBGIS

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In this paper a new methodology for breakwater damage assessment was developed to reflect the advances in monitoring techniques and to overcome some limitations in this process. The proposed methodology was implemented on a WebGIS called SIMOM - Monitoring System for Maritime Works. This system and the proposed methodology are presented using the Ericeira North breakwater (Portugal).

Keywords: Life-cycle Management; Breakwater; Monitoring; Damage Assessment; WebGIS tool

INTRODUCTION

Breakwaters have been constructed, repaired and have continuously deteriorated for decades with little attention to optimization of the life-cycle costs. Nowadays however, focus is placed on reducing these costs (ATPyC, 2012). The total life-cycle cost of a structure is estimated by adding the construction, monitoring, maintenance, repair, reconstruction and decommission/ reconversion costs. For structures designed many decades ago or underdesigned projects, the ensemble of monitoring, maintenance and repair/reconstruction costs frequently constitutes the largest parcel of costs. Furthermore, for a breakwater located in an energetic environment and with a long lifespan, the latter costs can be larger than the related construction costs or at least of the same order of magnitude. Minimizing these lifecycle costs through monitoring and risk management is critically important.

Thus, in the present paper, focus is placed on a new methodology for damage assessment of prototype rubble mound breakwaters. The new methodology was developed to allow an effective and efficient assessment of state-of-the-art topographic laser scanning and multibeam surveys. It has been implemented on a WebGIS system called SIMOM. This system is presented using the Ericeira North breakwater in Portugal.

BREAKWATER DAMAGE ASSESSMENT

State-of-the-art on breakwater monitoring

Breakwaters and other maritime works have traditionally been inspected visually and also by conventional survey techniques once some significant damage is found. Some detailed techniques making use of intrusive techniques are sometimes used when concrete elements exist. Nowadays, however, data from more dense surveys creates a challenge on how to perform structure condition rating.

Visual inspection is usually performed by filling forms. These forms include a list of expected degradations and levels to classify its severity. Some recommendations are presented on how to do this by several authors (Oliver et al., 1998; Pirie et al., 2005 and Lemos and Santos, 2007). Among these, the work by Oliver et al. should be stressed since it considers for the first time a method to explicitly consider visual inspection of the leeside, crest and seaside. The obtained results for these zones are then aggregated to higher levels: cross section, reaches and structure as a whole.

However, with respect to surveys the only recommendations are related to laboratory tests where damage parameters are mostly applied to cross sections and a limited part of the structure. Some of these were presented and used by Broderick and Ahrens (1982), Van der Meer (1988), Melby and Kobayashi (1998). Among the most common are the damage parameter S, the normalized eroded depth E and the normalized eroded length L.

A new methodology

The general monitoring process involves four phases: a) Preparation; b) Observation; c) Damage Assessment and d) Analysis. This may be seen schematically in Figure 1.

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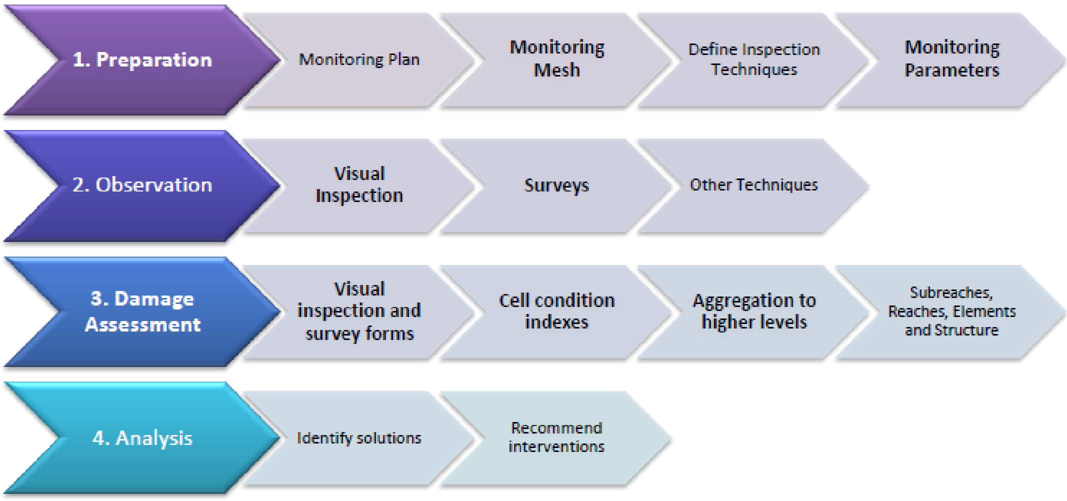

Figure 1. Monitoring methodology including 4 phases: preparation, observation, damage assessment and analysis.

The "Preparation" phase implies defining a monitoring plan, a monitoring mesh, inspection techniques and monitoring parameters. The monitoring plan should include all the information related to the process of monitoring: how it should be performed, by whom, which techniques to use, how to divide the structure and the monitoring parameters. Once the monitoring plan is defined it is important to implement it. This implies defining the monitoring campaigns, which techniques to use for each campaign, its goals and determining the present benchmark to serve as comparison. This process is presented schematically in Figure 2.

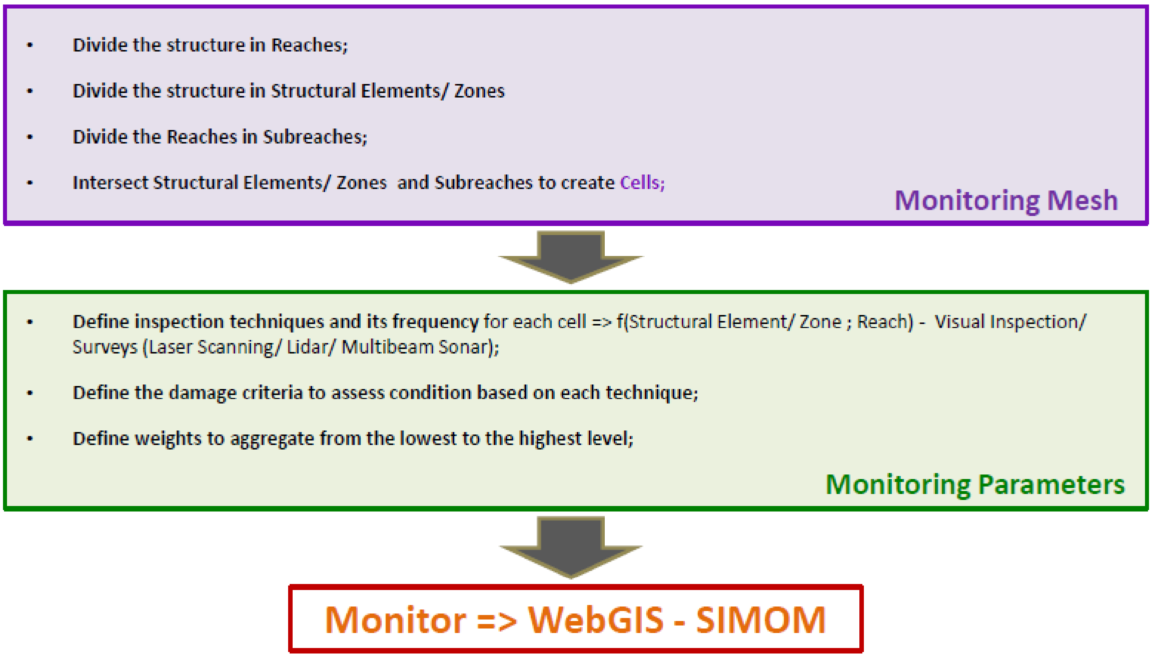

Figure 2. Monitoring methodology - Preparation phase.

The "Observation" phase implies inspecting the structure by any combination of visual inspection, surveys and other techniques. The most frequent observations should include a preliminary walk along the structure to detect major changes. Once this is performed a more detailed inspection may be prosecuted by taking notes and/or photographs related to the visual inspection forms to be filled up in the next phase. This process may be complemented for instance with surveys.

The “Damage Assessment” phase implies standardization of the results by filling inspection forms, computing cell condition indexes and aggregate these indexes to higher levels. Inspection forms may be of several types being the most important visual inspection forms and survey forms. The visual inspection forms – in case of visual inspection – are filled with field data obtained during observation. These visual inspection forms should consist of assigning some pathology damage values to the monitoring parameters considered but may also include notes and photographs taken by the responsible. The survey forms – in case of surveys – incorporate the damage criteria measured from the survey interpolation to a raster and comparing those to a reference surface. Based on these forms and by applying multi-criteria techniques, e.g. weighted averages, the cell condition indexes: material, structural, general and survey are computed. Once cell condition indexes are computed they should be aggregated to the higher levels: structural elements/ zone, subreach, reach and structure.

The “Analysis” phase comprises the identification of aspects to improve, identification of solutions and recommend interventions/ future actions. This process should take into account the previous and forecasted evolution and expected risk for a certain time horizon.

SIMOM – MONITORING SYSTEM FOR MARITIME WORKS

Considering the existing limitations and lack of automation to routine tasks in the monitoring process of maritime works there is a need to develop a system to overcome and solve these issues. SIMOM – Monitoring System for Maritime Works is an information system implemented as a WebGIS with three major parts: browser with a GIS interface – Figure 3, an Android app and a plugin for an advanced GIS software - QGIS.

The main purpose of this system is to make the management process of maritime works easier by focusing on data storage, including a GIS interface and by accounting to all the life-cycle phases. In this system it is possible to store all the information related to the work over its life-cycle. Furthermore the routine tasks of the monitoring process are automated both for visual inspection and surveys. Once the monitoring data was obtained its analysis is performed. After this analysis, the conclusions are inserted directly in some specific fields – summary, recommended actions and implemented actions and/or as a report file. In the next sections, SIMOM and the damage assessment methodology are shown using the Ericeira North breakwater.

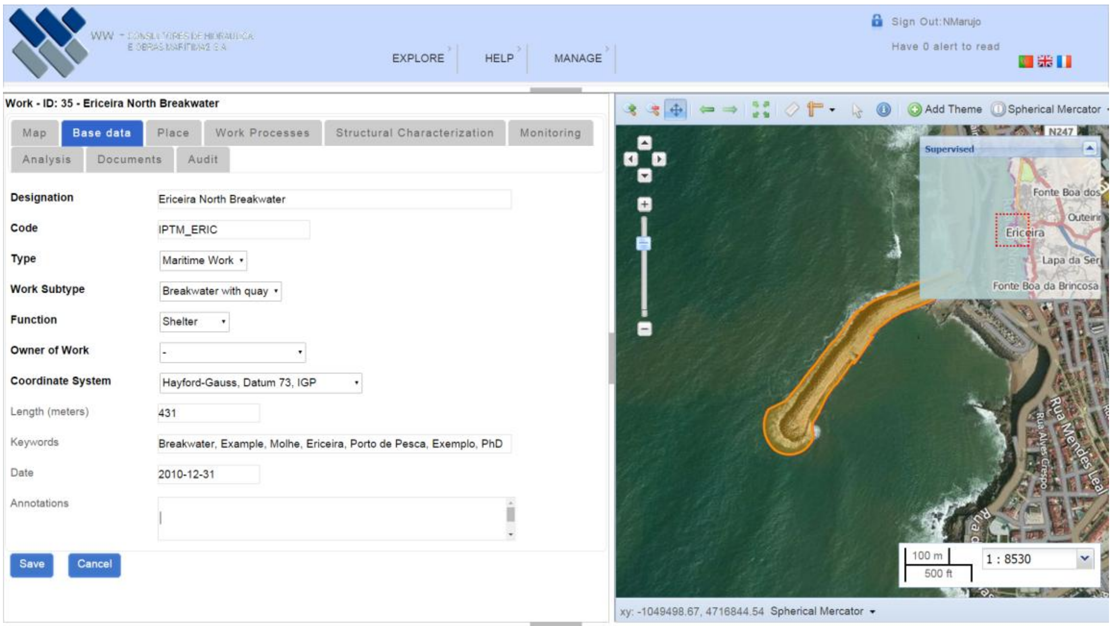

Figure 3. SIMOM – Base data for the Ericeira North Breakwater (left) and geometry (right).

The Ericeira North Breakwater

The Ericeira North breakwater is located 35 km Northwest of Lisbon and is exposed to the highly energetic north-westerly Atlantic Ocean waves. The breakwater has a length of 431 m and can be considered, for effects of monitoring, as having two different cross-section types: rubble mound (with superstructure) and horizontal composite breakwater (quay on the leeside).

It was constructed during the 1970's and until 2008 was subjected to severe damage. Once this damage were deemed unacceptable some effort was put on how to repair it. A solution was conceived, the design was approved and therefore it was reconstructed and extended between June, 2008 and December, 2010. However this process was not without some incidents, as an accident has occurred on 9-10 December 2009. This accident was due to an extreme storm during the construction stage at that moment (Costa et al., 2011) with most of it effect on the head and trunk of the breakwater. Some historical images of this evolution are presented in Figure 4.

Figure 4. SIMOM – Ericeira North breakwater evolution. a) 1983; b) 2001; c) August, 2008; d) December, 2009; e) December 2010; f) December 2012.

Preparation of the Structure to Monitoring

In design, cross sections were represented every 10 m (44 total cross sections) and, at the breakwater head, 3 radial profiles (45°, 90° and 135°), respectively. These sections were used both to determine the number of reaches, the structural elements and as cross sectional profiles to assess damage based on surveys obtained during the monitoring process. Based on those cross sections the structure was divided into 7 reaches represented in Figure 5. These reaches include rubble mound with superstructure, horizontal composite and transition reaches. The criteria used to define reaches were the structure function and structural homogeneity. Continuous transition areas were considered where homogeneity is not verified.

Once the structure was divided into reaches it was further divided into structural elements. These are represented in Figure 6 and include: armor layer berm and slope both imerged and submerged, crown wall, crest massif, pavement and quay.

After the structural elements were identified, each reach was divided into subreaches to facilitate the monitoring process. The reach length ranges between 10 and 20 m since the subreach length should be a submultiple of the reach length. Therefore the structure comprises 31 subreaches which are presented in Figure 7.

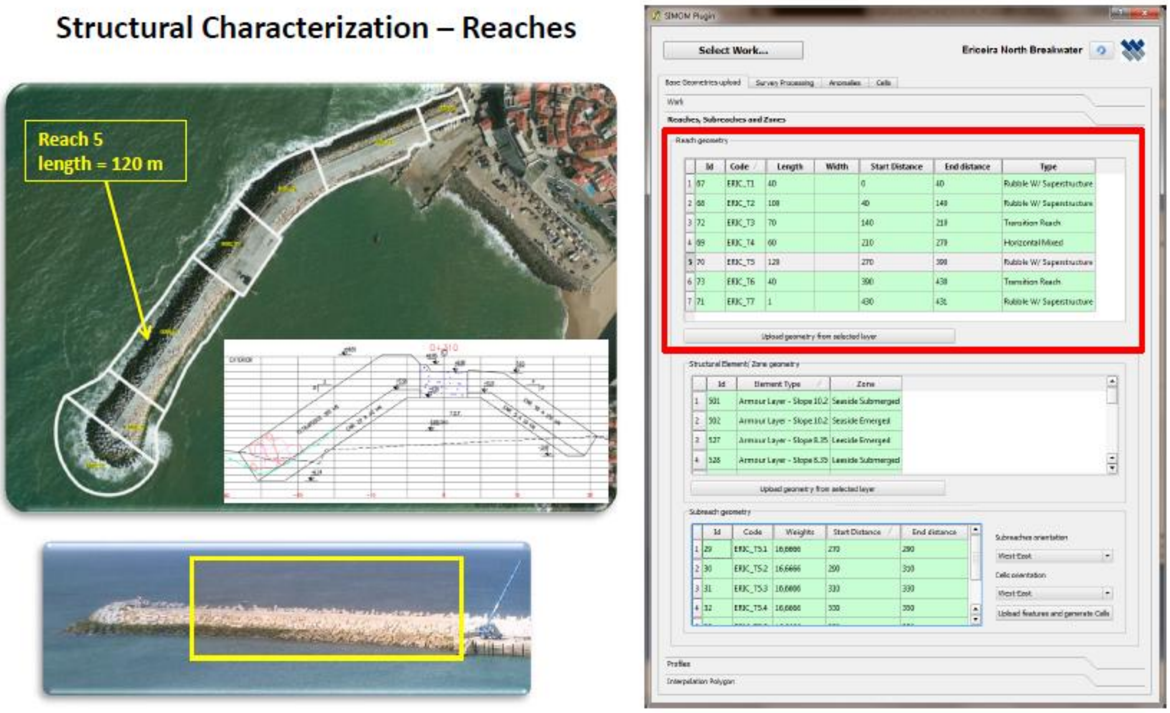

Figure 5. Reach division (left) and QGIS plugin with the associated metadata highlighted (right).

In Figures 5, 6 and 7 the QGIS plugin is shown to illustrate some of the details such as the name, length, weights, etc. It should also be noted that sensitivity analysis was performed, subjected to the practicability restrictions. It was found that this division assures maximum flexibility as well as maintains the number of reaches and subreaches within practical intervals for inspections and condition assessment purposed.

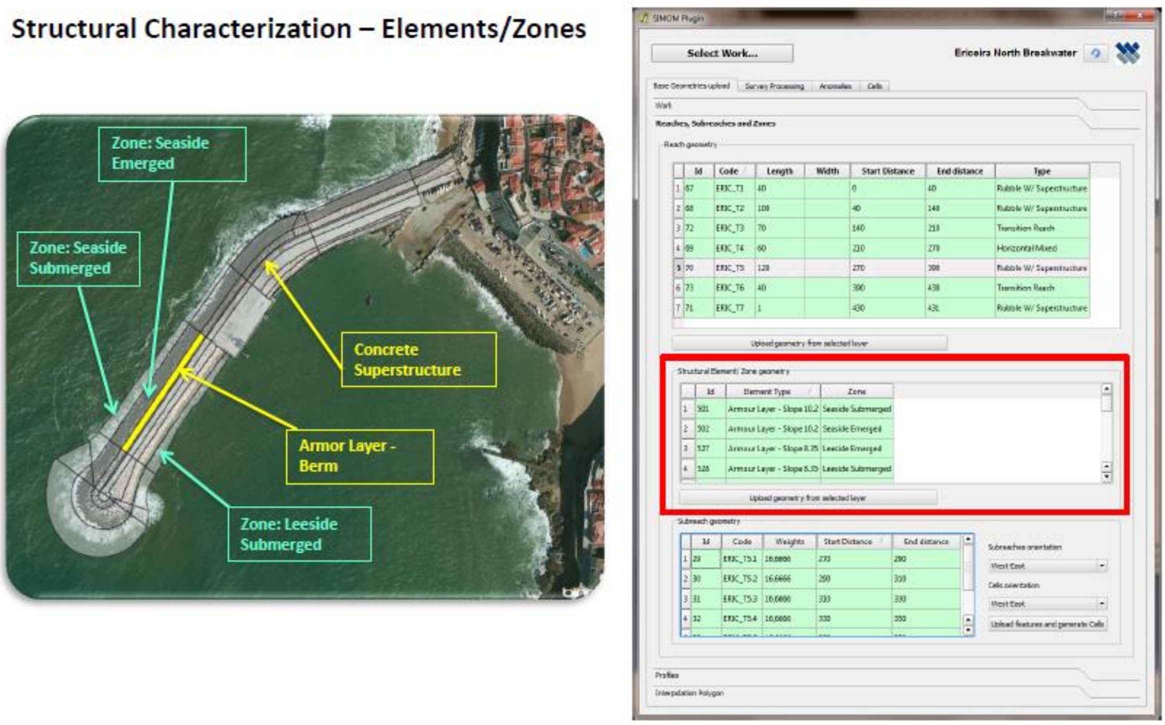

Figure 6. Division of the structure in elements and zones (left) and QGIS plugin with the associated metadata highlighted (right).

Once the structure has been divided into elements/zone and subreaches it is possible to intersect these to generate cells which constitutes the elementary units to monitor the structure. A schematic view is presented in Figure 8 as well as the navigation between reaches, subreaches and cells in SIMOM. In addition to the monitoring mesh comprised of cell, cross, longitudinal, radial and circular sections shall be considered for the purposed survey assessment as well. The spacing between these should be a function of the structural element/ reach it crosses.

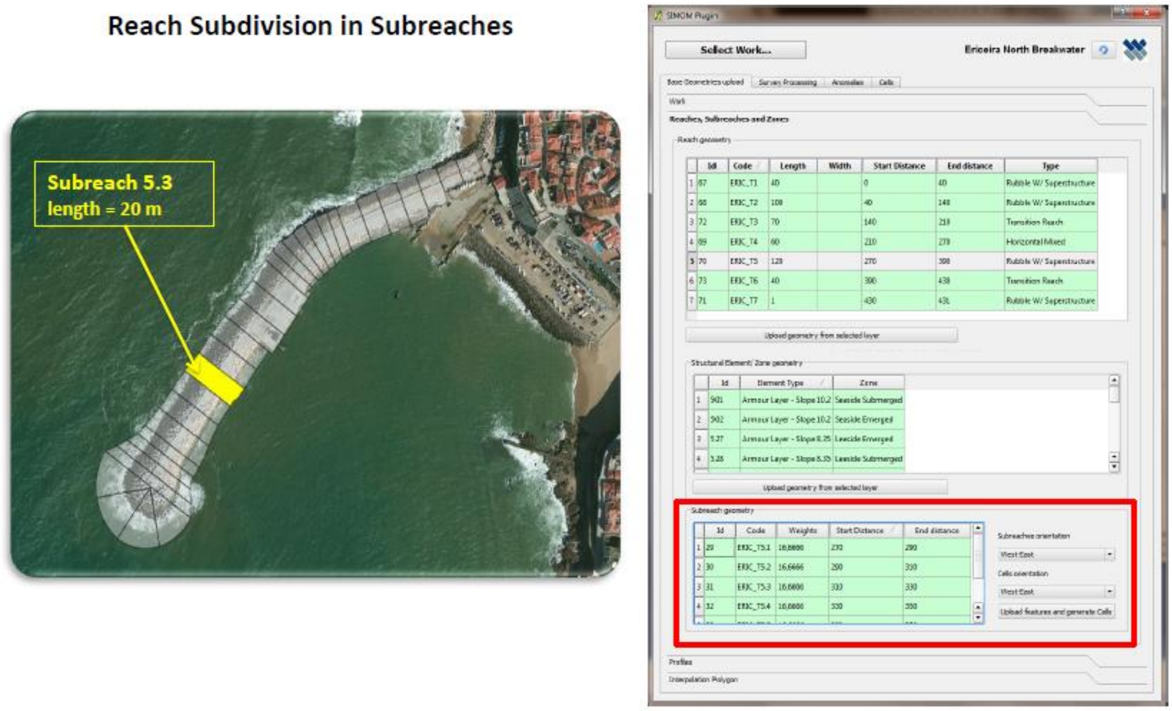

Figure 7. Division of the structure in subreaches (left) and QGIS plugin with the associated metadata highlighted (right).

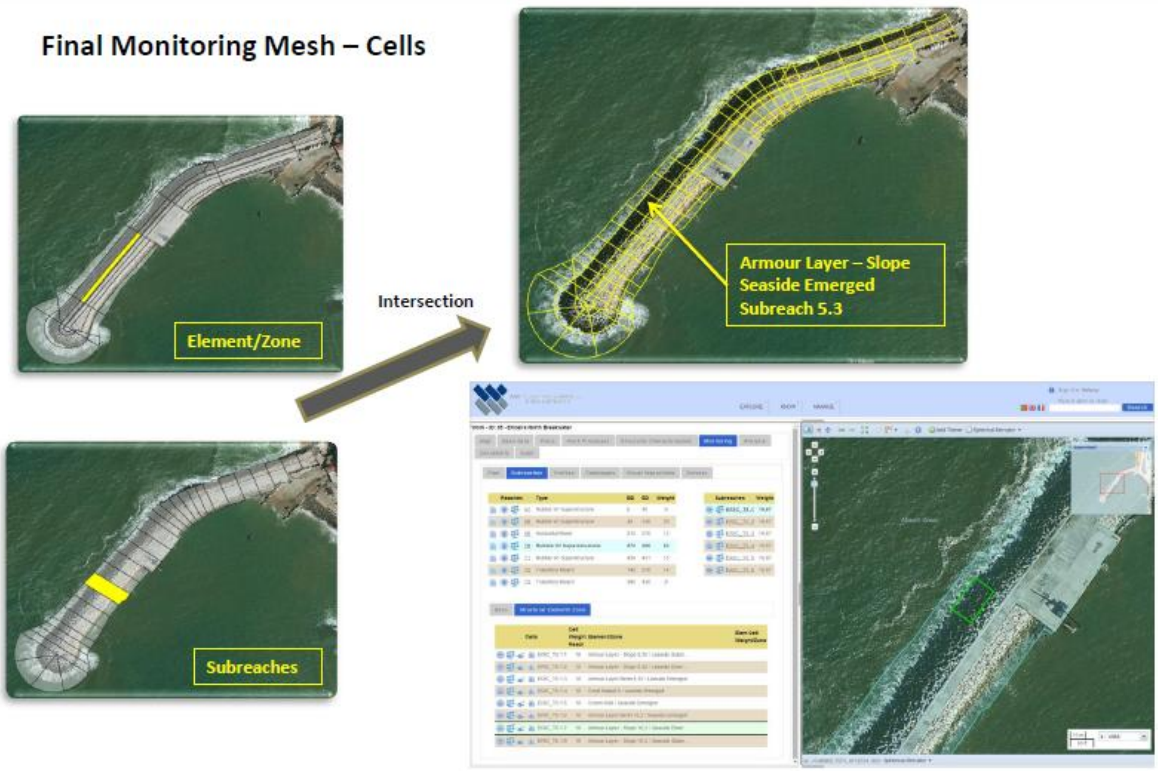

Figure 8. Ericeira North breakwater monitoring mesh and highlight of a cell in SIMOM.

To finalize the preparation process, it is necessary to assign weights to the reaches, subreaches, structural elements and cells to aggregate the cell condition towards the hierarchical higher levels.

The Monitoring process

The monitoring process despite similar is different for visual inspection and surveys. For visual inspection it implies visual inspection forms filled, assigning weights to both questions and answers as a function of the reach and the structural element. For surveys the xyz data is interpolated to a raster, this raster is compared to another – reference situation, the damage criteria are computed and adimensionalized such that via piecewise functions are converted to 0-100 and processed thereafter analogously to visual inspection. This process is detailed schematically in Figure 9.

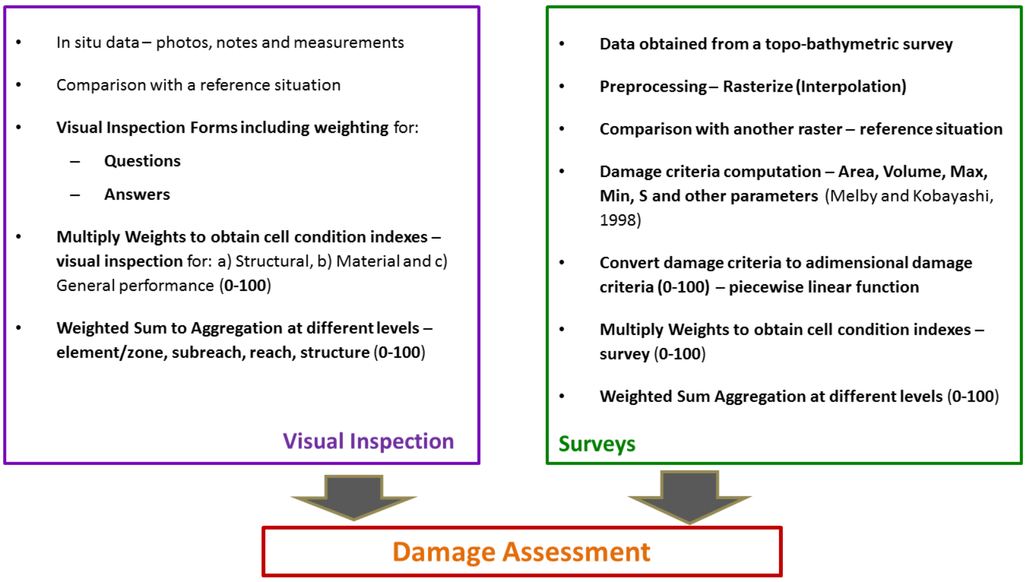

Figure 9. Comparison between visual inspection and survey based damage assessment

The process above can be illustrated. In Figure 10, a visual inspection form and some photographs are shown from SIMOM. In Figure 11 the configuration of weigths in a armor layer form is shown and some simple examples of results shown are depicted on the right part of the figure.

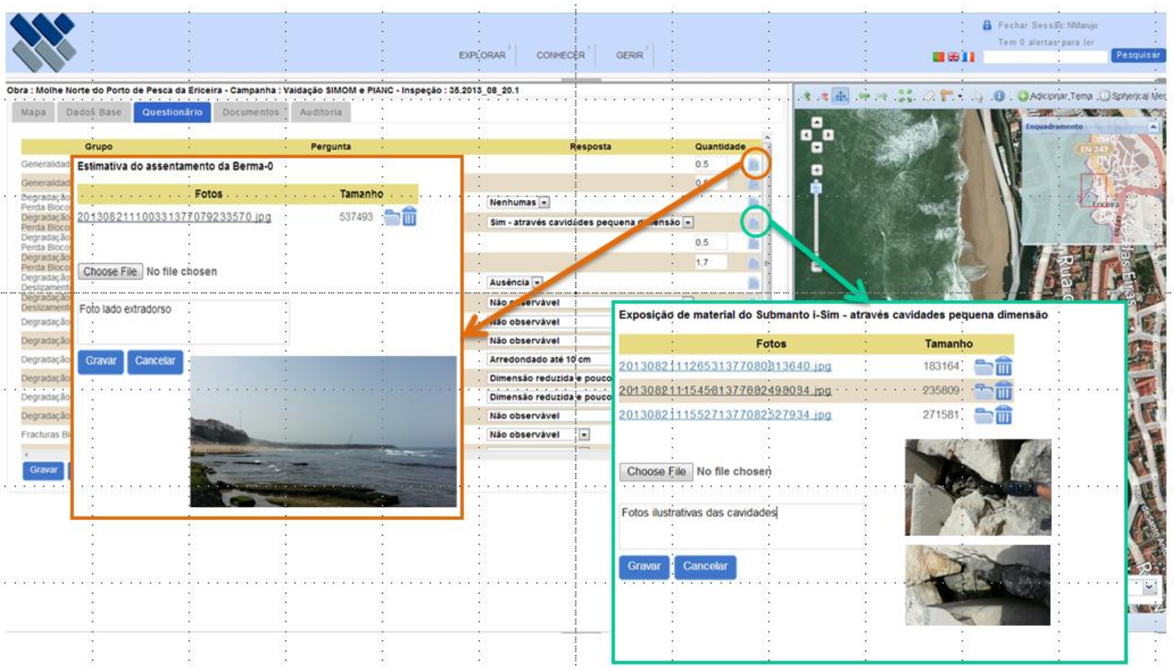

Figure 10. SIMOM – Ericeira North breakwater example of a visual inspection form with some photos

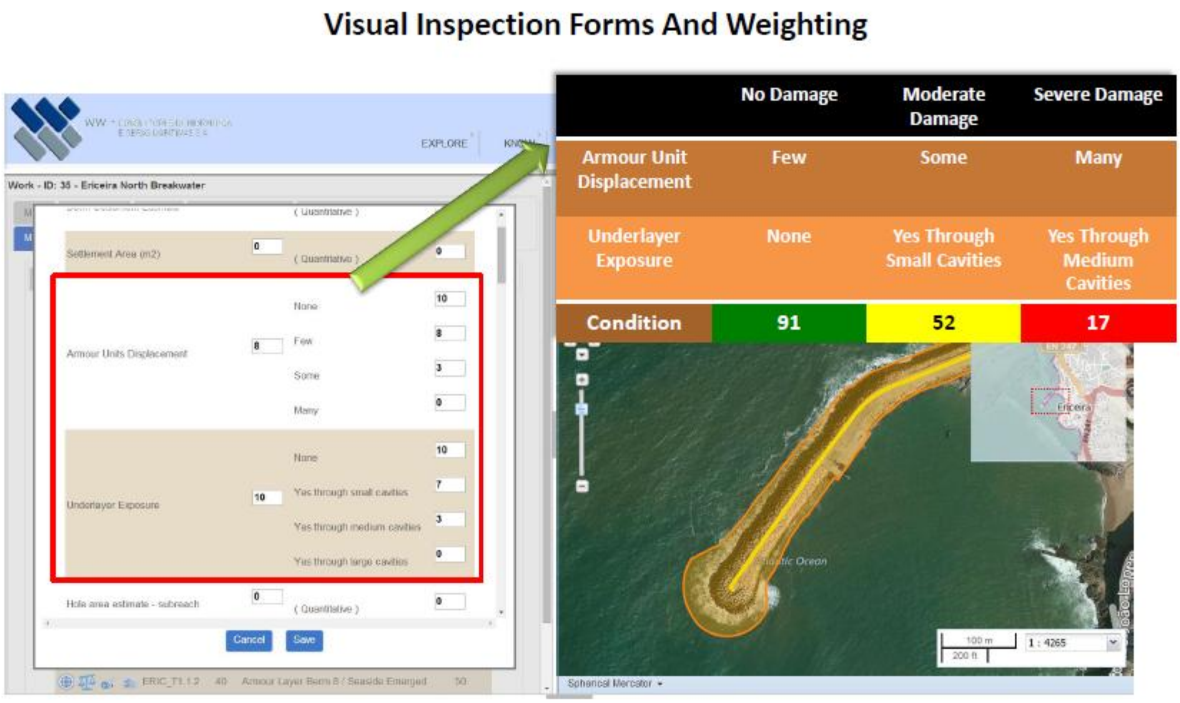

Figure 11. Example of visual inspection forms damage assessment. On the left, weights for questions and answers, and on the right the cell condition indexes for the 3 major damage levels.

In Figure 12 a survey is presented with variable resolution. The variable resolution should be standardized towards a constant spacing via interpolation towards a raster. Examples of rasters are presented in Figure 13. The most important output of this process is a comparison raster such as the presented in the right part of figure 13. Once this comparison raster is computed some anomalies can be identified using the QGIS plugin as presented in Figure 14. In Figure 15 it is presented the computation of the damage indicators for a cell.

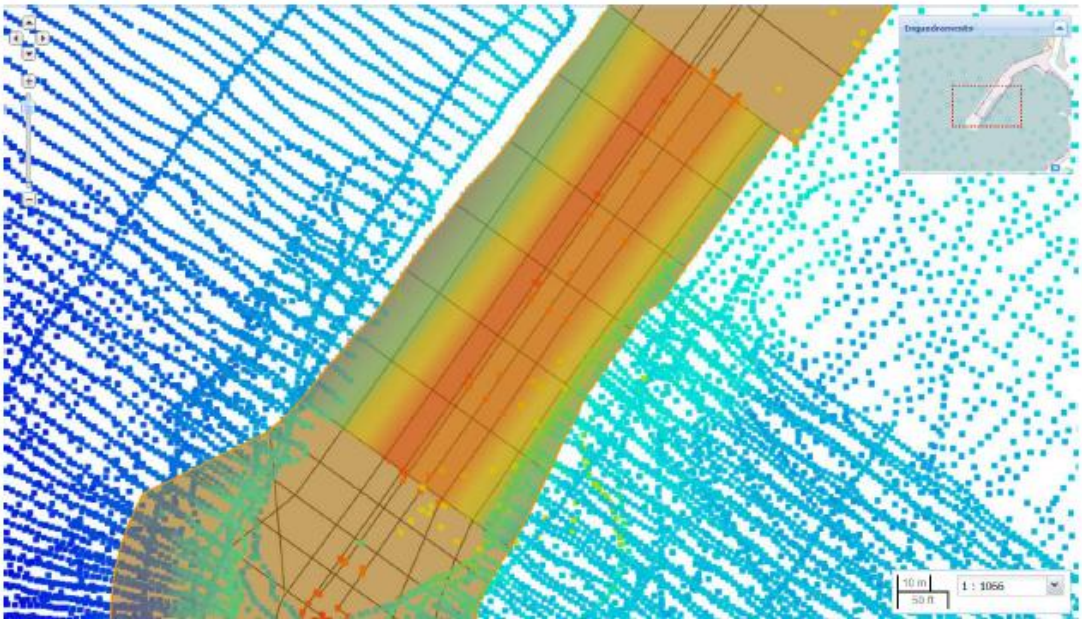

Figure 12. Survey example with variable resolution. This data will be used to interpolate to a raster file to allow condition performance.

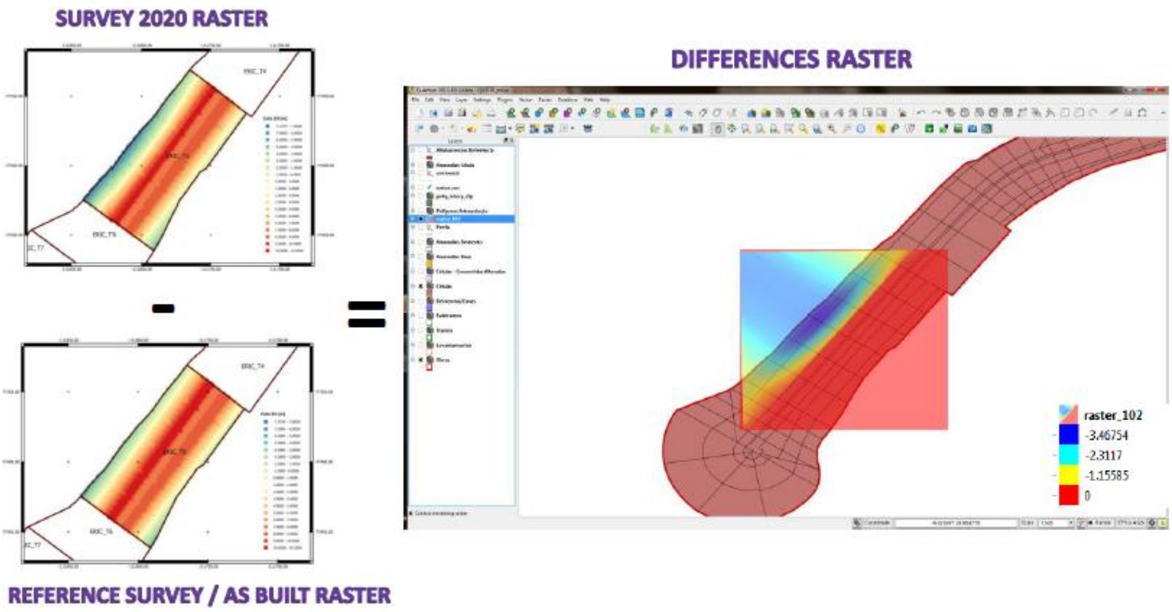

Figure 13. Comparison of two surveys rasters (left) to obtain a differences raster (right).

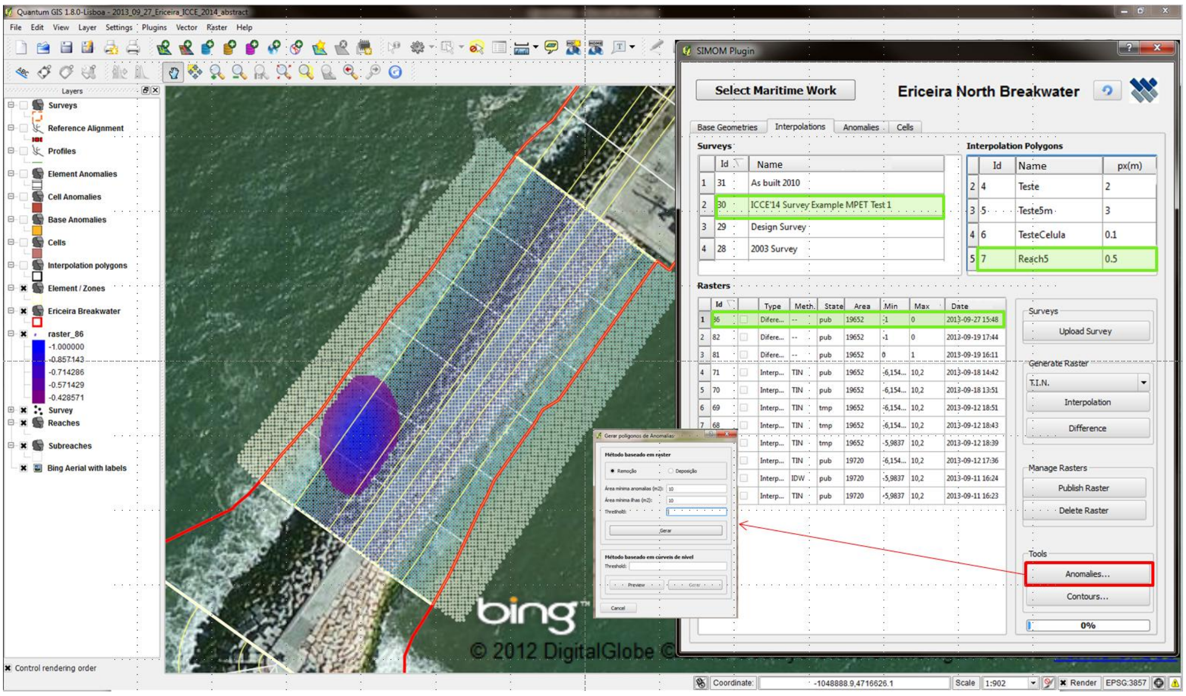

Figure 14. SIMOM – Ericeira North breakwater example of an anomaly identification using the QGIS plugin.

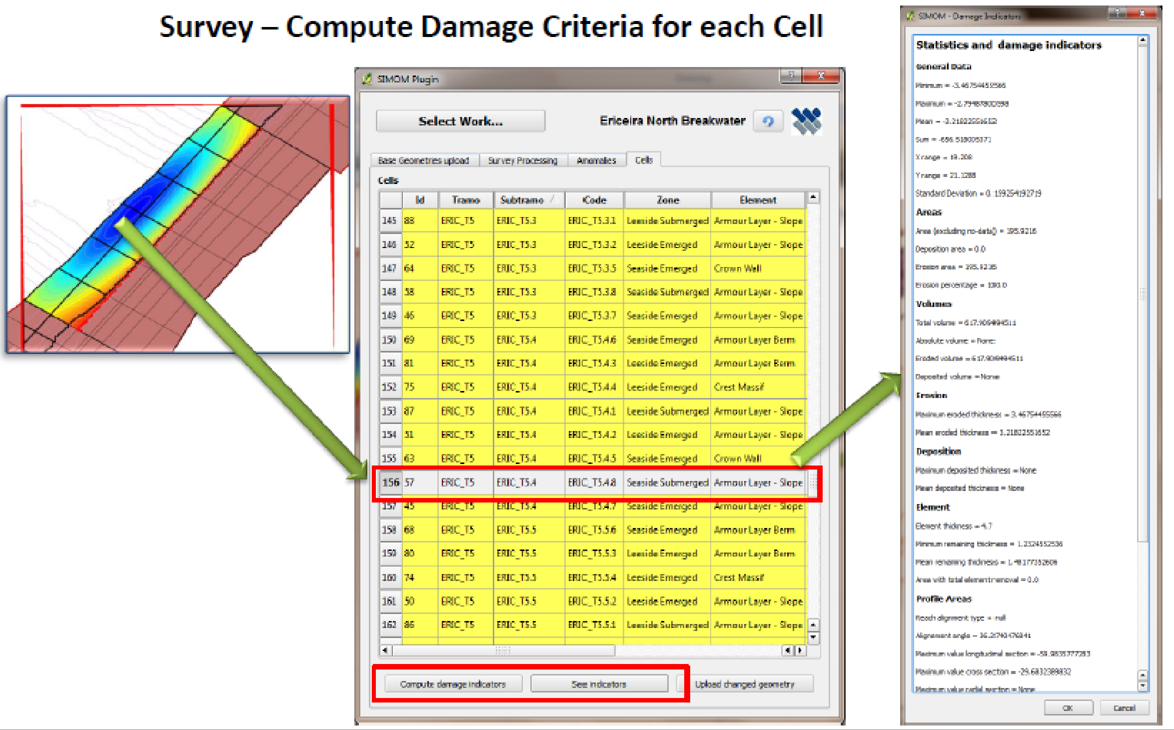

Figure 15. SIMOM – Base data for the Ericeira North breakwater (left) and geometry (right).

Once damage indicators are computed for each cell the results can be consulted in the WebGIS as presented in Figure 16 for reach number 5. In Figure 17 the final part of SIMOM is presented to recommend interventions and store the performed interventions.

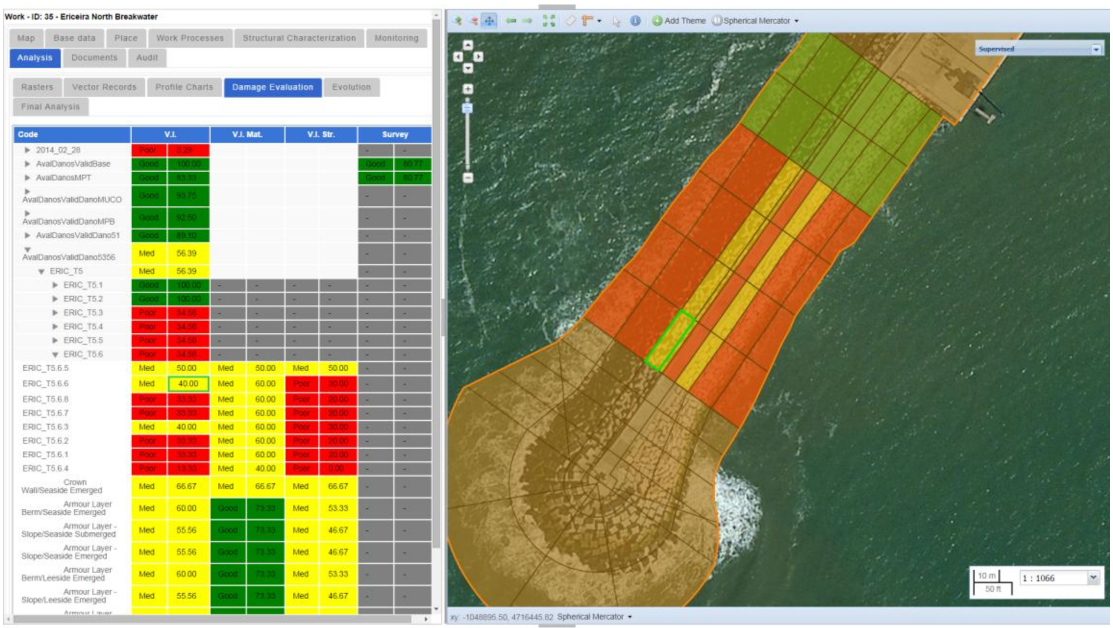

Figure 16. SIMOM – Ericeira North breakwater example of cell condition levels in the case subreaches 5.1 and 5.2 are not damaged and some severe damage may be found in subreaches 5.3-5.6 especially in the armor layer and pavement. Condition levels at the different assessment levels: campaign, reaches, subreaches, structural elements/ zone and cells (left) and map representation of these condition levels for cells in geometry (right).

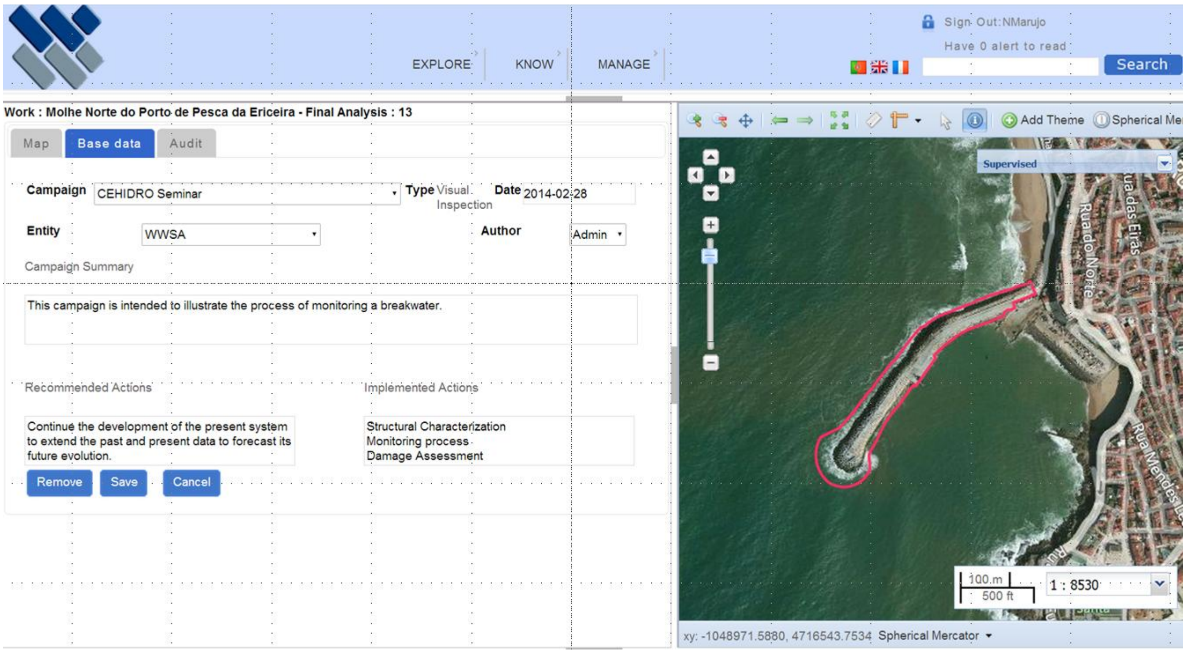

Figure 17. SIMOM – Ericeira North breakwater – example of the final analysis for a campaign including summary, recommended actions and implemented actions.

CONCLUSIONS

In the present manuscript a new methodology for breakwater damage assessment was proposed and implemented on a WebGIS called SIMOM. This system comprises three parts: WebGIS, android App and QGIS plugin. This system is still under development and continuous improvement but it may be already applied to real cases such as the Ericeira North breakwater. Among the most important issues of SIMOM is the need to address other types of maritime and port works besides breakwaters such as jetties, groynes and seawalls. Nonetheless the presented methodology may be applied to other types of structures such as quays, sand nourishment works, waterways, etc.

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