A Web Platform for the Systematic Monitoring of Coastal Structures

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Abstract: Due to both its geographic location and maritime importance, Portugal is equipped with a large number of port infrastructures, the majority of which built for goals such as to guarantee the tranquility of the sheltered areas of the harbour basins, to help controlling sedimentation by guiding the currents, to protect water taken from thermoelectric plants, amongst others. In Portugal, the most common of these structures is the rubble-mound breakwater. Due to its characteristics, maintenance or repair works are common throughout its lifetime. However, the need for these repair works should be evaluated in advance, in order to avoid significant costs associated to those works or, even worse, the collapse of the structure. It is therefore quite important to evaluate the Present Condition of the structure, as well its Evolution and Risk Conditions. The Present Condition is periodically checked on-site and all relevant data gathered is recorded, by filling in inspection forms, in order to perform further comparisons and analyses with previous inspections of the structure, as to eventually characterize Evolution and Risk conditions. To expedite all this process and prevent likely occurrence of errors in data collection, a monitoring tool, supported through a map-based online geographic information system (WebGIS) was developed, enabling the georeferencing of the structures concerned. This system adapts to the location of the user's device and to the capacities of the device itself. Media data, such as photos and videos can be associated to the structural data collected. The resulting platform was successfully evaluated by the involved researchers from Portuguese National Laboratory for Civil Engineering (which are the end users of the system), and by non-expert users.

1 INTRODUCTION

Coastal areas represent a dynamic environment of vital importance for human society. A significant part of human settlements are located near the coast. In coastal areas and in ports, the evaluation of wave breaking and overtopping in maritime structures is very important in order to assess the risk associated with either the failure of these structures or with the flooding of the protected structures. In Portugal, because of the length of the coast line, the concentration of population and economic activity near the sea and the importance of ports to the national economy, the impact of sea agitation on coastal buildings and structures needs to be taken into account. Recent examples of emergency situations in Portugal caused by sea waves hitting the coast are (Sabino et al., 2015):

Esmoriz. Flooding due to overtopping of the seawall in February 2011, with damages in the infrastructure and homes along the seafront;

Estoril. Frequent overtopping of the seawall, which afects its use and disrupts the nearby railway line;

Praia da Vitória Port, Azores. Strong overtopping of the breakwaters completely destroyed the structures after a December 2001 storm;

Marina do Lugar de Baixo, Madeira. Repeated events of massive overtopping of the breakwater in 2006, damaging the structure quite seriously and leading to the marina inoperability.

To this date, records of the condition of a maritime structure or of parts of it are mostly generated on paper, a media more prone to mistakes. The original paper filling forms will, on the other hand, most likely be passed onto a computer file. This further step means additional delay and constitutes another possible source of errors and inconsistencies.

It is therefore important to implement an online system to support and facilitate the direct digi-

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tal gathering of information during visual inspection of coastal structures, which is conducted periodically. Relevant information to be collected includes structural data as well as media content, such as photos and videos, captured from previously defined locations physically marked on the ground and considered relevant for the evaluation of the structure.

In this paper, a WebGIS system for the on-site collection of information concerning the current structural condition of coastal structures, is presented. The geographic features associated with each relevant structure can be periodically uploaded into the system, in shapefile format, and consequently overlaid on a map of the region. Information on the general properties of the structures, such as their length, width and other characteristics is also contemplated on the system's database. The location of Observation points (previously defined locations for analysis and photo capture) is also stored on the database and superimposed on the map as yellow markers. The gathered photos and videos can be accessed thanks to the association of these markers with the files located in a directory of the server. All of this enables the geographic referencing of the coastal structures and of the photos captured. The database also contains all the alphanumeric information that is collected during visual inspections.

The coastal structures considered in this system are composed of sections and the availability of this information enables the qualitative and quantitative evaluation of the so-called Present Condition of these sections. When more than one visual inspection of the same structure are available on the system, collected at different dates, Evolution Conditions can also be calculated. A Risk Condition can be calculated when the Present Condition, as well as the Evolution Condition, are available. These parameters help to define and prioritize the structure's needs for repair.

This system improves on the existing methodology for the evaluation of the condition of coastal structures, adding in productivity and minimizing mistakes, by saving the time previously used in inserting, into the computer, all the information that was gathered, on paper, during a visual inspection. It also enables the integration of all the relevant information, in the evaluation of the condition of coastal structures, into a single platform, instead of having the photos and the alphanumeric information completely separated. Moreover, the system facilitates the overall process of collecting data during visual inspection as well as accessing and visualizing them later on desktop (and other mobile) platforms.

This work results from a collaboration between researchers of the Portuguese National Laboratory for Civil Engineering (LNEC) and the NOVA Laboratory for Computer Science and Informatics (NOVA LINCS).

2 CONCEPTS

Ports are infrastructures where wave tranquility is mandatory in order to enable mooring, loading and unloading of ships and also to ensure the safety of people, goods and the ships themselves (Fortes, 2015). Ports were initially installed in naturally sheltered areas such as bays, estuaries and areas protected by islands. However, more recent harbours have been created in less protected regions, which led to the need for protective structures.

Ports can be classified according to type, location, use and size. We can highlight three types of ports:

Natural. ports are those where improvement works are not necessary to guarantee the shelter of the port and the access to the berths, since the natural conditions already provide these guarantees;

Artificial. ports are those where it is necessary to construct structures to improve the shelter and the conditions of access of ships to the berths;

Semi-natural. ports are located in a cove or are protected by promontories on both sides, and only necessary to ensure an artificial protection at their entrance.

Ports are composed of:

- Protective works (breakwaters, jetties and others);
- Access and navigation channels;
- Docking structures - to moor ships, transfer passengers and move and store goods;
- Earth facilities.

In the context of the platform presented in this paper, one will focus on rubble mound breakwaters. A breakwater is an obstacle that reduces the action of waves in the area sheltered by the structure. The action of the waves is reduced by a combination of reflection and dissipation of the energy on the breakwater protective structure. In broad terms, breakwaters can have the following goals:

- To protect port facilities;
- To enable the mooring of ships and their safe loading and unloading;
- To help in the control of sedimentation, in guiding the currents and creating areas with different rates of agitation;

- To protect water outlets from thermoelectric power plants and the coast line against the action of tsunamis.

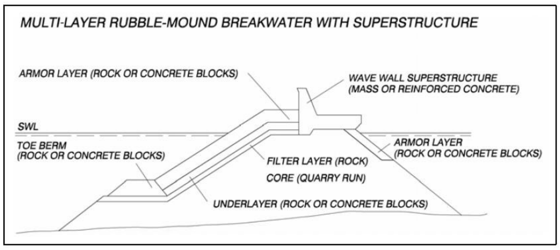

Figure 1: Rubble-mound Breakwater structure.

These structures may be divided into several types:

Rubble-mound Breakwaters. are the most common port protection structures that exist in Portugal (Lemos and Santos, 2007b). A rubble-mound breakwater has a trapezoidal shape (see Figure 1), with a core of undifferentiated loose materials that is protected by one or more layers of possibly different types of material, also loose. They are easy to build and maintain and efficient in dissipating wave energy;

Vertical-front Breakwaters. Vertical-front breakwaters are another major class of breakwater structures (USACE, 2006). The basic structure element is usually a sandfilled caisson made of reinforced concrete, but blockwork types made of stacked precast concrete blocks are also used. Caisson breakwaters might be divided into the following types:

Conventional, i.e., the caisson is placed on a relatively thin stone bedding layer (Figure 2);

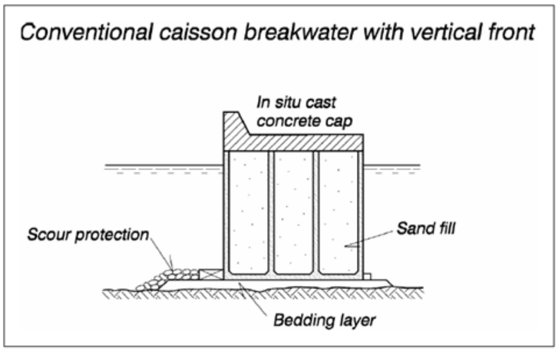

Figure 2: Conventional caisson breakwater with vertical front.

Vertical Composite, i.e., the caisson is placed on a high rubble-mound foundation (Figure 3). This type is economical in deep waters. Concrete caps may be placed on shore-connected caissons;

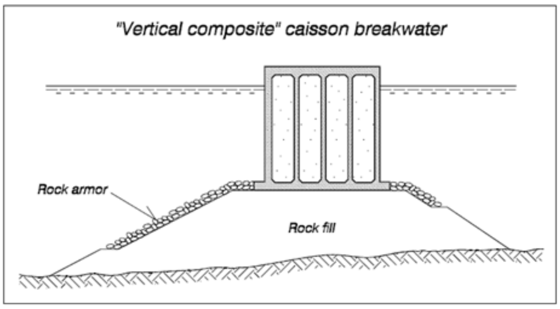

Figure 3: Vertical composite caisson breakwater.

Horizontal Composite , i.e., the front of the caisson is covered by armor units or a rubble-mound structure (multilayer or homogeneous) (Figure 4). This type of breakwater is typically used in shallow water; however, there have been applications in deeper water where impulsive wave pressures are likely to occur. The effects of the mound are reduction of wave reflection, wave impact, and wave overtopping. Depending on bottom conditions, a filter layer may be needed beneath the rubble-mound portion;

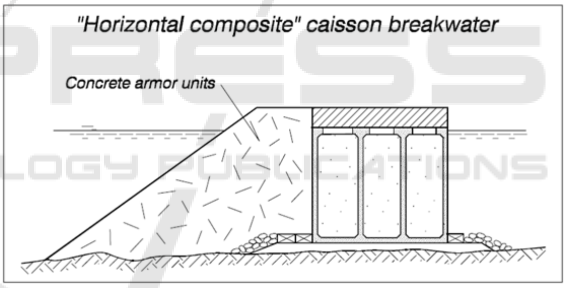

Figure 4: Horizontal composite caisson breakwater.

Coastal structures, particularly breakwaters, are structures to which a great risk is assumed at the design stage, due to the degree of uncertainty associated with the demands themselves and the characteristics of the materials used in their construction (Oliveira et al., 2005). Although this risk is assumed, since a possible collapse is not generally associated with the loss of human life, economic cost is, as a rule, very high.

It is known, therefore, that during the lifetime of the structure, repair works will be necessary as well as maintenance, due the fatigue of the parts and of the materials involved in the construction. However, in order for these interventions to be effectively carried out in time and at the lowest possible cost, the systematic inspection of the structures is highly recommended.

This is the main reason for the implementation of the software platform presented in this paper.

3 RELATED WORK

One of the goals of the work presented in this paper was to develop a WebGIS application to facilitate the task of collecting information during a visual inspection of the monitored structure. Moreover, the system should allow access to the stored information on the evolution of the condition of the structures over the years, enabling the comparison of the Present Condition of one structure with its stored condition, determined at an earlier relevant date (5 years before or at an earlier date, if repairing works took place). Previous related work has been accomplished with the aim of collecting and storing, in database format (in Microsoft Access), the data collected in previous inspections. This database was called ANOSOM and has been in use, these last years, by the researchers of LNEC.

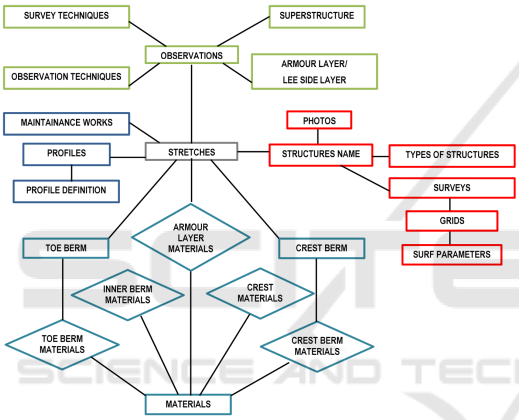

Figure 5: ANOSOM database tables' relationships.

The first version of the ANOSOM (Reis and Silva, 1995) database was developed in 1995, with the double goal of storing all the information gathered in visual inspection campaigns on coastal structures carried out by LNEC and facilitating the diagnosis of the problems presented by each inspected structure, in order to identify potential needs for maintenance or repair work. The collection of qualitative information related to the deterioration of the breakwater materials in profile elements, which can only be obtained through visual inspection, is of major importance in the evaluation of the condition of these structures. It was thus decided that the ANOSOM database should contain information collected in the visual inspection campaigns, in addition to the general information about the characteristics of the structure (Lemos et al., 2002; Lemos and Santos, 2007a). Thus, the basic functionality of the 2007 version of ANOSOM application included:

1. Inserting, correcting, and deleting data;
2. Processing the inserted data in order to diagnose the problems of the structure.

Three main categories of data were identified:

1. Structure data, which includes the data relating to the conceptual division of the structure into sections, the characterization of the profile envelope elements of each of these sections and the dates of repair/maintenance work performed on those sections;
2. Visual inspection campaign data, including the content filled in inspection forms and the photographs taken during those campaigns;
3. Structure survey data, containing the coordinates of the surveyed points and the envelope surface defined in a regular mesh.

Nevertheless, it did not contemplate functionality to handle multimedia data. In fact, the photos taken during inspections were not added to the database, rather they were gathered in folders and the GeoSetter application[1] was used to access the photos metadata, such as position (latitude and longitude) and orientation of photo captures.

The platform presented in this paper reveals some similarities with the work described by (Pires et al., 2009). This work provides a spatial representation of breakwaters and sea walls of the Espinho shoreline, in Portugal, and enables the evaluation of the current condition of coastal protection structures through photos and additional alphanumeric information. However, the system's user interface does not adapt when using a mobile device and the information presented to the user does not consider his location.

Another related project is the one presented by (Marujo et al., 2013), which contemplates a database with information on coastal structures and a GIS interface which supports the georeferencing of coastal protection works. Moreover, it enables the generation of inspection forms in printed and digital format. However, this system requires an Android mobile device 4.x version smartphone or tablet. The platform presented below is not restricted to one specific operating system.

(Marujo, 2016) lists a comprehensive number of similar systems, both national and international, by looking at their particular implementation details and by describing their advantages and disadvantages.

There is also a related work consisting on a database prepared by HR Wallingford and TU Delft (Allsop et al., 2009) with the assistance of the international breakwater community, made freely available for the benefit of breakwater designers, contractors owners and developers worldwide. Although this

[1]http://www.geosetter.de/en/

database provides some technical information, like some geometrical characteristics and design criteria, as well as the owner, contractor and consultant names, its aim is not the monitoring and diagnosis of the structures.

4 IMPLEMENTATION

The developed system follows an architectural structure used in the development of WebGIS systems. It is described in the next subsection.

4.1 Architecture

The general architecture of the developed application is represented in Figure 6. It is divided into three layers: the presentation layer, the logic layer and the database layer. This type of architecture enables a separation of functionality that supports its evolution and maintenance. The tools used for the development of each layer are also described.

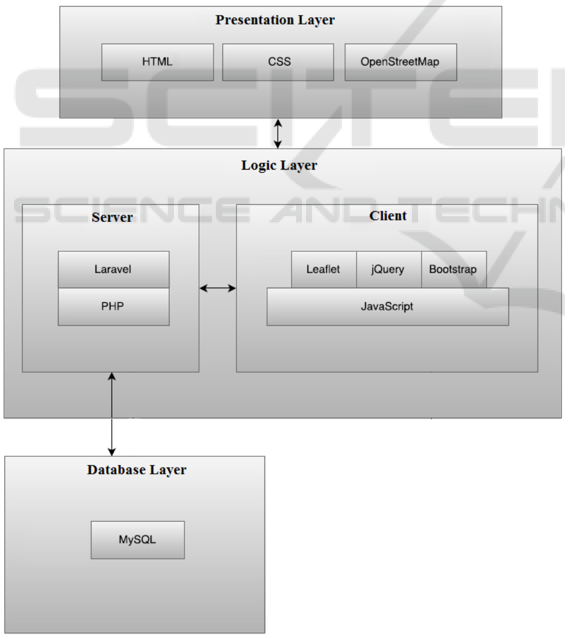

Figure 6: System architecture.

The presentation layer is the layer that enables the user to interact with the system and is developed in HTML, CSS and the base map was OpenStreetMap. HTML is responsible for displaying the elements that are present in the interface, while CSS is used to provide the style of those elements. The maps that are shown in the application, both on the home page and on the page corresponding to the photos of a section, are provided by OpenStreetMap. This is the layer through which the user interacts with the system and it is responsible for sending the input produced by the user to the logic layer, and consequently for displaying the data from the logic layer back to the user for feedback.

The logic layer is divided into two main components, the client side and the server side. The client side was developed with Leaflet, jQuery and Bootstrap, which rely on JavaScript. Leaflet allows the interaction with the OpenStreetMap map. Bootstrap is used to create a responsive interface in order to adapt to the user's device. Finally, jQuery supports the manipulation of interface elements.

The database layer is made available through the MySQL database management system, which stores all the information regarding the sections of the coastal structures, such as their characteristics, the data of the visual inspections and the various points of each section and their photographs/videos. The connection to the database is established through PHP.

4.2 Functionalities

Due to privacy concerns regarding the information handled by the system, only LNEC researchers can access it. Thus, some security measures were implemented, including password protection. After the login, the user is redirected to a page where he can now access the world map provided by OpenStreetMap. Once he accesses the map, the shapefile features, including all the breakwaters in the database, are loaded into the map. The geographic features are displayed in blue and each structure is divided into several sections. Each of these sections has a unique code that is stored in the .dbf part of the shapefile. This information allows the connection between the geographic representation of the sections of each structure, on the map interface, with their respective information on the MySQL database, enabling the contextual viewing of a breakwater section's general (as well as inspection) data.

4.3 Breakwater and User Location

One of the most important aspects regarding the visual inspections is the user's current location. Data capture is location-based, so the system must be able to associate the captured information with the correct breakwater section. To do this, the user must turn on the location identification of the device that she is using, and the system captures the user's current position, placing a red marker on the map interface. The system then tries to associate the user's current po-

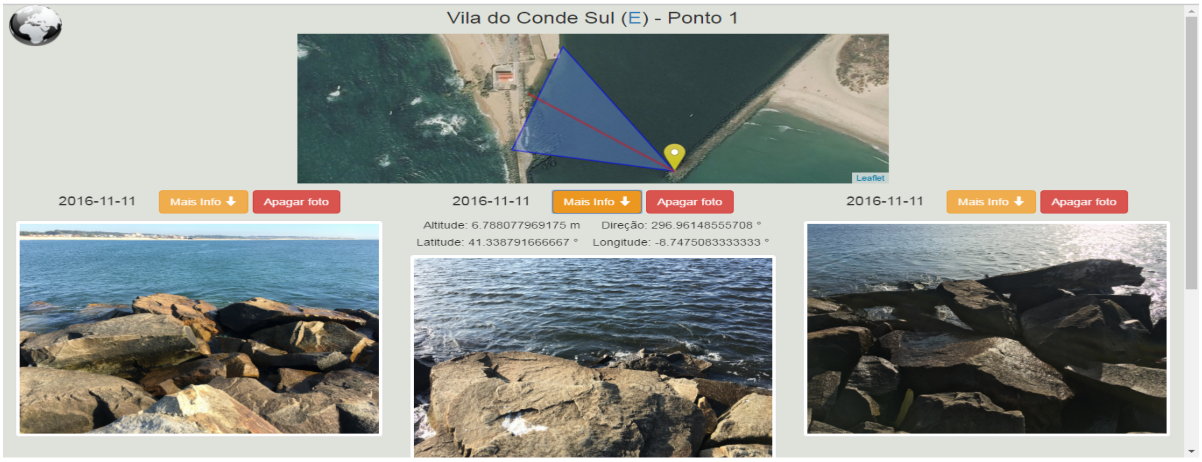

Figure 7: Photos from a section of a structure.

sition to a particular section of a structure (the one that is nearest) to be inspected. To speed up detection, only the structures that are visible on the map window, at the moment of detection, are considered for inspection. The time taken to detect the section chosen for inspection is important, as the number of structures to be added to the system is large and the search will be executed on a mobile device. The algorithm used for section selection is an adaptation of the Point In Polygon algorithm (Franklin, 2006) by W. Randolph Franklin.

Thus, once the user's location has been detected, as the user walks on a structure, the system will associate the data he collects with one of its sections. In this context, the user can either add observations on that section or define new points of observation.

4.4 Photos and Videos

Media data collection has been contemplated in the platform and, particularly for jpeg photos, it is possible to gather exif metadata from the file and directly add it to the system. Thus, when a jpeg photo is taken near a specific point of observation, the system captures latitude, longitude, altitude and orientation of the photo from the file's metadata and directly creates an association of the photo with the point. Afterwards, a request to view the photos gathered at this point of observation will include the corresponding photo. In fact, all the photos taken and collected on that point are presented to the user for viewing. Moreover, when viewing the photos, the user has the chance to check the photos' metadata, with the help of a map where the orientation of capture is displayed (see Figure 7). This feature enables the offline upload of photos into the platform, for example, when photos are taken using a particular camera and not using the mobile device.

The user can also capture and associate a video to a point of observation. However, in this case, only the date of upload is stored in the system, no metadata is loaded. The method for uploading videos is similar to the one used for photos. The user clicks on a point of observation, shown on the map, which causes the upload pop-up window to open, then presses the camera button icon (when using a mobile device), takes the photo/video (or chooses a photo/video that has been previously captured) and the file upload starts automatically. After a few moments, the photo/video is stored in a folder on the server, becoming associated with the chosen point of observation. Consequently, the file also becomes part of the observation information associated with the section of the breakwater that owns the observation point.

4.5 Information about a Rubble-mound Breakwater

Each section in a structure has very specific characteristics, as shown in Figure 8, such as its size in length and width, information about the superstructure/crown, the armour layer, the outer crest berm, the inner crest berm and so on. This information has to do essentially with the slope of the outer armour layer, the width, the values of the maximum and minimum dimensions and their materials (the type of blocks, the weight, the layout, etc). To facilitate information viewing and analysis, the section interface page 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 part. The interface has also been structured 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

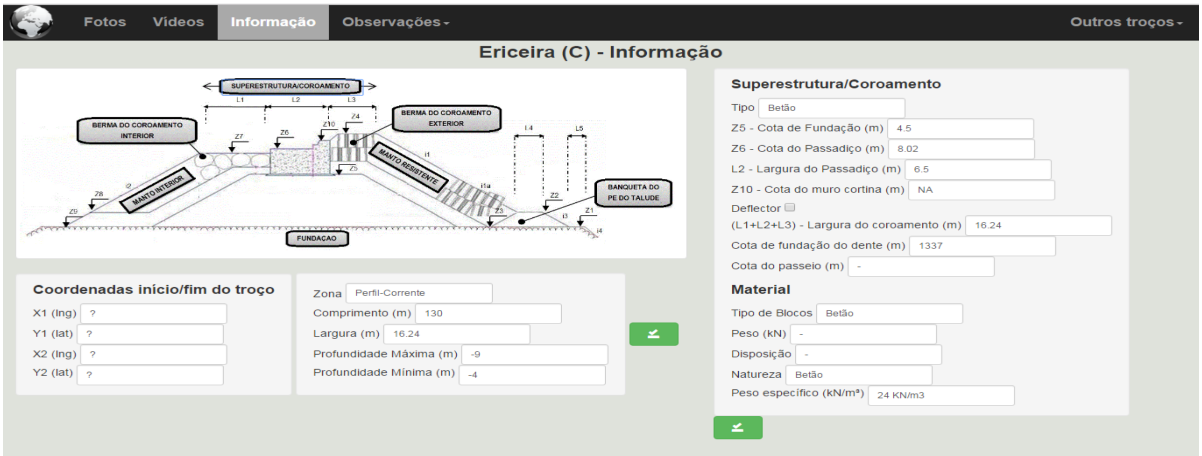

Figure 8: Information about a Rubble-mound Breakwater.

videos of the section, to access section observations (according to the selected date) and to analyse the characteristics of other sections belonging to the same structure.

4.6 Visual Inspections

Periodically, the structures are subjected to visual inspection, performed by LNEC researchers. In general, the structure is inspected yearly but additional inspections may be performed, specially after strong storms.The data collected refer to the current condition of the armour layer, the superstructure and the inner filters. To facilitate data gathering, most of these data are entered into the inspection forms via radio buttons. Predefined, qualitative, values scales have been defined as, for example, in the case of the number of unit displacements, which may have occurred, where values can be 0 (None), 1 (Few), 2 (Some) or 3 (Many). These and other values contribute to calculate the Present Condition of that part of the section of the structure, and these range between 0 and 5. LNEC researchers have developed a methodology that enables the evaluation of the Present Condition of the structure and its evolution (Santos, 2000; Santos et al., 2003). If at least two visual inspections have been performed, it is possible to calculate the Evolution Condition. The Risk Condition associated with the structure can be calculated from existing information on the Present Condition and the Evolution Condition.

5 EVALUATION OF THE SYSTEM

The aim of the evaluation process was to assess the usability of the developed platform as well as its usefulness for National Laboratory for Civil Engineering researchers in the data collection and structure evaluation activities. The methodology for the evaluation was designed with the goal of collecting as much qualitative feedback as possible, in order to obtain material for future improvements, as well as to evaluate the result of the developed application, in the final evaluation phase.

During the evaluation process, users were asked to perform various tasks in the developed system. Some tasks were to be performed on a desktop platform, while others were intended to be performed on a mobile device, as in a situation of a field campaign. After each task was completed, each user was asked to complete a questionnaire. The questionnaire was divided into two parts.

The first part consisted of the System Usability Scale (SUS). The second part was composed by specific questions related to specific functionalities of the application. The platform was evaluated by 14 non-expert users and by 4 LNEC researchers, which are the end users of the platform. The questionnaire was improved for the latter testers (there were some additional questions and some existing questions were made more specific), given the knowledge they have on the scope of the developed application.

The SUS (Brooke, 1996, 2013) was used because, as described by the authors, it provides a robust, reliable and cost-effective method for evaluating the usability of a computational tool. Because it has been widely used, it has become one of the top tools to support this type of evaluation, enabling effective differentiation between usable and unusable systems.

Another advantage of using SUS is that it is a small questionnaire, which leads to greater receptivity on the part of testers to answer its questions. SUS is composed of the following 10 sentences, each evaluated using a five-point scale, ranging from Strongly disagree (the lowest value) to Strongly agree (the highest value):

1. I think that I would like to use this system frequently;
2. I found the system unnecessarily complex;
3. I thought the system was easy to use;
4. I think that I would need the support of a technical person to be able to use this system;
5. I found the various functions in this system were well integrated;
6. I thought there was too much inconsistency in this system;
7. I would imagine that most people would learn to use this system very quickly;
8. I found the system very cumbersome to use;
9. I felt very confident using the system;
10. I needed to learn a lot of things before I could get going with this system.

Although SUS was only designed to measure usability, (Lewis and Sauro, 2009) suggest that two components can be derived from SUS - usability as well as learnability. Therefore, both components were considered to complete the overall value of the SUS, in order to provide a better perception of the total usability of the developed application. Figures 9 and 10 show the results of the SUS questionnaire for regular users and for LNEC researchers. Each vertical line represents a user and in each of those lines there are 3 values calculated based on the user's answers, the value for the overall SUS score, the value for the Usability and the value for the Learnability. Below those lines, one can see the adjective that the user chose for the user friendliness of the platform. It is a seven-point adjective-anchored Likert scale ranging from Worst Possible to Best Possible. There is a green line placed at value 68 and it represents the mean value for web interfaces according to (Sauro, 2011). A value above that line is thus considered, by the authors, above the average, while a value under that line is below average. From these graphics, the average, maximum, minimum and the standard deviation for each of the three components evaluated were calculated, with the resulting values shown in table 1 and table 2.

Both evaluation results put the platform above the 68 value, the average of the SUS questionnaire being 73.39 for regular users and 84.38 for LNEC researchers. The learnability average for regular users value is quite high (higher than the usability), which leads us to conclude that the platform learning curve is a reduced one, an interesting results for the purposes of the work, as the use of the platform in the field may often be performed by non-expert users. However, some evaluation results were not as good as the rest, which led to an analysis of the requests and suggestions provided by the testers. All the suggestions of the testers were analysed and added to the platform. Those suggestions were related with the usability of the platform. Warning and confirmation messages before deleting data were added. The User Interface also suffered some adjustments in order to become more user friendly. Geocoding was added, enabling a user to type the name of a place or city and the map becomes centered on that place. The possibility to upload videos was also only implemented after the tests. All of these improvements led to a successful improvement of the system.

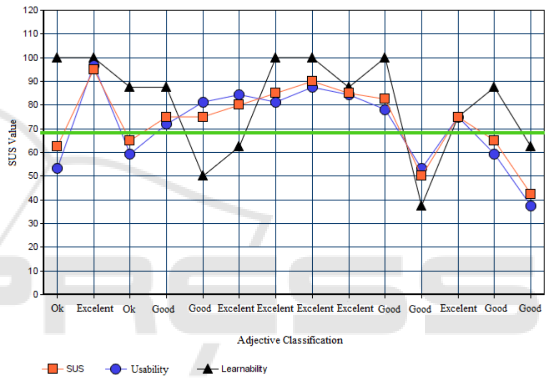

Figure 9: SUS results from regular users.

Table 1: SUS results from regular users.

	SUS	Usab	Learn
Medium	73.39	71.65	81.25
Maximum	95	96.88	100
Minimum	42.5	37.5	37.5
Standard Deviation	14.41	16.65	20.66

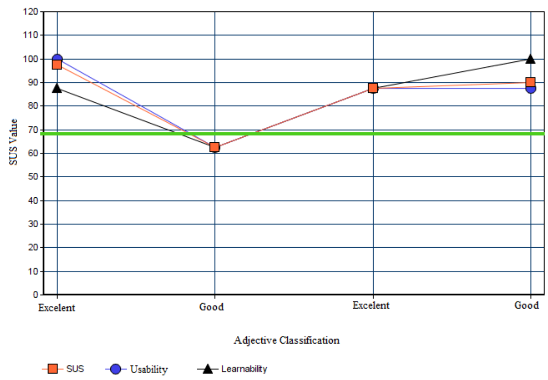

Figure 10: SUS results from National Laboratory for Civil Engineering researchers.

Table 2: SUS results from National Laboratory for Civil Engineering researchers.

	SUS	Usab	Learn
Medium	84.38	84.38	84.38
Maximum	97.5	100	100
Minimum	62.5	62.5	62.5
Standard Deviation	15.19	15.73	15.73

6 CONCLUSIONS

This paper presents the development of an online responsive platform, implemented to facilitate the visual inspections of coastal structures, carried out periodically by LNEC. The system, a WebGIS, enables the geographic visualization of coastal structures on mobile devices and lets the user collect a new observation, when located near a structure. Some of the inserted values are filled in by the user, like the type of unit displacement, the state of the armour slope, the degradation of the materials, etc. All these values are used to compute the Present Condition of a part of the section of the structure. A new point of observation of the structure can also be added, allowing the user to then associate photos or videos to it. As the photographic and video recordings are very important, this feature is crucial to the system. Also, the photos can be captured using a particular camera with no geotagging capabilities, and the association of geographic details to a point of observation can be performed offline. The system reads the metadata of jpg files, which includes latitude and longitude, and thus associates the photo to the retrieved location. The orientation and altitude are also read from the jpg file and stored in the database. To summarize, the functionalities present on the system can be divided into:

Georeferencing. Structures and their sections are displayed on a map. Points of observation of the structure are also present on the map with a yellow marker;

User Current Location. The system can geographically locate the user, using a red marker. Every 10 seconds the user location is updated and the red marker is moved, if the user has moved;

Photos and Videos The user can capture a photo or record a video, associate it to a point of observation and, consequently, to a section of the structure.

Information from a Section. Each structure is divided into several sections and each of those sections has several parts. The platform includes a visual (geographic) representation of the structure and associates structural database data with this representation.

Visual Inspections. Periodically, it is necessary to inspect the structures. The analysis may also be performed in place. Unit displacements which have occurred, fractures and degradations of materials must be considered. All these data are stored on the database and geographically associated with the corresponding location on the structure. The collected information is used to calculate the Present Condition of that part of the structure's section.

The platform was evaluated by expert and non-expert users with good results and all the suggestions and requests were added to the platform. Currently, the system is being installed at LNEC for production use.

6.1 Future Work

As coastal structures largely differ, the authors would like to update the platform to enable administrative configuration of the information viewed on the interface, so that the researchers could, by themselves, change and evolve the structure of the database. Moreover, an offline version, which would not need an Internet connection on location, would be most welcomed by the researchers and should be considered.

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