TOOLS FOR THE DIAGNOSIS AND AUTOMATED INSPECTION OF SEMI-SUBMERGED STRUCTURES

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INTRODUCTION

Rubble-mound breakwaters are quite commonly used to provide shelter in harbour basins. Due to their characteristics, these structures are designed under the proviso that maintenance and protection works will certainly be needed during the structure's life.

The cost of the structure, its expected behaviour, as well as the consequences of its failure on the harbour basin sheltering, do justify the existence of a monitoring programme which helps in the decision making process relative to the timing of the maintenance, or even repair, works. This process should be based on the structure diagnosis, which, in turn, should be based on a set of state variables.

However, the continuous monitoring of the status of any given breakwater stretch is not yet feasible. That is why the most common procedure consists of the periodic inspection of these structures. Due to the high costs of the underwater inspection, that inspection has been limited, in most cases, to the above water part of the breakwater.

This paper aims at presenting the work to be carried out by a team of researchers from the Portuguese Laboratory for Civil Engineering (LNEC) and from the Engineering School (IST) of Universidade Técnica de Lisboa, which has the following objectives:

- To develop a device able to perform high precision surveying of both the above water and submerged parts of the armour layer of rubble-mound breakwaters (or semi-submerged structures, in general). The objective is to produce tri--dimensional surveys with a spatial regularity adequate to this kind of structure;

- To condense the large volume of data from the periodic inspections into a small set of parameters that enables the characterization of the structure's status and evolution. The definition of the parameters thresholds, needed for the structure's diagnosis, will be based on LNEC's past experience as well as on results from scale model tests.

RUBBLE-MOUND BREAKWATERS INSPECTION IN PORTUGAL

The construction of harbour protection works in Portugal had a significant growth in the second half of the 20th century but, in spite of their costs, there are just a few of these structures, which, after their construction, are the subject of regular monitoring programs. The data gathered in this systematic monitoring, once properly processed, would improve our ability to plan out maintenance works and would provide also important information for the design of such structures.

In Portugal several studies on the safety and functionality of harbour protection works have been carried out. Abecasis (1939) describes the major problems arisen during the construction of Leixões breakwater, how they were solved as well as the observation of the structure's settlement after the construction. Castanho et al. (1974) studied the breakwaters of Aveiro and Portimão focusing on their efficiency in sheltering the harbour basins. In addition, they studied also the influence of the structures on the hydraulic and geomorphologic regimes of the surrounding areas.

The problem with those studies is the lack of systematization and agreement between the methods employed in them. This makes it difficult to have a clear picture of the phenomena involved and to define relations among them something that could enable the correct evaluation of the structures evolution as well as of their impacts on the surrounding areas.

Pita (1985) describes several monitoring techniques that can be used for rubble-mound breakwaters, the most common harbour protection work in Portugal, and presents a monitoring plan for these structures. This plan was implemented by LNEC, which, since 1985, is in charge of monitoring part of the Portuguese breakwaters. Within the scope of this program a database containing information on those structures, the results from inspection campaigns and their processing, was developed. From that processing it is possible to classify the structure status, to have an idea on its evolution and to assess its risk (Silva, 1996). Oliver at al. (1998) presented an inspection plan for rubble-mound breakwaters, very similar to that of LNEC, but covering both the structural and the functional states of the structure.

In spite of its importance, that database only contains results from visual inspection of the above water part of the structure, something of little use to detect underwater damages, which may cause problems that influence the structure's safety. In addition, there are nowadays more accurate monitoring techniques which allow the collection of information by inspecting either the above water part of the structure, Hough and Phelp (1998), or the underwater part, Prickett (1996), whose applicability to the Portuguese harbour protection works has not been investigated yet.

The inspection of the structure’s submerged part has been frequently carried out by scuba divers. Some attempts were made using acoustic probes. In this case several cross sections 40 to 50 m apart are surveyed. The problem with these surveys is the difficulty in repeating them: quite seldom the same cross-section is surveyed twice in consecutive surveys. This means that it is not possible to have a clear picture of the armour layer evolution, nor to evaluate the status of the structure.

TOOLS AND PROCEDURES FOR INSPECTION

This project aims at the development of a tool, fig. 1, denominated IRIS, for high accuracy bathymetric and topographic surveys of semi-submerged structures. In the project, a mechanically scanned sonar profiler and a 2D laser range finder will be used to survey the submerged and the remaining portions of the structure, respectively.

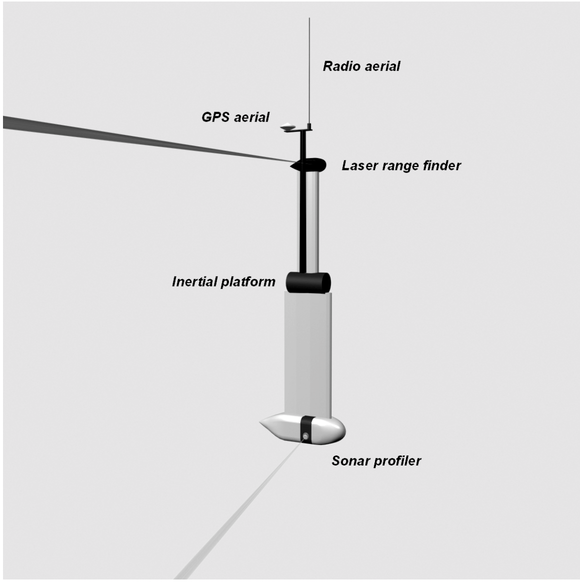

Figure 1: IRIS - a tool for high accuracy surveys.

IRIS will be equipped with the following sensors and systems:

- A high accuracy mechanically scanned sonar profiler, with a very narrow beamwidth (less than 1 degree of aperture), will allow conducting surveys of the immersed part of the structures. Using this profiler it will be possible to accurately map the submerged part of the breakwaters.

- A sidescan sonar can also be mounted on the IRIS to increase the speed of the survey although reducing the overall accuracy. This technique can be useful in the first part of the survey to identify possible areas of interest.

- A 2D laser range finder will provide data that will be used to produce the high-resolution topographic surveys of the emerged part of the structures.

- A Global Positioning System (GPS) receiver equipped with real time kinematics will measure accurately the IRIS linear position, relative to a universal reference frame, e.g. WGS-84.

- A Vertical Gyro will measure the roll and pitch angles, as well as the angular velocities and accelerations of the tool.

- A magnetic heading sensor.

- The Data Synchronization and Navigation System, responsible for the synchronization and sampling procedures of the aforementioned sensor suite, during the survey. This system receives commands from the Survey Coordination System and sends commands for positioning and triggering the different equipments on board. Finally, it computes the online corrections of the recorded profile data using linear position, motion data (e.g. linear accelerations and angular velocities), and attitude.

- The Survey Coordination System is responsible for the interaction of the IRIS with the Vehicle and Mission Control Systems of the autonomous vehicle where IRIS is installed.

- The Survey Monitoring Console will display in real time the data acquired for an in situ survey data quality assessment. Moreover, there will be installed in the IRIS a real time computer that will save the sensor data properly time and space tagged.

- The Survey Data Pos-processing Tool will process and integrate the data sets acquired during the survey mission using space and time data smoothing techniques. The final objective of the off-line data processing is to increase the overall survey accuracy resorting to sophisticated multi-rate algorithms to integrate and fuse the information obtained from the different sensors (GPS, motion and attitude). Finally, the corrected motion and position data will be used to compensate the profile data obtained from the sonar profiler and from the 2D laser range finder.

The tool to be developed includes a high accuracy navigation system that will be integrated with the precise path following control system that equips the autonomous catamaran DELFIM, Pascoal et al. (2000). During the surveys IRIS will produce transversal sections as well as dense three-dimensional data sets with the spatial regularity needed to build the three-dimensional mesh surface connecting the spot elevations. This surface three-dimensional mesh is usually denominated digital elevation model (DEM) or digital terrain model (DTM). The detailed and quantitative definition of the emerged and submerged shape of the structures, provided by the DTM, will be essential, to accurately monitoring its spatial evolution in time. Similar techniques could be used to inspect the placement of new blocks when repairing semi-submerged structures like breakwaters.

This tool (IRIS) will be specially designed to equip an autonomous catamaran owned by the Institute for Systems and Robotics of the Instituto Superior Técnico. Within the framework of this project, accurate path following control and navigation systems will be developed in order to guarantee the repeatability of the maneuvers so as to ensure the quality of the survey data sets obtained. Nevertheless, the IRIS can be used in standalone mode without the autonomous vehicle.

The autonomous catamaran, named DELFIM, is capable of following pre-assigned trajectories with a high level of accuracy. It is equipped with two back electrical thrusters and can travel at a maximum speed of 5 knots. In order to determine its position and speed it uses differential GPS and an attitude reference unit. Using the information available from its motion sensor suite the catamaran DELFIM computes its actual position and orientation and respective velocities

A real time computer network developed at the Institute for Systems and Robotics is used in the autonomous vehicle DELFIM. This network was specially designed for multi-vehicle robotic applications, uses wireless modems, and implements TDMA (Time Division Multiple Access). The network will effectively allow an operator to supervise the IRIS tool during the survey. Fig. 2 depicts the concept of the Catamaran DELFIM equipped with the IRIS, during a typical breakwater survey. The figure shows how the

Figure 2: A typical survey using the DELFIM Catamaran equipped with the IRIS

tool is placed in the Catamaran and illustrates how the 2D laser range finder and the sonar profiler can be used in a breakwater survey mission.

Due to the specificity of the project and the required high quality of the data sets obtained during the surveys, there will be a need to redesign the following systems onboard the Catamaran DELFIM.

- Mission Management System (MMS) plays a key role during the Survey Mission Preparation phase. During this phase, an operator without detailed knowledge of the technical aspects of robotic ocean vehicles can program a desired mission in a high level graphical language and have it translated into a mission program that will be compiled, downloaded to, and run in real time on the computers installed on-board the DELFIM and the IRIS. During Mission Execution, the MMS enables the operator to play a very active role in assessing the state of progress of the mission.

- Vehicle Control System: This will be of paramount importance to the success of the survey missions as well as guarantee the integrity of the platform. Only the repeatability of the maneuver will allow for the comparison of data sets obtained during different surveys. The vehicle control system will be required to execute missions with the following constraints:

    1. Low forward speed. During a mission the forward speed will be a function of the desired survey accuracy. It is the forward speed that dictates the spacing between measured points.

    2. Accurate path following parallel to the breakwater to obtain regular survey data sets.

    3. High accuracy attitude control in order to point the sonar and the laser in the desired directions.

4. High obstacle avoidance capabilities in order to safely maneuver the vehicle away from dangerous areas in case it approaches the breakwater dangerously due to strong waves, currents, or any unexpected disturbance.

The inspection techniques to develop within the framework of this project will be tested in a breakwater that will be used as test bench. Several surveys will be conducted during the project, to identify and tune the required the algorithms and tools for online data set acquisition and off-line processing. Along the different phases of the project the cooperation of the Sines Harbor authority will be of paramount importance either providing field test supporting logistics or helping setting the operational characteristics of the IRIS.

METHODOLOGY FOR THE STRUCTURE'S DIAGNOSIS

At LNEC there is already a methodology for the diagnosis of rubble-mound breakwaters based on the visual inspection of the above water part of the structure. The visual inspection programme that stimulated of that methodology has evolved according to both the available resources and the results obtained with the programme itself.

One of the objectives of the research project presented in this paper is the development of a methodology to assess the risk status of a rubble-mound breakwater based on the analysis of parameters from both the above water and submerged parts of the structure – the so-called state parameters.

This work will start with the analysis and synthesis of the available diagnosis methods. Based on that, a diagnosis method will be specified and the parameters to be measured will be defined as well as the inspection techniques and the periodicity of the measurements. Based upon data collected on both the above water and submerged parts of the structure, thresholds can be defined to enable the structure's diagnosis. In order to validate both the parameters and their thresholds, the results of scale-model tests and data from prototype measured with the instrument developed in the project will be used.

The breakwaters protecting two different harbours were selected as case studies. For these breakwaters, the available information on the environmental actions on the structure (sea waves, currents and tides) and on the structure resistance and its impact on the surrounding area (movements, deterioration and failure of the armour units, settlement of the superstructure, filling up of the structure with the sediments transported alongshore, etc.), as well as data from physical models, will be filtered and processed to get the state indicators, which reflect the safety and functionality status of the structure. All this information will be stored in an information system capable of producing the structure's status indicators.

Although LNEC has a large experience in the exploitation of scale model tests with rubble-mound breakwaters, the variables used to describe the behaviour of these structures in those models are usually the water volume spilled over the breakwater's crest due to overtopping and the number of armour units that oscillate or that are displaced from their original position in the armour layer due to wave action. Thus, it is necessary to purchase or develop a set of instruments that is able the characterize the armour layer geometry in the scale model tests. This set of instruments should produce data similar to those produced by the instrument that is to be employed in the prototype inspection.

The use of the instruments developed at project in the inspection of the breakwaters chosen as test cases will enable the tuning of both the operational performance of those instruments and of the inspection techniques based on the same instruments, namely the establishment of the most adequate dimensions for the grid used to characterise the armour layer slope. The co-operation of the harbour authorities is very important at this stage, namely in the support needed for the field campaigns and in the tuning of the instruments performance.

The inspection shall generate sets of coordinates for the points at the envelope of the armour layer slope that enable the construction of a digital terrain model for that slope and, based on this model, the definition of the relevant geometrical parameters needed for the characterization of the structure’s state.

In order to define the risk thresholds needed for the structure’s diagnosis, the following steps have to be taken: the assessment of the structure’s functions; the division of the structure into stretches based on its functional and structural characteristic; establishment of criteria for structural and functional requirements; definition of the inspection methodology; data analysis and evaluation of risk state. Each of these steps should be carefully studied, analysed and validated.

The result of all these procedures will be a validated method to analyse the risk state of any given rubble mound breakwater and a set of guidelines on the most suitable inspection procedure fro the same structure. Those guidelines shall include the definition oft he most adequate equipment, the recommended periodicity of inspection, the phenomena deserving a careful characterization and the data analysis to be carried out in order to get a measure of the structure’s actual state, evolution and risk.

CONCLUDING REMARKS

With this project, we will expect:

- Improve the accuracy and reduce the costs of bathymetric and topographic surveys of semi-submerged structures;

- Increase the efficiency of rubble-mound breakwater maintenance plans, as well as of the repair planning, with inherent reduction of costs;

- Get better information on the “in-situ” behaviour, which allows a better design of similar works in the future.

The development of an instrument able to characterize the state of harbour protection works and the establishment of a methodology for the diagnosis of this kind of structures will enable a better planning of the structures’ repairs, with the consequent cost reduction. This improved knowledge on the in-situ behaviour of these structures will certainly drive a better design of them.

An adequate inspection and a good maintenance plan for rubble-mound breakwaters will ensure their stability and functionality.

In addition, the instrument to be developed during this project to survey both the above water and the submerged parts of harbour protection works can be used in the inspection of other submerged structures, helping in the assessment of both their evolution under normal conditions and their status after an accident.

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