PHOTOGRAMMETRIC PROFILE SURVEY IN SCALE MODEL TESTS OF RUBBLE-MOUND BREAKWATERS

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Abstract

Profile surveying in scale model tests of rubble-mound breakwaters, during a test series is, somehow, a time consuming procedure.

Aiming to speed up this procedure, a photogrammetric method has been tested, as an alternative to the mechanical profiler.

This technique makes use of a software package that allows one to correct the refraction of light at the air-water interface, enabling the realization of surveys without having to empty the canal. This survey technique was already tested for two-dimensional scale models. The goal of the present work is to extend this survey technique to three-dimensional scale models.

1. Introduction

In Portugal, rubble-mound breakwaters are a very common harbour protection structure and scale model tests are still a valuable tool in their design and lay-out.

During stability scale model tests, the eroded volume from the armour layer can be determined from consecutive surveys of the breakwater envelope and the damage of the structure can be inferred from it.

Alternatively to the mechanical profiler, the measurement of the eroded volume can be carried out using a technique based upon the reconstruction of stereo pairs, in which, refraction due to the air water interface, is corrected (Ferreira, 2006). This means that it is not necessary to empty the flume or tank in order to get a good coverage of the whole armour layer with one of such pairs.

This survey technique was already tested intensively in long-term scale models for two dimensional scale models where rock elements were used (Lemos, 2010). Several tests were also carried out, aiming to measure the breakwater armour layer erosion, in which both natural and artificial units were used (Lemos *et al*, 2012).

The goal of the present work is:

- To briefly describe the performance of the photogrammetric method survey, applied to two-dimensional scale models tests of rubble-mound breakwaters, whose armour layers is a combination of artificial and natural units;
- To describe the on-going tests for the application of his survey technique to breakwaters three-dimensional scale models.

2. The Photogrammetric Method

This technique consists of identifying depth from two different views of the same scene (stereo image pairs). Since the scene-reconstruction software used, rectifies the distortion introduced by the air-water interface, it is possible to reconstruct both the emerged and submerged scenes thus avoiding the need of emptying the tank.

The photographic equipment consists of two cameras mounted side by side in a support structure

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and able to photograph simultaneously the same scene (Figure 1).

Throughout the tests herein described, we used two digital SLR cameras (Canon EOS 350D) fitted with fixed focal length lenses (Canon EF 35mm ƒ/2). This setup is capable of acquiring images with 3456 by 2304 pixels (8.0 megapixel), as well as images with 2496 by 1664 pixels (4.1 megapixel) and 1728 by 1152 pixels (2.0 megapixel).

Figure 1. Photographic equipment

Because the photographic equipment is made of two separate cameras, the separation between the lenses centre can be customizable.

Being stereopsis the base of reconstructing a three dimensional scene from a pair of images acquired from two slightly different locations, a larger separation between the two cameras lens centre should imply a better ability to reconstruct the three dimensional scene. However, the separation between the two cameras lens centre has to be kept within an acceptable size since too large separations may lead to photographing different faces of an object with each camera, which would render the scene reconstruction impossible.

In the present study, the profile surveys were carried out with a fixed separation of 16 cm between the camera lenses centre.

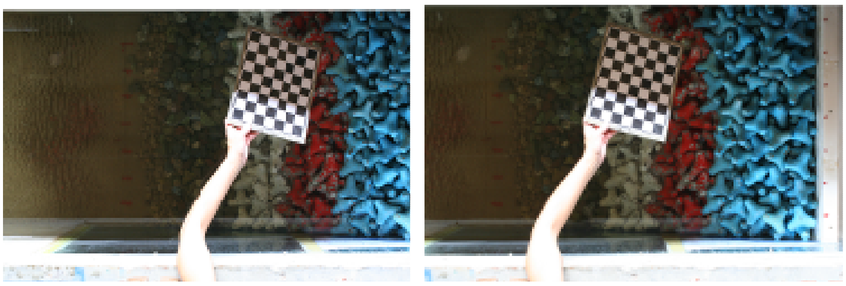
The software package available allows a complete 3D reconstruction environment, using stereo image pairs as input. It consists of two distinct applications implemented in MATLAB™ (Ferreira et al, 2005) each with a specific objective:

- Camera calibration, which consists of identifying the parameters describing the projective cameras used and their position and orientation within the observed world;
- Scene reconstruction, which consists of identifying depth from two different views of the same scene.

Camera Calibration

As camera calibration is of utmost importance in any serious precision measurement system using stereo vision, before each test session, the camera setup was calibrated. It is recommended that each session of image acquisition has its own calibration step.

The calibration process defines the metric used to measure distances and angles, as well as absolute positions in the reconstructed 3D world. To accomplish this, several shots of a planar calibration chequered pattern were taken (Figure 2).



IMG_8031_l IMG_8031_r

Figure 2. Set of stereo pairs used to calibrate the camera setup

The calibration procedure consists of clicking the inside 4 corners of the calibration pattern in a specific order (counter clockwise). The first clicked corner specifies the origin of the pattern and the second clicked corner the direction of the X axis (Figure 3).

In the present study, it was possible to successfully calibrate the system using as few as 18 stereo image pairs.

At the end of the calibration process, for each set of stereo pairs (left and right), it is obtained a file containing the camera parameters.

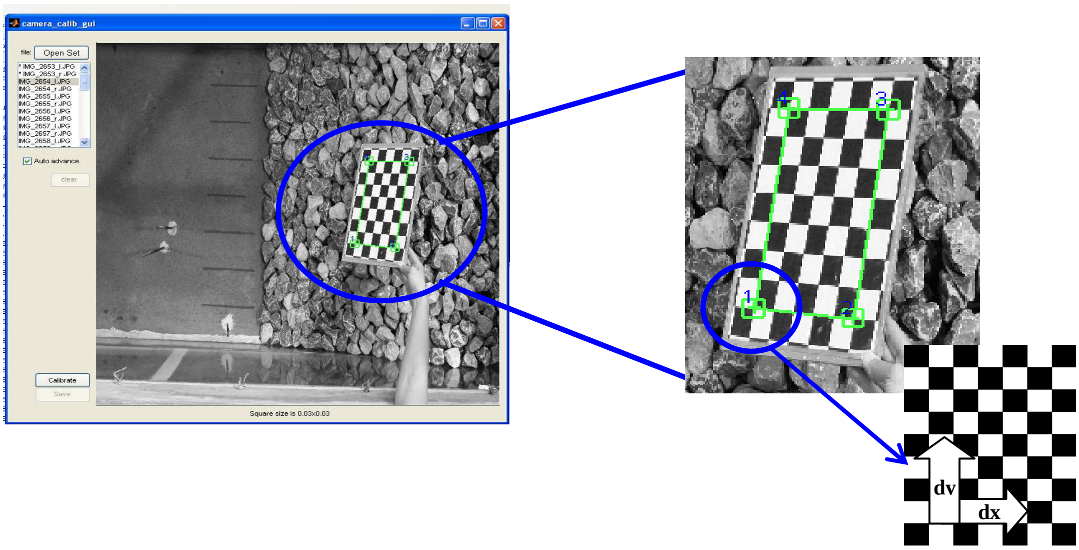


Figure 3. Clicking the inside corners of the calibration pattern

<u>Scene Reconstruction</u>

Reconstruction consists of identifying depth from two different views of the same scene (Figure 4). It is possible to reconstruct both above water and/or submerged armour slope.

The output of the package consists of a (x,y,z) file describing the cloud of reconstructed points. This is a standard file format which can be imported by various modeling tools. Using the Golden Software Surfer™, it is possible to create regular grids, enabling profile definition as well as the armour slope envelope (Figure 5).

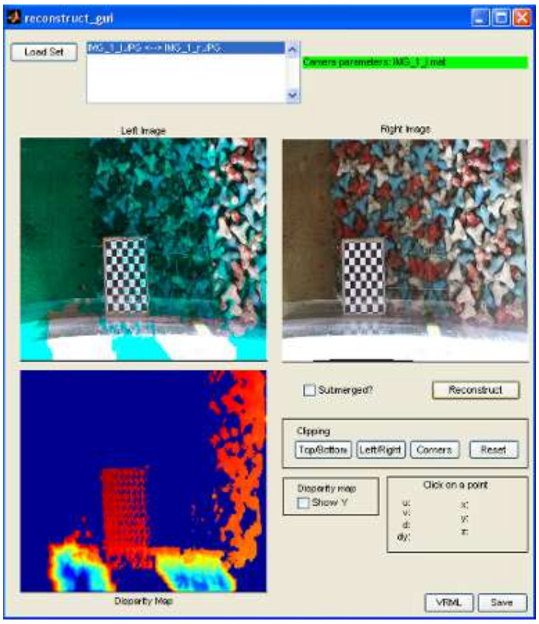


Figure 4. Reconstruction of a partially submerged scenery

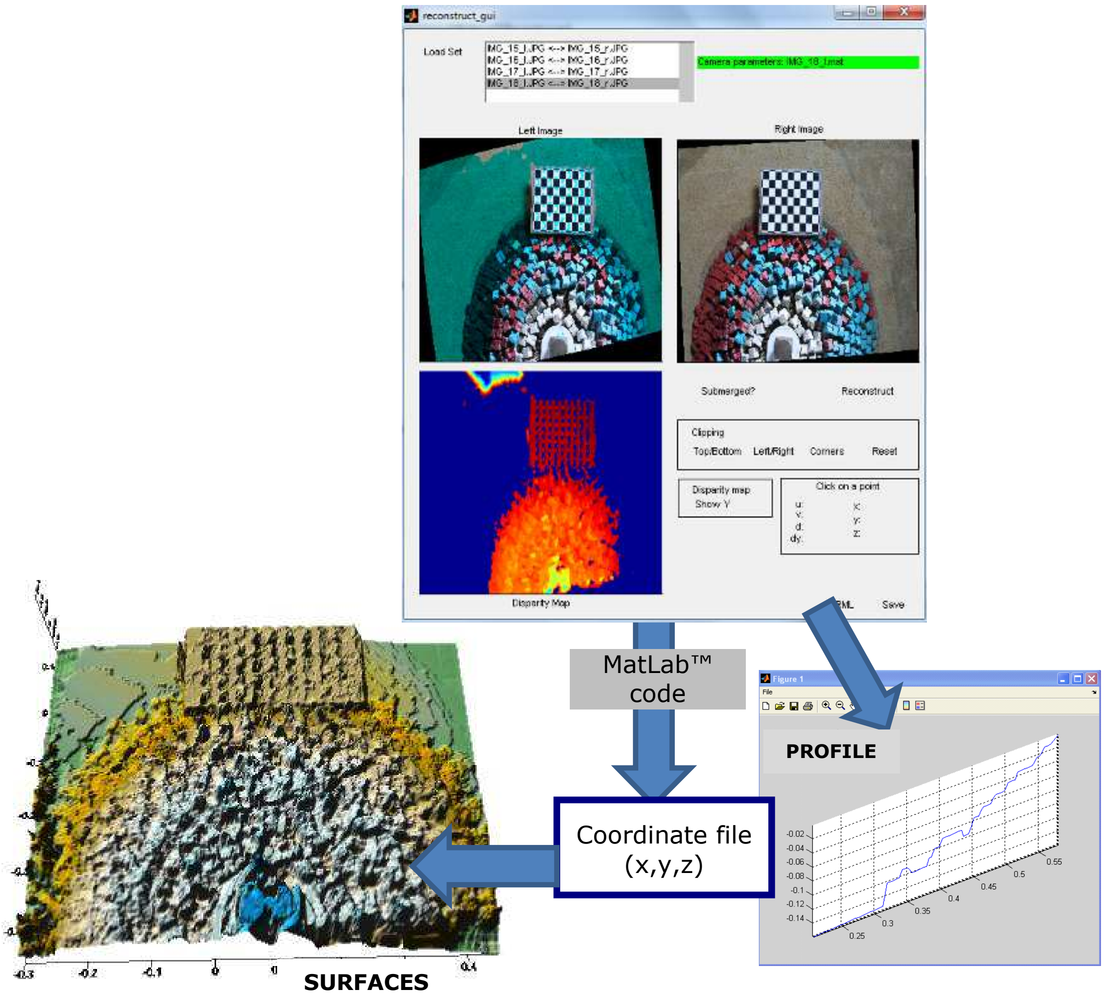


Figure 5. Profile and surface obtained from the stereo image pair reconstruction

For damage progress assessment, damage is defined as a dimensionless index ($S=Ae/Dn^2_{50}$). using profile data (Broderick e Arens, 1982 and and Van der Meer, 1988).

For each survey, it is possible to measure the eroded area, Ae, using a Visual Fortran™ code, which enables to compare each surveyed profile with the undamaged profile.

3. Physical Scale Models

3.1 Two-dimensional Scale Model

Tests were conducted in one of the LNEC's irregular wave flumes, named COI1, which is approximately 50 m long and it has an operating width and an operating water depth of 80 cm (Figure 6). It is equipped with a piston-type wave-maker and an active wave absorption system, AWASYS, (Troch, 2005), which allows the dynamic absorption of reflected waves.

The tested structure was a regular rubble-mound breakwater, comprising a quarry-run core and an underlayer consisting of a double rock layer. The armour layer and the toe berm were adjusted, in what concerns to blocks type, weight and placing mode, as well as blocks chromatic arrangement (factors which could potentially affect the survey reliability). Figure 7 illustrates some of the tested model variants.

Figure 6. Overview of the COI1 flume

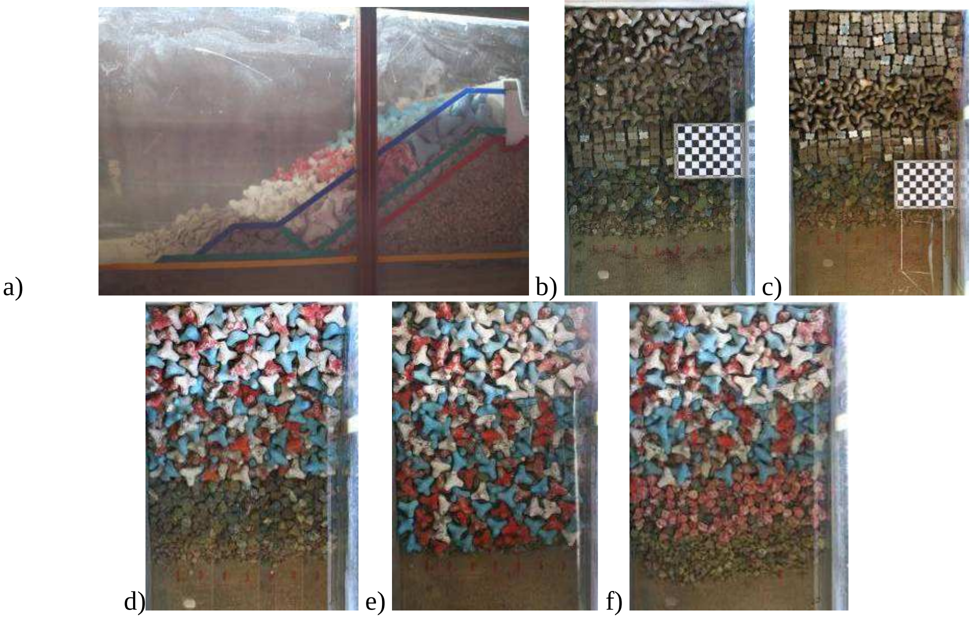


Figure 7. a) Tested profile for Variant 1 b) Variant 2, c) Variant 3, d) Variant 4, e) Variant 5 f) Variant 6

3.2 Three-dimensional Scale Model

Three-dimensional tests were conducted in one of the LNEC's irregular wave basins, approximately 40 m long and 23 m wide (Figure 8).

Figure 8. Overview of one of the LNEC's irregular wave basins

The breakwaters´s head armour layer consisted of a double rock layer Antifer cubes of 80 g. (Figure 9). The crest height, measured from the bottom of the wave basin, was of 19 cm (model dimensions).

Surveys of the breakwaters´s head section were performed with and without water in the wave basin, in order to test the mobility of the floating chequered pattern and how much this mobility affected the reconstruction quality.

Figure 9. Overview of the three-dimensional model.

The two cameras, mounted side by side in a 2 m high support structure, were plugged into laptops, being able to photograph simultaneously the photogrammetric pairs by remote triggering from the computers (Figure 10).

Figure 10. a) Set-up of the cameras b) Simultaneous photo shooting from two laptops.

4 RESULTS

In this section, some profile surveys comprising the different armour layers variants, carried out in the two-dimensional model, are graphically presented.

Preliminary tests, aiming to apply the photogrammetric method to 3D scale models, are also described.

4.1 Two-dimensional Model

Model physical conditions as well as artificial units arrangement and color patterns were optimized, in the tests performed for several armour layer variants (Lemos *et al*, 2012).

In this paper only Variant 6 results are presented, because it is the one that best represents this optimization.

During these tests, the quality of the surveys of both the armour layer envelope and of a cylindrical rock-filled structure was assessed by comparing the cylindrical structure actual size with its dimensions obtained through the survey (Figure 11).

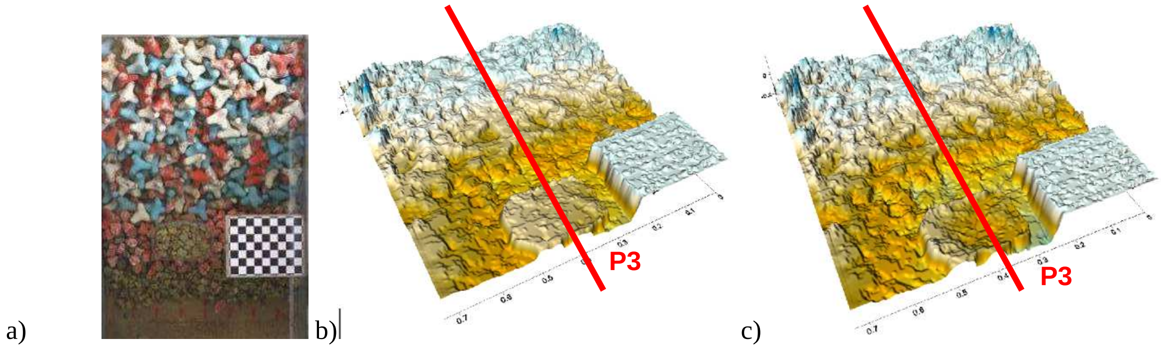


Figure 11. Variant 6 (a). Armour layer surface corresponding to initial survey (b) and final survey (c)

Both the undamaged and the eroded profile surveys are presented in Figure 12.

The survey error (difference between the actual maximum rock-fill level and its surveyed level) was of 2 mm.

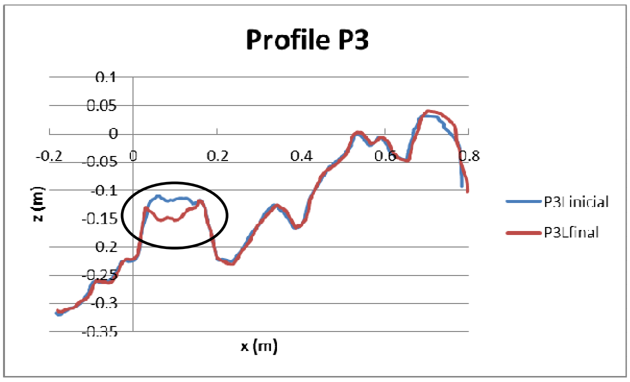


Figure 12. Profile P3. Inicial and final surveys

4.2 Three-dimensional Model

A survey was conducted with the empty tank and another one with the partially submerged model. For a better evaluation of the technique, three different profiles were surveyed;

- For both surveys: Profile P1 representing a cross-section from the bottom of the tank to the superstructure level. The cross-section actual dimensions are 19 cm high at crest level and 0.6 m wide (model values).
- For the survey conducted with the empty tank: Profile P2 representing a head profile cross-section at an armour layer level of 17 cm up to the bottom of the model. The actual section width is approximately 1.10 m.
- For the survey conducted with the partially submerged model: Profile P3 representing a head profile cross-section at an armour layer level of 16 cm up to the bottom of the model. The actual section width is approximately 0.8 m.

Figure 13 illustrates a photogrammetric pair reconstruction, obtained with the empty tank.

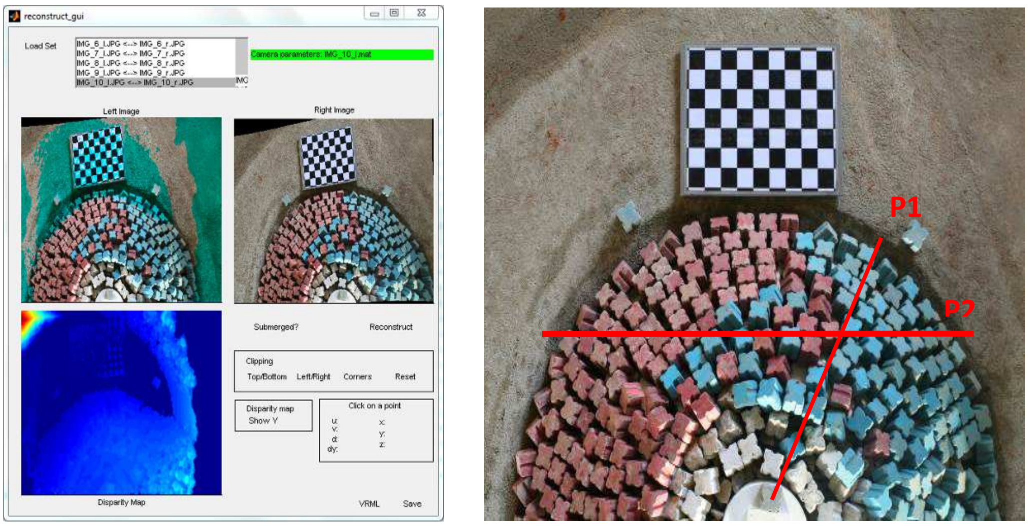


Figure 13. Photogrammetric pair reconstruction obtained with the empty tank

Figure 14 illustrates the armour layer envelope, as well as the surveyed profiles P1 and P2. In this survey, profile P1 also comprised a 3 cm height Antifer cube located on the superstructure.

Despite some deficiencies at the left side of the model, probably due to a poor color contrast of the armour layer blocks, the surveyed profiles P1 and P2 dimensions are consistent with the actual model geometry.

Figure 15 illustrates a photogrammetric pair reconstruction obtained with the partially submerged model. Some Antifer cubes were relocated, in order to provide some random color placement. A 6 cm high concrete cube was placed on the superstructure, to test the profile survey reliability.

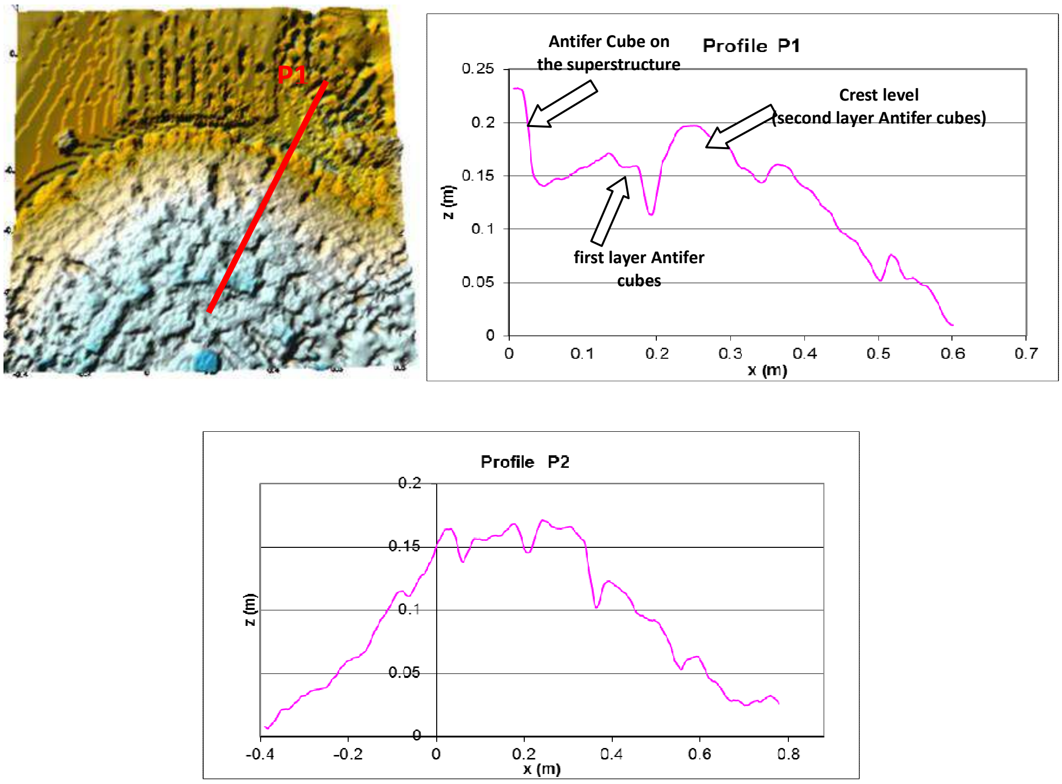


Figure 14. Armour layer envelope and surveyed profiles P1 and P2 obtained with the empty tank.

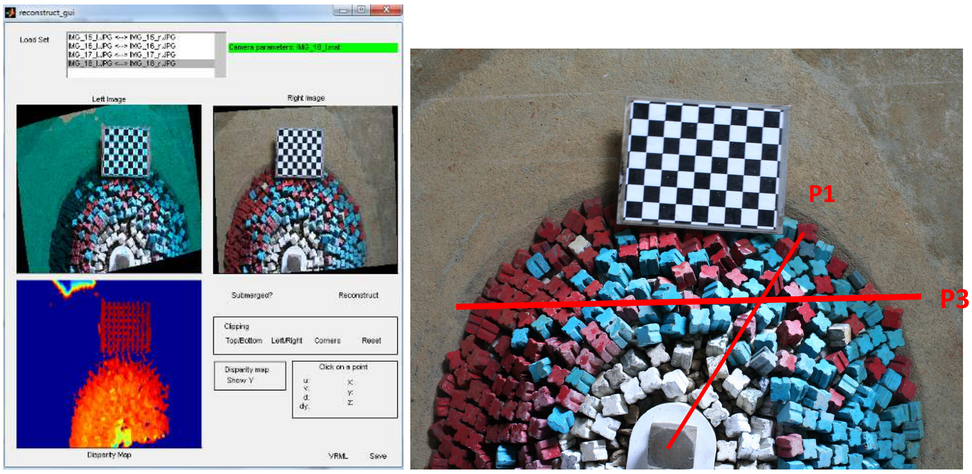


Figure 15. Photogrammetric pair reconstruction obtained with the partially submerged model

During the survey with the partially submerged model, the floating chequered pattern suffered some movements, resulting in a poorly accurate reconstruction, impeding the profile survey in the vicinity of the reconstruction right lower corner.

The concrete cube was not well represented in the reconstructed model, probably due to its poor contrast due to shadows. Despite the poor definition of the profile surveys, mainly in the right side of the model, the general geometry of the model was well represented.

The armour layer envelope, as well as the surveyed profiles P1 and P3 with the partially submerged model are also illustrated in Figure 16.

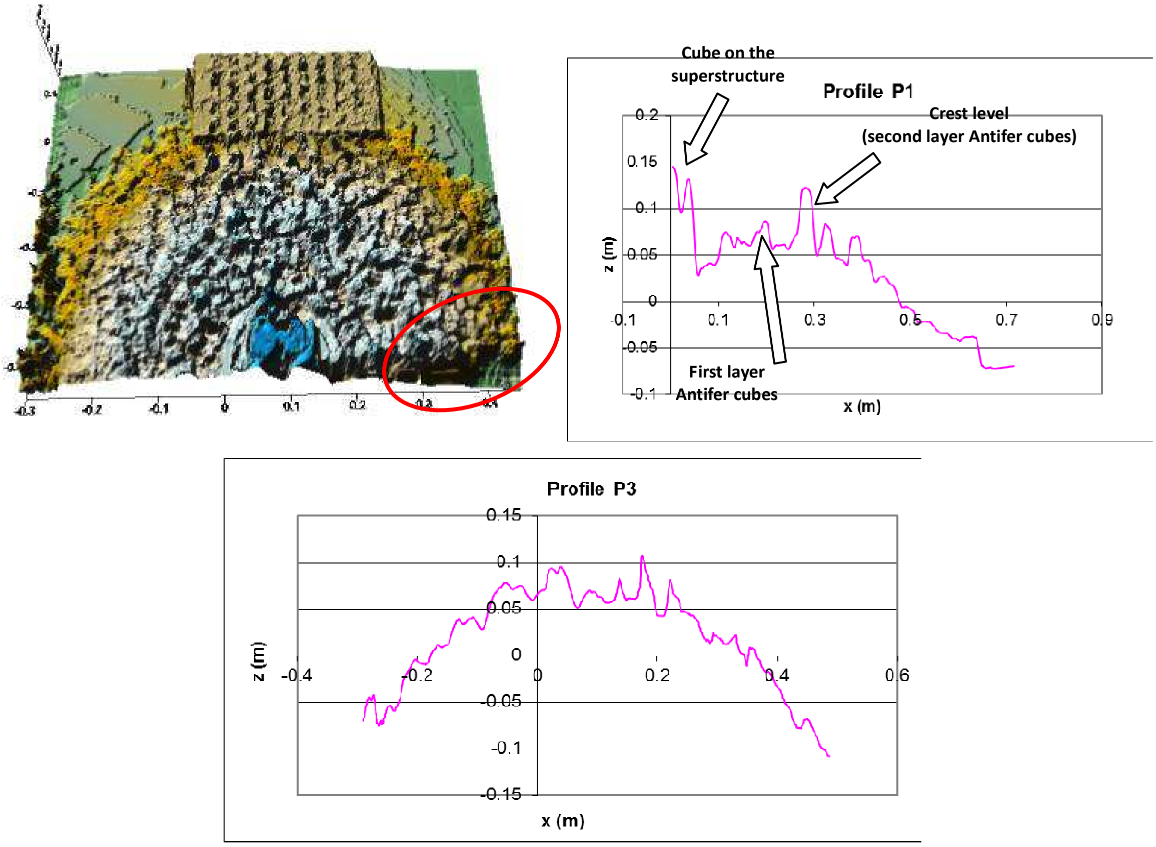


Figure 16. Armour layer envelope and surveyed profiles P1 and P3 obtained with the partially submerged model.

4. CONCLUSIONS

In what concerns the performance of the photogrammetric technique, the main conclusions arisen from the tests performed both in two-dimensional and three-dimensional models are:

- It is of simple use. Nevertheless, the camera calibration procedure should be carefully carried out, since all the following procedures depend on it;
- It requires quite cheap equipment - only two photographic cameras;
- Test performed at the 2D model, using different colour pattern arrangements of the armour layer blocks, showed that the more heterogeneous the pattern, the better the photogrammetric reconstruction;
- In the 2D model, light reflection in the water, caused distortions in the photogrammetric reconstruction;
- In the 3D model, motion of the chequered pattern caused distortions in the photogrammetric pairs reconstruction;
- For large scale three-dimensional models, it may be difficult to get an appropriate focal length, while framing the complete scenery.

In order to minimize those adversities, the following actions should be considered:

- The use of contrasting colours in the armour layer units;
- To confine the chequered pattern mobility, so as to limit it movements in all directions;
- To test the use of circular lens polarizer in order to minimize light reflection.

The present work is part of an on-going study at LNEC. The continuity of the study comprises carrying out more experiments in order to optimize the application of the photogrammetric technique to three-dimensional scale models.

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