Survey of a two-dimensional scale model of a rubble-mound breakwater using different stereo-photogrammetric techniques

Rute LEMOS, Maria HENRIQUES, António MURALHA, Ricardo JÓNATAS, Conceição FORTES, Rui CAPITÃO

Laboratório Nacional de Engenharia Civil
Lisboa, Portugal
E-mail: rlemos@lnec.pt, mjoao@lnec.pt, amuralha@lnec.pt, rjonatas@lnec.pt, jfortes@lnec.pt, rcapitao@lnec.pt

Abstract

This paper focus on the study of different methodologies for surveying two-dimensional scale models of a rubble mound breakwaters.
Tests were conducted in one of the LNEC's irregular wave flumes and comprised the use of four different methodologies using photogrammetric and structured light techniques.
This paper describes the materials and methods used during the experiments, as well as the results obtained.
Data analysis comprised profile and mesh comparison between techniques, in order to evaluate their application in scale model tests of rubble mound breakwaters. Also, the specific experimental conditions needed for using each of those techniques were investigated.

Key words: Maritime structures, Scale model tests, Damage evolution, 3D surface models Photogrammetry

1 INTRODUCTION

Breakwaters are constructed to create sufficiently calm waters for safe mooring and loading operations, handling of ships, and protection of harbour facilities. In Portugal, the most common breakwaters are the rubble-mound ones which are usually composed by rock or artificial armour units.

During the design process of those maritime structures, scale model tests are often required to evaluate their hydraulic and structural behaviour and therefore to characterize the structure's response to incident sea waves in terms of overtopping (overtopping tests) or damage in the armour layer(s) (stability tests). The assessment of damage evolution of scale-model tests of rubble mound breakwaters is traditionally determined by comparing damage profiles and by determining the eroded volume between consecutive surveys. In fact, armour layers damage is characterized by parameters based either on the number of displaced armour units as N_{od} (van der Meer, 1988) or on dimensionless parameters based on the eroded area of a profile of the armour layer, S (Broderick and Ahrens, 1982) or on the maximum eroded depth, E (Hofland *et al.*, 2014).

During stability tests, damage progression is assessed for different incident wave conditions, making use of visual observation, video and photographic techniques, or mechanical profilers when profile surveys are needed.

Image processing tools, based upon photogrammetric methods, can be a good alternative to mechanical profilers, due to its simple use and to its cost-effective equipment required. For these reasons it is increasingly used in many scientific and technological areas. However, each photogrammetric technique has its own advantages and limitations. Also, its domain of application depends not only on the specific experimental conditions (namely light conditions) but also on the post-processing tools needed to construct the 3D surface models, a key point for the success of the photogrammetric technique.

The objective of this paper is to describe and compare the use of different photogrammetric techniques to create and analyse 3D surface models made up of point cloud using both commercial and open-source post-processing tools. Within this framework, a two-dimensional scale model study was set up on the maritime hydraulic facilities of the National Laboratory for Civil Engineering (LNEC). Several techniques have been applied in this study to survey, through the use of digital images, the armour layer of the rubble-mound breakwater model using two DSLR cameras and a Microsoft® Kinect® sensor. To create the 3D surface models from the point cloud, different commercial and open-source post-processing tools were used, namely: the Microsoft® Kinect® sensor application; Python Photogrammetry Toolbox; the MicMac software and a in-house software specially developed for the reconstruction of submerged scenes. Comparison between these techniques based on the above outputs is made with the scale model dimensions in order to evaluate the accuracy and associated errors of those techniques. Also, the specific experimental conditions needed for using each of those techniques were investigated and classified.

2 PHYSICAL SCALE MODEL CHARACTERISATION

Tests were conducted in one of the LNEC's irregular wave flumes, named COI1, a 50 m-long wave flume with an operating width of 0.80 m and an operating water depth of 0.8 m. The tested model is a multi-layer rubble-mound coastal protection, consisting of a trapezoidal core covered by a 10-30 kN rock under layer, protected by a 300 kN Antifer cubes armour layer, with a 30-60 kN rock crest berm. The slope is approximately 3:2. The model was 1.2 m long, 0.75 m wide and 0.59 m high (*Fig. 1*).

The equipment used for the four survey techniques consisted on:

- Kinect sensor (model: Kinect 2.0), connected to a laptop, mounted in a camera support, able to scan the entire breakwater slope.
- A single digital SLR camera Canon EOS 600D with an EF 35mm f/2 lens handled and triggered manually, able to acquire around 50 photos the entire breakwater slope, with overlapping areas of about 80%.
- Two digital SLR cameras (Canon EOS 600D) fitted with fixed focal length lenses (Canon EF 35mm *ƒ*/2) cameras, mounted side by side in a support structure above the flume and able to capture, simultaneously, the same scene, being triggered from a desktop computer. This setup is capable of acquiring images up to 18 megapixel of resolution.

Fig. 1 Overview of the COI1 flume and of the two-dimensional scale model

For the first three techniques, the reference coordinates were given by target points deployed in different points of well-known dimensions of the model and surveys were conducted without water. For the fourth technique, the coordinate system was defined by using a checkered board with accurate dimensions, stabilized above water, with a water depth of 0.27 m. Only this last technique enables the survey of submerged scenes with light refraction correction. Fig. *2* illustrates the equipment used for the four methodologies. For the four techniques, the resulting clouds of points were manipulated with an in-house MatLab algorithm, using open-source *CloudCompare* software, and commercial *Golden Software Surfer*®.

Fig. 2 Survey equipment. SLR cameras (left) and Kinect 2.0 (right)

3 THE 3D MODELLING TECHNIQUES

Photogrammetry is the science of making measurements from photographs, especially to determine the exact positions of surface points. A special case, called stereo photogrammetry, involves estimating the three-dimensional coordinates of points on an object employing measurements made in two or more photographic images taken from different positions, where common points are identified on each image. A large range of scan techniques is also available for 3D modelling. Both techniques also enable the creation of cartographic products.

Nowadays, different commercial and open-source post-processing tools are available for a wide range of applications. In the following points, four methodologies for 3D surface modelling will be described in order to determine their pros and cons, when applied to surveys of scale models of rubble-mound breakwaters. Those methodologies are based on the application of the Python Photogrammetry Toolbox, on the Microsoft® Kinect® sensor application, on the Mic Mac software and on an in-house software specially developed for the reconstruction of submerged scenes.

3.1 MICROSOFT® KINECT® SENSOR APPLICATION

The Kinect sensor used (model: Kinect 2.0) is equipped with a depth sensor composed of an infrared projector and a monochrome CMOS (complimentary metal-oxide semiconductor) sensor wich work together to "see" in 3-D regardless of the lighting. It is also equipped with a colour VGA video camera which aids facial and other detection features by detecting three colour components: red, green and blue. It is called "RGB camera" referring to the colour components it detects. The use of structured light as a technique to generate point cloud is made by the projection of a known non-uniform light grid towards an object. The final pattern made by the IR light in contact with the object is captured by the cameras. Then, an algorithm will compare the known grid pattern with the captured one, which is distorted, and determines the distance between the sensor and each point. It produces then a depth map from which the software derives the point cloud of the surface illuminated.

The Microsoft Kinect Fusion application uses the Kinect built-in cameras and projector to generate geometrically accurate 3D models meshes (Izadi *et. al*, 2011) by applying structured light analyses technique with infrared light. This opens the possibility of rapidly and easily capturing data from objects or surfaces with high reflectivity index and in low-lighting conditions. Using the sensor and the software associated, it is possible to capture objects at distances ranging from 0.5 m to 4.5 m. According to tests performed by Fankhauser *et al.* (2015) the measured depth distortion was found to oscillate between ±6 mm.

Several kind of studies, including the comparison of clouds and meshes, demand that it is established a local reference frame As in meshes generated by Kinect Fusion is impossible to identify areas or points from the reference frame there is a need of using post-processing software to transform the mesh into a point cloud.

The cloud of the model, extracted in real-time, has 2 922 123 points. Due to a MATLAB matrix size limitation, that number was reduced to 730 531 points, which allowed a good manipulation of the points cloud.

3.2 PYTHON PHOTOGRAMMETRY TOOLBOX

The Python Photogrammetry toolbox uses multiple processes to determine a 3D model of the area of study. The first process named bundler performs the camera calibration and determines the position (x, y, z) of the camera in each photo. This process is based on the common points founded in the set of photos and on the size of the camera sensor. After the determination of the camera position of each photo is necessary to perform another process called Patch Multi View Stereo, (PMVS). This process has as input the set of photos, the coordinates of the cameras to create a 3D point cloud based on the common points of each photo. Based on the 3D cloud it is possible to create a mesh in which the set of photos will be associated, in order to create a coloured 3D model with graphical information.

3.3 MICMAC SOFTWARE

Micmac is an open-source photogrammetric suite developed at the IGN (French National Geographic Institute) and ENSG (French national school for geographic sciences). It can be used in a variety of 3D reconstruction scenarios – from small objects to large ones, like buildings, breakwaters, dams – to produce point clouds, ortho-mosaics and, from these, depth maps, digital surface models, etc. Micmac (standing for Multi-Image Correspondences, Méthodes Automatiques de Corrélation) it's a powerful and accurate tool that has, as a drawback, being of complex use. It can be used either with terrestrial photos (terrestrial photogrammetry) or aerial photos (most usually taken by digital cameras on UAV).

3.4 SOFTWARE DEVELOPED FOR THE RECONSTRUCTION OF SUBMERGED SCENES

This stereo photogrammetric technique consists in scene-reconstruction software which rectifies the distortion introduced by the air-water interface, which means that it is possible to reconstruct both the emerged and submerged scenes, thus avoiding the requirement of emptying the tank. The software package available (Ferreira *et al.*, 2006) allows a complete 3D reconstruction environment, using stereo image pairs as input. It consists in two distinct applications implemented in MatLab. The first application enables the camera calibration, which consists of identifying the parameters describing the projective cameras and their position and orientation within the observed world. The second one has as objective the scene reconstruction, consisting in estimating the three-dimensional coordinates from two different views of the same scene and has as output a reconstruction file which contains the matrixes for x, y and z positions, from which is possible to extract the point cloud and subsequently the surface and pre-defined profiles. Despite being of simple use, this technique requires a careful calibration procedure, since all the following procedures depend on it. Since surveys can be conducted for submerged sceneries, light reflection in the water should be avoided in order to prevent distortions in the photogrammetric reconstruction. The point cloud number, with 89377 points was limited by the commitment between camera highest resolution and the software code limitations. The computing time for extracting the point cloud and surface modelling for each survey is about twenty minutes for the camera calibration procedures and about five minutes for the point cloud extraction (considering an average performance PC, e.g, Intel core i5 @3.20 GHz).

4 RESULTS AND DISCUSSION

In order to compare the different survey techniques, a surface representation was conducted, using a regular grid of 0.01 m, as well as a profile extraction approximately at the middle of the cross-section (y=0.4 m). Differences between the surveyed profiles and a a theoretical profile based on the model real dimensions were computed. Fig. *3* illustrates the slope envelope obtained with each technique. Note that for the kinect sensor technique, "y" coordinates are mirrored over the "x" axis, due to the sensor inversion. Table 1 shows the average, maximum and minimum differences for surveys with the four techniques. Figure 4 illustrates depth differences between the surveyed profile with the different methodologies and the theoretical profile (an imaginary, delimitating line, created upon the model real dimensions and on its slope angle). The lower difference statistic parameters were found with the use of software for surveys of submerged sceneries. The higher difference statistic parameters were found with the use of MicMac techniques. The quantification of the depth differences between grids are depicted in Figure 5.

Table 1 Average and Maximum depth differences, related to a theoretical profile

	Depth differences related to a theoretical profile (m)			
	Kinect	Python	MicMac	Submerged
Average	0.045	0.042	0.056	0.021
Max	0.107	0.114	0.123	0.076

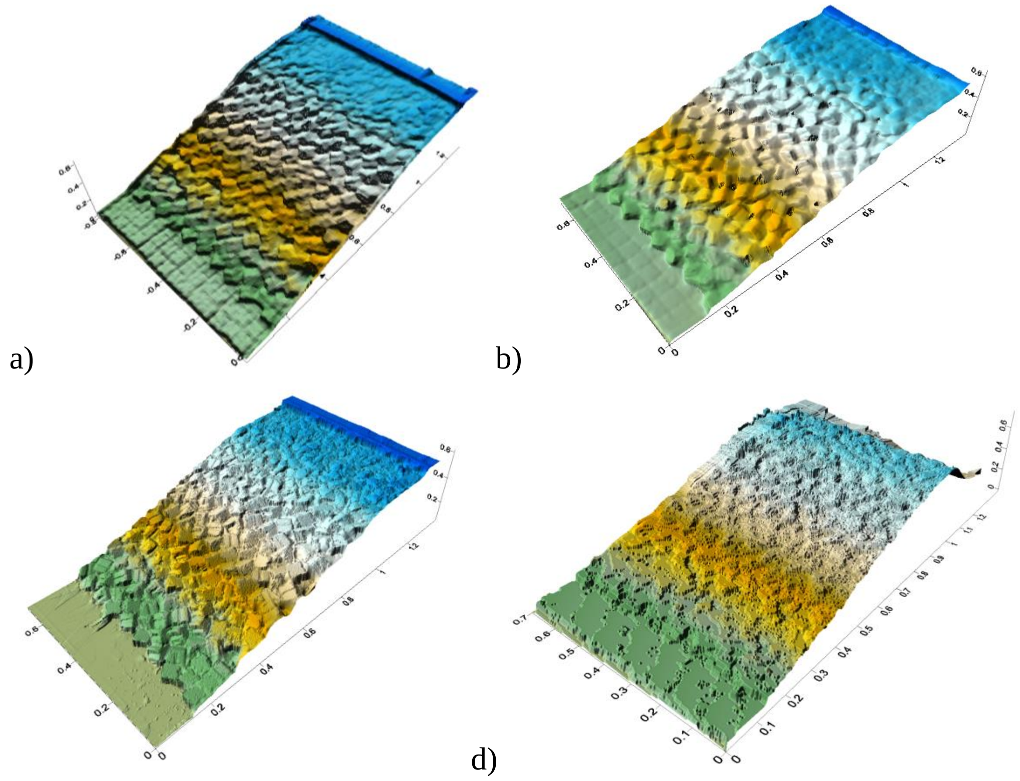

Fig. 3 Model envelope obtained with the four different methodologies. a) Kinect sensor b) MicMac software c) Python Photogrammetry Toolbox and d) Stereo photogrammetric reconstruction of submerged scenes

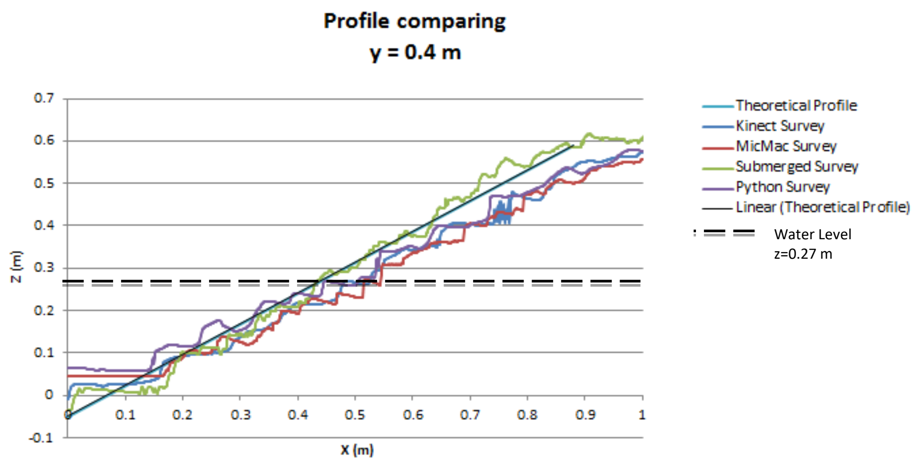

Fig. 4 Profile comparing using the four methodologies

The higher median depth difference occurred between the survey of submerged scenes and the MicMac survey and was of 0.032 m and the minimum median depth difference occurred between the survey of submerged scenes and the Python survey and was of 0.010 m (Fig. 5).

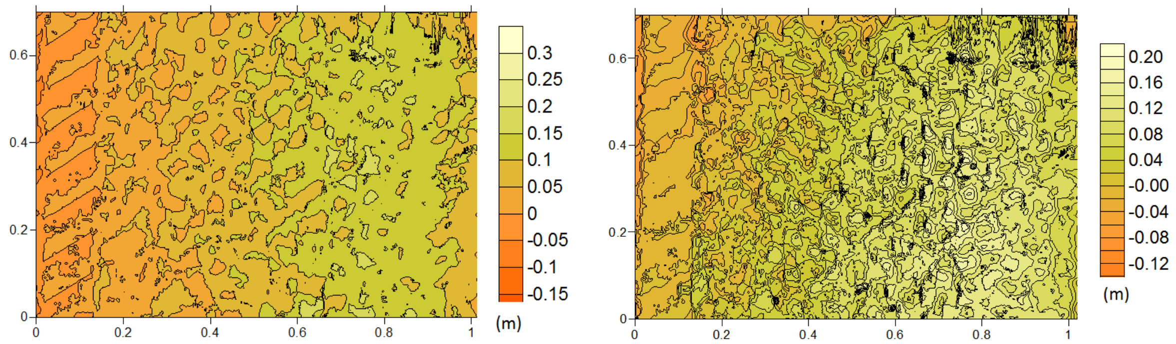

Fig. 5 Higher (left) and lower (right) median depth differences

Table 2 synthetizes the main characteristics and quantified differences of the four techniques relating to real model depths.

Table 2 Main characteristics of the four techniques

	Technique			
	Structured light with Kinect	Photogrammetry with MicMac	Photogrammetry using air/water interface correction	Photogrammetry with Python Toolbox
Number of photos/scan per survey	1	50	15 pairs for camera calibration +1 pair per survey	215
Photo processing complexity	None	High	Medium	Medium
Points in the point cloud	2.9 million	2.6 million	89 377	166 264
Point cloud post-processing complexity	Medium	Simple	Simple	Simple
Computing time with an average performance PC	20 min	Hours	25 min	Hours
Submerged sceneries allowed	No	No	Yes	No
Expected precision based on previous experiments	Better than 2.5 mm	Not yet determined	Better than 2 mm	Not yet determined
Light conditions dependency	Not very dependent	Dependent	Dependent	Dependent

5 CONCLUSIONS

The conclusions arisen from this study point that all the techniques satisfy the required precision. For breakwaters scale model surveys, a precision better than 5 mm is suitable. The computing times of the Kinect sensor and the photogrammetry using air/water interface correction are similar, despite some differences on the point cloud extraction and post-processing times. On the other hand, the surveys with MicMac and with Python Toolbox present longer processing times.

Kinect sensor revealed to be able to provide the highest density of the point cloud, which resulted in high quality images. Nevertheless, to fasten its post-processing procedures, the point cloud was reduced to a quarter of its number of points, which was fair enough to obtain well defined profiles. In what concerns to the precision obtained with the present study (0.045 m), it was lower than the expected precision based on previous experiments (0.0025 m).

In what concerns to profile analysis, despite the poor resolution of the surface obtained with the software for submerged scenes and an error of 0.04 m (greater than the expected precision, 2 mm), this technique revealed the lower differences comparatively with the theoretical profile of the testes section, with a good agreement with the slope steepness. Since this was the only technique where cameras were mounted in a support structure above the flume, the relevance of the position of the cameras should be investigated with additional surveys using the same camera position for all the survey techniques, since cameras positioned in a normal plan are favourable to sloping sceneries and unfavourable to prismatic volumes.

In what concerns to mesh differences, the higher values were found between the software for survey of submerged scenes and the MicMac software. On the other hand, the lower mesh differences were found between the software for survey of submerged scenes and the Python survey. Finally, one can conclude that the differences associated with all the methodologies are suitable for profile survey of scale models of rubble-mound breakwaters, attending the dimensions of the surveyed scenes and that all of the techniques have a fair processing time. Nevertheless, for surveys of submerged scenes the software developed for the reconstruction of submerged scenes is recommended.

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