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APPLICATION OF STEREO PHOTOGRAMMETRY TO PHYSICAL SCALE MODEL TESTS WITH MOBILE BEDS

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ABSTRACT

The phenomenon of scour in the vicinity of coastal and harbour protection structures, wind farms, offshore platforms and marine outfalls is one of the causes associated with its collapse. During the design of such structures, the prediction of the maximum erosion depth located in the vicinity of the structure is of utmost importance, requiring, frequently, a validation by scale-model tests. The objective of this study is to validate the use of stereo photogrammetry in such tests. To accomplish this goal, two sets of tests were conducted: A stereo photogrammetric survey of a well-known shape molded in a sand box was carried out in order to infer on the accuracy of the technique when applied to a sand bed. The second set of tests consisted on the survey of the scour around a pile, using the stereo photogrammetric method as well as a bed profiler in order to compare the results obtained with both methods.

Keywords: Scour/ Scale model tests/ Stereo photogrammetry

1. INTRODUCTION

During scale-model tests of maritime structures, the eroded volume can be determined from consecutive surveys. The surveyed surface can be composed by rock or artificial armour units as in the case of the armour layer of rubble-mound breakwaters or simply by sand, when the aim of the study is to assess the scour of the structure foundation.

In the case of armour layers of rubble mound breakwaters, several authors have already used different damage assessment techniques, together with visual assessment of displaced armour units. Each technique can be applied under different conditions and damage levels.

One of the usual techniques is stereo photogrametry since it is a very low budget technique, it enables the 3D reconstruction and the profile extraction.

Ferreira et al. (2006) and Ferreira (2006) proposed a method for the reconstruction of submerged scenes from image pairs using a procedure which is essentially similar to the one used in close-range photogrammetry or stereo photogrammetry. Such procedure enables the survey of the armour layer envelope and avoids the downtime associated to emptying the wave flume or the wave tank. This is a quite interesting and innovative procedure. There is notice of a similar problem being tackled by Kwon (1999) to study the motion of swimmers using a different approach. This technique was applied in different situations to evaluate the damage on physical models of armour layers rubble mound breakwaters.

The reliability and accuracy of this technique has been previously assessed (Lemos, 2010), (Contente, 2012) and (Jalles, 2013), where objects of well-known dimensions were surveyed and the results obtained were compared with the dimensions of the real-world objects. Recently, Pedro et al. (2015) assessed damage progression in scale-model tests of the toe berm of Praia da Vitória south breakwater using this technique.

Van Gent and Van der Werf (2011) studied the stability of breakwater roundheads during construction. Damage was accessed for the entire slope (toe to crest) using pictures taken before and after each test to identify stones that were displaced more than one diameter (camera overlay technique).

In Van Gent and Van der Werf (2014) scale-model tests with rock toe structures were described and a prediction method for the required toe stone was derived. In those tests, the damage to the toe structures was measured using conventional overlay photographs for the final damage numbers and stereo photography for a quick assessment and verification of the obtained damage values. Damage was also assessed and analysed by counting the number of displaced stones.

Wolters and Van Gent (2010) and Van Gent (2014) described a set of scale-model tests to assess the effects of oblique waves on the stability of rock slopes and of cube armour rubble-mound breakwaters. Damage assessment was carried out using digital overlay photographs and the displaced armor units were counted. For a number of those tests, surveys of the armor layer envelope were also performed with a mechanical profiler.

All of the previous studies considered a fixed bottom, which, in most of the cases, is not the real situation. In some case studies as, for example, piles, it is necessary to represent in the scale-model the sandy bottom since the erosion around those structures is sometimes the cause for their collapse. On the other hand, several numerical models to simulate the scour phenomena and to forecast scour depth were recently developed. A complete review on the numerical modeling advances in this area is presented by Sumer (2015). In order to calibrate those models, scale modelling is of utmost importance (Bento et al., 2016).

Several methods, like laser scan, bed profilers and photographic techniques have been used in order to survey scour transects.

In Prepernau et al (2008) the scour around a monopile was studied in a large scale facility, using a digital camera fixed on a vertical lift system inside a 7 m high and 0.55 m diameter monopile. The digital images, taken by the camera in time steps of some minutes during the tests, were transferred online by a telemetric system to a computer enabling the measurement of the eroded depth.

D'Alessandro et al. (2010) conducted a set of scale model tests of dune erosion, where measurements were carried out using a mechanical profiler. Photogrammetric surveys were carried out in the rear side of the dune, in order to evaluate topographic changes due to overwash action.

Apart from being a very expensive equipment, laser scan and bed profilers have some limitations. In fact, laser surveys require the flume to be empty, resulting in a time consuming technique. Bed profiler surveys require additional equipment to move the profiler within the study area.

Santos (2015), following the work of Lemos (2010) and Pedro (2015) applied the stereo photogrammetric developed by Ferreira (2006) to survey a sandy bottom where some artificial blocks were placed. Although those tests showed the potentialities of this technique, the survey technique reliability and precision were not quantified.

The objective of the present work is to apply the above technique to sandy bottoms and well-known shapes, in order to evaluate its perfomance. For that, two surveys were considered, the first one, without water, consists on moulding the bottom of a sand box with shapes of well-known dimensions and the second one, with water, consisted on rooting a pile on the sand bottom, where scour was simulated and compared to bed profiler surveys.

2. MATERIALS AND METHODS

2.1. Stereo Photogrammetry

The stereo photogrammetric technique consists of identifying depth from two different views of the same scene (stereo image pairs).

The available software package 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 and their position and orientation within the observed world;
- Scene reconstruction, which consists of identifying depth from two different views of the same scene.

The output of the package consists of a (x,y,z) file describing the cloud of surveyed points. This is a standard file format which can be imported by various modelling tools. Using a MATLAB™ algorithm (Lemos, 2013), it is possible to create regular grids, enabling to extract the breakwater surveyed surface, as well as profile definition, in order to quantify the eroded Area (Ae). Pedro (2015) and Pedro et al. (2015) have also included an algorithm to quantify the eroded volume between two surveys. Since the used scene-reconstruction software rectifies the distortion introduced by the air-water interface, it is possible to reconstruct both the emerged and submerged scenes thus avoiding the requirement of emptying the tank.

2.2. Scale-model tests

Tests were carried out in one of the LNEC's irregular wave tanks, named TOI2 and consisted on two sets of laboratory experiments with the objective of testing the accuracy of the stereo photogrammetric technique when applied to mobile beds. A first set tested the accuracy of the technique by surveying a shape of known dimensions moulded in sand, without water. The second set, with water, had the objective of simulating the scour and compare results obtained with the stereo photogrammetric method with those obtained with a bed profiler.

In all tests, the photographic equipment consisted of two cameras mounted side by side in a support structure and able to photograph simultaneously the same scene (**Fig. *1***). Throughout the tests herein described, two digital single-lens reflex (SLR) cameras (Canon EOS 600D) fitted with fixed focal length lenses (Canon EF 35mm ƒ/2) were used. This setup is capable of acquiring images ranging from 3.5 to 18 megapixel). For the calibration, a chessboard made of 3 cm x 3 cm squares was used.

The bed profiler model was a PV-09 Profile-Indicator WL from Delft Hydraulics (Fig. 1) with the following technical characteristics: Calibration: 10 V/m; Resolution: 0.01% of the full scale; Linearity: 0.1% of the full scale; Maximum stroke: 1 m.The measurement principle of this instrumentation is based on conductivity differences, necessarily implying that beds must remain under water during surveys.

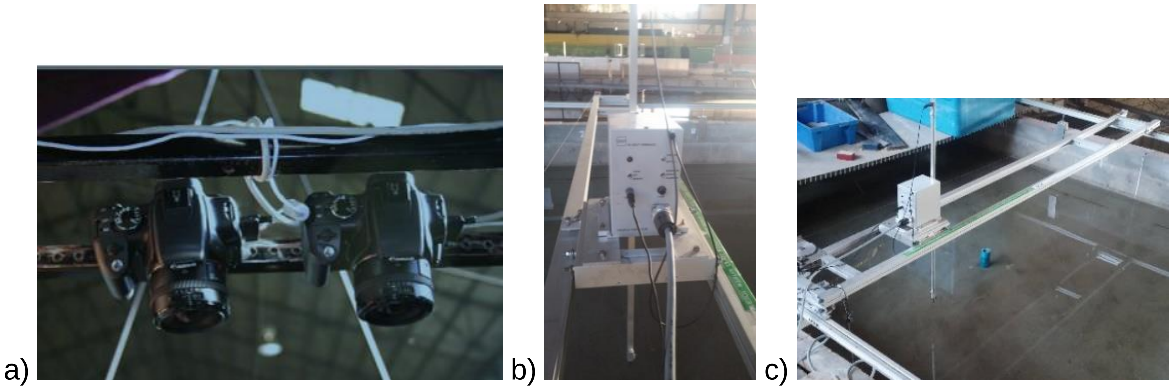
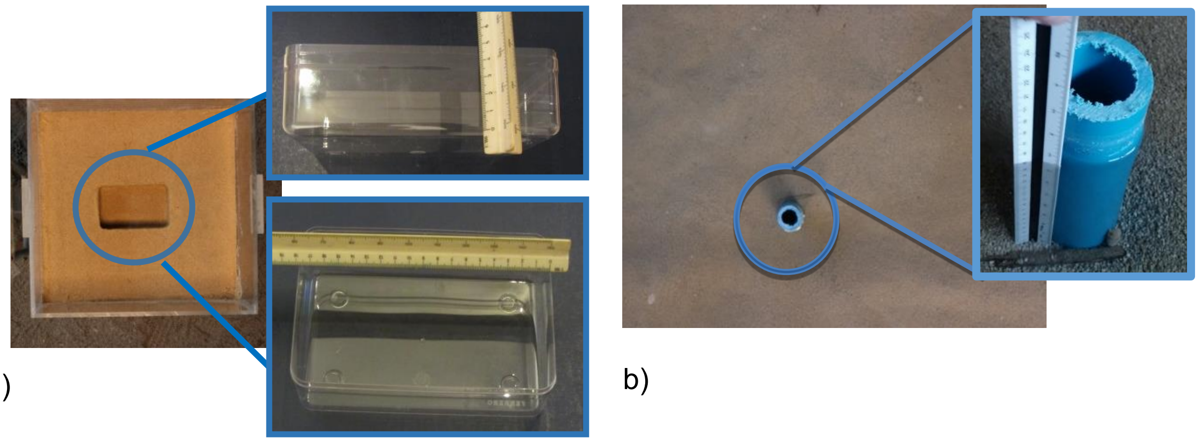


Fig. 1 - Photographic equipment; b) bed profiler; c) Set-up

The first set of tests consisted on moulding the bottom of a sand box with well-known shape. The surveyed dimensions of the moulded shape was then compared with its real dimensions (0.178 x0.111x 0.05 m), leading to the determination of the surveyed error. These preliminary tests were carried out without water (Fig. 2a).

The second set of tests consisted on rooting a pile on the sandy bottom, where scour was simulated (Fig. 2b). Subsequently, a survey of the submerged area was conducted, using both a bed profiler and the stereo photogrammetric method, aiming to compare the surveys conducted with both methodologies. The height of the submerged part of the pile was also measured with the two methodologies. The pile diameter and height were 0.06 m and 0.195 m respectively.

All tests were conducted with a water depth of 0.158 m in front of the pile, which means that the emerged portion corresponds to 0.037 m, being 95% of the pile submerged.



a) b)

Fig. 2 - Tests: a) Moulded shape in a sand box b) Scour around a pile

The image resolution used for both tests was of 2496 by 1664 pixels. The computing time for each stereo photogrammetric reconstruction of the envelope survey was about three minutes with an Intel Core i7 computer at 2.93GHz.

3. RESULTS AND DISCUSSIONS

3.1. 1^{ST} Test – Sand box survey

The surveyed surfaces were defined at a regularly spaced grid (0.0005 m in the x direction and 0.0005 m in the y direction) by linear interpolation of the points in each cloud of the reconstructed scenes.

Fig. 3a presents the 3D reconstruction of the moulded shape in the sand box as well as the location of the surveyed profiles in the model. Despite some distortion caused by shadows, the surveyed transects at P1, P2 and P3, presented in Fig. 4, demonstrate that the reconstruction dimensions were similar to those of the moulded shape. As referred above, the moulded shape dimensions are 0.178 x 0.111 x 0.05 m.

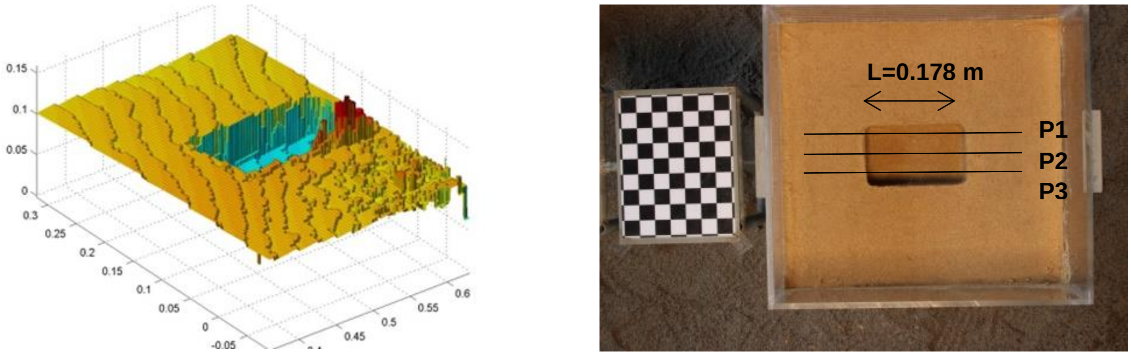


Fig. 3 - Sand box survey: a) Reconstructed surface of the moulded shape b) Location of the surveyed profiles

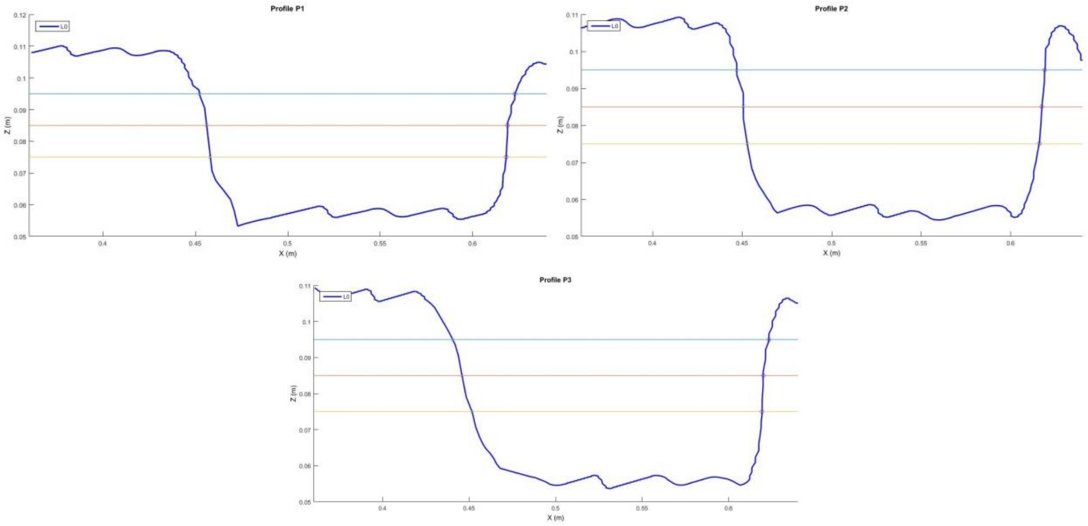


Fig. 4 - Sand box survey: Surveyed transects at a) P1; b) P2 and c) P3

For each of the three transects represented in Fig. 3a and Fig. 4, the moulded shape dimension “L” was determined for increasing depth values, in order to relate, for each section, the “L” dimension error with the depth.

From the above, it is clear that the “L” dimension error increases with the shape depth, as expected, due to occlusion problems, which are very common when surveying prismatic shapes, since a point of the reconstruction grid cannot have simultaneously two different z values, leading to survey errors. However, in this experiment the average error is around 0.0102 m, corresponding to an error of 6.14 %, when compared do the real object length. This error may be considered acceptable, having in mind that prismatic shapes are the most unfavourable cases for application of stereo photogrammetric techniques.

Table 1 presents the surveyed (x,z) values as well as the error for each transect.

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Table 1 – Surveyed dimensions and error associated with the depth

Transect	Sand box depth Z(m)	Shape depth (m)	Xleft (m)	Xright (m)	L= Xright - Xleft (m)	Error (m)	Error/ shape depth (m)	Error (%)
P1	0.095	0.015	0.4523	0.6229	0.1705	0.0075	0.499	4.39
	0.085	0.025	0.4563	0.6189	0.1626	0.0154	0.617	9.48
	0.075	0.035	0.4580	0.6182	0.1602	0.0178	0.508	11.09
P2	0.095	0.015	0.4470	0.6191	0.1721	0.0059	0.394	3.44
	0.085	0.025	0.4506	0.6174	0.1668	0.0112	0.449	6.73
	0.075	0.035	0.4528	0.6159	0.1631	0.0149	0.425	9.11
P3	0.095	0.015	0.4405	0.6232	0.1827	0.0047	0.316	2.60
	0.085	0.025	0.4459	0.6199	0.1741	0.0039	0.157	2.26
	0.075	0.035	0.4517	0.6193	0.1677	0.0103	0.295	6.16
					AVERAGE	0.0102	0.407	6.14

3.2. Scour erosion around a pile

The second set of tests, aiming to simulate the scour around a pile, the surveyed surfaces were defined at a regularly spaced grid of 0.003 m in the "x" direction and 0.003 m in the "y" direction, using a linear interpolation.

Fig. 5 presents the 3D surface corresponding to the sand bottom around the pile and the photo obtained during the survey. There are also some distortion points due to shadows of the pile on the bottom.

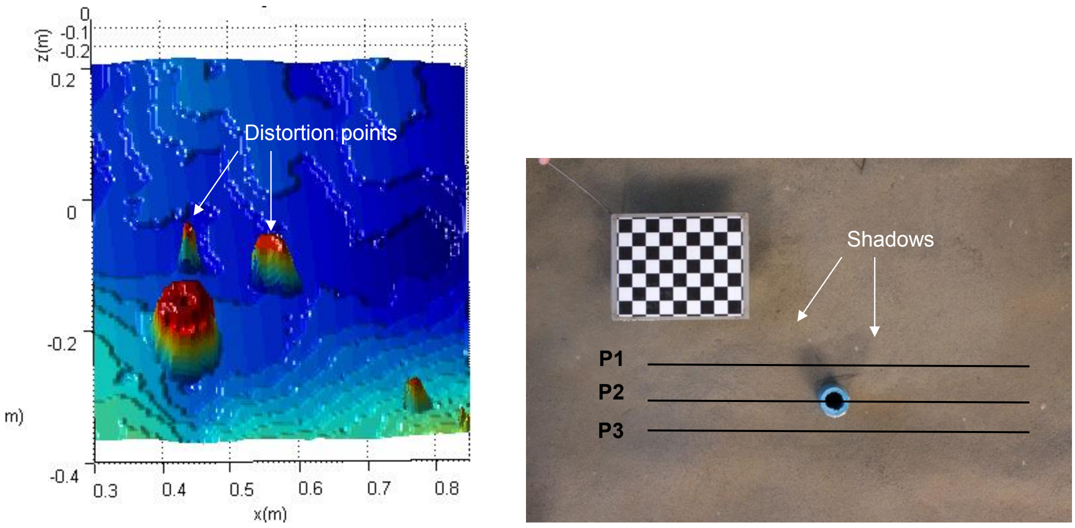
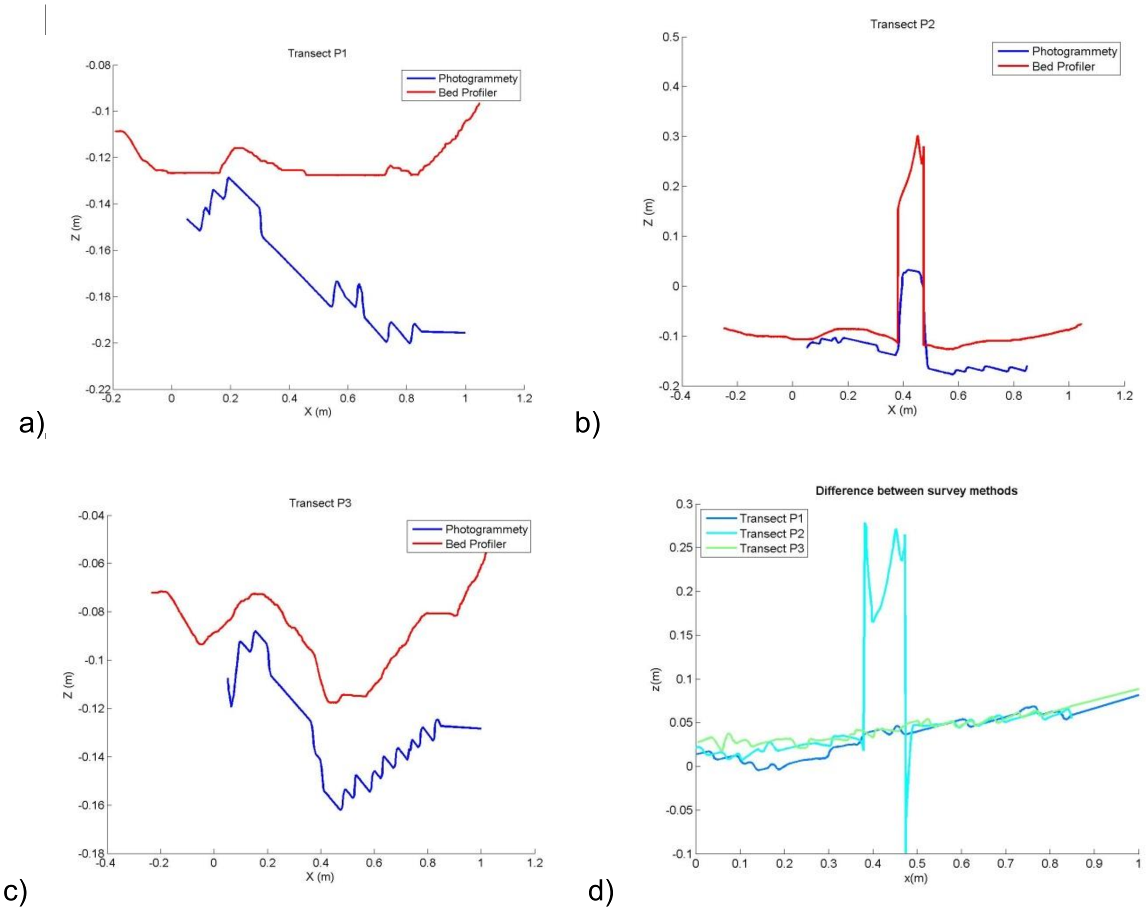


Fig. 5 - Scour around a pile: a) Reconstructed surface b) Location of the surveyed profiles

Fig. 6 presents the surveyed transects obtained using both methodologies (stereo photogrammetric and bed profiler) for the three transects defined at Fig. 5. Differences between the "z" values obtained with both surveys methods are presented in Table 2.



a) b) c) d)

Fig. 6 - Scour around a pile. a) Transects obtained with stereo photogrammetric (FP) and bed profiler (BP) surveys: a) P1, b) P2; c) P3; d) Differences between survey methods

Table 2 – Maximum and minimum differences between surveys conducted with stereo photogrammetry and with the bed profiler

	Transects		
Differences (m)	P1	P2	P3
Max	0.139	0.385	0.113
Min	0.028	0.015	0.036

The maximum and minimum differences occurred on Transect P1 and was of 0.139 m and 0.028 m respectively. Differences in transect P2 should be disregarded, as the emerged portion of the pile hampered the survey with the bed profiler requiring it to be manually moved.

In what concerns comparing both techniques with real world dimensions, the surveyed dimensions conducted with the stereo photogrammetric technique led to values consistent to the pile real dimensions. The surveyed height of the pile was around 0.196 m (Fig. 7), against the 0.195 m real world dimension, leading to an error of 0.001 m. Furthermore, the water depth estimation in front of the pile resulting from the stereo photogrammetric survey is consistent with 0.158 m. Nevertheless, all the surveys conducted with the bed profiler led to a water depth of around 0.10 m, which represents an error of about 0.058 m.

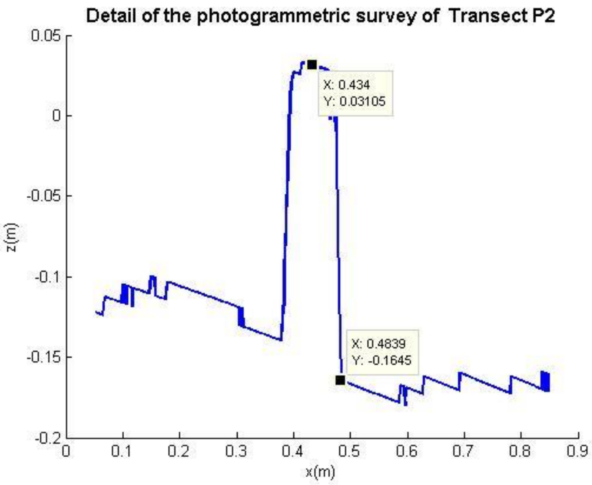


Fig. 7 - Detail of the stereo photogrammetric survey for Transect P2

4. CONCLUSIONS

In this paper, the application of a stereo photogrammetric technique to sandy bottoms is described.

Two sets of tests were conducted. The first set was carried out without water and consisted surveying a well-known shape (0.178 x 0.111 x 0.05 m), moulded on the bottom of a sand box which was then compared with its real dimensions, leading to the determination of the surveyed error. The second set consisted on rooting a pile in a sandy bottom, where scour was simulated. In this case, transects surveyed with the stereo photogrammetric technique were compared with corresponding ones obtained when using a bed profiler. The results from both techniques were also compared with real world dimensions, namely the water depth and the pile height.

In what concerns to the sand box survey test, the results show that the technique error in the horizontal plan is around 0.0102 m, corresponding to an error of 6.14 %.

From the tests conducted to determine the scour around a pile using a stereo photogrammetric technique and a bed profiler, the results led to the following conclusions:

- The survey conducted with the bed profiler overestimated “Z” values comparing to the photogrammetric method, with a maximum and minimum differences of 0.139 m and 0.028 m respectively;
- When comparing the results from both techniques with real world known dimensions, the surveyed water depth in front of the pile with the photogrammetric technique led to an error of 0.001 m;
- Surveys conducted with the bed profiler led to an error of about 0.058 m, for the same water depth. This technique did not allow surveying the emerged part of the pile, as it is based on conductivity differences, necessarily implying that beds/objects must remain under water during surveys;
- For surveys of partially immerse structures, the stereo photogrammetric methodology can be a useful and quite accurate tool, both for fixed and mobile bottom. Nevertheless, it requires special attention to light phenomena and water turbidity, in order to minimize reconstruction errors.

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