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Estimation of Bed Topography near the Cylindrical Pile under Breaking Waves by Close Range Photogrammetry

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ABSTRACT

Waves propagating to the shore can experience breaking in the near-shore zone which can cause sediment transport due to the large vortices and turbulence generated by broken waves. The pattern of sediment transport can be affected by the presence of slender cylindrical members forming the major components of many coastal and offshore structures. In this paper an experimental investigation was performed to measure the bed morphology due to the breaking wave impact on a slender vertical cylinder. Exact and rapid measurement of bed topography is very important in experimental hydraulics as it helps understanding of these complex processes and measured bed mapping. This can substantially aid in the design of particular projects. This paper gives a brief description of the close-range photogrammetry method that is currently available for bed mapping in hydraulic modeling. Digital Elevation Models (DEMs) and 3D maps are created; thus 3D bed figures and scouring patterns are determined.

1.Introduction

Slender cylindrical piles are the main components of coastal structures which are installed in shallow waters. Local scouring around these piles is recognized as the major cause of failure in such structures. In literature, several studies have been carried out about the scouring around the piles under wave and or current action which are reviewed in several comprehensive publications such as Chiew and Melville (1987), Sumer et al. (1992), Melville (1997), Melville and Coleman (2000), Sumer et al. (2001), Sumer and Fredsoe (2002), Sheppard (2003), Coleman (2005), Elsebaei (2013), Amini Baghbadorani et al. (2017), Chen and Li (2018), Gazi et al. (2019), Liang et al. (2020) [1-13]. However, there are a few data about the scouring around a monopile induced by breaking waves which consist of full 3D water-air-sand interaction. Bijker and Bruyn (1988) studied the scouring around a pile under combined breaking waves and current [14]. Carreiras et al. (2000) performed experiments about the scouring around a pile in breaking waves on a 1:20 slope [15]. They concluded that, “When the pile is located at the breaking point or onshore of it, global large scale bed changes, namely the formation of the bar, are superposed to the local scour processes”. Nielsen et al. (2012) studied the scour process around monopiles caused by breaking waves experimentally using regular waves [16]. They found that, “the scour was caused by turbulence generated by breaking and was diverted toward the bottom by the pile”. They monitored the development of the scour depth by a camera inside the pile and they used some point gauges to estimate bed morphology so they just recorded the maximum scour depth which was approximately about 0.6 D.

Actually bed topography measurement has a significant role in the validation of sedimentary processes in hydraulic experiments. For mapping bed surface within a hydraulic model test, several techniques are currently available: wool threads, depth pointer gauges, echo sounders, photogrammetric methods, projection Moiré and 3D bed profilers. Optical techniques such as photogrammetric methods, projection Moiré and 3D bed profilers allow measuring the whole bed surface instantly and thus experimental work can continue with lowest delays [17-21].

The photogrammetric methods and the terrestrial laser scanning instruments are now the most commonly used techniques, able to measure the bed topography. But the terrestrial laser scanning instruments are so expensive and need some special calibrations and attention. These tools are sensitive to impact which may disrupt their function in the future. On the other hand, the potential of photogrammetry has also been restricted by hardware limitations (surveying camera

and high-resolution camera) and high time consuming for subsequent image processing after the test (required special software). However, with the advancement of mobile phone technologies and improvement of mobile phone image quality, these devices can be easily used for photography instead of digital cameras. Today, mobile phones are available to all people, especially students. Therefore, the photogrammetric methods is one of the techniques to obtain high-resolution digital elevation models (DEMs) from fluvial surfaces in the laboratory and field.

Among the different photogrammetric methods, the close range photogrammetry method is one of the simplest, fastest and cheapest techniques which is also exact and convenient to provide a digital model of beds and a three-dimensional model of objects. So test timing is reduced by this method. Recently; these techniques have experienced enormous progress.

2. Materials and Methods

2.1. Methodology

Photogrammetry can be defined as the science, art, and techniques of obtaining qualitative and quantitative characteristics of objects from the images recorded. Then objects are identified and qualitatively defined by observing photographic image information such as shape, pattern, tone, and texture. This is done through a process of recording, measuring, and interpreting aerial and terrestrial photographs.

Photogrammetry involves three main steps: Data acquisition, photogrammetric procedures, and photogrammetric products. There are many methods used in photogrammetry to extract information from photos. These methods can be divided into two main groups: 1) Aerial Photogrammetry and 2) Close Range (or Terrestrial) Photogrammetry [22].

In addition, aerial photogrammetry may also be classified into three categories: 1- Analytical Photogrammetry, 2- Analog Photogrammetry and 3- Digital Photogrammetry. Digital Photogrammetry uses the same mathematical principles as Analytical Photogrammetry. However, Digital Photogrammetry uses Digital Photos. Digital Photos may come either from scanning existing analog photos or directly acquired from digital camera [20]. In digital cameras, photographic processing isn't needed. Hence it is possible to control image quality rapidly and reacquire if necessary.

Digital photogrammetry method has been used in a vast variety of applications such as morphometric measurement of corals, topographic models, archeological surveys and various topics in geomorphology and it can be used to measure and quantify the morphological change, both in laboratory canals and rivers. The capability of this method to measure surfaces in a non-intrusive way makes it a good alternative to quantify changes in sediment beds in laboratory experiments [23-26].

The method has some problems such as data processing which includes essential number of images (longitudinal and transverse coverage, low altitude and small sensor dimensions), low quality images compared to advanced cameras used in aerial photogrammetry (geometric distortions, image noise, high tilting and image elongation) and time-consuming processing (strong processing systems is needed e.g.Core-i9 7900, 64 GB RAM, GeForce GTX 1080 Ti, SSD: Samsung EVO 512Gb, HDD: 4TB WD Black).

Importing of images has also some problems that can restrict the modeling procedure:

- lack of focus
- Movement of object or camera during photography
- Existence of shiny and reflective objects
- Unsuitable lens (ultra-wide or fisheye)
- So much distortion of the lens (poor quality lens)
- Any changes on images (wrap or crop) before processing
- The low overlap on images

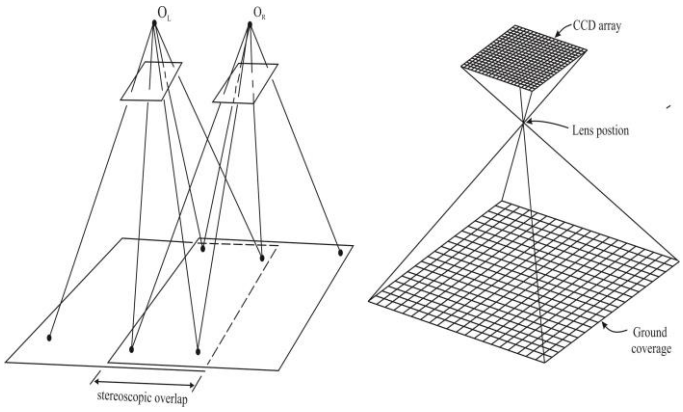

Figure 1. Digital photogrammetry; geometry of stereoscopic coverage (left), and of digital camera (right) [17].

In literature, it is verified that close range digital photogrammetry can be used to extract high quality DEMs of submerged topography in both flume and field fluvial environments, which represents a particularly exciting progress for fluvial geomorphologists [27]. Geisler et al. (2003) considered different methods including wool threads, depth pointer gauges, digital photogrammetry, and projection Moiré for river bed mapping in hydraulic modelling. They also presented instrumentation used at Hermann-Grengg Laboratories together with an example for its application on a bridge scour test [17]. Bertin et al. (2013) presented a low cost stereo photogrammetric system which was applied for gravel-bed topography measurement at the grain-scale. It demonstrates the advent of the new method, which allows data to be obtained with minimum disturbance [28]. Lo Brutto and Termini (2014) described a laboratory study in which the automatic digital photogrammetric survey was applied to derive the high-resolution Digital Surface Model (DSM) of the bed topography in a large

amplitude meandering flume. In order to evaluate the advantages of the procedure, the bed profiles obtained by the DSM was compared with those obtained using a servo-controlled vertical profiler (PV09) [29]. Bertin and Friedrich (2016) investigated the field application of Close-Range Digital Photogrammetry (CRDP) for grain-scale fluvial morphology studies [25]. Li et al (2018) applied the combination of Structure from Motion (SfM) methodology and Close-Range Stereo Photogrammetry for studying the appropriately scaled gravel bar DEMs. They showed that it is possible to collect high-quality topographic surface data by only using cameras, and alleviate the need for Ground Controlled Points (GCPs) [30]. Bento et al. (2018) studied the full characterization of the scour hole geometry around an oblong pier developed in a sand bed flume experiment by means of a Kinect sensor and a Close-Range Photogrammetry. Reliable and accurate estimates of the topographic representation of the scour hole and inherent features were obtained [31]. Karmacharya et al. (2021) applied the SfM technique on three physical model studies of different scales and objectives. They revealed that it is a cheap, quicker, easy to use and satisfactorily precise alternative for representing the model geometry especially the river bed levels [32].

In this study, digital photogrammetry is used. Project implementation process includes:

- Providing high quality Camera (Canon Power Shot SX160IS) and Surveying camera (Leica TS06 Plus 5" R500 Total Station is used)
- Installation benchmarks and field survey (six benchmarks are prepared)

Taking photos of case study (sandy bed)

- Select specifically software for photo analysis (Agisoft Photo Scan)
- Insert photos and investigate their quality
- Align photos and determine camera locations and create sparse points
- Introduce control points
- Triangulation , Self-Calibration, Error analysis
- Create sparse cloud points with classification ability and take output points
- Create mesh , geometric structure and 3D polygons
- Construct and texture action or texture action to model
- Create Ortho photo, DEM (Digital Elevation Model) and other outputs

In addition, the above mentioned points must be considered during the experiments. Hence, during the experiments, in order to prevent light reflection and obtain good photographs, the flume was drained and dried completely to allow in-air photogrammetric measurements. Also, the camera is rigidly attached to the sheet on the metal rail above the flume until there is no movement during photography. To achieve the best stereoscopic overlap, more than 22 photos were taken in every test and 18 megapixels' camera is used for the best quality.

2.2. Experimental set-up

The experiments were carried out in a well-controlled programmable wave generation facility, 33 m long, 5m wide and 0.9m deep wave flume, at Department of Coastal and River Engineering, Soil Conservation and Watershed Management Research Institute (SCWMRI), Iran. The wave flume has a piston-type wave maker at one end and rubble mound wave absorber at the other end.

The wave tank was divided into three channels: two meters and one meter wide flumes by a partition wall which was installed 10 m away from the wave generator (Fig.2). The model pile was installed in the 100 cm flume. The piston-type wave generator in the wave tank could generate both regular and irregular waves. Flume end is made by Plexiglas to view the inside of flume. In the test series, the water depth varied between 0.4 and 0.6 m.

Sediment reservoir was placed after the sloped steel section across the entire width of the flume beginning approximately 25 m(2 m long) from the wave paddle (d_{50}=0.02 cm).

Figure 2.A view of wave flume

2.3. Experimental Procedure

2.3.1. Data Acquisition

In this study a high-quality digital camera is provided for imaging on the bed which its specifications are explained in Table 1. A wooden frame and metal rail are manufactured at altitude of 1.06 m above the bed for the easy and horizontal movement of the camera (Fig.3). As the maximum number of images was 28 points so for a suitable coverage of studied area, the photos are taken in four rows with five points in each row (Fig.4).

Table 1. Camera specifications

Camera Model	Resolution	Focal Length	Pixel Size	Pre-calibrated
Canon Power Shot SX160 IS (5mm)	3456 x 3456	5 mm	1.34 x 1.34 µm	No

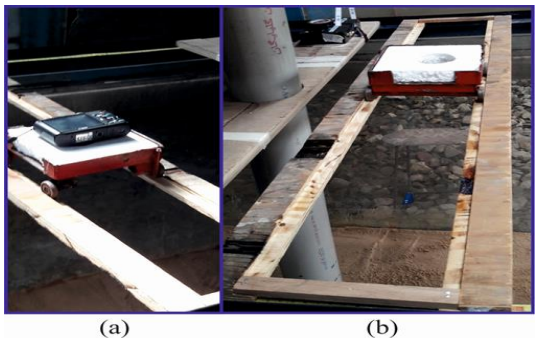

Figure 3. (a)Camera on rubber over metal rail (b) Wood frame and metal rail to set camera

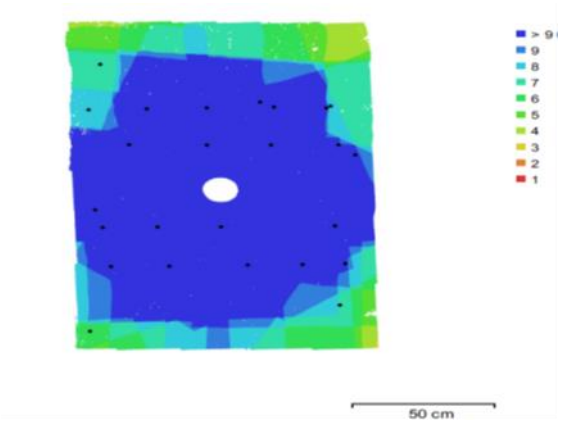

Figure 4. Camera locations and image overlap

2.3.2. Camera Calibration

Agisoft PhotoScan software (Version 1.4.5) is used for calibration. Before importing photos, inappropriate images are deleted. Then photos are aligned and created sparse cloud points. After that some points are removed based on the number of images, reprojection and reconstruction errors. Then some others with little nodal points and poor scattering points are also ignored. In the next step, optimization and calibration is made by selecting additional parameters and repeating the filtration of sparse cloud points (Fig.5).

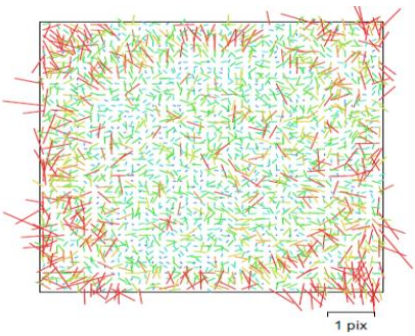

Figure 5. Image residuals for Canon PowerShot SX160 IS (5mm).

2.3.3. Ground Control Points (GCPs)

Six benchmarks are constructed with a polymer material to determine elevation on the field. Then they are numbered from 1 to 6 and are pasted on the Plexiglas and fixed on the wall (Fig.6). Leica TS06 Plus 5" R500 Total Station is used for surveying and determining of bed elevation. Then Ground Control Points (GCPs) are introduced in the software environment. It is necessary that the points' data file must be imported to the software in the text format with a specific format including point number, it's related X-Coordinate (easting), Y-Coordinate (northing), and Z-Coordinate (height). Also, the center of images' coordinate system and the control points must be the same. Then the control points' flag sign are detected and fixed on the targets for those images that they are included. Later, the aerial triangle mesh process is run and optimization step is implemented. This step involves analysis, error detection at control/check points and removal of suspicious or incompatible points and final optimization. Z errors are represented by colored ellipse and X, Y errors are presented by ellipse shape (Fig.7). Estimated GCP locations are marked with a dot or crossing. Typical control points' errors and their RMSE are presented in Table 2 and 3. Some processing parameters are presented in Table 4.

Finally, the optimized mesh with developed 3D model including its related texture or configuration, DSM including all of the sparse cloud points, orthomosaic map, point classification by algorithms and some other methods which are defined in the software and final DEM map are created. The topographic maps are not prepared in this software. They can be produced by using other software e.g. LPS (Leica Photogrammetry Suite).

Figure 6. GCPs locations on Plexiglas wall

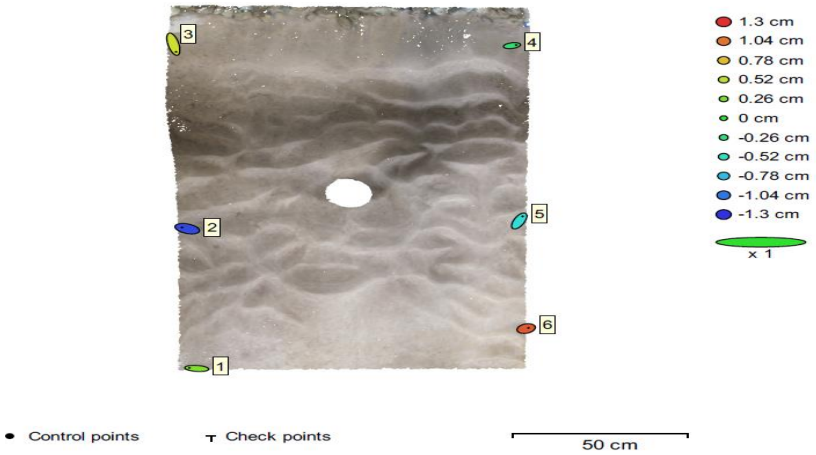

Figure 7. GCPs locations and error estimates

Table 2. Control points' errors

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
1	-4.16	0.449551	0.313631	4.19595	0.005 (3)
2	-2.97286	1.0859	-1.2054	3.38675	0.013 (7)
3	1.52083	-6.77874	0.593266	6.97253	0.002 (3)
4	2.39855	0.521058	-0.225683	2.46485	0.011 (3)
5	1.93348	4.11112	-0.62489	4.58586	0.026 (9)
6	1.28007	0.611045	1.14927	1.82559	0.066 (4)
Total	2.5686	3.28833	0.781618	4.24521	0.029

Table 3. RMSE of Control points' errors

Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)
6	2.5686	3.28833	0.781618	4.17263	4.24521

3. Results and Discussion

Finally, four output files are created: Text formatted files, AutoCAD Drawing files, files with PRJ extensions and image files with TIF extensions. In order to calculate the related data it is necessary to convert text documents to excel data. To edit the topographic map, AutoCAD data can be used. ArcGIS software can be used for generation of DEM maps (Fig.8). Also, TIF files can be opened by this software. Then they can be revised and 3D maps can be created by this software (Fig.9). The highest and the lowest bed elevations can be detected by ArcGIS software.

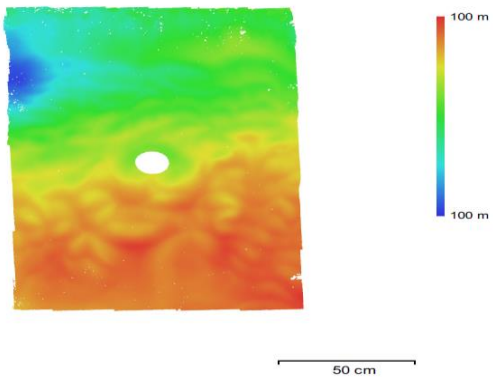

Figure 8. Reconstructed digital elevation model.

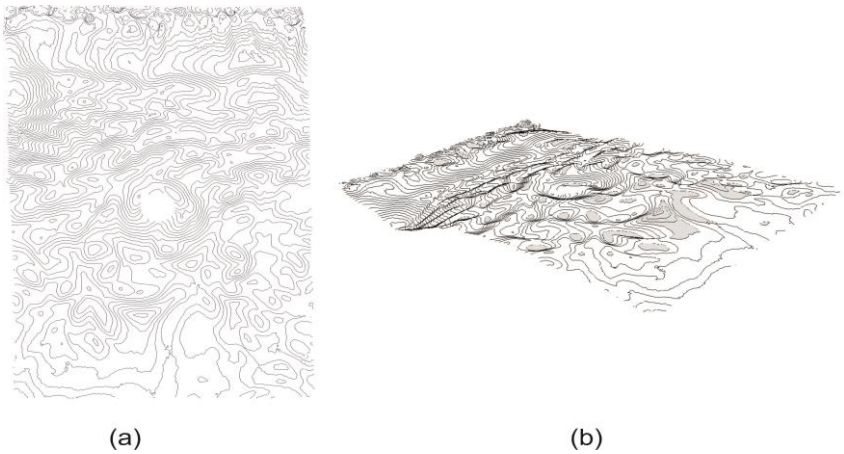

Figure 9. Topographic map with counter lines.-(a): 2D (b): 3D

Table 4. Some Processing Parameters

Parameter	explanations
Aligned cameras	26
Markers number	26
Poly lines number	312
Polygons number	158
Mean key point size	7.55644 pix
Dense Point Cloud	Points 1,769,587
DEM Size	1,565 x 1,975
Coordinate system Coordinates type	Coordinate system Local Coordinates (m)

6. Conclusion

Close-range digital photogrammetry (CRDP) is one of the techniques to obtain high-resolution digital elevation models (DEMs) from fluvial surfaces in the laboratory and field. However terrestrial laser scanning instruments are the common methods for 3D models in laboratories but they are restricted in the laboratory and are very expensive. Also, the CRDP method can be updated over time as new cameras with high resolution and new software are developed.

The CRDP is the perfect remote-sensing technique, theoretically capable of high-spatial point density and accuracy, necessary for precisely measuring bedforms' micro topography.

The CRDP can be efficiently installed in the field to collect high-resolution and high-accuracy DEMs from exposed bedforms. The only resources needed are one digital camera mounted on a rail box and some supporters. Although, this method is not suitable for underwater conditions. These terrestrial laser scanning instruments cannot be used in the field condition easily.

So the CRDP technique, is the cheapest and fastest procedure that can be used at the hydraulic laboratories and fields. In other words, this technique is simple, exact and available in any hydraulic laboratories and fields. Therefore, hydraulic researchers can use this simple method instead of expensive devices with equal accuracy. As a result, it can reduce the cost and time duration of the test. With the advancement of technology, mobile sets can be used for taking high obvious photo. Despite the technique simplicity, it has good accuracy.

In this paper an experimental investigation was performed to measure the bed morphology due to the breaking wave impact on a slender vertical cylinder. Close-range digital photogrammetry technique is applied and Digital Elevation Models (DEMs) and 3D maps are created; consequently 3D bed figures and scouring patterns are determined. Exact and rapid measurement of bed topography was the main output of this study.

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