MONITORING OF PLAYA CALDERA AND COASTAL STRUCTURES WITH UNMANNED AERIAL VEHICLES (UAV)

GEORGES GOVAERE[1], RONALD VIQUEZ[1], HENRY ALFARO[1], DIEGO CORNEJO[1]

1 Engineering Research Institute, University of Costa Rica, Costa Rica, georges.govaere@ucr.ac.cr, ronald.viquez@ucr.ac.cr, henry.alfaro@ucr.ac.cr, diego.cornejo@ucr.ac.cr

ABSTRACT

The monitoring of costal structures is required to verify that they are operating properly, to assess potential for functional and structural damage, and to correlate processes that are not contemplated in the original designs. Digital camera technology advances in combination with Unmanned Aerial Vehicles (UAV) can be used to obtain survey data using photogrammetric techniques in a precise and effective way. This approach yields high productivity in comparison with traditional methods, such as using total stations, and carries lower operational costs than LIDAR, conserving data quality.

Correlation of physical processes and changes in interaction with natural and artificial costal structures is important due to information provided. These data can be use in future circumstances to anticipate damages and changes. The current study determined the effect on the principal breakwater at Caldera Port and beach, caused by a storm. Included herein are a brief description of the UAV photogrammetric methods, the study area, the data acquisition and the limitation of these techniques. Results of the study and concluding remarks have been included as well.

1 INTRODUCTION

Traditionally, ports are built in sheltered areas created by natural morphological accidents. However, due to a need for greater depths required for larger vessels, the modern trend is to build outer ports. (Molinero-Guillén, 2010; Corredor et al., 2013). The latter are exposed to higher energy surge dynamics causing damage to protective structures, mainly if they do not have proper maintenance. Gradual deterioration can sometimes go unnoticed until it causes greater damage. These inconveniences include displacement and breakage or loss of elements, which can be controlled with proper monitoring. Periodic assessment of protective structures, such as a breakwater, provides information about the damages that could be associated with sea conditions, allowingthe determination of mechanisms of failure, and providing data to improve designs and maintenance techniques (Gómez-Martín and Medina, 2006; Lomónaco et al., 2009; Burcharth et al., 2010; Van Gent and Van der Werf, 2010).

Common methods currently used to supervise non-rebasable coastal structures are based on geomatics. Total stations and LiDAR are common for above water structures. Similarly, hydrographic methods such as single-beam echo sounders, multibeam sonar and side-scan sonar are used under water. The combined use of these techniques allows a very complete supervision of structures. However, downsides such as the low productivity of total stations or computational costs in LiDAR have not been solved yet(Gómez-Martín and Medina, 2006; Lomónaco et al., 2009; Burcharth et al., 2010; Van Gent and Van der Werf, 2010).

For these reasons, IMARES has used photogrammetry since 2015, as a method of monitoring beaches and marine infrastructures, at affordable price and with easy-to-use approaches (Govaere et al., 2016). Results that only could be appreciated with the use of aerial photographs, such as in land topography, displacement of the protection elements over time and changes in beach profile have been recorded. The presentwork focuses on comparing the results obtained from monitoring the breakwater of the Caldera port and the Caldera beach before and after a storm event recorded on Costa Rica´s Pacific coast.

1.1 STUDY AREA

Caldera beach is located on the pacific coast of Costa Rica, in the Gulf of Nicoya, at N 9° 55' 50" y W 84° 43' 16" (WGS84). Administratively, this beach is in the Espiritu Santo district of the Esparza canton in the province of Puntarenas. The port of Caldera is located on the southern portion of the beach, and its design contemplates a protective breakwater as shown in Figure 1.

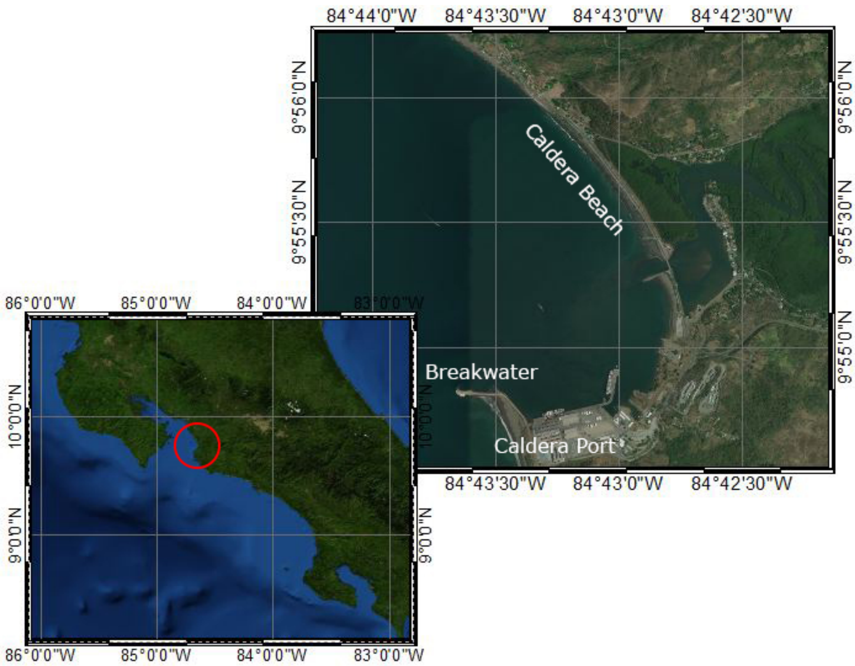


Figure 1. Location of Caldera Port.

1.2 DATA ACQUISITION

The tridimensional information was generated with photogrammetric techniques. Aerial images were obtained using a DJI Phantom 4 Pro UAV, holding a 20 Megapixel FC6310 camera, with a resolution of 5472 x 3078 pixels, a focal distance of 8.8 mm and a sensor pixel dimension of 2.53 x 2.53 µm. For land positioning and generation of control points, two GNSS Sokkia GRX1 antennas (base and rover) were used, offering a precision in RTK mode of 10 mm with 1 ppm in horizontal data and 15 mm with 1 ppm in vertical.

The photogrammetric monitoring flights took place in low tide to determine most of the measurable land contours. Control points, both fixed and mobile, were established in land before flights. Fixed points were placed on structures with long stability over time, with metal nails pointing at their center, and checked before flights. Mobile points were set using metal and wood plates (40 x 40 cm), or by painting marks in rock as is seen in Figure 2. The tridimensional positioning is calculated using GNSS techniques with the RTK measurements on all control points.

a) Control point painted on a rock **b) Control point plate**

Figure 2. Mobile control points for orientation of photogrammetric process.

Flights were carried out at a maximum speed of 5 m/s, a shooting picture interval of three seconds and a flight elevation between 30 and 60 meters above ground. These parameters allow an overlap equal o bigger to 70% between consecutive aerial photos, in a longitudinal path(Georges et al., 2016).

There are many advantages of using UAVs for surveying and monitoring of structures. In particular, multi rotor UAVs allow high maneuverability of structure inspection where conventional surveying methods can pose dangers to personnel. Also, the data products of the photogrammetry with UAV flights have a similar precision of aircraft flights and conventional surveying with much lower costs(H. Eisenbeiss, 2009).

1.3 PROCESSING METHODOGY

Photogrammetric image processing requires good hardware due to high computational requirements when information is analyzed. We use Agisoft Photoscan Professional, which makes the ortorectification and orientation process of the aerial photographs for the generation of ortophotos, digital elevation models and point clouds.

Autocad Civil 3D is then used for analysis, by importing ortophotos and point clouds. This system allows the observation of changes in reliefs. In the last process, overlap of ortophotographics allows detection of moved structures, with a pixel size below 5 cm. Volume calculations and profile comparisons are carried out during this stage, using the resulting point clouds of each measurement campaign.

1.4 CONSTRAINTS

Dealing with UAVs, flight autonomy is the most important limitation. The batteries of the Phantom 4 last approximately 30 minutes, time that can be reduced to 5 minutes depending on wind conditions.

Plant cover affects primary results because ground level information is not possible to calculate. Similary, nearby surf from water bodies increases noise (see Figure 3) producing non-representative data. To correct these issues manual post processing using Photoscan tools is conducted. Elevation in these conditions is interpolated, as long asthere is reliable information about the general area.

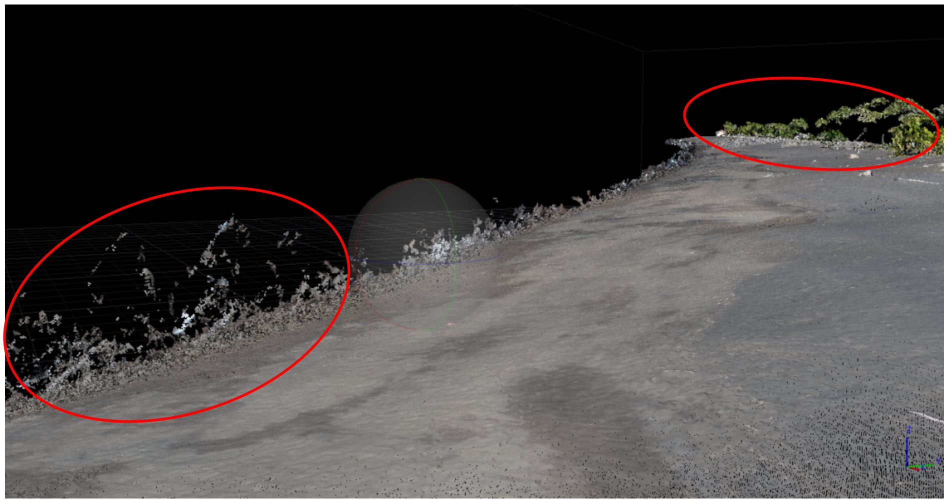


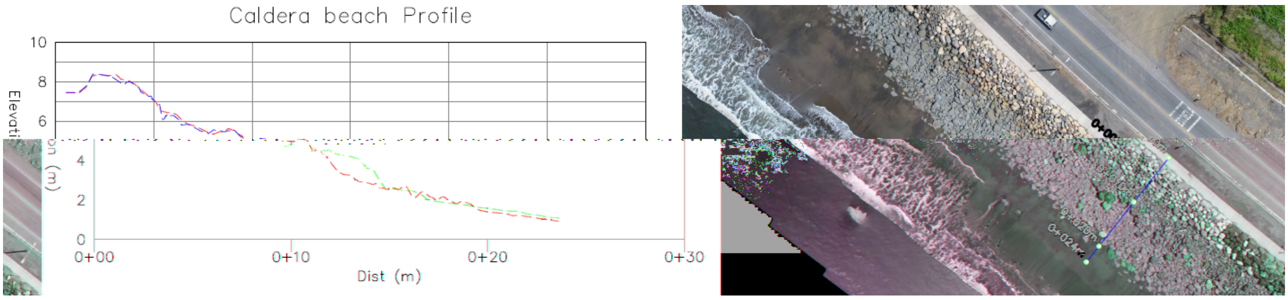
Figure 3. Noise due tosurf in water and vegetation presence.

2 RESULTS

In a regular inspection of the breakwater heads from a field visit,changes were detected after storms, but their magnitude is hard to establish given the steep field conditions. Similar control profile linesare difficult to maintain after storms, and UAV surveys can detect where some of the rocks an dolos moved. This can be calculated even though the profiles of the breakwater stay in a similar shape after the storm.

During August 2017, there was a significant stormin the pacific coast of Costa Rica, corresponding to one of the largest registered by an IMARES buoy measuring surges since 2015. For this event, the buoy registered a significant wave height of 3.7 m and a peak period of 17.66 s (August 14, 2017 at 5 am).Since photogrammetric surveys are carried out monthly, it was possible to detect the damage caused after the storm contrasting before and after results. The latter showed a material loss of up to 0.75 m in a section of beach profile according to a previously traced profile in the zone of most impact (Figure 4a). In that image, red color represents the beach profile measured in July, and blue color represents the beach profile measured in August after the storm.

The storm effect was also detected in the orthophography generated. Rock absence and displacement were detected. Changes suffered in this area of the beach put the existing road at risk, because they allowed waves to cause a greater impact. A volume calculation, showed that there was a loss of approximately 2000 m^3 of material, between sand and rocks, in the stretch of the beach that is usually seen most affected when storms occur, which corresponds to an area of 1.0 hectare, approximately (Figure 4b).



a) Caldera beachprofile **b) Plan view of the profile near a road**

Figure 4. Caldera beach cross profile comparison, before (red) and after (blue) storm.

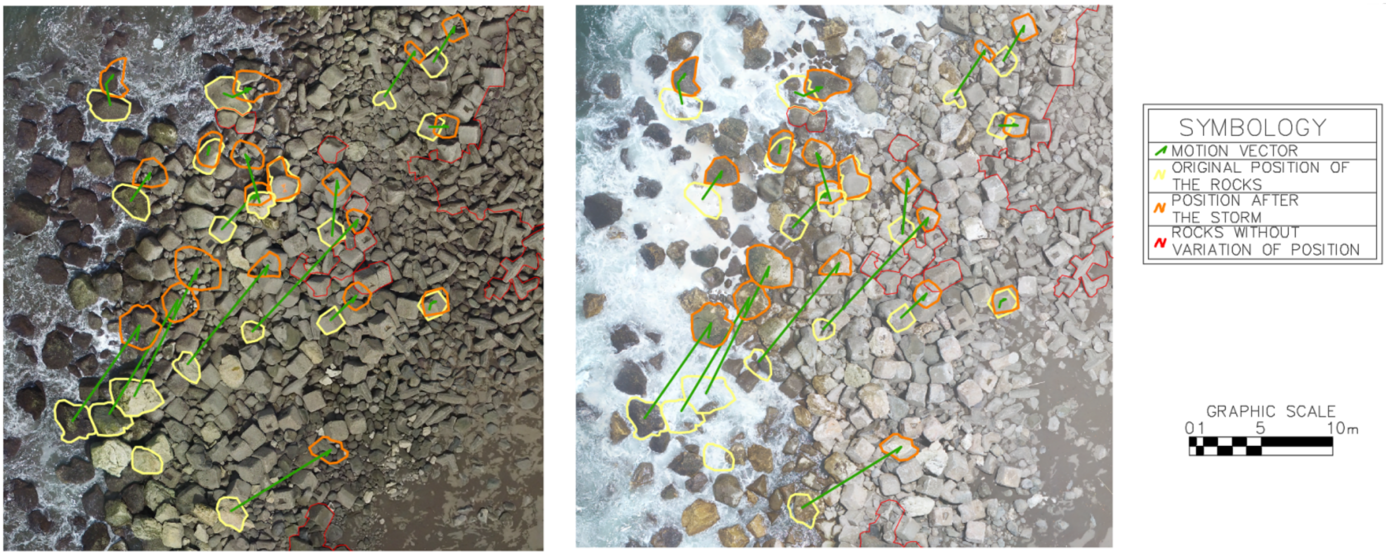
In the breakwater of the port of Caldera no damage of the structure was detected. However, in an accumulation of rocks adjacent to the hill, product of a previous damage, it was possible to document the movement of rocks and dolos, as indicated in the red circle in figure 5. These movements can be appreciated in greater detail in Figure 6, where the before (a) and after (b) conditions are shown. The red box shows an initial position of the rocks and the blue box the rearrangement of them after the storm, showing a generalized displacement of these elements. Both images were taken at low tide.

Figure 5. Caldera Port Breakwater heads damage.

a) Position of the rocks before the storm **b) Rock displacement after the storm**

Figure 6. Damage suffered on breakwater's head, the red area show a control zone before and after the storm and the blue one the place where stones and dolos pile up after the storm.

An overlap analysis of the orthophotos was performed, and it was detected that large elements moved with a predominant northwestern direction (Figure 7). The magnitude of the movement reached 8 meters with respect to the position previous. The image shows the original position in yellow and the final position of rocks in orange indicating the direction and magnitude of displacement with a green arrow.



a) Original position of rocks before the storm **b) Displacement of rocks after the storm**

Figure 7. Displacement of rocks in the breakwater's head before and after a storm.

The variation of the elevations by the movement of rocks and dolos, can be observed in Figure 8, where a 0.3 m movement is considered as invariant in magnitude. Red and yellow colors represent decreases in elevation and blue colors increase in this variable. With this figure is possible to make a validation of what was observed with the movement to the northeast of the rocks, since in the central sector of the hill is possible to see the red colors and to the northeast of this point the blue ones.

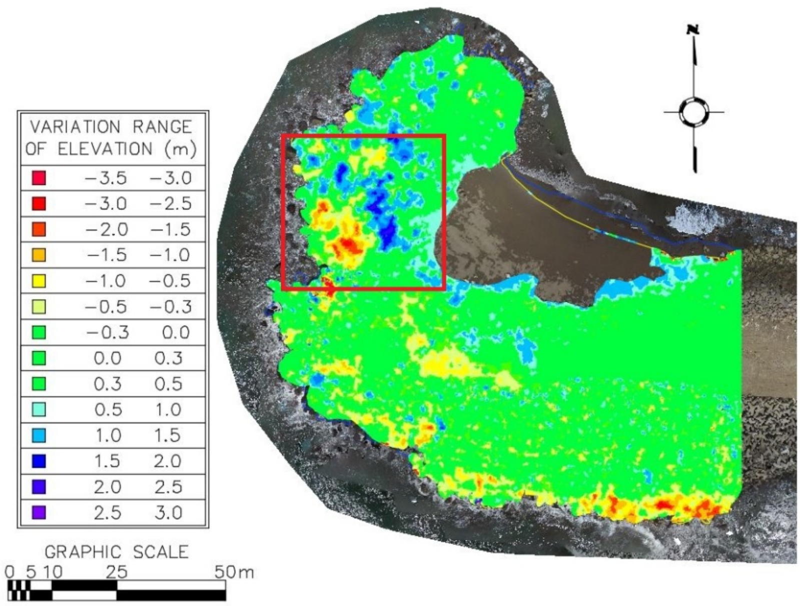
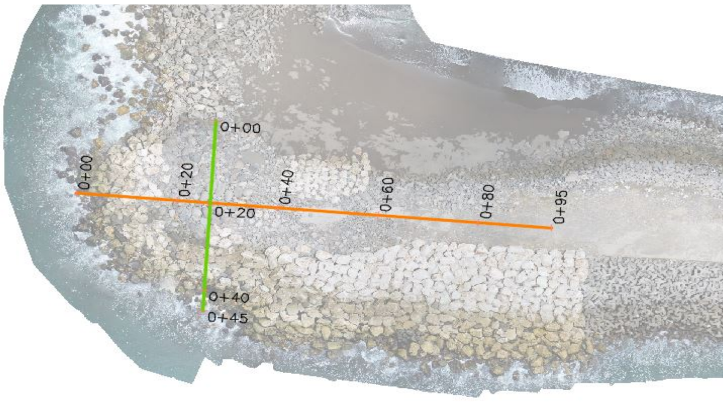
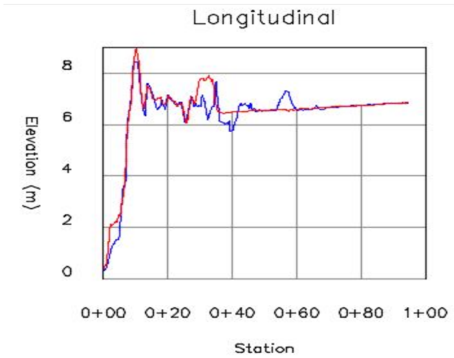


Figure 8.Elevational change of elements in the breakwater after the storm.

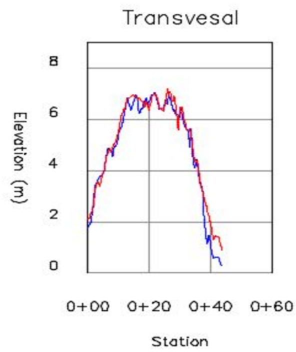
Although the movement of rocks and dolos can be appreciated, Figure 9 shows that the slope did not change drastically, especially on the slope. This result would have been difficult to assess using conventional methods since the density of the points taken is lower than that obtained by UAV methods. The interpolation of the levels for the creation of a digital model of terrain would have had lower resolution and less resemblance reality.



a) Plan view of the profile location



b) Longitudinal profile (Orange)



c) Transversal profile (Green)

Figure 9. Breakwaterprofilechanges

Regular inspection of the breakwater heads by field visitscould detect changes after storms but not necessarily the magnitude of the element displacement in a precise way, because of the steep field conditions. A similar profile line is difficult to maintain after storms and UAV methods can determine changes, even though the profiles of the breakwater stay in a similar shape after the storm.

3 CONCLUSIONS

UAV technology has been successfully used to monitor changes in the morphology of beaches and coastal infrastructures, because of the dynamic agents to which they are exposed.

Monitoring using aerial photographs decreased the time conducting field campaigns, increasing considerably the amount of information obtained. Similarly, resolution is very high, providing greater precision than conventional methods. Complex surfaces such as a breakwater in slope are possible to analyze, presenting a solution to an otherwise hard problem.

UAV monitoring and the use of photogrammetric methods, can determine the change of the position of the different elements that make up the costal structures. This kind of analysis is almost impossible using conversional methods like those conducted with total stations. The result of this work shows that there can be areas with almost a constant profile and volume in the material forming the structures.

Among the limitations, short flight autonomy, current cost of equipment, the need to establish control points, dependence on the water conditions for the flight and the high sensitivity of the equipment to dust and sand can be mentioned.

The photogrammetric survey, in turn, is safer since it can be carried out without exposing personnel to dangers, such as areas of high traffic of heavy machinery, or difficult to access. Also, these surveys can be conducted without interrupting normal construction processes or operations.For the latter, however, control points should be placed strategically so that the accuracy of the digital terrain model is the desired one.

REFERENCES

Burcharth, H. F., Andersen, T. L., and Medina, J. R. 2010. Stability of cubipodarmoured roundheads in short-crested waves. A comparisonbetween cubipod and cube armour stability. *Coastal Engineering*, 32, 1–10.

Corredor, A., Santos, M., Pe˜na, E., Maci˜neira, E., G´omez-Martín, M. E., and Medina, J. 2013. Designing and constructing cubipod armored breakwaters in the ports of Malaga and Punta Langosteira (Spain).Proc., *Institution of Civil Engineers (ICE) coasts*, Marine Structuresand Breakwaters Conf., London.

Eisenbeiss, H. 2009. UAV photogametry (Doctoral tesis).University of Technology Dresden. Alemania.

GovaereG., Víquez,R., Alfaro.H., 2016. Use of drone technology and photogrammetry for beach morphodynamics and breakwater monitoring, *Coastlab 2016*, 1-8.

González-Jorge, H., Puente, I., Roca, D., Martínez-Sánchez, J., Conde, B., Arias, P. 2016. UAV Photogrammetry Application to the Monitoring of Rubble Mound Breakwaters, *Journal of Performance of Constructed Facilities*, 1-8.

Gómez-Martín, M. E., and Medina, J. R. 2006. Damage progression on cube armored breakwaters. Proc., I*nt. Conf. onCoastalEngineering (ICCE)*, 5229–5240.

Laboratorio de Ingeniería Marítima y Fluvial, Instituto de Investigaciones en Ingeniería, Universidad de Costa Rica, 2013. Dinámica litoral y propuesta de actuación para la estabilización de playa Caldera. *Proyecto de cooperación UCR-MOPT*. San José, Costa Rica.

Lomónaco, P., Vidal, C., Medina, J. R., and Gómez-Martín, M. E. 2009. Evolution of damage roudheads protected with cube and ubipodarmour units. Proc., *Institution of Civil Engineers (ICE) Coastal, Marine Structures and Breakwaters Conf., London*, 169–180.

Molinero-Guillén, P. 2010. Construction of large port infrastructures atthe north of Spain. Proc., *Congreso de Ingeniería Civil*, Madrid,Spain, 1–20.

Van Gent, M. R. A., and Van derWerf, I. M. 2010. Stability of breakwaterroundheads during construction. *CoastalEngineering*, 32, 1–15.