

APPLICATION OF DRONES AND OSS FOR MAPPING AND VISUAL INSPECTION OF EMBANKMENT DAMS



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ABSTRACT

To evaluate the safety conditions for a geotechnical structure, particularly a dam is very important to know its actual geometry and to perform visual inspections as a tool to aid the dam monitoring.

Nowadays drone technology is becoming more available making it a valuable tool to aid for visual inspections and geometry assessment. On the contrary, the software for image processing and model generation is still quite expensive and requires up-to-date hardware. Open Source Software (OSS) is a different approach in which instead of a copyright user are granted a copyleft licensing allowing for a more versatile use and a better resource management. For example, with OSS one can take advantage of distributed high-performance clusters without any licensing issues.

The application of drones and open-source software for mapping geotechnical structures is a very interesting and productive solution, because with a low cost and fast solution one can produce quality orthophotos, surface models and cross-sections, to be used for other analysis like slope-stability and stress-strain and seepage finite element analysis.

This paper describes the application of the drone for inspection and mapping of Sambade Dam, as well the application of open-source software to process and to produce data and models to aid in the dam safety evaluation.

Keywords: Dam safety, Drone, Aerial mapping, Visual inspection, Monitoring of Embankment, Surface model, Photogrammetric, Open Source Software (OSS), Orthophoto.

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1. INTRODUCTION

Dam failure can cause immense damage and loss of life when they occur. However, these events may be avoided when the causes of these failures are detected early. Bulletin 138 (ICOLD, 2009) has the following definition:

“Dam surveillance aims at managing this risk and reducing the probability of occurrence by providing a means of early identification of undesirable events that can possibly cause failure. The organization of any surveillance process should thus aim to reduce the probability of failure as much as possible by:

- *identification of potential failure modes and providing a surveillance program to cover these;*
- *early detection of initial stages of evolving phenomena that can lead to failure mechanisms;*
- *understanding the behaviour of the dam and its components using physical parameters;”*

In this sense, aerial mapping with drones is an excellent tool for spatial modelling and understanding of possible failure modes, enabling the generation of a three-dimensional model of the current conditions of the structures, as well as the extraction of sections, area calculation and volumes of the materials involved in the problem.

It also allows an ample inspection of the structure, enabling visualization of inaccessible places, since the drone can film and shot high resolution photos of places of interest, making it possible to prepare a high resolution orthophoto and facilitating the early detection of anomalies like resurgence points, humid areas, seepage signs, boils, growth of trees and brush, cracks, slumps, which may be indicators of problems in the structure.

It is also possible to model and monitor deformations in the structure, through spatial modelling, in which it is feasible to have an accuracy of 5 cm using ground control points. Whereas the accuracy is not, at the moment, excellent, it is still improving.

Nowadays drone technology is becoming more available, making it a valuable tool to aid for visual inspections and geometry assessment. On the contrary, the software for image processing and model generation is still quite expensive and requires up-to-date hardware. Open Source Software (OSS) is a different approach where instead of a copyright, a copyleft licensing is granted, allowing for a more versatile use and a better resource management. For example, with OSS one can take advantage of distributed high-performance clusters without any licensing issues.

In this paper we will present the aerial mapping performed at the Sambade Dam the processing results obtained with WebODM, which is available as OSS.

2. MONITORING OF EMBANKMENT DAMS

2.1. Instrumental monitoring and visual inspection

Monitoring of dams is achieved through several activities, comprising the so-called instrumental monitoring and also visual inspection. While the former requires the installation of equipment in the dam body the latter implies the detailed visualization of the dam and the detection of signs of anomalies and the evaluation of its progression. Both play an essential role in the safety assessment of dams, but very often, especially in small and older dams, instrumental monitoring is not used and, therefore, visual inspection gains importance.

Instrumental monitoring is normally concentrated in special areas, either those that represent the overall behaviour of the dam or those where some singularity exists. It is, by nature, punctual. On the other hand, visual inspection has a more widespread nature as it addresses areas (although some anomalies are also located in small areas, for example, water springs and sinkholes).

Another aspect distinguishes instrumental monitoring and visual inspection though. In instrumental monitoring numerical data is collected either by means of automatic data collection or manually by operators. This data is stored in databases and mathematical models are applied to compare the actual response of the dam to model predictions. The comparison allows for an opinion on the dam safety. On the other hand, in the visual inspection records consist of a filled form or a report with the opinion of the inspector and a collection of photographs and, sometimes, videos. These are valuable elements but are usually incomplete (in the sense that it is impossible to register all the dam and the viewpoint is limited to the photographer's). Despite their limitations visual inspections are of paramount importance in dam monitoring and any developments are welcome.

2.2. SAMBADE DAM

The Sambade Dam is located about 1.5 km south of the village with the same name and 6.5 km north of the village of Alfândega da Fé. It is an embankment dam with a zoned profile.

The dam has a maximum height of 29 m and about 327 m of development at the crest level, with 8 m width.

The reservoir has a maximum volume of 1,159 hm³, which corresponds to a net volume of 1,063 hm³. The storage is destined for urban supply, and the reservoir flooded a 14 ha area. The catchment basin of the Sambade Dam is about 6.4 km².

The embankment volume is approximately 247,000 m³ and has slopes of 3 H / 1 V on the upstream side and 2.5 H / 1 V on the downstream side. Upstream protection is made of riprap, with $D_{50} = 250$ mm and thickness of 0.40 m, while the downstream is protected with vegetable coating. The Fig. 2 shows the typical cross-section of the dam, roughly in the highest zone, and, Fig. 1, the dam plan with indication of the monitoring cross-sections.

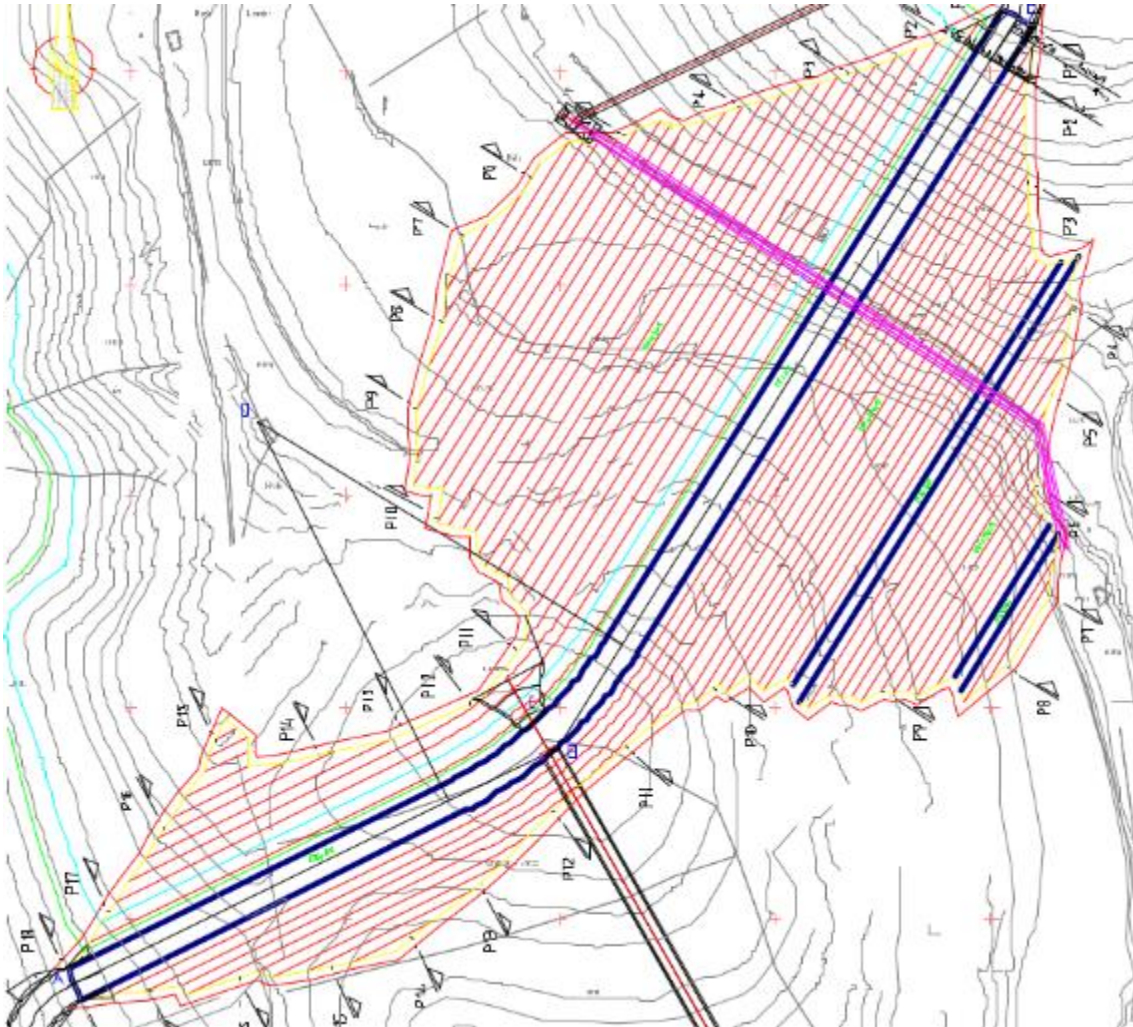


Fig.1 – Dam plan with indication of the monitoring cross-sections

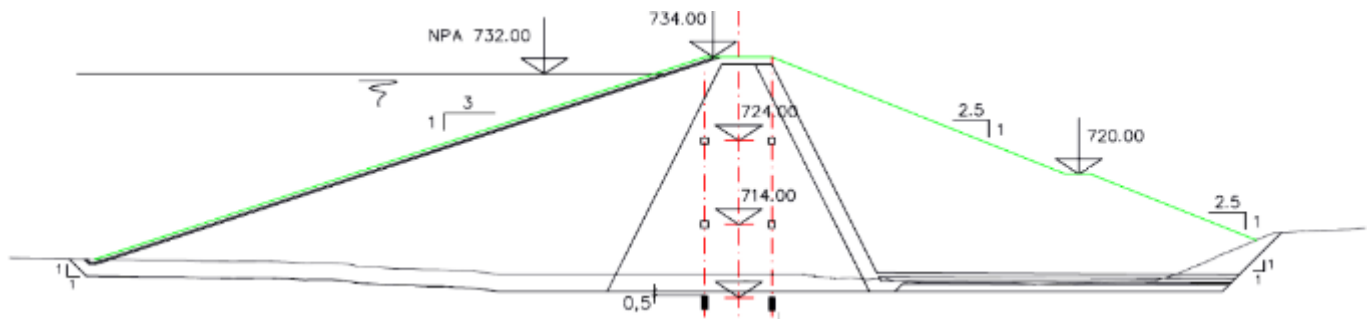


Fig.2 – Typical cross-section of the dam

The Full Supply Level (FSL) is located at 732 m, the Maximum Flood Level (MFL) at 733.15 m and the Minimum operating level (MOL) at level 712 m.

3. USING DRONES TO MAP DAMS

The aerial mapping process with a drone is similar to the aerial photogrammetry process with an airplane, which uses triangulation between overlapping images to obtain the topography and where, through the use of the triangle similarity ratio, it is possible to get the real scale dimensions on the photographs (See Fig.3).

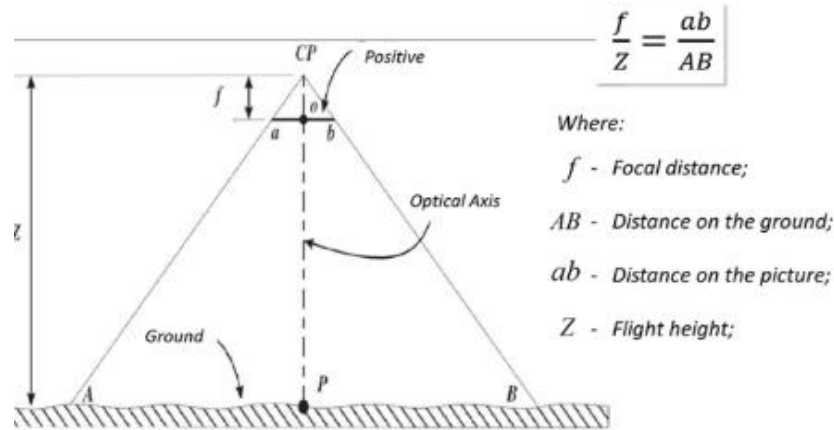


Fig.3 – Geometric relationship between the photo and scene (Elen, 2010)

However, aerial mapping with drones has the advantage of flying at lower heights, allowing for a higher resolution in the captured images, which in turn enables greater precision in topographic and orthophoto surveys, which with the use of support points on the ground allows to achieve an accuracy of about 5 cm.

Taking as an example the aerial mapping of Sambade Dam, where flyovers were carried out at two altitudes, 20 m for the survey elevation of crest of the dam and 60 m for the entire area, it was possible to obtain images with a resolution of 1 cm / pixel (See Fig.4).



Fig.4 – Detail of aerial photo of the crest of Sambade Dam

The images presented in Fig. 4 were obtained using the Phantom 4 Pro drone, which has a 20 Megapixel camera, flight range of 30 min and a distance range of 7 km.

The first step in aerial mapping with Drones is flight planning, where a study of the area to be overflown is made.

The flight plan of the Sambade Dam was prepared using the DroneDeploy application, that allows a delimitation of the polygon of the area to be overflown and to define the flight altitude as well as the resolution of the images, among other settings.

To fly over an area of 11 hectares as shown in Fig. 5, it was necessary to use 3 full loaded batteries of the Drone Phantom 4, with which, despite the bad weather and the unfavourable wind conditions, was possible to carry out this overflight on a full morning.

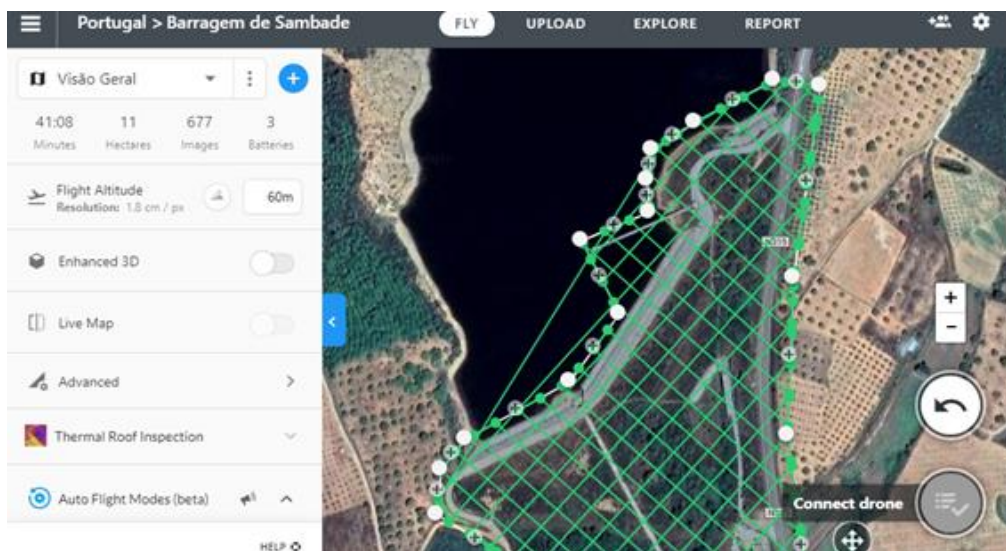


Fig.5 – DroneDeploy - Flight plan of the Sambade Dam

Another important aspect of the flight planning is the definition of support points in the field, which must be located over points of interest, where there are wide variations in altitude in order to verify and refine the topography. In this case, 9 wooden targets with 50 cm x 50 cm were located on the crest and on the downstream berm of the dam, which were mapped with a Geodetic GPS (See Fig. 6).



Fig.6 – Sambade Dam - Location of support points

Besides the technical aspects, and once the overflight area is delimited, it is important to obtain the necessary authorizations to perform the flight.

In Portugal it is necessary to obtain authorization from the National Aeronautical Authority (ANN) for permission to the acquisition of images and the National Civil Aviation Authority (ANAC) that controls the airspace (for more information on obtaining a flight authorization, in Portugal see the website www.voanaboa.pt).

4. USING OSS TO PHOTOGRAMMETRIC PROCESSING AND 3D SPATIAL DATA GENERATION

Normally, the images captured by drones have useful metadata related with the coordinates, flight height, tilt of the drone, among other information which enable the triangulation of the images and 3D Spatial data Generation, which in turn, allows the generation of point clouds, orthophotos, and all the related geometric entities.

However, this processing involves the use of expensive software or services as well as demands computer power for image processing.

In this sense, OSS has the advantage of being acquisition cost-free and being open source, allowing for a large community of programmers to constantly update the platform. As a side advantage, it also allows for improvements by each user, that, in return may decide to share or not its contributions to the scientific community.

For the processing of images from the Sambade Dam WebODM (www.opendronemap.org/) was used. WebODM is a software for generating maps, point clouds, DEMs and 3D models from aerial images.

WebODM is cross-platform having versions for Windows, Mac and Linux and can be installed on personal computers as well as in high performance clusters (See Fig. 7).

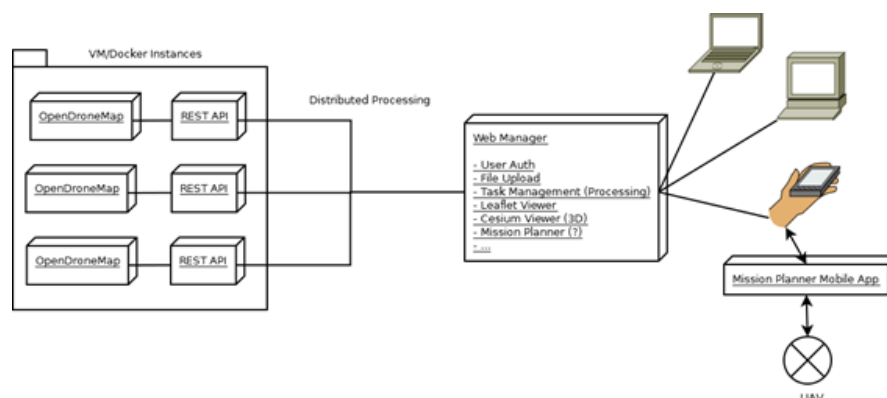


Fig.7 – Scheme for installing the WebODM software
(<https://github.com/OpenDroneMap/WebODM/issues/7>)

For more information on WebODM software, visit: <https://www.opendronemap.org/webodm/>

The processing of the images of the Sambade Dam was made in the cluster of the National Engineering Laboratory (LNEC) in Portugal.

The program has an intuitive interface and is very simple to operate. It is accessed by an internet browser, therefore it is possible to access the server from anywhere with any type of device as long as it has a internet browser (see Fig. 8).

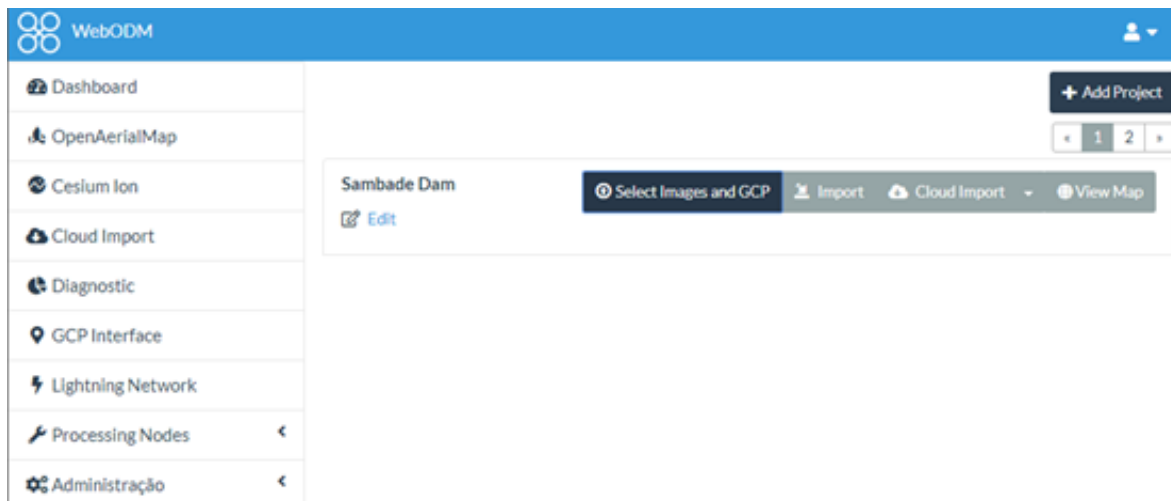


Fig.8 – WebODM software interface

When adding a new project, it is possible to upload the images, together with a Ground Control Points (GCP) file, which contains the information about the ground control points obtained in the field, i.e. its coordinates.

The processing of the images depends on the capacity of the computers, for the processing of the Sambade Dam, with 1430 hi-res images and a demanding configuration the processing took about 22 hours.

For reference the settings used in processing are the following:

smrf-scalar: 2.5, smrf-window: 30, mesh-octree-depth: 11, smrf-slope: 1, orthophoto-compression: JPEG, texturing-nadir-weight: 32, orthophoto-resolution: 1, dtm: true, dem-resolution: 1, mesh-size: 500000, ignore-gsd: true, debug: true, use-exif: true, dsm: true, dem-gapfill-steps: 5, depthmap-resolution: 900, texturing-data-term: area, smrf-threshold: 0.6, rerun-from: dataset

After processing, it is possible to access a 2D or a 3D WebODM interface. In the 2D mode it is possible to obtain the Orthophotos, draw contour lines, measure distances and calculate areas, which can be exported in a Geotiff file and imported into other CAD and GIS programs (See Fig. 9).

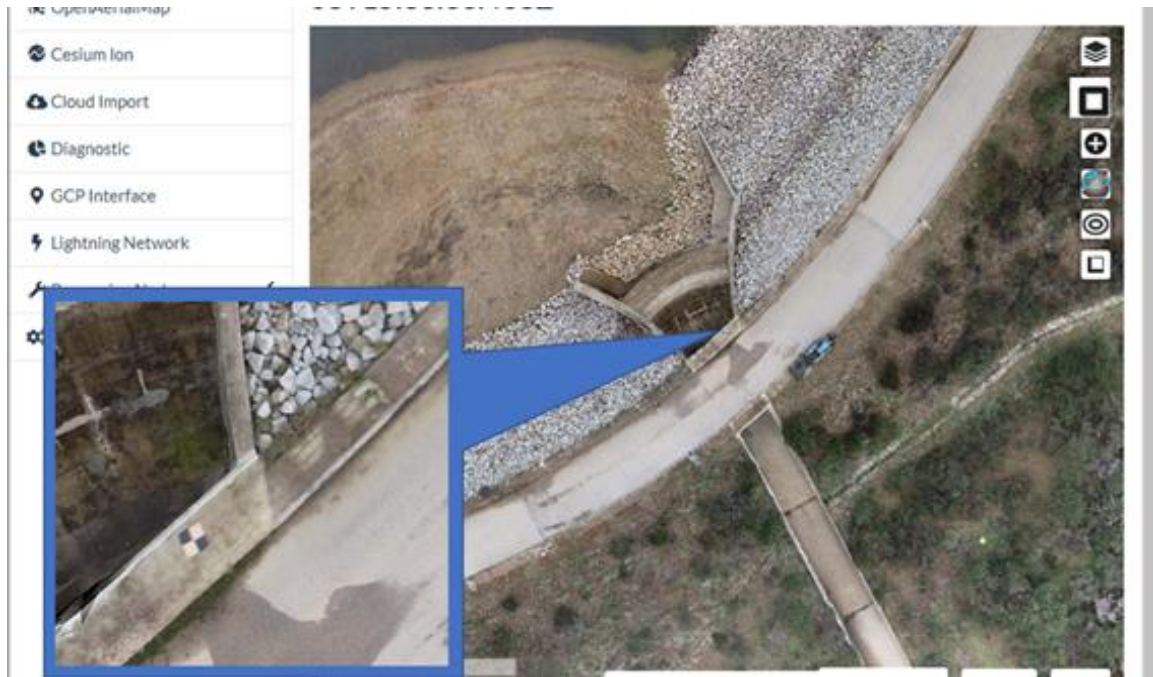


Fig.9 – 2D WebODM interface

As demonstrated in Fig. 10, in the 3D interface it is possible to view a dense point cloud and navigate the model in a 3D view, generate sections and profiles and calculate volumes. The program also exports the point cloud in LAZ, Geotiff and other formats that interface with CAD and GIS programs.



Fig.10 – 3D WebODM interface

5. RESULTS

In the following paragraphs, some results of this preliminary application of drone technology for the visual inspection of embankment dams is presented.

Fig. 11, presents part of the orthophoto of the crest of Sambade Dam, near the spillway entry. Details like the presence of cracks in the crest of the dam are captured, as well as the conservation conditions of the concrete structures. The image can be zoomed in to get more detail, preferably using an external application. For example, QuantumGis can be used to explore the orthophoto image (<https://qgis.org>).



Fig.11 – WebODM - Orthophoto of the crest of Sambade Dam

Through the orthophoto it was possible to perform a wide and virtual visual inspection of the embankment. In this case, for example,, it was possible to observe the detail of the work of clearing the vegetation that was undergoing on the day of the inspection and overflight, and it was also possible to observe the growth of vegetation in the areas of higher humidity at the base of the slope near the left abutment (See Fig. 12).



Fig.12 – WebODM - Orthophoto of the slope of the Sambade Dam

In addition to visual inspection, it is possible to have a topographic record and perform deformation analysis, as shown in Fig. 13 of the elevation map generated in OSS WebODM.

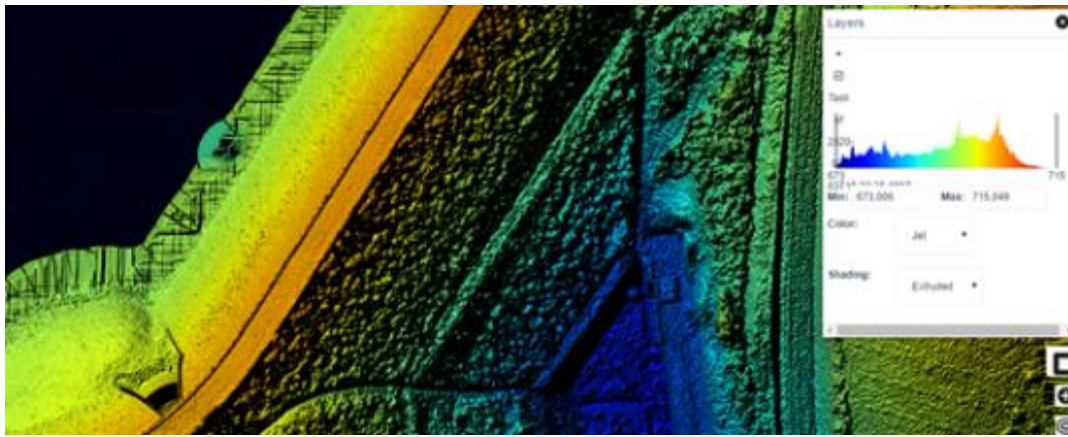


Fig.13 – WebODM - Elevation map of the Sambade Dam

The software allows the generation, as well as the export of DTM for the generation of contour lines (See Fig. 14) and the generation of sections and profiles (See Fig. 15).



Fig.14 – CAD - Generation of contour lines



Fig.15 – WebODM - Generation of sections and profiles

As demonstrated by aerial mapping with drones, it is a powerful tool for carrying out visual inspections, enabling the early detection of anomalies.

It should be noted that these anomalies detected in the Samade Dam do not compromise the safety of this structure, since this dam is in perfect operating condition.

However, the constant monitoring of the dams minimizes the risk of the accidents and making the effective use of this technology very useful of the safety dam.

6. CONCLUSIONS

The use of aerial mapping with drones has enabled a new perspective for the visual inspection of embankment dams.

As demonstrated, through spatial modeling of the structure it was possible to capture and to record the conservation conditions of the dam. These records can be used for future inspections to compare the evolution of anomalies.

The same technology can be improved by using different cameras, namely those in the range of infrared or thermal cameras, allowing for the detection of other anomalies or features.

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