Geophysical investigation of the structure of Lago Paranoá Dam: An application of sonography and bathymetry techniques

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This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.

Abstract (Font: Arial Bold, 9)

The monitoring of dams is a necessary procedure regulated by law to prevent potential disasters and can be carried out through various multidisciplinary approaches. In this article, geophysical methodologies such as sonography and multibeam bathymetry were employed to map the contour and morphology of the structure of the Paranoá Lake Dam, which generated maps revealing the layout, depth, and morphology in close proximity to the dam structure and within the submerged structure itself.

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Introduction

Dams are structures built to control the flow of fluids or solids and are used for various purposes, such as electricity generation in hydroelectric power plants, containment of solid waste generated in mining or industrial processes, or even to impound watercourses for water supply to cities and industries, irrigation, flood control, and navigation facilitation (ANA, 2021).

The rupture, partial or total destruction of a dam structure has the potential to cause immense damage, some of which may be irreversible, such as loss of lives, for example. Therefore, considering accidents like Brumadinho (2019) and Mariana (2015), it becomes necessary to create a National System that gathers the records and conditions of the more than 22,654 existing dams in the country (ANA, 2022). To this end, Law No. 12,334, dated December 20, 2010, established the National Dam Safety Policy (PNSB) and created the National Information System on Dam Safety (SNISB), which relies on regulatory bodies to ensure the proper compliance with the guidelines of the Law (Brasil, 2010). The National Water Agency (ANA) annually prepares a safety report on the conditions of all registered dams in the country, gathering information from the 33 regulatory bodies currently in operation (ANA, 2022).

Following the guidelines governing the PNSB, all entrepreneurs and those responsible for the supervision of each dam must periodically review the dam structure, reservoir, and associated structures through a multidisciplinary approach involving various professionals and methods (ANA, 2016).

Therefore, the objective of this work is to utilize acoustic geophysical methods, specifically sonography and multibeam bathymetry techniques, to generate maps and products that attest to some of the current conditions of the Paranoá Lake Dam.

Method

Sonography is an acquisition technique of acoustic geophysical methods based on the propagation of sound waves. These systems were initially used only for navigation assistance but have proven to be excellent tools for systematic investigation of the seafloor and are now used for generating mosaic images of the bottom of submerged areas (Klauke, 2018).

Its operation involves the repetitive emission of high-frequency sound waves by a pair of transducers pointed to the sides relative to the vessel's navigation direction. The acoustic signal is emitted in a narrow main beam in the direction of navigation but wide in the perpendicular direction. When the signal interacts with the seafloor, it undergoes scattering if the contrast in acoustic impedance at the interfaces is sufficiently large. Only a portion of the incident energy is returned to the system's receiver, in a phenomenon called backscatter, carrying information about depth and the characteristics of the seafloor materials (Klauke, 2018; Souza, 2006).

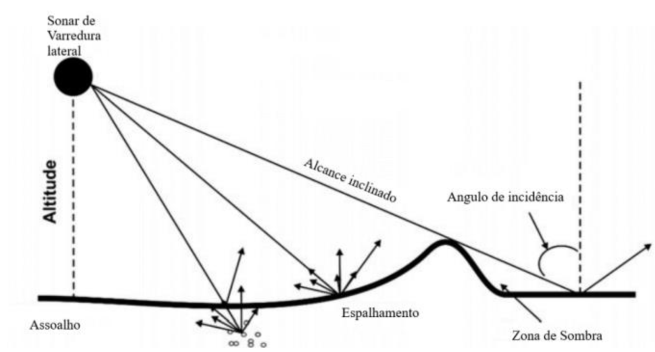

Figure 1 - Illustration of beam interaction with the seafloor at different inclinations. Source: Modified from (Klaucke, 2018)

Being the most traditional technique for investigating submerged areas among acoustic methods, echosounders are resonant systems that emit high-frequency acoustic waves and are towed or mounted on the hull of the vessel (Souza, 2006). It is a technique used to measure the water column by transmitting acoustic pulses from the ocean surface and receiving the reflections of these pulses from the seafloor (Street, 2000).

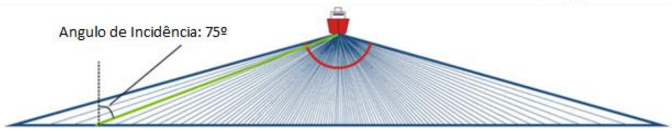

Figure 2 - Diagram illustrating the setup used to illuminate the target area for mapping in multibeam bathymetry technique.Source: Modified from (Zhao et al, 2020)

Multibeam bathymetry, applied in this study, allows data from different frequencies to be recorded simultaneously. The system consists of a pair of transducers where, during signal transmission, a transverse corridor is illuminated with a narrow beam. Then, upon receiving the returned signal, multiple channels are formed simultaneously from beams spaced at different transverse elevations (Clarke, 2017).

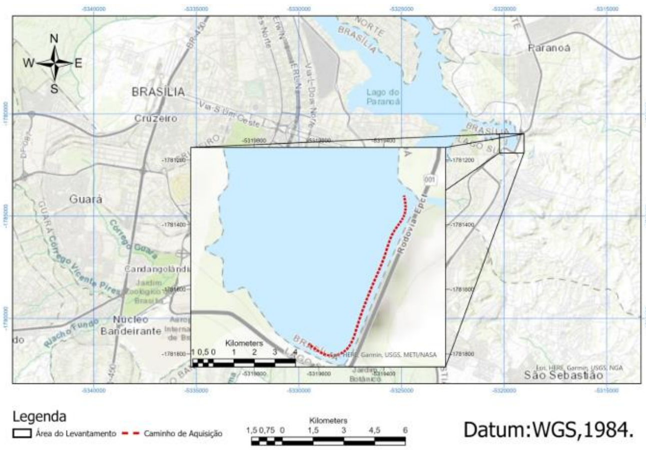

Figure 3 - Location Map of the Study Area

For data acquisition, an EdgeTech 3100P side-scan sonar, owned by the Institute of Geosciences at UnB, a Norbit iWBMS multibeam echosounder, and the hydrographic vessel Stella VII, kindly provided by RuralTech Ltda, were used for this study.

Figure 4 - A) Side-Scan Sonar B) Multibeam Echosounder C) Hydrographic vessel Stella VII docked during equipment setup.

The sonographic acquisition was performed using a frequency of 500 kHz, and the acquired dataset was processed using the SonarWiz® software. Considering the transmission loss due to spherical spreading that affects the quality of the acquired sonographic data, it was necessary to use a gain that enhances the dataset. Thus, the Time-Variable Gain (TVG) was applied with different beam attenuation coefficient values to port and starboard. The reason for this is the proximity of the towfish to the mapped structure, which resulted in signal saturation to starboard. The gain of the transmission loss, corrected by attenuation, is given by the following formula:

$$TL = 20 \cdot \log(R+1) + \alpha(R) + b$$

Where:

R is the range in meters.

b is the static offset in dB.

α is the attenuation coefficient in dB/m.

In the data processing, an attenuation coefficient of 0.10 dB/m was chosen for port and 0.05 dB/m for starboard, and zero static offset for both sides.

Results

In this way, a georeferenced map was generated, presenting various characteristics of the submerged region near the dam. In the figure below, three regions were emphasized: zone 'A' reveals undulations that possibly correspond to sediment accumulations caused by the low current flow caused by the dam. Zone 'B' marks the possible intersection between the reservoir floor and the dam's tilt, as well as various elements that may represent rolled blocks from the tilt, sediment accumulations, or unknown submerged objects. Finally, zone 'C' shows the spillway region of the Paranoá Lake Dam, revealing the pillars that support the vehicle track above the dam.

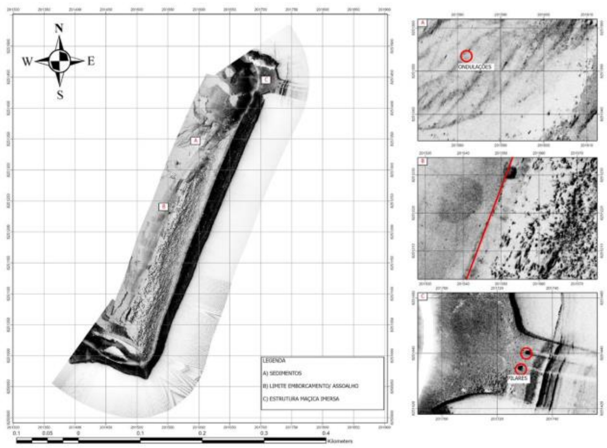

Figure 5 - Sonographic Map of Paranoá Lake Dam

To generate the bathymetric map, a point cloud with XYZ coordinates created using the Qimera QPS® software from the multibeam echosounder dataset was filtered and then exported for interpolation in another software called Surfer®. The interpolation method used was Kriging. Figure 6 shows the variogram graph generated by the software, indicating that the variability is related to distances up to 150 meters.

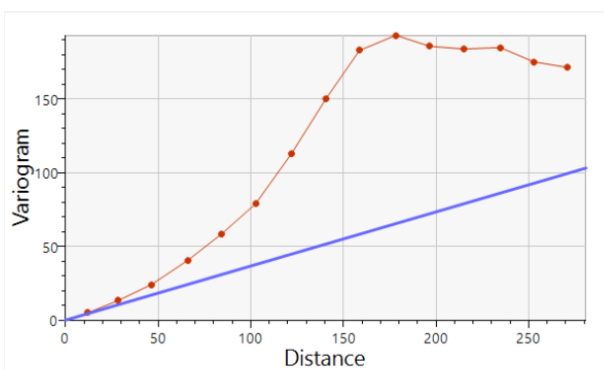

Figure 6 - Variogram graph

Thus, the bathymetric map was obtained, showing the distribution of depth points and the morphology of the relief near the dam structure. With a maximum depth of about 40 meters, the bathymetric map reveals different features compared to the sonographic map. As Lago Paranoá is an artificial lake, the primary purpose of the dam was to accumulate water for the creation of the ornamental lake. However, it also houses a hydroelectric power plant with the capacity to generate enough energy to supply an average of 11,000 consumer units (CEB, 2022). Below, Figure 7 shows the bathymetric map with a zoom on the spillway area.

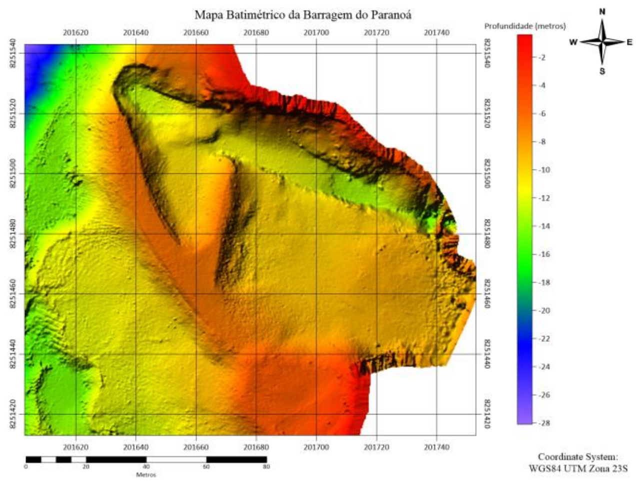

Figure 7 - Bathymetric Map of Lago Paranoá Dam.

Additionally, a 3D representation of the submerged part of Lago Paranoá Dam was generated.

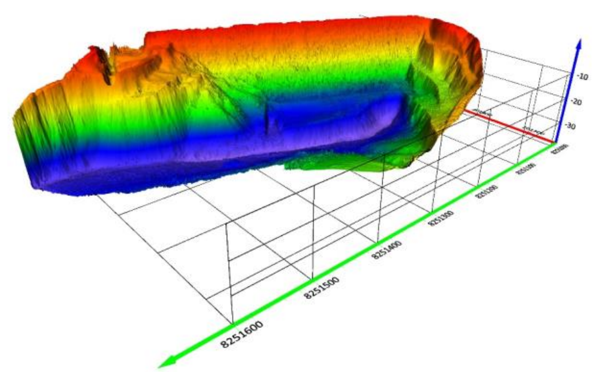

Figure 8 - Mapped Surface in 3 Dimensions.

Conclusions

Based on the generated maps, it is possible to infer that the dam structure is well-preserved with no significant accumulation of sediment or debris. However, the applied techniques are not capable of providing information about the condition of the interior of the structure or the thickness of the sediment layer deposited near the structure. For safety reasons, the spillway area is protected by a barrier of buoys that prevents the approach of vessels to the gates. As a result, it was not possible to examine this region with the towed and hull-mounted equipment used in this research, leading to a lack of information beyond the reach of the sonography and multibeam bathymetry techniques. As mentioned earlier, monitoring the condition of a dam structure is a multidisciplinary task, and taking this into consideration, it was concluded that additional geophysical methodologies such as the electrical resistivity method and seismic method are required to complement the information and provide a more precise comparative analysis of the current conditions of the Lago Paranoá Dam structure.

Acknowledgments

"The Author would like to thank Ruraltech LTDA for providing the vessel and equipment used in this work, and the University of Brasília, particularly the Institute of Geosciences, for making this study possible and for all the research support.

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