Reservoir monitoring using a multi-phase echo sounder: a case study

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***Abstract*— The monitoring of reservoirs presents three major challenges: accessibility to the spatially complex shallow water shoreline, the natural intra-annual, inter-annual and decadal temporal dynamics; and the large spatial extent. These challenges render the acquisition of useful geospatial/geophysical information costly and inefficient. Temporal variations in hydrology caused by natural meteorological events constantly impact the infrastructure and surrounding landscape of the reservoir system. In order to effectively monitor and evaluate these patterns of change and better understand the impact of contributing environmental factors, engineers and scientists need access to current geospatial/geophysical survey data. Historically, access to survey data at the spatial and temporal scale required to effectively monitor and evaluate the integrity of the reservoir system has been plagued by long acquisition time and high costs. The utilization of the latest developments in swath bathymetry and an innovative acquisition approach proposes to overcome this cost barrier. The EdgeTech 6205 is the first of its kind to employ the new Multi-Phase Echo Sounding (MPES) technique to simultaneously acquire high quality bathymetry data along with dual frequency side scan imagery at much longer ranges than traditional systems. The wider swath coverage allows for fewer sweeps across the survey area and reduces the processing time to co-register the imagery to the three-dimensional (3D) bathymetric point data. This case study evaluates the efficacy and affordability of exploiting the latest MPES technology in shallow-water survey systems.**

Keywords*— *reservoir; Taiaçupeba; multi-phase echo sounding; side scan sonar;applied acoustic

I. INTRODUCTION

Maintaining dam and reservoir infrastructure requires accurate bathymetric mapping and monitoring, with depth data required over the complete submerged area. Accurate maps of the water depth are used in dam maintenance and monitoring, allowing improved planning, safe operation, and informing risk analysis. Survey images can also aid in the maintenance of the submerged infrastructure such as sluice gates. Accuracy requirements for the data supplied to engineers and scientists from the dam surveys are similar to that required for ship navigation channels.

Hydrographic surveys in dams and reservoirs are typically carried out by small vessels of opportunity, often operating in less than 20m water depth. Survey of the submerged dam topography and infrastructure presents several challenges to the hydrographic surveyor. The shoreline may be spatially complex and shallow, with submerged hazards to navigation such as trees and structures. The dam level may be subject to natural intra-annual, inter-annual and decadal temporal dynamics. Access to the shoreline for survey vessel mobilization may be difficult, precluding the deployment of larger survey vessels, and the dam may have a large spatial extent. Using traditional survey methods these challenges render the acquisition of useful geospatial/geophysical information costly and inefficient.

Temporal variations in hydrology caused by natural meteorological events constantly impact the infrastructure and surrounding landscape of the reservoir system. Siltation, scour, submerged channel movement and slope slumps can alter the topography over time, so regular re-surveys are required in order to effectively monitor and evaluate these patterns of change and better understand the impact of contributing environmental factors. The requirement for regular re-surveys in shallow water means that survey efficiency is key in providing a cost-effective monitoring program.

This paper presents a method to address these challenges utilizing a recent development in swath bathymetry and an innovative acquisition approach. A case study of a dam survey is presented where a multi-phase echo sounder (MPES) swath bathymetry system was deployed, mounted on a low draft catamaran float platform which was maneuvered around the reservoir using a 7m open launch. This system was used for a trial survey of the northern 20% of the Taiaçupeba reservoir, 100 km from Sao Paulo in Brazil (Fig. 1).

Taiaçupeba Reservoir is part of Alto Tiete System, composed by five reservoirs, and was implemented in 1976 to help in regularizing the Tiete river flow and, consequently, to avoid floods. Also, the System was built as alternative water source for Sao Paulo city, specially the eastern sector, which was suffering from serious water shortage in the beginning of 90's. In 1992 the Taiaçupeba dam started to send water to supply Sao Paulo city [1]. The total area of the reservoir is around 10 km^2 and the storage volume roughly 85 x 10^6 m^3.

Nowadays the Alto Tiete System is one of the most important water supply systems to Sao Paulo city, producing around 15.0 m3/s of water for more than 4 million people. Because of the 2014 water shortage in the metropolitan region of Sao Paulo the reservoir was chosen to receive engineering projects to enhance its capacity to collect and send water to the population of Sao Paulo city (an additional 4.0 m^3/s, total 19.0 m^3/s), avoiding water-use restriction.

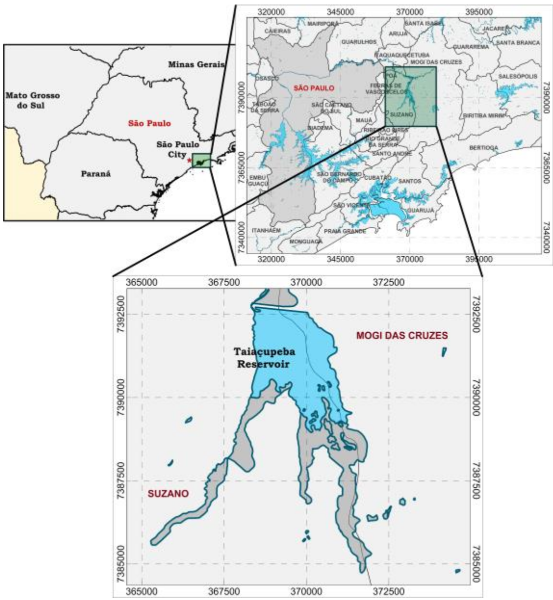

Fig. 1. Localization of Taiaçupeba reservoir.

II. METHOD

The dam survey objectives were to achieve of full coverage bathymetry with simultaneous side scan imagery, while maintaining a bathymetric high accuracy over wide swath in shallow water (0m-10m deep). An EdgeTech 6205 combined swath bathymetry and side scan sonar was deployed. The EdgeTech 6205 is the first of its kind to employ the new Multi-Phase Echo Sounding (MPES) technique to simultaneously acquire high quality bathymetry data along with dual frequency side scan imagery at much longer ranges than traditional systems, with a field of view of over 200 degrees and a swath width of over 10-12 times water depth [2].

The survey sonar was mounted on a 2.5m long catamaran survey float constructed from two small hulls and rigid frame, with attachment points for the sonar head, GPS antennae, and motion sensor (Fig. 2). This catamaran float was tied alongside the vessel containing the survey crew, data collection PC and generator (Fig. 2b). The ancillary positioning, heading and motion sensors were on fixed mounts on the catamaran's rigid frame. This saved space, maintained the same physical arrangement of the sensors between survey days, and allowed the survey equipment to be manually carried into the water in one piece (Fig. 3a, 3b).

In this way the various sensors on the catamaran float formed a complete survey system, not requiring any sensors to be deployed on the vessel carrying the crew, acquisition PC and generator. One of the advantages of the 6205 sonar for this type of small boat work is the compact integrated sonar head, weighing less than 20kg. The shallow draft of the sonar head that could be achieved with this set-up allowed surveying in shallows near the shoreline, and the light and robust nature of the deployment meant that any accidental grounding would leave the system undamaged.

Fig. 2. Catamaran float tied aside to the launch.

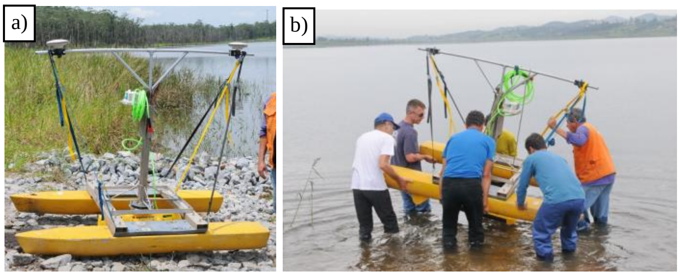

Fig. 3. a) catamaran float with sonar head, GPS antennae and motion senor; b) catamaran being carried to the water.

The survey equipment used was:

- Sonar: EdgeTech 6205, with 550 kHz bathymetry and 550 kHz/1600 kHz side scan (Fig. 4a);

- Dual antenna GPS, for position and heading, and motion sensor: SMC IMU-108 (Fig. 4b).

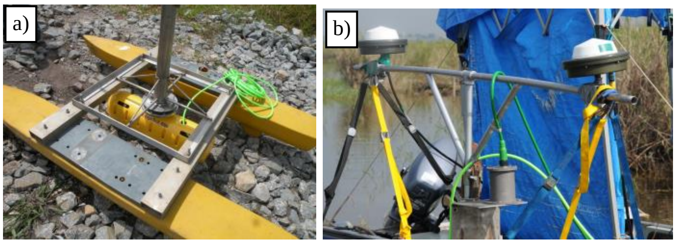

Fig. 4. a) multi-phase echo sounder Edgetech 6205; b) inertial motion unit SMC IMU-108.

Survey planning and data collection was carried out in Hypack software, and data post processing was done with Hypack and SonarWiz software. The data deliverables were files of processed bathymetry and side scan imagery. During the survey the real-time side scan displays proved very useful for data interpretation on-site, allowing real-time identification of different bottom types and seabed features.

III. SURVEY DESCRIPTION

The survey was carried out on 24-28 February 2015. The survey equipment was transported on a SUV fully assembled (Fig. 5), and brought as near to the waterside as possible. The equipment was manhandled to the waterside and deployed by hand, lifting the catamaran into the water separately from the survey launch. The catamaran was then secured to the side of the survey launch and the cables connected. The fact that the ancillary survey equipment and the sonar head were integrated into a single unit meant that the offset measurements and calibrations between the sonar and ancillary sensors remained fixed and did not need to be re-measured each day.

Fig. 5. SUV which carried the survey equipment.

Deployment took about 3 hours on the first day, followed by a patch test for system calibration which took about 1 hour. On subsequent days deployment and setting to work took less than 1 hour from arrival at the shore. A typical survey day then consisted of 4 hours data collection. The northern 20% of the dam area was covered in about 12 hours survey time (approx. 80 line-km at 4kts survey speed), covering an area of roughly 2.4km by 1.2 km, mostly in areas around 4m to 8m deep.

The optimal swath width achieved in the survey was 8 times the water column, but 12 times could also have produced high level data quality. But since no sound velocity profiles were taken during the survey, corrections for acoustic raybending could not be applied, so a conservative swath width was chosen.

IV. MPES TECHNOLOGY

The compact wide swath sonar mounted on a small survey vessel is an accepted solution for high resolution full coverage surveys in the nearshore environment, where the shallow draft and maneuverability of the vessel enables safer operations around shorelines and hazards. In the past the Multibeam Echosounder (MBES, or beamformer), originally developed for deeper water surveys, has been used in this role. However, smaller MBES systems have a limited beam spread, limiting the survey efficiency and requiring the vessel to spend extended time in shallower areas [3]. In addition, the typical lower resolution of backscatter imagery from MBES systems, compared with side scan systems, can affect feature interpretation.

In the late 1990s an alternative sonar technology started being widely deployed commercially, the Phase Differencing Bathymetric Sonar (PDBS, or Interferometer). The side-scan geometry of these sonars gave a very wide field of view, and could offer a wider swath width which was maintained in shallower waters, increasing area coverage productivity. This advantage was offset by the inherent sensitivity to noise, which results in a cloud of data points spread around the seabed. These systems could suffer from a wide nadir gap, sometimes of several meters.

Increasing demand for higher efficiency full coverage shallow water mapping has led to the development of a novel swath sonar technology, the multiphase echosounder (MPES). This utilizes a side-scan transmit geometry, with an increased number of receive sonar staves. These multiple receive staves allow the application of beamforming and beamsteering techniques to direct the sonar sensitivity toward the seafloor to optimize the performance. The side-scan stave geometry maintains the wide swath capability, while beamsteering reduces the data noise and eliminates the nadir gap.

EdgeTech's MPES technology uses 10 elements to derive up to 9 phase difference measurements per side. These multiple phase measurements provide several benefits when resolving for the seafloor soundings. First, the increased channel count provides additional information to derive mean and standard deviations for each sample in order to statistically filter out the dual echo (or multi-path) contaminated samples. This approach is analogous to the statistical processes used by beamforming systems to derive the result for each beam, and has similar benefits in terms of making the data much cleaner and more accurate [4].

Second, the high channel count in each transducer allows some beamforming (like traditional MBES systems) to take place to help focus the energy at nadir to create a denser data set in this region. EdgeTech's MPES technology enables clean, wide swath coverage (out to 12x water depth) while maintaining real acoustic data at nadir with a data density that remains almost constant from nadir to the outer swath.

Finally, traditional bathymetric systems receive the side scan or backscatter data from one of their relatively short receive elements. This short receiver naturally has a very wide beam, thus producing very poor resolution imagery. The EdgeTech 6205 includes dedicated full length transmit and receive channels for both high and low frequencies to enable the user to simultaneously collect ultra-high resolution and accurately geo-referenced side scan imagery with the bathymetry, without interference or loss of resolution.

The 6205 MPES also uses chirp sonar pulses and matched filter processing techniques, which increases range and resolution compared with single frequency systems. The system deployed in this work used 550 kHz bathymetry with 550 kHz/1600 kHz side scan, which is designed for very shallow waters and high resolution nearshore operations. Other frequency combinations are available for different survey environments.

V. RESULTS

The EdgeTech 6205 survey system described was able to maintain high survey productivity even in water depths less than 5m, as well as collect bathymetry and imagery data to the waterline. Fig. 6 shows the Digital Terrain Model from the processed data, covering 20% of the total reservoir area. Fig. 7 shows a combined bathymetry and side scan image, with side scan imagery draped over the bathymetry map. This combined data set could be quickly generated from the data collected without excessive additional processing effort, as the two data sets were simultaneously collected from the same sonar head, so all navigation and timing matches.

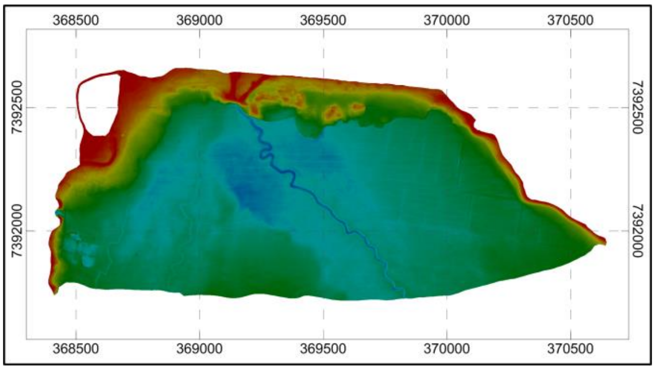

Fig. 6. Bathymetric map of the northern 20% of Taiaçupeba reservoir.

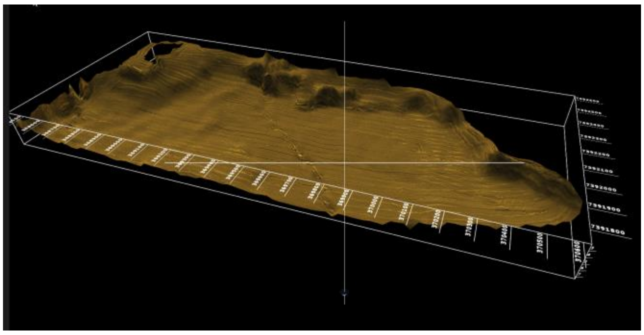

Fig. 7. Combined bathymetry and side scan image created by SonarWiz software.

The availability of the side scan imagery also aided interpretation of the bathymetry when processing, for example over different seabed types or schools of fish. This aid to data interpretation significantly decreases the time required for processing the bathymetry data, especially in complex nearshore environments.

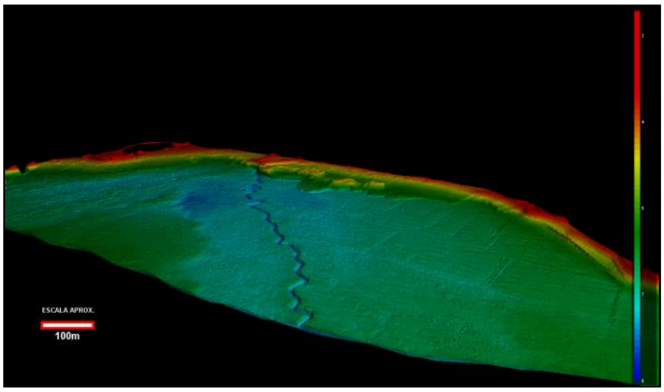

Fig. 8. 3D bathymetric map, created by Hypack software, showing riverbeds and linear structures in the eastern part of the reservoir.

This new tool used in Taiaçupeba reservoir showed the bottom lake morphology in a new perspective. It was possible to see, in the bathymetric map, the Taiaçupeba-Mirim, Taiaçupeba-Açu e Balainho riverbeds. It is also possible to identify, on the eastern part of the reservoir, some linear manmade structures related to the remnants of constructions prior to the flood of the lake, which could be interpreted as plantation paths

Fig. 8).

VI. Conclusion

This case study demonstrated the advantages of using a recently-developed wide swath sonar technology deployed using a novel catamaran float for shallow reservoir monitoring. Several benefits to using the MPES approach were demonstrated in this survey. The wider swath coverage allowed for fewer sweeps across the survey area and increased the survey efficiency. The single deployment to collect co-registered and simultaneous dual-frequency side scan and bathymetry aided feature detection and data interpretation and allowed a simpler and less time consuming post processing workflow.

The information collected with Edgetech 6205 has a huge potential to help authorities maximize the utility of the reservoir, obtaining the volume of the lake accurately and, consequently, calculating the best average flows necessary to keep its volume in a safe level, trying to avoid the depletion of its waters in drought scenarios.

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