Acoustic Imaging and Profiling: A New Tool for Underwater Inspection

Use of underwater acoustic imaging and profiling technology enabled the owner of the 50-year-old D'Arbonne Dam in north central Louisiana to pinpoint potential problems and make timely and cost-effective repairs.

By Zahir Bolourchi, Kenneth J. LaBry, Paul E. Booth, and Richard L. Glenn

For each of 20 reservoirs constructed by the state of Louisiana, the state's Department of Transportation and Development is authorized to operate and maintain the dam, water control structures, gates, spillway, and related appurtenances. Structures at these reservoirs are approximately 40 to 50 years old. The department's mandate is to ensure that the man-made impoundment structures and the attendant water-control devices are functioning to design capabilities.

One of these dams, the ½-mile-long, 54-foot-tall D'Arbonne Dam, located on the quite turbid and shallow Bayou D'Arbonne in north central Louisiana, was built in the early 1960s. The dam, of concrete slab and buttress design with an interior gallery, impounds a reservoir constructed for water supply and recreational purposes. The structure features a 1,646-foot-long earthen embankment and a 799-foot-long concrete spillway. At the south end of the spillway section, there are four 60-inch-square sluice gates used primarily for dam maintenance and reservoir management. The drainage area for the system is 1,585 square miles with a lake surface area of 15,250 acres.

In 2007, the department's Public Works and Water Resources Division was seeking a way to evaluate the subsurface condition of the dam using the latest available technology. During a previous underwater inspection, divers spotted a depression in the downstream side of the dam and suspected the possibility of a sinkhole. (Owing to the high turbidity of the water, the divers had difficulty clearly seeing the depression and were unable to draw any conclusions.)

Upon learning about the availability of underwater acoustic imaging and profiling technology and conducting additional research, the Louisiana Department of Transportation and Development (LA DOTD), Public Works and Water Resources Division decided to employ the technology to inspect and assess the condition of the structure underwater at D'Arbonne Dam.

Essentially, the technology provides a way to "see," visualize, and map the condition of a structure underwater. The technology provides an alternative to and/or complements the use of divers or to dewatering. Information gleaned from the use of the technology can be used to pinpoint where problems might be and more specifically define what repair work is needed.

In essence, acoustic technology works this way: pulses of sound are emitted from a transducer and, after encountering an object, are reflected back to the transducer. The amount of time that elapses between the transmission of the signal to an object and the receipt of the echo reflecting off that object is measured, and then multiplied by the relevant speed of sound. This provides an accurate determination of the distance to the target. Each measurement is represented by a point in three-dimensional space. By collecting several thousand points that define a surface, the as-built geometry of a structure and the present condition of the structure's surface can be determined. Scanning sonar equipment can be configured for either imaging (in which the acoustic pulse "sweeps" across the area of interest and records the intensity of the reflection) or for profiling (in which the equipment is used to collect data in such a way that it can be displayed, and then worked with, in a three-dimensional format).

For the LA DOTD's Public Works and Water Resources Division, use of the technology resulted in detailed and comprehensive information useful for making sound, cost-effective decisions about dam maintenance and repair. Use of the technology

was an effective complement to using only divers in the turbid water at this site.

Repairs at D'Arbonne Dam are expected to be complete in early 2009. Repairs included sluice gate repairs and adjustment, re-sealing of the joints in the spillway structure, and armoring of the earthen embankment.

The division is using the acoustic imaging and profiling technology to conduct underwater surveys at the other 19 state-maintained reservoirs in Louisiana. Information obtained as a result of the underwater inspections will be used to prepare plans and obtain funding for the repair of these structures.

Conducting the survey at D'Arbonne Dam

In 2007, the LA DOTD, through the Bayou D'Arbonne Lake Watershed Commission1 and its engineering consultant, Riley Company of Louisiana, Inc., contracted with Fenstermaker to perform a comprehensive survey and inspection of D'Arbonne Dam using underwater acoustic imaging and profiling technology. Fenstermaker, headquartered in Lafayette, La., is a consulting company specializing in engineering, surveying, environmental, and advanced technologies.

Using underwater acoustic imaging and profiling at the 50-year-old D'Arbonne Dam in Louisiana, contractors generated a detailed model of sub-surface conditions. This model verified the presence of voids under the spillway apron; repair is nearing completion.

The work consisted of developing a comprehensive surface and high-resolution topographic model of the dam system as well as conducting a visual inspection of the inside and outside of the dam and all surrounding appurtenant structures. Approximate cost of this work was $70,000. After reviewing the results of the inspection, it was decided to proceed with further investigation at specific locations at an additional cost of $81,000.

The field inspection consisted of three components: a high-definition laser scanning of the dam's superstructure and surroundings above water, an underwater acoustic imaging survey, and a visual inspection.

The field inspection work took place November 6-9, 2007. Throughout the four days, the weather was sunny with temperatures varying from 30 to 70 degrees Fahrenheit (F). The lake's pool stage was below the spillway's crest, which facilitated laser scanning of the spillway face of the dam down to the base of the sluice gates. Heavy vegetation on the embankment crown was removed, allowing accessibility for laser scanning from the crown of the embankment to the water's edge. The lake depth at the site of the dam is about 18 feet; visibility was approximately 1 foot.

To conduct the high-definition laser scanning survey above the water, a combination of two scanners from Leica Geosystems was used: a ScanStation I and an HDS 6000 scanner, which allowed scanning from 40 different positions.

To perform the underwater acoustic imaging and profiling, Fenstermaker used its proprietary remote-sensing system developed in 2005. This system, a modified version of the MS1000 from Kongsberg Mesotech, features an acoustic beam pattern especially effective in shallow turbid waters. In addition, the beam can be pointed in any direction, which allows observation of submerged objects from the best vantage points. The acoustic data collection method included calibration using an Odom Hydrographics DigiBar, which provides accurate speed of sound measurements.

Multiple scans at various positions were performed in order to ensure coverage from many vantage points and ensonify (i.e., illuminate using sound pulses) features from as many perspectives as practicable. This resulted in scanning from a total of 20 different positions.

Data from the high-definition laser scanning survey and from the underwater acoustic imaging and profiling (which consisted of the submerged dam

structure and the water bottom within 500 feet of the structure) was then processed to generate spatial values – X, Y, and Z – in relation to each point recorded. The data from each system was then integrated to generate a comprehensive data set, over which the sonar imagery was "draped" to provide a visualization of the underwater features of the structure and a three-dimensional model of the dam system. (See Figure 1 on page 62.)

Using results from the inspection and model

In reviewing the results from the inspections and the model, the features of immediate concern were two pairs of depression signatures (i.e., holes) in the sediment at the toe of the upstream side of the concrete dam structure. While relatively small in cross section, these signatures were of a similar nature to those that would signify the occurrence of piping in the sediment beneath the structure. Another potential explanation for these signatures was the transport of sediment through non-functioning water stops into the interior of the dam. A linear feature – observed with the underwater acoustic imaging technology – exiting near the floor blocks on the dam apron and projecting to the end of the apron supports this potential explanation. This feature was in alignment longitudinally along the dam with the northern pair of depression signatures, which were also the most prominent. The southern pair of depression signatures had no remarkable prominent correlation on the spillway side of the structure. However, they did correlate to a depressed area at the end of the spillway apron that was in alignment with the depression signatures on the spillway side of the structure.

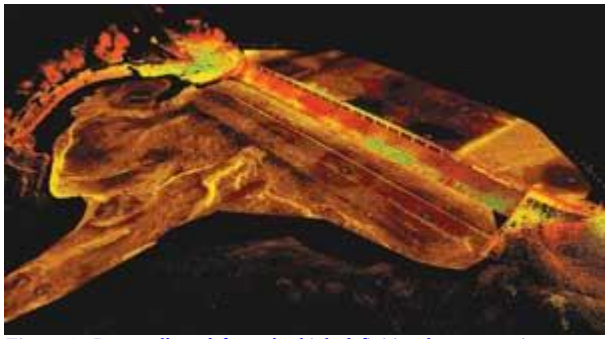


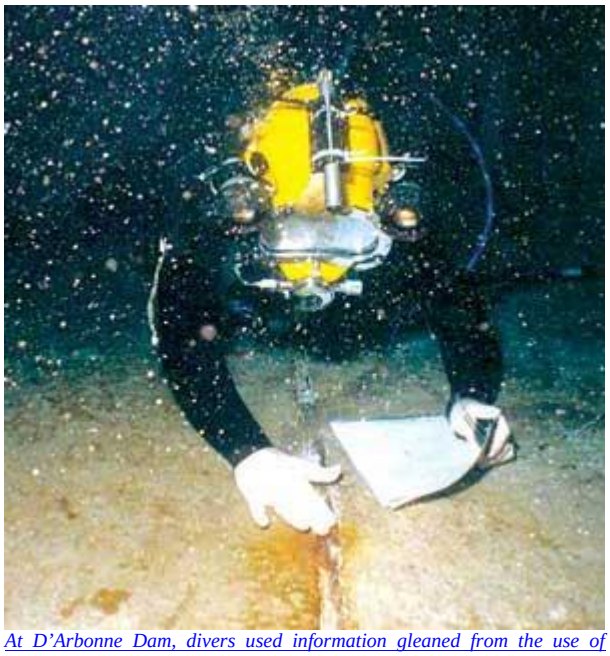
Figure 1: Data collected from the high-definition laser scanning survey and from the underwater acoustic imaging and profiling were integrated to generate a comprehensive data set. The sonar imagery was then "draped" over the data to provide this visualization of the underwater features of D'Arbonne Dam.

Whatever the explanation for the cause, if these signatures did indicate piping, this could potentially result in abrupt dam system failure. Consequently, Fenstermaker recommended that the LA DOTD employ divers to conduct a visual underwater survey of the area in which these holes were observed acoustically. Fenstermaker also proposed that the divers be aided by an underwater acoustic imaging system in order to maximize efficiency, provide increased visualization in a low-visibility environment, and produce an objective, digital record of the divers' investigations.

The divers from Glenn Underwater Services were mobilized to the D'Arbonne Dam on January 15, 2008. The divers utilized dye injection, directed by the acoustic imaging system, to first determine if significant flow existed at these holes. The dye did not pool on the lake side injection area, but was also not observed on the downstream side of the dam. This would indicate that significant flow did not exist at the holes. The divers subsequently investigated parallel areas inside the gallery, finding a compromised seal and water stop at a construction joint. This was allowing the intrusion of water and sediment into the gallery with the sediment slurry then, presumably, being carried through the gallery drains.

To reduce leakage, the divers temporarily repaired the joint until permanent re-sealing of the joint could be performed. They also noted debris at the toe of the upstream side of the dam structure in the area of the compromised joint. Debris in these areas can be a cause of turbulence, which, in turn, could cause joint erosion. Results and findings from the divers' investigation indicated that piping was not occurring.

Another area of concern when studying the acoustic imagery was a highly convoluted erosion pattern in the spillway discharge area. This was substantiated by the water bottom topography generated from the acoustic profiling data. These observations denote a very complex hydraulic flow condition that does not follow the original design discharge pattern downstream of the dam to the confluence of the Bayou D'Arbonne. The acoustically generated water bottom topography showed significant scour depressions in the spillway discharge area.



At D'Arbonne Dam, divers used information gleaned from the use of acoustic imaging and profiling to pinpoint specifically where underwater repair work was needed.

In addition to identifying areas of concern, the results of the acoustic survey were used to confirm findings from previous inspections at the dam. For example, results from the acoustic profiling of the spillway apron corroborate the findings of spillway apron borings performed in 1991. The 1991 borings pointed to voids under the concrete slabs of the spillway apron. These voids were also detected through the 2007 underwater acoustic survey. The general pattern of the acoustic indications is in accordance with that described as a result of the boring analysis in 1991. The theoretical capability to determine void extents and volume from this type of acoustic data has been shown historically; however, this has not been practically validated or verified. As such, no attempt has been made to characterize the size or extent of the void indications beneath the apron slabs. However, the acoustic profile survey of the apron slabs did not indicate any differential settling. It should be noted that there has been no change in the apron slab elevation since the 1991 boring project.

Acoustic imagery showed that the chute blocks and floor blocks on the spillway apron are in good condition, exhibiting good edge definition at the intersections of the block surfaces with minimal rounding of the edges. Generally, there is only minor evidence of erosion on the blocks. In two instances, the acoustic imagery showed debris (i.e., large tree branches) entangled within the blocks.

Using results from the survey, Fenstermaker provided a report of recommended repairs to ensure the safe operation and long-term sustainability of D'Arbonne Dam. The LA DOTD's Public Works and Water Resources Division concurred with the recommendations, and provided the necessary funds to the Bayou D'Arbonne Lake Watershed District and assisted the commission's consulting engineer, Riley Company of LA, to prepare plan and specification and proceed with the recommended repair work.

Repairs to the spillway are being performed by construction contractor, McInnis Brothers Construction, Inc. Repairs began in October 2008 and are scheduled to be completed in 2009. Repairs include cleaning and re-sealing construction joints, repairing damage to spillway gates, raising the elevation of the stoplogs, armoring the side slopes of a scour area downstream of the spillway, and replacing steps and handrails in the interior gallery. The estimated cost of the repair is $1.4 million.

Repairs to submerged construction joints are being made using the epoxy polyamide Carboguard A-788 Splash Zone Mastic manufactured by Carboline. Repairs to non-submerged construction joints are being made using the polyurethane-based, elastomeric sealant Sikaflex-1A manufactured by Sika Corporation.

References

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Zahir "Bo" Bolourchi, P.E., is director, water resources programs, for the Louisiana Department of Transportation and Development's Public Works and Water Resources Division. Ken LaBry is underwater acoustics manager for Fenstermaker. He managed the evaluation described in this article. Paul Booth, P.E., is a geotechnical and dam safety manager for Arcadis. He worked with Fenstermaker to perform the visual inspection of the dam. Rick Glenn is president of Glenn Underwater Services, Inc. He managed the diving inspection component of the work described in the article.