Could a tunnel constructed more than 50 years ago still rapidly drain a reservoir if a catastrophe happened? This was the question Terracon helped answer regarding the 185-foot deep reservoir at the Broken Bow Hydroelectric Dam in Broken Bow, Okla.

Following Hurricane Katrina in 2005, the United States Army Corps of Engineers (USACE) mandated that each public reservoir be retrofitted to drain if there was a catastrophic event threatening the stability of the reservoir’s dam. To comply with this requirement, Terracon joined the team led by Mead & Hunt to evaluate the complex geology, subsurface conditions, and the concrete tunnel liner condition to determine the stability of the existing tunnel. To make sure the 18-foot diameter diversion tunnel met stability requirements, the USACE needed a geotechnical study performed. In the study, the USACE requested that no test borings, rock coring, or destructive testing of the tunnel liner be performed.

**DISCOVERING HISTORICAL RECORDS**

As part of the team, Terracon developed a multi-stage work plan to understand the original tunnel construction and assess its current condition. Boxes of USACE files of the original dam construction documents were reviewed, including 14 soil test boring logs, geological studies of the steeply dipping rock formations, and construction plans and photographs of the 1960s construction.

The 18-foot diameter tunnel at the Broken Bow Hydroelectric Dam in Broken Bow, Okla., was examined to determine its stability. A team from Terracon and USACE are documenting the condition of the tunnel liner. Photo credit: Miro Kurka, Mead & Hunt.
Determined Stability: Evaluating a Tunnel to Predict Performance Under Catastrophic Loading  (continued from cover)

UNDERSTANDING GEOLOGIC CONDITIONS

After gaining a thorough understanding of the tunnel design and the geotechnical/geologic conditions, it was time to investigate the tunnel with the team. With the safety of the workers a priority, Terracon crafted a 200-plus-page safety plan including an activity hazard analysis for each team member responsible for accessing the wet tunnel and climbing the rock outcrops.

The work plan included a review and geologic mapping of nearby outcrops of the same rock formations cut by the original tunnel excavation and performing sensitivity analyses. Geologic strike and dip measurements were made, as well as joint spacing and the location of faults and discontinuities. The team then interpreted aerial Light Detection and Ranging (LiDAR) images of four major outcrops for joint patterns and bedding characteristics of the native bedrock. Rose Diagrams and Stereonet Pole plots were created to define structural geology properties such as the dominant orientation of bedding planes, folds, and faults. Using the collected data, Terracon provided calculated estimates for the Rock Mass Rating characterization parameters (RMR) and the Rock Quality Designation (RQD) for the rock along the tunnel alignment, as well as Headcut Erodibility indices.

DOCUMENTING TUNNEL CONDITIONS

The next stage of work included conducting a detailed visual condition study of the concrete tunnel liner, documenting the location and width of all cracks, mapping areas of seepage, and estimating seepage flow. To approximate the compressive strength of the tunnel’s liner concrete, the team also performed Windsor Probe testing. Terracon performed ground penetrating radar (GPR) data acquisition to determine the concrete liner thickness, assess the presence of voids in the liner, and to detect the presence of delaminations within the concrete.

Terracon concluded that most of the original tunnel liner was in good structural condition and suitable for use as an emergency spillway of the Broken Bow Reservoir under high velocity flow. The conclusion that the 55-year-old liner could perform under catastrophic loading was great news. The report did document local areas where the concrete liner was detached from the bedrock face, as well as many areas where active seepage was occurring. To control seepage and fill voids in the liner created by the original wooden blocking points and rotted timber cribbing, Terracon recommended the tunnel liner be pressure grouted with chemical grout. Controlled and engineered weep holes would be designed and placed through the concrete tunnel liner to relieve hydrostatic pressures.

This fast-paced, detailed study was impacted by record rainfalls during the data-gathering field operation. This project was truly a collaborative and seamless effort with Mead & Hunt and the Tulsa District USACE personnel.

GEORGE WEBB, P.E., LEED AP

George is a senior geotechnical engineer in our Cincinnati office. He has served as the geotechnical engineer of record for many unique projects in the Midwest and has provided geotechnical consultation for projects around the world.

Did You Know?

The Broken Bow Diversion Tunnel was constructed in 1962 to divert the Mountain Fork River during the construction of the 225-foot high earthen dam for the Broken Bow Reservoir. The reservoir is 22 miles long, and covers 14,000 acres. In 1974, the diversion tunnel was retrofitted with gates and control mechanisms to serve as a low flow outlet facility.
Located just 10 nautical miles from the Atlantic Ocean in Jacksonville, Fla., Dames Point Marine Terminal is JAXPORT’s newest marine facility. Opened in 2009, it includes a state-of-the-art container terminal capable of handling an annual volume of 800,000 to 1 million Twenty-Foot Equivalent Units (TEUs). With an increase in container volume, JAXPORT recognized the need for an effective rail connector and the development of an efficient intermodal transfer facility (ICTF). In 2014, it decided on a design-build delivery for the project. Terracon partnered with TranSystems and D.B. Kenyon to deliver a quality project while optimizing the budget within a tight timeframe.

**FACING COMPLEX PROJECT COMPONENTS**

The new facility was constructed on approximately 45 acres of JAXPORT property and required relocating a mile-long public road that bisected the site. Components included remediation of lead from an old gun range facility, wetland mitigation, clearing and grubbing, unsuitable material removal, excavation and filling, importing base material, rock, asphalt pavement, reinforced concrete, roller compacted concrete, high mast LED lighting, buildings, gates, canopy, and railroad track.

According to Tom Selfridge, senior geotechnical engineer in Terracon’s Jacksonville, Fla., office, the team decided to further investigate a minor mention made in a preliminary report of possible debris buried in the soil at the construction site. Historic aerial photos were quickly reviewed and indicated relatively large areas of disturbed ground. These areas were scanned with a geophysical survey, utilizing ground penetrating radar (GPR) and electromagnetic induction, to look beneath the ground surface for possible voids or debris deposits. Finally, suspect areas were ground-truthed with backhoe-excavated test pits. Results of the testing were significant. More than eight acres of the site had debris hidden under ground level, including pieces of charred wood timbers and sheets of metal intermixed with sand.

“Without a thorough investigation of the site, the debris could’ve been missed and negatively impacted the construction,” said Selfridge. Terracon’s early awareness and resolution of the debris issue protected the project’s budget and schedule. Additional value was added by Terracon’s recommendation to screen the excavated debris deposit which allowed for re-use of its sand component and reduction in the volume and cost of the off-site waste disposal.

Terracon’s resourcefulness continued to the construction phase as Chris Martin, Terracon materials specialist also in the Jacksonville office, adopted use of a geophysical tool (Kessler MIT Scan T2) to obtain real-time measurements of layer thicknesses during placement of roller-compacted concrete (RCC) pavements. After an initial test strip was completed to calibrate the contractor’s equipment and methods, the RCC was placed in multiple lifts up to a maximum total thickness of 20 inches. In addition to the value of real-time data, the scanner tool saved approximately $20,000 in testing cost as compared to the conventional rotary coring method, according to Martin.

Testing of the rail components required knowledge and application of requirements set forth by The American Railway Engineering and Maintenance-of-Way Association (AREMA). Field density testing was completed on the sub-ballast material and welding of the steel rail tracks was checked by ultrasonic testing.

In January 2016, the Port took beneficial occupancy of a $25 million state-of-the-art ICTF, delivered via design-build, on time and within budget.

**EXPERIENCE PREVAILS**

Uncovering Hidden Obstacles

More than eight acres of the site had debris hidden under ground level, including pieces of charred wood timbers and sheets of metal intermixed with sand.

DOUG DUNKELBERGER, P.E.

Doug is a senior engineer in Terracon’s Florida offices. He has more than 20 years of experience providing consulting engineering services throughout the U.S. with expertise in the unique challenges faced by ports and waterways, and intermodal facility projects.
A touchstone to the Hispanic community in Utah, Centro Civico Mexicano (Centro) is a place where generations celebrate the traditions of their heritage. Centro was first established in 1935 by Mexicans who came to Salt Lake City and surrounding communities to work on the railroads and in the mines. Today, the well-loved cultural center is solidifying its commitment to future generations by revitalizing its downtown property; made possible through a combination of brownfields funding tools.

**IDENTIFYING HISTORICAL USES**

Originally purchased in the 1950s, the Centro property was facing the all-too-familiar challenges of urban neighborhoods—aging facilities in need of repair, pressure from surrounding development as part of downtown gentrification, and options to sell the property and relocate. Knowing the challenges at hand, community leaders decided it was time to reconstruct and design a new facility at the site of Centro’s existing home.

“The best reason for the cleanup and new construction is to build a showpiece representing the history of Hispanics in Utah and to give them something to be proud of, including taking part in an environmental improvement of the District,” said Brandy Farmer, president and CEO, Centro Civico Mexicano.

Serving as a trusted partner, Terracon helped Centro assess the property’s history, identifying past industrial uses on the site and surrounding properties as part of the Phase I Environmental Site Assessment. Terracon discovered the site had been contaminated by Polycyclic Aromatic Hydrocarbons (PAHs) from past coal use, and chromium and petroleum hydrocarbons from other past industrial activities. These needed to be cleaned up to meet the requirements of the new development. Development money was raised to cover the new proposed Centro buildings, but not the environmental costs.

**BROWNFIELDS FUNDING SOLUTIONS AID CLEANUP**

Terracon provided solutions to address both the environmental issues identified and the unexpected financial challenges associated with the cleanup. By helping Centro prepare successful applications for both an EPA Brownfields Cleanup Grant and a Revolving Loan Fund Cleanup Subgrant from the Wasatch Brownfields Coalition, Centro received $400,000 in funding to aid in the cleanup.

Although a small footprint, this piece of downtown Salt Lake City has a powerful future. The new plan for mixed-use development will include low-income senior housing, offices, classrooms, a multipurpose gymnasium, a rooftop soccer facility, and a black box theater.

“This has been one of my favorite projects. The people working on this are fantastic, and together they are all bringing solutions to the table,” said Craig Eaton, Terracon’s environmental department manager in Salt Lake City. “My thanks go out to everyone at Centro Civico Mexicano, Corroon Development Company, Salt Lake City Corporation, Salt Lake County, Utah’s Voluntary Cleanup Program, EPA Region 8, EPA Office of Brownfields & Land Revitalization, and the generous foundations in the local community.”

Belinda Richard, Terracon’s national Brownfields program manager added, “This project is a wonderful example of how local partners, community members, and regulatory agencies can come together to make a project happen—it takes a village.”

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**Terracon helped Centro assess the property’s history, identifying past industrial uses on the site and surrounding properties as part of the Phase I Environmental Site Assessment.**
HELPING A HOSPITAL

Diagnosing Indoor Air Quality and Building Operation Issues

Hospital culture demands that nothing is as important as the people in its care and those who serve them. So when a healthcare facility experienced elevated relative humidity levels, condensation on ductwork, and mold growth following general renovations and building additions, the building owner contacted Terracon. Our team began an evaluation of the performance of the heating, ventilating, and air conditioning system (HVAC) to determine if the system was maintaining cooling, dehumidification, relative humidity, and positive indoor air pressure per the original design.

DIAGNOSING THE ISSUES

A diagnostic assessment of the building mechanical HVAC and exterior enclosure systems were conducted to determine the potential causes of elevated humidity levels and related issues. Additionally, spotted ceiling tiles and mold growth on interior walls was found in several care rooms and common areas. Our facilities experts determined that the HVAC system was operating at a negative indoor air pressure and was in need of repairs along with recalibration of the automatic controls. With help from the commissioning agent, mechanical contractor for the project, and owner’s maintenance personnel, the automatic controls of the HVAC were re-calibrated and air balanced to provide a net positive indoor air pressure in the building and to correct and maintain relative humidity levels in the acceptable performance range.

The Terracon team of building specialists also provided extensive diagnostics of the building exterior to determine the pathways of moisture infiltration into the building interiors. Partial destructive investigative work was required to the building façade to observe the condition of the building exterior construction, air barriers, and sealants. The building height and limited access to the façade necessitated the expertise of our building exterior professionals trained to access the exterior façade via rope access. Architectural details for the building renovations and additions were studied to understand the designed versus installed methods of weather proofing and placement of air barriers. Extensive visual observations of the building exterior wall sections were also conducted to locate potential pathways of outside air infiltration and air movement between the outdoor environments and the indoor conditioned areas.

MONITORING MOVEMENT

In a further effort to investigate the potential areas of air movement between the outside environment and inside conditioned areas, and due to the urgency and target height, an infrared camera was mounted to an unmanned aircraft system (UAS) to scan the southern façades and identify variations in building surface temperatures. Scanning revealed isolated areas of the building façade that were possible areas of air movement between the outdoor ambient and indoor areas. To perform even more in-depth diagnostics, one area was selected for testing. A propeller blower door fan was installed with calibrated airflow and differential pressure measurement software to accurately determine air movement through the building façade. By testing a baseline of air leakage at an indoor air pressure of approximately 0.01-inches water gauge, air movement was quantified through the selected test area for comparison to any future repairs and improvements to the façade and air barrier. Safe smoke was introduced into the ceiling plenum of the test area to trace movement of air through the façade and other pathways in the exterior wall. The results from testing indicated that careful, detailed repairs to the façade and air barrier would be needed to reduce air movement from the outside environment to the inside areas, mitigating condensation and biological growth inside the building.

To develop a plan for detailed repairs to the elements of the building façade, Terracon assisted the design and contracting team in selecting fire-rated materials and sealants suitable for use in performing needed repairs that would improve the effectiveness of the air barrier and withstand typical building pressures generated by the HVAC system. Terracon performed a test of a prototype of the detailed repair for the test area and identified further areas in the façade for repairs.

MAINTAINING BUILDING HEALTH

As the detailed repairs were being performed, Terracon provided observations and testing of the installed repairs. Terracon will also observe the ongoing operation of the mechanical HVAC system to verify that the representative interior areas in the building are maintained at desired positive pressure and an acceptable relative humidity. This hard work has paid off, providing a safer, more comfortable environment for the facility’s occupants.

JEFFREY MILLER, P.E.

Jeffrey is a senior engineer and principal for Terracon in Houston. Jeffrey has more than 40 years of experience specializing in mechanical, electrical, and plumbing diagnostics, engineering, and commissioning.
TERRACON FOUNDATION AWARDS $136,390 IN GRANTS

Established as the community investment arm of Terracon, the Terracon Foundation’s goal is to serve and support company employees and the communities where they live and work. The recent award of $136,390 in grants was presented to six universities, 12 community organizations, and two national partners in grant categories of university and community organizations, scholarships supporting dependents of employees, and national partner grants. To date, the Foundation has distributed more than $1.6 million in grant funds.

For more information about the Terracon Foundation and a full list of grant recipients, visit terracon.com/foundation

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