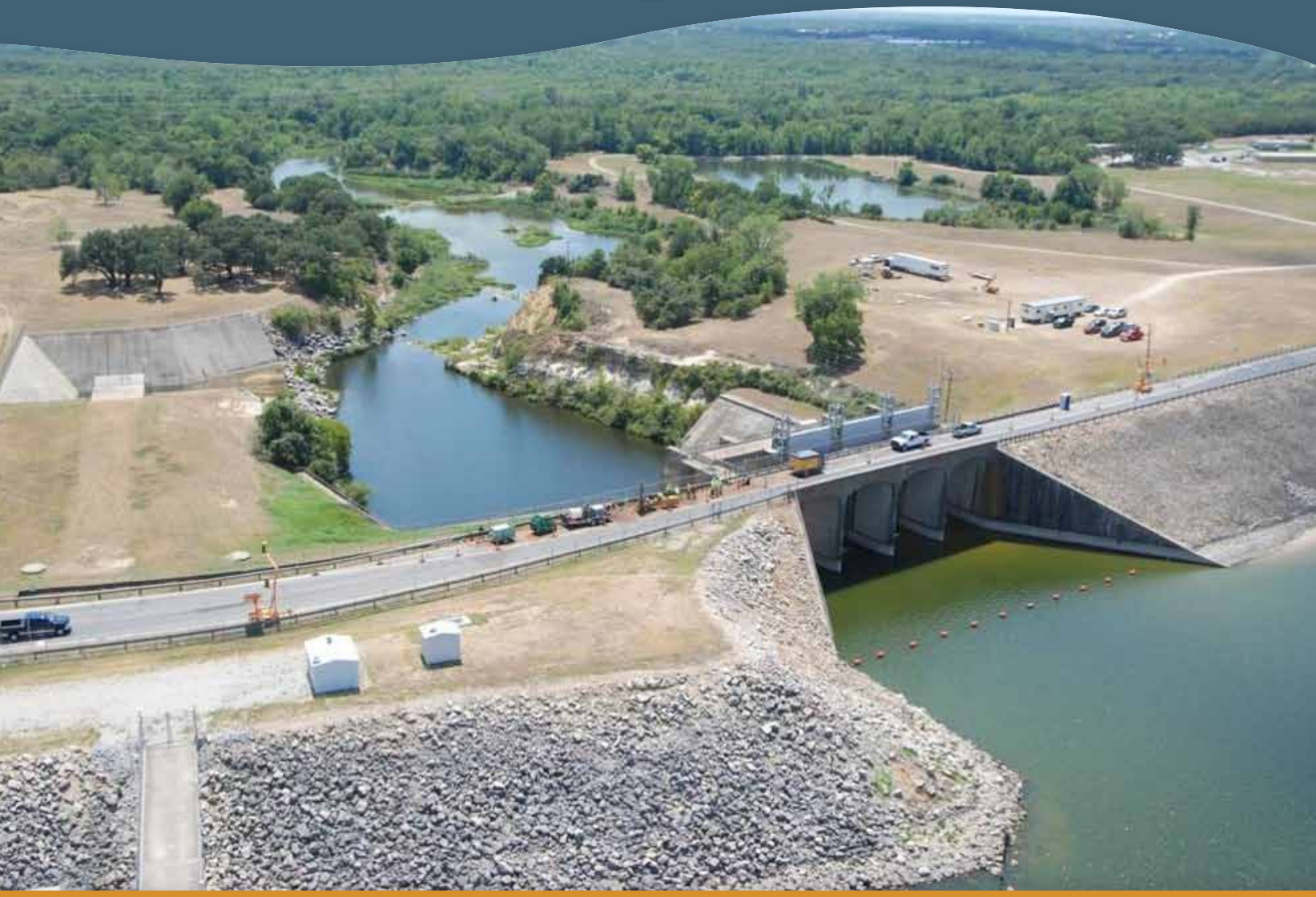
ASSOCIATION OF STATE
DAM SAFETY OFFICIALS

THE JOURNAL OF Dam Safety

VOLUME 13 | ISSUE 4 | 2015

ISSN 1944-9836



**Congratulations to Tarrant Regional Water District and Parsons Brinckerhoff, Inc.
ASDSO 2014 National Rehabilitation Project of the Year for the
Rehabilitation of Eagle Mountain Lake Spillway Dam, Fort Worth, Texas.**

CLOSING SEEPAGE WINDOWS AT THE EAGLE MOUNTAIN SPILLWAY DAM

JAMES PARKES

LOUIE VERREAULT

INTRODUCTION

Tarrant Regional Water District (TRWD) provides water to more than 1.7 million people in the North Central Texas area, including the cities of Fort Worth, Arlington, and Mansfield. TRWD's operations include maintenance of dams for the Water District's four reservoirs, which include Eagle Mountain Lake. The lake is located northwest of Fort Worth and is 179,880 acre-feet in size. The lake provides drinking water and flood control for a large portion of the Trinity River Watershed. These two functions are critical for continued sustainable development and growth of one of the largest cities in the state of Texas and fourth largest metropolitan area in the United States.

The lake is impounded by two embankment dams. The main dam is approximately 85 feet high and 4,400 feet long. The spillway dam is approximately 60 feet high and 3480 feet long and includes the spillway structures. The dams were built in the early 1930s and have a crest elevation of 682 feet. Conservation lake pool elevation is 649 feet and probable maximum flood (PMF) elevation is near the crest. To date, the highest flood level recorded in the lake has been approximately elevation 659. Since original construction, the dams have performed adequately under historical loading conditions.

In 2007, TRWD tasked Parsons Brinckerhoff to perform a comprehensive seepage and stability assessment of both dams as part of a proactive management strategy for its existing infrastructure. Although there were no indications of concern, there were no stability analyses on file, so TRWD chose to perform the assessment in order to provide confidence in another 80+ years of service of the embankments. The comprehensive assessment included a desktop study and analysis, an investigation and testing program and a detailed analysis and modeling study. The assessment found that the spillway dam had several "seepage windows," or gaps, within the foundation seepage cut-off. Parsons Brinckerhoff assessed alternatives for creating a continuous cut-off, developed a permeation grout program, prepared bid documents, and performed construction oversight of the grout curtain. The grout curtain was constructed by Hayward Baker between 2012 and 2013 using grout provided by Green Mountain International. The project won the 2014 ASDSO National Rehabilitation Project of the Year Award.

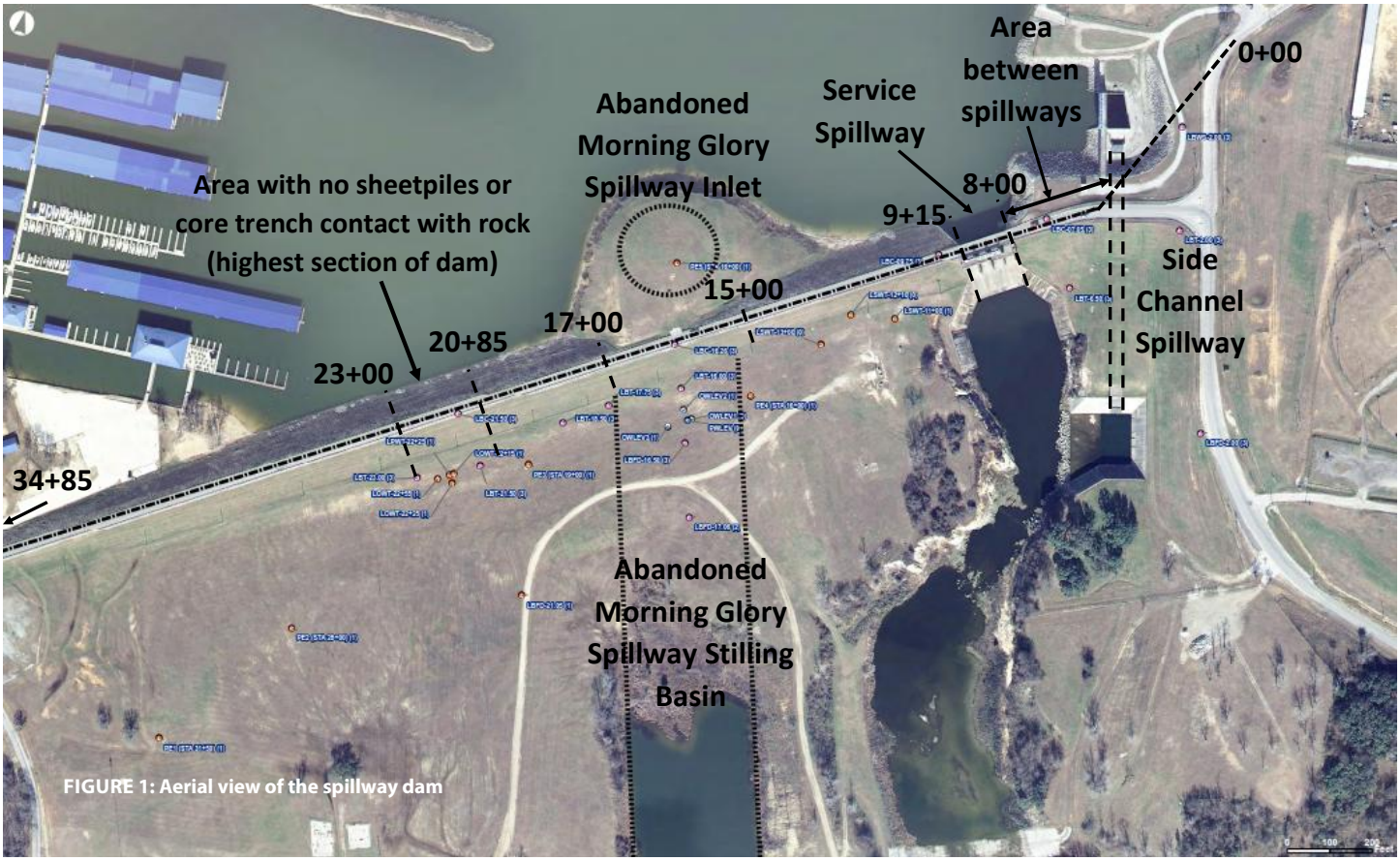


FIGURE 1: Aerial view of the spillway dam

DESKTOP STUDY AND ANALYSIS

The initial phase of the assessment consisted of a desktop study of available records and development of preliminary seepage and stability models. The spillway dam, shown in figure 1, includes the original service spillway and a side channel spillway that was added in the early 1970s. Construction of another spillway, a morning glory (MG) spillway, was attempted but abandoned in the late 1960s. The stationing along the dam increases from east to west (right to left in the figure).

ORIGINAL DAM CONSTRUCTION

TRWD's files contained extensive construction records including memos, letters, observations, reports, and detailed construction progress cross sections from the 1930s as well as the modifications in the 1960s and 1970s. Although TRWD had a significant volume of materials in their files, a single comprehensive review had never been performed prior to this work. This review led to several significant findings.

The spillway dam is a homogeneous earth embankment consisting of clayey sand or sandy clay, classifying as SC or CL in accordance with the Unified Soils Classification System (USCS). The embankment was built using "wetted and rolled" construction, which consisted of wetting the soils to the point where rubber tire equipment almost became bogged down. Subsequent investigations indicated that the embankment soils are medium dense or medium stiff to stiff.

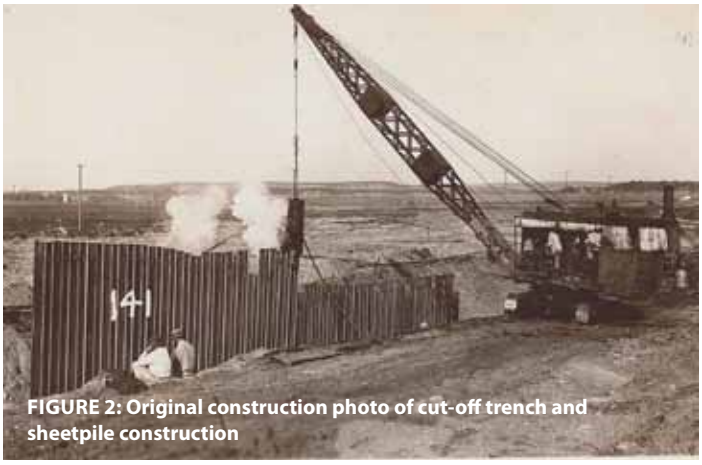


FIGURE 2: Original construction photo of cut-off trench and sheetpile construction

Foundation conditions include a layer of pervious sand and gravel overlying rock of the Paluxy sandstone formation, which is a fine sandstone with shale interbeds. Foundations soils classify as silty sand, poorly graded sand with silt, clayey sand, or poorly graded gravel with clay (SM, SP-SM, SC, and GP-GM in accordance with the USCS). The thickness of the foundation sand and gravel layer varies from a few feet to over 40 feet under the highest section of the dam.

Construction of the dam included a seepage cut-off extending to the top of rock. The cut-off consisted of a clay core trench excavated to the top of rock where rock was within a depth of 20 feet or less. Where rock is deeper, steel sheetpiles were driven through the base of the core trench to the top of rock as shown in figure 2. Records indicate that the sheetpiles extend from Sta. 13+00 to 20+85.

POST CONSTRUCTION MODIFICATIONS

In the 1960s and 1970s, the dam was modified by adding a second spillway. A Morning Glory (MG) spillway was attempted between Sta. 15+00 to 17+00 in the late 1960s (see figure 1). The MG spillway consisted of an inlet shaft on the upstream side of the dam which would connect to a stilling basin on the downstream side through a tunnel under the dam. The shaft and stilling basin were excavated, but uncontrollable seepage into both excavations led to the abandonment of the construction. In particular, seepage channels formed within the foundation sands at the north face of the stilling basin excavation, near the toe of the dam, as shown in figure 3. The excavations were backfilled except for the south half of the stilling basin, which has become a pond.

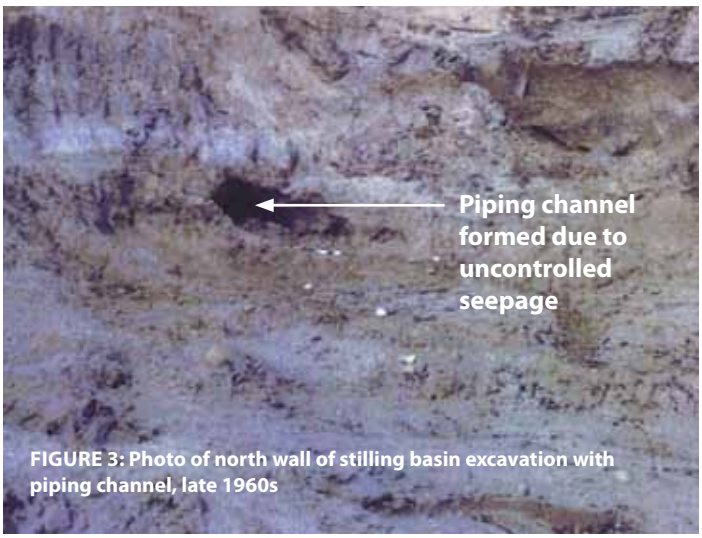


FIGURE 3: Photo of north wall of stilling basin excavation with piping channel, late 1960s

Following the abandonment of the MG spillway, a side channel spillway was constructed through the rock in the east abutment in the early 1970s. The side channel spillway was completed as designed without any adverse construction conditions.

DESKTOP STUDY FINDINGS

Three areas, shown in figure 1, were identified as having potentially incomplete cut-off measures. Construction records indicated that the core trench excavation did not reach rock between Sta. 13+50 and 23+00, and that sheetpiles were driven from Sta. 13+00 to 20+85. This indicated a potential gap of 215 feet, from Sta. 20+85 to 23+00, with no foundation cut-off to rock. This area also corresponds to the highest section of the dam.

Records of the failed MG spillway construction indicated uncontrollable seepage had occurred in an area with sheetpiles driven to rock. Review of available borings from the MG work as well as from original construction and comparison with the sheetpile records indicated that the sheetpiles terminated above the top of rock in this area. Based on the boring descriptions, it appeared that the sheetpiles may have achieved refusal on gravels within the foundation soils instead of rock.

The third area of potential concern is between the service and side channel spillways. Construction records indicated that recommendations were made to install a concrete cut-off wall along the centerline of the dam between the spillways. However, no records of construction exist for such a wall, and field observations in 2008 indicated observed seepage at the toe of the dam in this area as shown in figure 4.

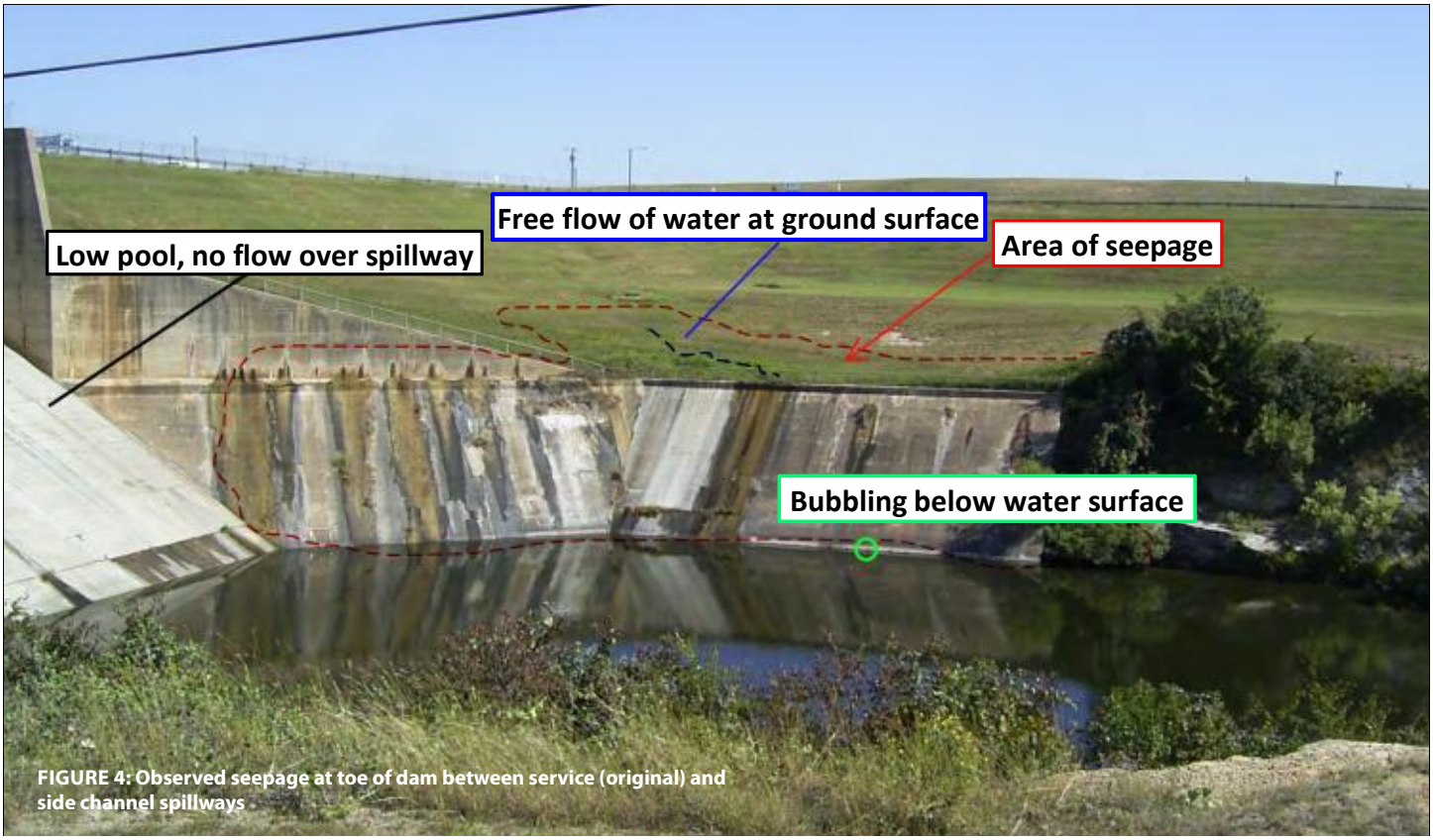


FIGURE 4: Observed seepage at toe of dam between service (original) and side channel spillways

FIELD INVESTIGATION AND TESTING PROGRAM

The desktop study indicated the potential for several seepage windows within the foundation of the dam, thereby rendering the foundation cut-off ineffective. However, the desktop study was based on records from multiple sources spanning several decades, and therefore the accuracy of the findings was uncertain. A multi-phased investigation was developed to verify the findings as well as obtain data for the comprehensive seepage and stability assessment. The investigation included geophysics, cone penetrometer (CPT) soundings, borings, and aquifer pumping tests. The investigation phases were conducted in series, with the more generalized and least expensive (geophysics) followed by more focused investigations covering large areas and obtaining more detailed data (CPTs and borings) to focused investigations in localized areas (pumping tests).

GEOPHYSICS INVESTIGATION

Zonge Geophysics performed an investigation consisting of total field magnetic surveys, self-potential (SP) and direct current electrical resistivity imaging (ERI), and compressional-wave refraction surveys. This investigation allowed a large area to be assessed quickly with the results used to focus the remaining investigations.

The magnetic survey confirmed the presence and the approximate limits of the sheetpiling, which were consistent with the limits indicated in the historical records. The SP and ERI surveys were used to detect possible preferential seepage paths. The SP survey was performed to identify areas of unusual seepage conditions, followed by the ERI survey which was used to obtain site-specific data in those particular areas. The ERI survey consisted of three parallel lines run longitudinally along the dam crest, downstream slope, and toe, from the west abutment to the service spillway.

Two areas indicating seepage anomalies were identified based on the SP and ERI survey as shown in Figure 5. In the figure, the blue anomalies indicate areas of high water content, which can be interpreted to indicate areas of concentrated flow. One area, at Sta. 20+85, was more concentrated under the dam crest and dissipated in the downstream direction. This location coincides with the end of the sheetpile cut-off in an area where the core trench does not meet rock, and is consistent with concentrated seepage around the edge of the sheetpile under the crest.

The other seepage anomaly corresponds to the former MG spillway location. This anomaly is more concentrated at the toe and is less concentrated towards the crest. This is consistent with the open channels in figure 3, which would result in more concentrated seepage at the toe into the former stilling basin excavation. This appeared to indicate that the seepage channels observed in the 1960s may still be open.

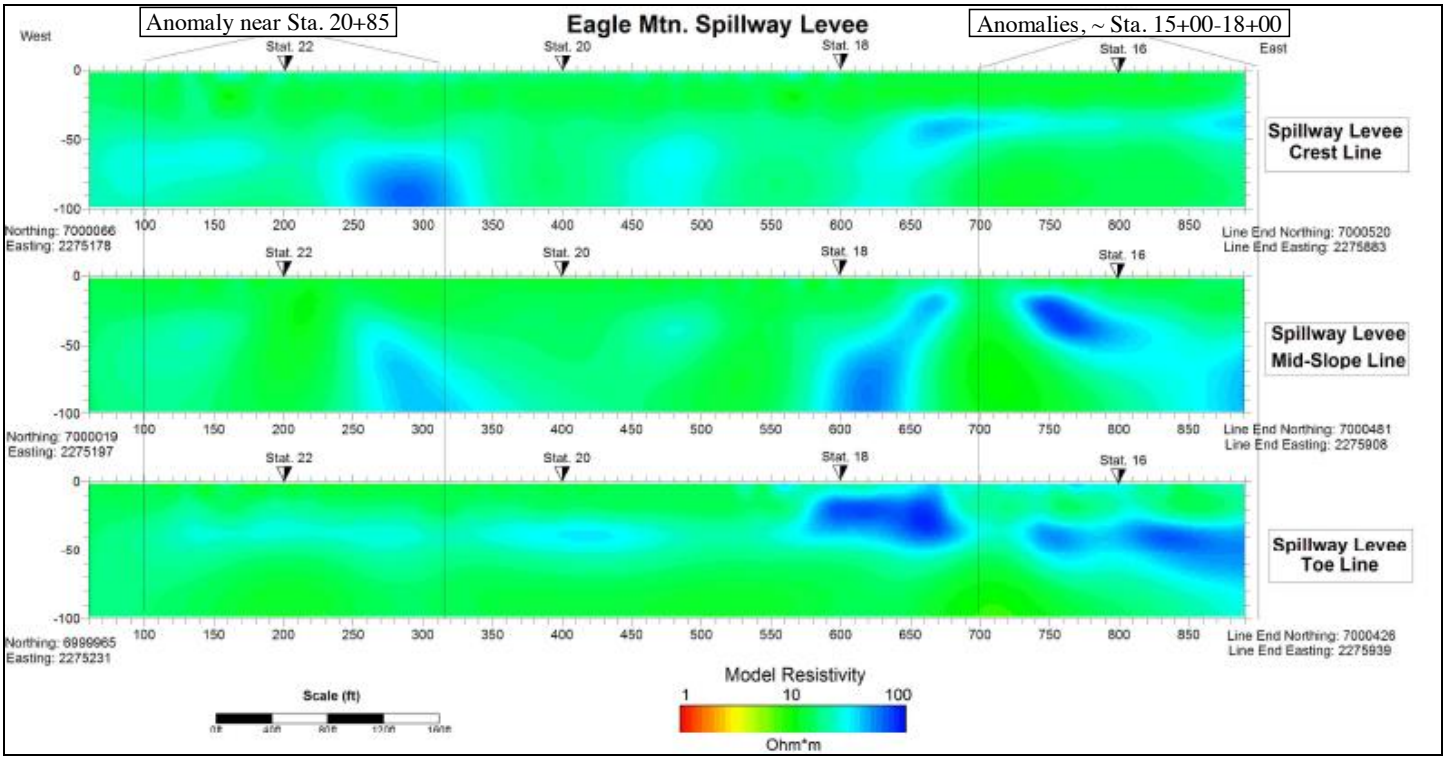


FIGURE 5: Results of ERI investigation showing seepage anomalies

ISSN 1944-9836 - Association of State Dam Safety Officials

The presence of a concrete cut-off wall between the two spillways, as recommended in the 1970s, was investigated using a seismic refraction survey (SRS). If a concrete cut-off wall had been constructed, the density of the concrete would be different from the surrounding soil and sandstone, and would therefore be detected by SRS. The results of the SRS did not indicate the presence of any denser materials or anomalies between the spillways, indicating that the concrete cut-off wall was likely never built.

BORINGS AND CPT INVESTIGATIONS

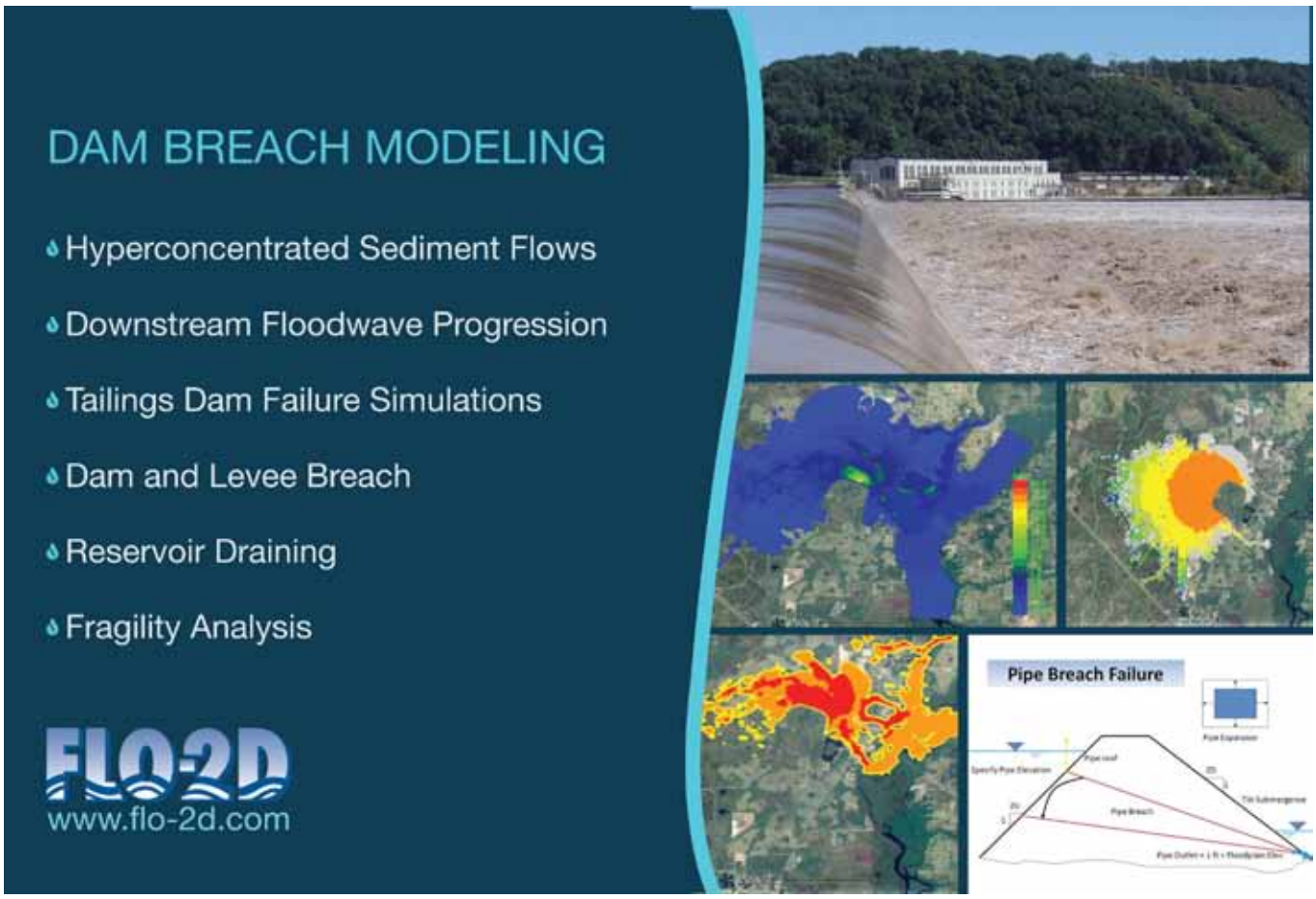
A detailed investigation consisting of 33 CPT soundings and 11 borings with standard penetration testing (SPT), Shelby tube soil sampling, rock coring, packer testing, and installation of vibrating wire piezometers (VWPs) and open standpipe piezometers was performed at the spillway dam. Findings were used to confirm the understanding of the construction methods and materials, to characterize subsurface conditions, and to obtain data for engineering analyses. Photos of the investigation are shown in figure 6.

Based on the boring and CPT results, the top of rock within the area of the MG spillway was found to be consistent with the estimated rock elevations from the desktop study, which was below the estimated sheetpile tip elevations. This confirmed that the sheetpiles did not reach rock, which is consistent with the ERI results. In addition, packer test results showed that the rock is relatively impervious, which indicated that the foundation cut-off would be effective if it contacted rock.





FIGURE 6: Photos of field investigation borings performed on crest and upstream slope



AQUIFER PUMPING TESTS

Two aquifer pumping tests were performed by LCA Environmental. The tests were performed at the toe of the dam at Sta 16+00 (at the abandoned MG spillway) and at Sta. 22+00 (where there were no sheetpiles or core trench contact with rock). The hydraulic properties of the foundation sand layer were investigated. Also, water quality testing on the pumping discharge was performed and compared with samples from within the rock formation and from the lake. Nine specific ions were identified in each sample: bicarbonate, carbonate, iron, calcium, magnesium, potassium, sodium, sulfate, and chloride. If an effective cut-off existed, then seepage from the lake would have to pass through the rock, and water quality tests should be similar to water samples from the rock formation. If the cut-off were incomplete, then seepage would pass through the sand layer directly to the downstream side of the lake. The results of the tests, presented in table 1, indicated high permeability in the foundation sands and a direct connection between the soils downstream of the dam and the lake (i.e. no effective cut-off).

Table 1: Summary of Pumping Test Results for Foundation Sand Layer

Pump Test Location	Permeability (cm/sec)	Comments
Sta. 16+00	$6*10^{-2}$	Water quality of pumping test discharge from foundation sand layer at toe of dam is consistent with lake water and differs significantly from rock water samples.
Sta. 22+00	$4*10^{-3}$	

ANALYSIS AND MODELING

The results of the field investigation and desktop study were consistent and confirmed that the foundation cut-off was incomplete. A comprehensive seepage and stability analysis of three critical sections was performed for both conservation pool and PMF conditions. These sections corresponded to the three areas of inadequate cut-off, which also included the highest section of the dam.

The analysis results indicated acceptable factor of safety (FS) values for conservation pool conditions. However, under PMF conditions, the FS values were below generally accepted industry standards, although still significantly above unity. The results indicated that the spillway dam was not in imminent danger of failure, but would not have the desired margin of safety under the PMF loading conditions.

The analyses were also evaluated including a complete cut-off in each of the sections. The results indicated that closing the seepage windows would increase the FS values well above industry minimums. Considering the size of the dam and good engineering and operation practices, TRWD chose to pursue a program to close the seepage windows. This would increase the margin of safety under all loading conditions and provide confidence in continued performance of the dam for the foreseeable future.

DESIGN OF UPGRADE MEASURES

Several methods for creating a continuous cut-off were assessed, including closing the seepage windows using permeation grouting or jet grouting, or construction of a new cut-off wall, either under the crest or under one of the slopes, using deep soil mixing, slurry trenching, jet grouting, or sheet piles. Permeation grouting of the foundation soils in select areas was considered the best remediation alternative for several reasons.

A permeation grouting program could be focused only on the areas and depths that required treatment, and could therefore minimize costs and disturbance to the dam. The treatment could be overlapped with the existing cut-off features, therefore making the most use and economy of the existing cut-off measures. The grouting pattern and depth could be adjusted if obstructions, such as the existing sheetpiles, were encountered. The use of permeation grouting would improve the soils in-situ without disturbance to the soil structure, which in turn would minimize spoils and potential post-construction settlements.

The spillway dam also includes a public roadway on the crest of the dam. Closure of this roadway for heavy construction operations would result in an hour-long detour around the dam, including impacts to school bus routes. Permeation grouting could be performed using compact equipment, which would allow one lane of the roadway to remain open during construction and therefore minimize impacts to the public.

TEST GROUT PROGRAM

A test grout program was developed to verify that the permeation grouting would be effective, as well as to assess grouting procedures, equipment, and verification testing for development of construction specifications. The test grout program was performed at Sta. 16+00, in the area of the pumping test at the MG spillway excavation.

The grout to be used had to satisfy several criteria. It had to be chemically and biologically inert, unaffected by filtration, environmentally safe, and capable of forming an effective seepage barrier within the soils at the site. The grout had to be able to expand beyond its liquid volume in order to provide confidence in the formation of a complete cut-off, including overlapping the existing core trench and sheetpiles. The grout also had to be hydrophobic, meaning that it does not require contact with water to maintain its shape and volume, in order to mitigate the potential for void formation due to shrinkage of the grout from water loss. As noted previously, the foundation soils generally classified as poorly graded sand with silt, silty sand, clayey sand, or poorly graded gravel with silt (SP-SM, SM, SC, and GP-GM in accordance with the USCS). The higher fines content in some of the samples (SM and SC soils), as well as the requirements mentioned above, indicated that a chemical grout would be the best alternative. Mountain Grout HL-100, a liquid chemical grout by Green Mountain International, was selected because it satisfied all of the requirements.

The test program consisted of twelve grout holes in three rows of four holes, with the center row offset. Center to center spacing between

the holes was 3 feet. Grouting was performed using tube-a-manchette procedures with grout pressures of 100 to 400 psi measured at the top of the injection line. A volume per lift versus time procedure was developed to limit the grout volumes to provide a cost effective quantitative method to evaluate grout performance. Pre- and post-grouting in-situ testing confirmed an effective reduction in the in-situ permeability of the foundation sand layer.

The results of the test program verified that the grout product and system would create an effective cut-off barrier. The results were also used to develop grouting inspection procedures for construction to provide effective oversight, monitor grout volumes, minimize cost overruns, and maintain quality control. The test program also enabled an accurate construction schedule to be developed, which allowed for a better assessment of the potential impacts to the public. Finally, the grout program was used to develop a cost estimate which was used to secure funding for the construction contract.

DESIGN OF THE GROUT PROGRAM

Bid documents were prepared based on the test grout program and included requirements to use the polyurethane chemical grout HL-100. Specifications included the requirement of achieving a permeability of 10^{-6} cm/sec in the grouted soils.

A grouting program to close the seepage windows was developed that included four areas as summarized in table 2: the three areas of seepage windows identified previously and an additional area on the west side of the spillway structure. This last area was added because there are often preferential seepage paths at the interfaces between concrete structures and embankments, and, considering the life of the structure and historical construction, it was considered good practice to grout this area as well. The grout areas extend beyond the estimated seepage window limits in order to provide overlap with the existing cut-off features. A 3-D rendering of the grout program is presented in figure 7. The program consisted of three rows of staggered grout holes as shown in figure 8.

Table 2: Summary of Grout Zones

Grout Areas	Station limits	Seepage "window" limits	Comments
Zone 1	20+25 to 23+50	20+85 to 23+00	Gap in cut-off trench and sheetpile
Zone 2	14+25 to 17+75	15+00 to 17+00	Abandoned MG spillway excavation
Zone 3	9+20 to 9+75		West side of service spillway
Zone 4	5+53 to 8+00	5+53 to 8+00	Area between spillways

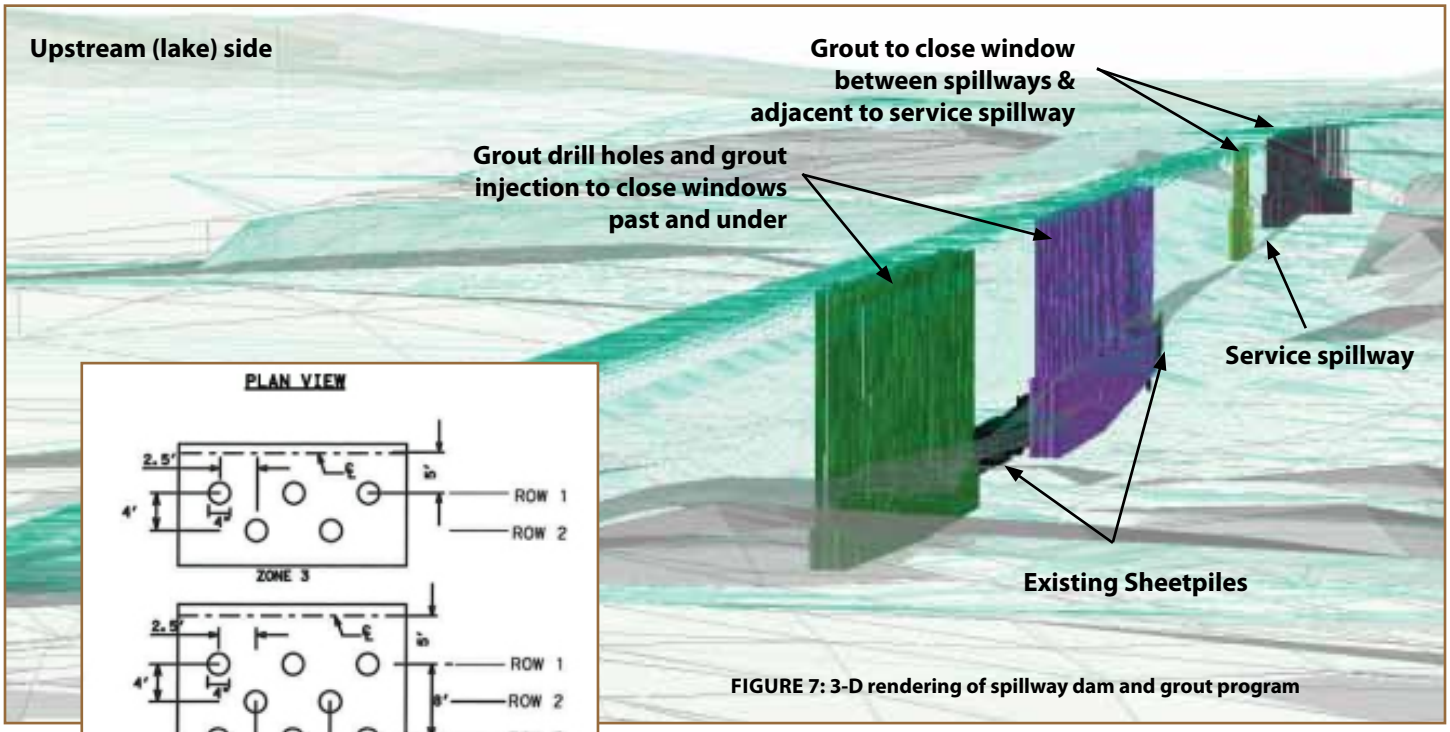


FIGURE 7: 3-D rendering of spillway dam and grout program

FIGURE 8: Grout hole layout (pattern is on the downstream side of dam centerline)

CONSTRUCTION OF THE GROUT CURTAIN

Construction of the grout curtain was awarded to Hayward Baker, Inc. of Fort Worth, Texas in June 2012 for approximately $4 million. Parsons Brinckerhoff performed construction management and inspection of the grouting program. Grouting lasted approximately eight months, from August 2012 through December 2012, with final site restoration and verification testing completed in early 2013.

The grouting procedure involved placing six gallons of grout in the bottom stage to provide an effective connection to the rock, then injecting grout in one-foot intervals up through the foundation sands. Above the foundation sands, the drill holes were grouted with one gallon per stage to ensure that no voids or preferential flow paths were left within the cut-off trench or embankment. Maximum pressure used in grouting was three psi per foot of drilled depth. Pumping would continue until the volume or pressure criteria were reached. Grout quantities were continuously monitored and adjusted using the inspection and monitoring procedures developed in the test program. Approximately 57,200 gallons of grout were used. Photos of the grouting are shown in figure 9.



FIGURE 9: Photos of the grouting operation on the crest of the spillway dam



ISSN 1944-9836 - Association of State Dam Safety Officials



FIGURE 10: Crew drilling grout holes and crew injecting grout and pulling casing with jacks

The grouting procedure consisted of drilling holes using air or water flush, setting the steel pipe for grout injection, injecting the grout in one-foot intervals, and extracting the casing with jacks as the grouting progresses. This operation allows one crew to drill the holes and set the casing and another crew to perform the grouting and casing extraction as shown in figure 10. This allowed the schedule to progress as quickly as possible.

VERIFICATION OF PERFORMANCE

Verification was performed using falling head tests within the treated zone. Test results, summarized in table 3, indicate permeabilities on the order of 10^{-6} cm/sec. A post-construction pumping test was performed at the toe of the dam as a final verification measure. Results of the pumping test indicated a significant reduction in



Table 3: Results of Post-Grouting Falling Head Tests in Grout Zones			
Grout Zone	Number of Tests	Average Permeability (cm/sec)	Assessment
Zone 1	7	$4.6*10^{-6}$	Acceptable
Zone 2	5	$3.8*10^{-6}$	Acceptable
Zone 3	3	$2.3*10^{-6}$	Acceptable
Zone 4	6	$2.5*10^{-6}$	Acceptable

subsurface permeability, and water chemistry testing indicated that a direct connection between the foundation soils at the toe of the dam and the lake no longer exists.

CONCLUSION

A comprehensive investigation and analysis enabled TRWD to locate and close seepage windows under one of its embankment dams. Parsons Brinckerhoff utilized a rational, phased approach with each phase building on the findings of the previous phase to investigate concerns and develop an effective rehabilitation plan.

The comprehensive review of TRWD's historical records was integral to the success of the project. The fact that TRWD maintained these records and saw the value in performing the review was invaluable. The use of multiple, progressive field investigations, from low-cost non-invasive surveys (geophysics) to more invasive investigations (CPTs, borings, pumping tests) was effective at confirming the initial findings while managing costs. The test grout program proved vital because it verified the effectiveness of the proposed grout program and enabled the development of construction oversight procedures and realistic cost and schedule estimates. Finally, the use of in-situ testing after construction was effective in verifying the results of the grouting.

In addition to improving the safety of the dam, the closing of the seepage windows has also reduced the amount of water "lost" due to uncontrolled seepage under the dam. This creates an added benefit in an area that has been suffering drought conditions in recent years.

ACKNOWLEDGEMENTS

This project was a team effort. The authors would like to acknowledge the contribution of firms Zonge Geosciences, Inc., LCA Environmental, Inc., and Prototype Engineering, Inc. during the investigation and design phases. Hugh Kelly, P.E. served as the Project Manager and overall technical lead for the project. Henry Russell, P.E. of Parsons Brinckerhoff was instrumental in developing the design of the grouting program. The successful completion of the grouting program was the result of quality work performed by Hayward Baker, Inc. and Green Mountain International.



James Parkes, PE
Supervising Geotechnical Engineer
Parsons Brinckerhoff
100 South Charles Street
Tower 1, 10th floor
Baltimore, MD 21201
410-843-3306
parkes@pbworld.com

James Parkes is a Senior Professional Associate with Parsons Brinckerhoff. He graduated summa cum laude in civil engineering from Virginia Tech in 1998 and earned his master's degree in civil engineering from Virginia Tech in 1999. He is currently the geotechnical discipline lead in Parsons Brinckerhoff's Baltimore, Maryland office. He has worked on a variety of infrastructure projects including tunnels, bridges, highways, and dams. His experience with dams and levees includes engineering inspections, investigations, assessments, and design of new structures as well as improvements to existing structures. He has worked on numerous dams and levees of all sizes throughout the United States including several high hazard embankment dams.



Louie Verreault, PE
Dam & Levee Safety Engineer
Tarrant Regional Water District
808 E Northside Dr
Fort Worth TX 76102
817-720-4260
louie.verreault@trwd.com

Louie Verreault is the Dam and Levee Safety Engineer for the Tarrant Regional Water District (TRWD). He earned a B.S. in civil engineering from the University of Texas at Arlington in 1991 after leaving Chevron USA where he was a drilling supervisor. In his 24 years at TRWD, he has worked with many disciplines related to dams, levees, wetlands, water resources, and project management. The four major water supply and flood damage reduction dams provide unique opportunities for operations and maintenance, structural performance, and long-term instrumentation development and monitoring. Mr. Verreault is also the engineering interface with the USACE on the Fort Worth floodway project.



ASDSO's mission is to improve the condition and safety of dams through education, support for state dam safety programs, and fostering a unified dam safety community.

Join us on our mission.

Join ASDSO and our nearly 3,000 members in building a unified dam safety community through educational programming, networking with dam and levee safety stakeholders, increased public awareness, legislative advocacy, industry research, and so much more.

Who is a part of ASDSO? Our members are State and Federal Dam Safety Officials, Civil, Geotechnical, Environmental, and Structural Engineers, Scientists and Technicians, Dam Owners & Operators, Service and Product Suppliers, Engineering Consultants, Hydrologists/Geologists, Emergency Management Professionals, Academic Professors and Researchers, and Students.

Learn more at DamSafety.org.

Become a part of the ASDSO community and enjoy these membership benefits and more:

- Professional Development Opportunities
- Discounts on ASDSO Training
- Networking Opportunities
- Subscription to ASDSO E-News
- Subscription to *The Journal of Dam Safety*
- Career Growth
- Technical Training Opportunities
- Voice in Policy Making
- Access to More Than 3,000 Professionals
- Peer/Program Review
- Committee Involvement
- Legislative Activities
- Information Services
- Access to ASDSO's "Members Only" Website Section
- One (1) Complimentary Archived Webinar

Association of State Dam Safety Officials

239 S. Limestone, Lexington, KY 40508 I (859) 550-2788 I info@damsafety.org