Observations from the 2017 Mexico Earthquake

Risks and Benefits Associated with the USACE Levee Portfolio

2018 Annual Conference Highlights

Soil Strength Measurement for Embankment Dam Deformation Modeling
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USSD, as the United States member of the International Commission on Large Dams, is dedicated to:

ADVOCATE: Champion the role of dam and levee systems in society
EDUCATE: Be the premier source for technical information about dam and levee systems
COLLABORATE: Build networks and relationships to strengthen the community of practice
CULTIVATE: Nurture the growth of the community of practice.

Dams and Levees is published by the United States Society on Dams three times a year. The deadline for articles, news items and advertising is February 1, June 1 and October 1.

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On the Cover: Plywood prevents filter contamination, Chilhowee Dam North Embankment Remediation Project

www.ussdams.org
Summer is in full swing and I am sure many of you are enjoying vacation and time with your families. It won’t be long before we will be wondering how 2018 came and went so quickly. I’d like to bring you up to speed with what has been happening within our organization. This spring, many of us attended the very successful Annual Meeting and Conference in Miami, Florida. This conference was quite a milestone event, with record-breaking attendance as well as some adjustments to our program format that I believe reflect the changes we’ve seen in membership and within our industry. Christina Winckler and her Planning Committee did a fantastic job putting together a very impressive program, full of rich technical content and enjoyable networking activities. As the anchor of our Educate Imperative, the conference allows members to exchange ideas, learn from one another, and make new relationships through the vast network that is our community of practice. As you may have noticed, the typical closing banquet was replaced with an evening at the ball park to watch the Marlins, have a few refreshments and socialize with friends in a relaxing atmosphere away from the conference center. I encourage you to look for similar activities at next year’s conference in Chicago. We also had the good fortune to recognize one of our members with a Lifetime Achievement Award, Dr. Hank Falvey. Dr. Falvey attended the Awards Luncheon with his wife Inge, daughter and grandson. As expected, Dr. Falvey reflected on his career and shared some amusing anecdotes, demonstrating how much he truly enjoys what he does.

Hopefully by now you have had a chance to meet or speak to our new Executive Director, Sharon Powers. In keeping with the Cultivate Imperative of our Strategic Plan, Sharon continues to improve the way we conduct our day-to-day business. Sharon has worked with Board Members Phoebe Percell and Stuart Harris to update our Bylaws and Operations Manual. This had not been done in quite some time and turned out to be a significant effort. I truly believe it will improve our organization and facilitate future changes the organization will go through as we continue to grow and offer more opportunities for our members.

As part of our Collaborate Imperative, USSD seeks to engage with other organizations to jointly advance the state-of-practice. This effort is best reflected by USSD’s membership in the International Commission on Large Dams. I encourage you to visit the ICOLD website, icold-cigb.net (email.info@ussdams.org for member login information). As a member, you have full access to ICOLD publications, the World Registry of Dams, and useful information about our industry from the perspective of the ICOLD technical committees and ICOLD member countries. This year on November 24th, ICOLD will celebrate its 90th birthday, and what better way for USSD to engage in this celebration than with our support of ICOLD’s new President, Mike Rogers from Stantec. At the 2018 ICOLD Annual Meeting and Congress in Vienna, Mike took over as president following in the footsteps of only three previous ICOLD presidents from the U.S. (C.A. Hathaway, 1952-1958; G.T. McCarthy, 1967-1970; and J Veltrop, 1988-1991). Please join me in congratulating Mike and thanking him for his commitment to USSD and ICOLD.

Please keep an eye out for information on the 2019 ICOLD Annual Meeting which is being organized by the Canadian Dam Association (CDA) and will take place June 8-14, 2019 in Ottawa (http://icold-cigb2019.ca). This offers a unique opportunity for USSD members to participate in an ICOLD Annual Meeting right next door. Also please look for more information on the next Dam Safety in the Americas international workshop event in Paraguay, February 18-22, 2019. USSD is also planning 2018 and 2019 fall technical workshops, and we are evaluating collaborative opportunities with FEMA and IAHR.

The newly rechartered USSD Committee on Advocacy, Communication, and Public Awareness has been busy in recent weeks. Chair Keith Ferguson represented USSD at the Vienna meeting of the ICOLD Committee on Public Awareness, which is in the process of updating its charter. Keith will continue to work with the ICOLD committee, as their activities parallel closely with those of the ACPA. One ACPA initiative that is of particular interest to ICOLD is our effort to develop position statements on important issues facing the dam and levee community. A workshop is being considered, to be held during ICOLD 2019 in Ottawa, to develop a similar initiative on the international level. ACPA is continuing its effort to develop six key position statements, with a goal to have these statements prepared, reviewed, and ready for Board approval by the next annual meeting in Chicago.

Thank you all for your continued support of USSD. I look forward to the second half of 2018 and continuing to work with all of you to strengthen the community of practice and enhance our collective commitment to dam safety.

Dean B. Durkee
President, USSD
The 39th USSD Annual Conference and Exhibition will take place in Chicago, April 8-12, at the historic downtown Chicago Hilton. The Federal Energy Regulatory Commission is the Host.

The 2019 USSD Conference theme is Second City, Second Chances: Stories of Rehabilitation, Modification, and Revitalization. Dams and levees continue to provide essential public benefits including flood control, water supply, renewable energy, recreation, navigation, and habitat and environmental enhancement. The need to maintain and improve our aging infrastructure has been well publicized, making it important to also share the great success stories of restoration and upgrades for dams and levees.

Technical Program
The technical program will be developed by the Conference Planning Committee, chaired by Rachael Bisnett, Stantec. Presentations will be selected from abstracts submitted in response to the call for papers. Concurrent sessions will feature research or experience relating to the Conference Theme, or corresponding to topics addressed by USSD Technical Committees. A Plenary Session on Tuesday morning will include invited presentations addressing contemporary issues related to dams and levees.

Conference Activities
A full range of activities will include USSD committee meetings, plenary sessions, and concurrent technical sessions. Events throughout the week will offer plenty of networking opportunities.

Field Tours. Two field tour options to significant nearby dam projects will be featured during the conference.

Workshops. Several concurrent workshops, organized by USSD Technical Committees, will be held during the week. USSD Committees are invited to submit proposals.

Exhibition. The 2019 exhibition, the largest to-date, has been 50% pre-sold in Miami. The remaining 50% of available booths will go on sale in September

Sponsorships. A robust sponsorship program will allow organizations to showcase their products and services to a wide range of professionals involved in dams, levees and water resources. Look for more details this fall.

Hotel Reservations
The conference hotel is the beautiful Hilton Chicago, 720 South Michigan Avenue, in the heart of the city. Committee meetings, technical sessions, the exhibition, and most networking events will take place in the Hilton. The USSD conference rate is $229, plus tax. A limited number of rooms are available at the prevailing government rate.

Online: https://book.passkey.com/go/USSD19

Phone: 877-865-5320, group USD.

The cutoff date is March 15, or until the room block fills, whichever is earlier.

Alternate Hotel
A limited number of rooms have been reserved at the nearby Congress Plaza Hotel, 520 South Michigan Avenue. The room rate is $120.

Online: https://bit.ly/2LnStL6

Phone: 800-635-1666.

Conference website:
https://ussdams.wildapricot.org/event-2471270
Fall Workshop: Public Safety and Security around Dams

USSD will present a Workshop on Public Safety and Security for Dams, scheduled to take place in Ashburn, Virginia, November 6-8, 2018. The Workshop is hosted by Loudoun Water, and will include a field tour and site assessment.

This course, presented by Gannett Fleming, is designed for all security and dam industry professionals with a requirement to manage public safety and security for dams and/or water retention sites.

The three-day workshop will cover the Canadian Dam Association’s Public Safety Guidelines and the Security for Dams Requirements of the U.S. Department of Homeland Security. William Foos and Paul Schweiger of Gannett Fleming will be the lead instructors. Topics addressed during the Workshop will include:

- Legal Responsibilities
- Policy, Plans and Procedures
- Security Program and Assessment
- Public Safety Program and Assessment
- Dam Vulnerabilities and Public Hazards Analysis
- All Hazards Risk Assessment
- Risk Treatment Solutions
- Physical Security and Public Safety Measures

Registration is limited to 50 participants. Additional details are on the USSD website.

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Chilhowee Dam North Embankment Remediation Project

Complex geotechnical conditions, significant access challenges, high levels of public interest and tight schedule constraints all contributed to making the timely completion of the Chilhowee Dam North Embankment Remediation Project an equally challenging, rewarding, and impressive feat. The project, constructed by Barnard Construction Company, Inc. (Barnard) and designed by WSP USA (WSP) for Brookfield Smoky Mountain Hydropower LLC (Brookfield), earned the USSD’s 2018 Award of Excellence in the Constructed Project. The project’s success held implications for the livelihood of recreationalists, the safety of downstream residents, and the progress of future similar dam repair projects.

Background

Located approximately 50 miles south of Knoxville, Tennessee, on the Little Tennessee River, the Chilhowee Dam and Hydroelectric Facility was originally constructed in 1955 to supply power to a nearby aluminum plant. This 85-foot-high, 1,500-foot-long clay core dam has two rockfill embankments and continues to generate hydroelectric power and control lake levels. After discovering cloudy-water seepage at the downstream toe of the dam’s north embankment, Brookfield launched a full-scale investigation in September 2015 to determine the source of the seepage and potential need for remediation. Lake levels had been drawn down 37 feet below normal operating range to allow for geotechnical investigations. These investigations rendered the typically bustling lake off limits to the public for recreational use. Results showed that missing or inadequately placed fine and medium filter material had caused portions of the dam’s clay core earthen embankment to migrate downstream, opening up a seepage path. This discovery warranted a large-scale effort to remediate the dam’s north embankment to cut off the seepage path, replace contaminated material, and prevent further damage.

The Project

In 2016, Brookfield contracted with Barnard to rehabilitate the dam’s north embankment. The initial 40-foot excavation of the dam’s earthen embankment required a slow and careful excavation, which consisted of high levels of survey mapping and material sampling throughout. This excavation required skilled equipment operators and close coordination between surveyors, engineers and field personnel to prevent over-excavation and allow for material sampling and data acquisition. During the excavation process, the newly-exposed portions of the dam’s clay core to remain in place
were immediately protected from potential damage due to temperature, precipitation and equipment.

Following completion of the initial 40-foot excavation, crews placed a concrete slab for large equipment to access the north embankment area. Next, a major portion of the project began with the installation of 88 secant piles. Each secant pile was one meter in diameter and approximately 40 feet long. The secant pile work was defined by three major areas: an arc wall (27 piles), an impervious water barrier (26 piles) and a secant pile box (35 piles). The arc wall, completed first in the sequence, arced from the southernmost portion of the embankment at the concrete non-overflow face of the dam heading north to the toe of the excavation boundaries. The impervious water barrier, installed second, formed two parallel secant pile walls from the northernmost end of the arc wall heading west toward the concrete non-overflow face of the dam. The secant pile box, installed last, formed a trapezoid between the arc wall and the concrete non-overflow face of the dam. Every other secant pile placed as part of the secant pile box was reinforced with a W24x131 steel beam. These reinforcement beams were later welded to an internal bracing system using W36x231 steel beams to support the open secant pile box excavation during the following construction phase.

The next — and most daunting — challenge involved excavating inside the secant pile box. This 35-foot excavation to bedrock was performed meticulously and cautiously to allow for ample investigation of the existing materials being removed. Internal bracing members were installed at two elevations inside the “box” to provide structural support for the immense pressure from surrounding embankment materials and lake water. Surveys were performed regularly to ensure that the excavation area was stable and safe for admittance to the confined space until excavation was completed.

The excavated secant pile box cavity was then backfilled with a cement-bentonite slurry mix. Through weeks of coordination, the project team, a local batch plant, and outside consultants developed this specific mix design to have properties of imperviousness and resistance to shrinking and cracking.

The last major construction phase involved the calculated and careful rebuilding of the zoned earthen embankment. Management of sensitive materials, survey oversight, a robust quality control program and effective contractor/engineer coordination contributed to the successful completion of this final phase.

Pressure to safely and effectively address the seepage issues was compounded by the immense amount of recreational use that Chilhowee Lake and the surrounding areas receive from locals and visitors alike. The area offers a wide variety of activities including boating, fishing, hiking, motorcycle riding and biking. The team was determined to complete the project by mid-June 2017 to facilitate the Chilhowee Lake refill process and return the once bustling recreational area to its former luster.

Rising to the Challenge

The project team’s ability to collaborate and overcome challenges was tested after the initial excavation of the embankment had been completed and secant pile installation began. During the first week of secant pile work, it became clear that the actual conditions of the rockfill...
and bedrock materials were vastly different than what had been assumed at bid time. As a result, the drilling subcontractor was unable to meet the production rates established prior to the work beginning. This posed a serious threat to the project schedule and on-time completion. Barnard worked closely with the subcontractor to devise methods to overcome this discrepancy in production rates and maintain the schedule. The team immediately implemented a second shift and worked 24 hours per day, six to seven days per week, helping to regain the lost schedule time. The team worked diligently to involve all parties in discussions and ensure that all were apprised of corrective actions being made.

The project team was tested again near the completion of secant pile work. A subcontractor’s temporary drill casing became lodged in a drilled secant pile and could not be removed. As the contractor, Barnard was credited with getting intimately involved to find a solution acceptable to all parties. Ultimately, this solution meant abandoning the lodged steel drill casing around the concrete secant pile. To maintain the secant pile’s imperviousness to water, Barnard implemented a drilling and grouting program in the surrounding secant piles. A bituminous coating protected the portions of the steel casing that would’ve been exposed to the new clay core.

The final phase of construction, embankment rebuild, presented one of the toughest challenges. Knowing the project could not afford to fall behind, the team met regularly to discuss areas of potential improvement in production and quality. By keeping a small, protected, self-draining stockpile onsite, the team ensured that there was no down time in production between the rain storms. In addition to ensuring that materials were readily available, the team used a cover system after each lift placement to protect the clay from rain and heat damage before the next lift could begin.

**Overcoming Obstacles**

While the team solved every construction challenge in stride, the project site posed inherent obstacles that required careful planning and solid teamwork. Chilhowee Dam is located adjacent to U.S. Route 129, a popular motorcycle and sports car road known as “Tail of the Dragon.” Already challenged with working in the limited space of the dam’s crest, the team had to remain mindful of the thousands of enthusiasts driving the winding road year round. The team implemented an effective traffic control program to ensure safety of the public and crews alike.

Through consistent discussions on safe work practices near traffic, the project finished with no incidents with the public. For example, one particular discussion yielded a plan to stage traffic control personnel on both ends of the blind corners leading to the site. With radio communication, the traffic control personnel notified equipment operators of oncoming traffic. As heavy equipment and onsite materials increased, the limited space of the dam’s crest reduced. Through use of limited access zones, effective communication, and constant reinforcement of safe practices, no incidents occurred between crews and mobile equipment.

In addition to site’s limited space and busy location, the team had to contend with adverse weather. Eastern Tennessee is notorious for sudden and intense springtime rains. Rebuilding the zoned filter embankment of the dam — including the very sensitive and moisture-controlled clay core — proved challenging during spring. To avoid damaging the clay core, the team remained ever-ready to shut down backfill operations and begin an “all hands on deck” material protection procedure at a moment’s notice. The risk posed by rain required close collaboration between the project team and the warehouse where the clay was stored and conditioned.

**Innovating on the Job**

Although the project design was considered complete prior to the start of construction, the team found many opportunities to apply innovative construction techniques. These techniques significantly contributed to the team’s ability to regain the schedule and complete the project on time.

The first opportunity for innovation came through the design of a 40-foot-deep excavation to gain access to the embankment’s main work area during subsurface phases. To gain and maintain access to the primary work area, the team had to devise a method to install an access road that would not infringe on other construction activities. The team pioneered a road on the far upstream limits of the north embankment with the toe of the ramp seated at the edge of the primary work.
area's concrete slab. The road was installed by placing more than 3,000 cubic yards of shot rock topped off with a crusher run finish coarse. The resulting 16-foot-wide access road offered safe and stable access to the work area without interfering with any of the project phases.

While stockpile locations for the specified materials were dictated by project specifications, the team developed innovative methods for acquiring, conditioning, protecting and stockpiling the materials. The team used an existing warehouse to serve the dual purpose of a stockpile and conditioning location for the sensitive earthen materials. Separating the differing materials while stockpiling and conditioning the clay core proved challenging. The clay's specified moisture content range was dependent on the proximity of placement to the concrete section of the dam. Coordination between the material handling and placement teams ensured that the materials met the specifications for the specific location of placement. This material stockpile location, paired with a team dedicated to handling and conditioning the material, resulted in the successful production, protection and delivery of embankment materials that met the project's stringent requirements.

To combat the adverse weather conditions onsite, the team protected each completed lift of clay with a polyethylene cover.

As part of the dam remediation scope, Barnard was responsible for developing the secant pile box cement-bentonite slurry infill material. This material was loosely specified to have the characteristics of imperviousness to water, crack resistance and minimal shrinkage properties. The team took a hands-on approach to fulfilling this material need by employing the help of a local batch plant and an outside consultant. Through the process of mix design revisions, trial batching, and rigorous testing, an acceptable mix design emerged that met the criteria for strength, imperviousness, bleed, shrinkage, and heat of hydration. In addition to developing a mix design, the team used this collaborative approach to determine lift thicknesses and placement methods for this highly controlled material.

Designing for Efficiency

In 2008, Brookfield conducted initial investigations to determine the cause of Chilhowee Dam's seepage. They discovered that the seepage path caused by filter materials inadequately placed during initial construction resulted in the softening of portions of the existing clay core and contamination of other filter materials. This widespread contamination rendered the material properties no longer beneficial to the impervious qualities of the dam's earthen embankment. In some locations, the contaminated areas extended as far down as the top of bedrock at approximately an elevation of 810 feet. The typical operating water elevation of the Chilhowee Lake is approximately 872 feet. The drawdown for the investigation decreased the lake level by 37 feet, leaving a significant head of water above the top of the bedrock elevation where some of the soft clay material was found.

To avoid the need for cofferdams — or worse yet — a full lake drainage program, WSP designed a plan to access the bedrock elevation to remove and replace contaminated material while maintaining the water level at the drawdown elevation of approximately 835 feet. This plan involved a unique construction process and significant monitoring efforts to ensure safe access for workers and engineers alike.

This excavation and installation of bracing members inside the secant pile box was perhaps the most complex and unique phase of the project. To ensure safe access to the excavation area, survey monitoring pins were installed atop the secant piles surrounding the excavation. Each pin was surveyed daily to ensure the 40-foot-deep secant piles did not move under the immense pressures of the surrounding embankment and significant head of water. In addition to the topside monitoring pins, survey hooks were installed within the excavated area at three elevations as a secondary means of confirming the stability of the surrounding structure.

Holding the outside pressures at bay as the excavation progressed towards bedrock proved challenging. The team used horizontally-oriented wide-flanged steel beams at two locations welded back to the internal vertical secant pile support members with 11/16-inch fillet welds. Stiffener plates were welded onto the wide-flange members to provide additional resistance to buckling. With the excavation area considered a confined space, access was limited and strictly regulated. The team used air quality monitors and a dedicated confined space attendant.

Compacting filter materials.
remained in the excavation while work occurred.

This highly engineered, careful and calculated operation also allowed time to acquire data and materials to corroborate the theory for the cause of the dam’s seepage. The material within the secant pile box was excavated in maximum 2-foot lifts. After completing each lift, the team performed a thorough survey mapping on the limits of the existing materials and assisted the engineers in collecting samples of each type of material encountered. This process enabled WSP to develop a 3D model depicting the pre-remediation conditions of the dam’s interior down to bedrock.

Working within a small and ever-changing jobsite presented a moving target for hazard recognition, mitigation and elimination. The team used interactive daily safety meetings, job-specific briefs, and Barnard’s hazard recognition program. From working on steep, rocky surfaces near excavators to working near the rotating barrel of a drill rig, the team discussed new hazards every morning and anytime the work changed or someone observed a potentially unsafe situation.

Building on the project’s already robust safety program, Barnard held a surprise man-down drill onsite during the construction industry Safety Week in May 2017. By enacting the response procedure for a confined space rescue, the man-down drill reinforced the team’s knowledge of strategies learned in safety trainings preceding this phase of construction and outlined in the project’s emergency action plan. The team’s quick reaction time and positive feedback from all involved was a testament to this method of continued education and involvement.

Brookfield and WSP were not only welcomed but encouraged to attend and contribute to the daily meetings. By blending Brookfield’s and Barnard’s safety cultures into one cohesive program, the project finished with a record of zero OSHA recordable, zero OSHA reportable, and zero lost-time injuries.

**Resulting Benefits**

The integrity of Chilhowee Dam is critical to controlling and maintaining the functionality of Chilhowee Lake. The lake, bordering Great Smoky Mountains National Park and the Cherokee National Forest, provides ample recreational activities for outdoor enthusiasts. Prior to beginning dam remediation construction, Barnard understood Brookfield’s goal of reopening this recreational haven for the 2017 summer season. Many of the project’s local subcontractors and suppliers fondly recalled memories of times spent on or near the lake. Generations of families flocked to the lake each summer, and losing one recreational season would deeply affect the community both economically and socially. Knowing this, the project team worked tirelessly to ensure this project was completed safely and in an environmentally responsible and timely manner to facilitate the lake’s reopening.

The Chilhowee Lake drawdown not only affected recreational use of the lake, but also exposed culturally-sensitive areas and fish spawning zones susceptible to disturbance. These exposed areas posed a hazard to the community as interest and curiosity in the area increased. The project’s on-time completion would not only appease recreational users, but also alleviate safety concerns.

After nine months of fast-tracked construction, with crews often working 24 hours a day, six to seven days a week, Brookfield refilled Chilhowee Lake on schedule for a climactic Fourth of July Weekend opening.

**Lessons Learned**

Ultimately, the entire project team’s ability to collaborate and work cohesively led to the project’s success in terms of safety, quality, cost, and schedule. If not for the effective communication and involvement between Brookfield, WSP and Barnard, the project would not have progressed as fluently as it did.

Early project involvement played a key role in building this collaborative relationship. Barnard’s involvement in the project began in early 2016 following investigations into the dam’s seepage issue. Brookfield, along with Engineer of Record WSP, solicited Barnard’s help to brainstorm potential repair options, ultimately leading to finalizing a design for repairs. With the goal of ensuring public safety and the continued use of the Chilhowee Dam and Hydroelectric Facility, Brookfield contracted with Barnard to address the seepage issues and rehabilitate the dam’s north embankment.

This collaborative partnership between the project team and Owner began in the project’s planning stages and remained at the core of its overall success. Benefits of this partnership included strong communication and early identification of potential issues. This partnership helped streamline issue resolution as well, yielding productive solutions to the project’s most challenging obstacles.
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Observations from the 2017 Puebla-Mexico City Earthquake

Introduction

A large subduction zone earthquake occurred on September 19, 2017, approximately 60 km southwest of Puebla, Mexico and 120 km southeast of Mexico City, Mexico. The earthquake had a moment magnitude of 7.1 and occurred at a depth of 57 km. More than 28 million people were exposed to shaking from this event, including more than 8.6 million residential dwellings, 54,000 schools and 5,700 hospitals. The earthquake led to widespread damage to infrastructure in central Mexico and the loss of 369 lives. Many homes were damaged or destroyed and states of emergency were declared in 320 municipalities across central Mexico.

The authors participated in a geotechnical reconnaissance team that was dispatched to the region immediately after the September 19 event to investigate and document the effects from the earthquake. This trip was a joint effort organized between the Universidad Nacional Autónoma de México (UNAM) and the Geotechnical Extreme Events Reconnaissance Association (GEER), which is sponsored by the U.S. National Science Foundation (NSF). This article offers an overview of some of the findings from this reconnaissance effort, which are documented in detail in the GEER report Geotechnical Engineering Reconnaissance of the 19 September 2017 Mw 7.1 Puebla-Mexico City Earthquake (Mayoral, Hutchinson, and Franke et al. 2018) available on the GEER website (www.geerassociation.org).

Reconnaissance Effort

The UNAM-GEER reconnaissance teams for the Puebla-Mexico City earthquake consisted of 25 researchers from universities, public agencies and private companies in the United States, Mexico and Chile. The researchers had a broad array of expertise, including geotechnical engineering, structural engineering and engineering seismology. The researchers were split into two teams with the advance team arriving in Mexico City on September 24 followed by the main team on September 29. The teams were based out of Mexico City, but traveled to many other central Mexico cities including Cuernavaca, Jojutla, Puebla and several towns near the epicenter. The goal of both teams was to identify locations for case histories of performance of buildings, bridges, dams, slopes and lifelines. The teams used a variety of equipment to document the case histories including ground-based LiDAR, unmanned aerial vehicles (UAVs), handheld GPS devices, digital cameras and seismic testing equipment to measure shear wave velocities and site periods at key sites.

The findings of the reconnaissance teams are documented in two versions of the GEER report referenced above. The first version of the report was released on October 16, 2017 to provide immediate preliminary observations from the UNAM-GEER advance team. These observations were used to inform and assist the UNAM-GEER main team in its investigation. The second version of the report (Mayoral, Hutchinson, and Franke et al. 2018) was published on February 16, 2018, and builds upon the first version, presenting additional details of specific sites where further reconnaissance was suggested by the advance team, while also presenting new and important observations made by the main UNAM-GEER team.

Figure 1. Complete collapse of a seven-story building.
Infrastructure Impacts

Buildings, bridges and lifelines throughout Mexico City and the states of Puebla and Morelos were damaged during this event. In Mexico City, official reports from CICM (Colegio de Ingenieros Civiles de Mexico) released in late November 2017 indicated that a total of 38 buildings suffered total collapse, 340 buildings were identified as high-risk buildings and 273 buildings were found to be security uncertain in the investigated areas. The majority of the buildings documented as collapsed or with significant damage were within mapped to areas underlain by soft lacustrine soils, which can modify and amplify the ground motions from the earthquake. The reconnaissance team observed that the majority of the buildings that suffered collapse or significant damage were in the height range of four to eight stories (Figure 1). The natural period of these buildings likely aligned with the range of periods where the greatest ground motion amplification occurred.

In the states of Puebla and Morelos, many buildings were damaged by the earthquake, including tens of thousands of homes. Adobe and unreinforced masonry buildings in this region were especially vulnerable to collapse. Approximately 20,000 houses were damaged to some extent in 22 of 33 municipalities in the state of Morelos.

Lifelines and critical infrastructure generally performed well during the 2017 Puebla-Mexico City earthquake, with some exceptions. Millions of users in the affected region lost access to potable water and electricity in the days following the earthquake, although much of this service was restored within two weeks. The team noted that many of the pipeline breaks in the Del Mar area of Mexico City occurred in locations that were damaged in the 1985 earthquake and repaired using stiff steel sections. The team observed repairs being made in 2017 using the same method. According to Secretarfa de Comunicaciones y Transportes (SCT), severe highway infrastructure damage was reported on bridges on Oaxtepec-Cuautla highway, Amecameca-La Alborada highway and Mexico-Acapulco highway (La Razón, 2017). The reconnaissance team documented damage to six bridges, including two collapses. Minor embankment failures in the Puebla-Oaxaca highway near Leon-Huajuapan and Huajuapan-Nochixtlán and Santa Barbara highway in Izúcar de Matamoros were also immediately reported after the event (La Razon, 2017).

Performance of Slopes

The Puebla-Mexico City earthquake led to multiple instances of slope instability in southern Mexico City and Morelos. Increased activity of the Popocatépetl volcano was also noted immediately following the earthquake. The UNAM-GEER reconnaissance visited several locations where rockfalls and landslides were observed to document movements and impacts using a combination of visual observations, unmanned aerial vehicle (UAV) photography and LiDAR scans. The impacts of the investigated failures on infrastructure varied significantly and included damage to buildings, roadways and retaining structures.

The UNAM-GEER advance and main teams visited an unstable slope that had developed in the hills of Xochimilco, a municipality in southern Mexico City. Local residents informed the team members that the slope had been moving slowly for many years, although movements accelerated after the earthquake. The district’s water pumping station is located at the bottom of the slope and appeared undamaged. The earthquake-induced movements led to damage to multiple retaining walls, large cracks in the roads and damage to several water lines. The reconnaissance team believes the slope was likely unstable before the earthquake and that the shaking exacerbated the movement.

More frequent slope instability cases were observed in the rural regions of the state of Morelos. The reconnaissance team investigated several slides including one rockslide near Tlayacapan and failures of quarry walls in Totolapan and Atlatlahucan. Some of the slope instabilities were expected given previous movements and slide activities at the respective location. The rockslide occurred when a large portion of the ridge above Tlayacapan dislodged during the earthquake. Geologic maps of the area show that this ridge is composed primarily of sedimentary breccia and the reconnaissance team observed evidence of previous rockslides in this location. The failures in Totolapan and Atlatlahucan occurred when the quarry walls slid into the quarry. The quarry in Totolapan had been converted into a landfill and some of the failed soil had covered part of the landfill. In Atlatlahucan, more than six “landslides” were observed in old quarries along the hills that run parallel to Route 115, to the SE, over a distance of about 2 km.

Performance of the Manuel Ávila Camacho (Valsequillo) Dam

No reports of significant damage at dams in the Puebla-Mexico City vicinity were publicized immediately following the earthquake and the UNAM-GEER team did not hear of any additional reports during the visit. The team visited one dam, located in the epicentral region, for potential damage observations. The Manuel Ávila Camacho (Valsequillo) Dam, built in 1946, is located approximately 49 km northeast of the epicenter.
The dam likely experienced significant shaking although no instrumentation was available. The dam is a 3,900 m long and 23 m high rockfill dam. The dam has created the largest reservoir in the State of Puebla (with a surface area of 740,000 acres). The dam site was visited on September 28 and was at full capacity with excess water running through the spillway during the visit. The crest (Figure 2) and both upstream and downstream slopes of the dam did not show any signs of distress or longitudinal or transverse cracks. No permanent displacements or deformations were observed either. At the toe of the downstream slope no cracks or impounded water were noticed. The outlet tower (Figure 3) and spillway structure did not show any apparent damage (Figure 4) and were operational during the visit. It seems that during the earthquake the dam was also at full capacity. Overall the seismic performance of the dam was satisfactory.

Summary

The 2017 Puebla-Mexico City earthquake led to significant damage to infrastructure across a large region in central Mexico. The UNAM-GEER reconnaissance team observed significant damage to residential and commercial buildings in multiple cities, including a number of collapsed buildings in Mexico City. The damage patterns in Mexico City demonstrate the need to account for site response when evaluating the seismic performance of buildings. Adobe and unreinforced masonry buildings accounted for many of the collapses in the states of Puebla and Morelos, which is not unexpected. The performance of dams, slopes and lifelines was generally good with a few exceptions. In the case of the slope failures, the observed cases mostly occurred in areas that had a history of instability and therefore the failures were expected.

Acknowledgments

The work of the GEER Association is based in part on work supported by the National Science Foundation through the Geotechnical Engineering Program under Grant No. CMMI-1266418. We would also like to acknowledge and thank UNAM for the resources, space and personnel provided to the GEER team during this reconnaissance effort. The authors of this article also acknowledge the hard work of the entire UNAM-GEER reconnaissance team, which greatly contributed to documentation of all of the case histories discussed here. Any opinions, findings and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of these organizations or individuals.

References


Reservoir Sedimentation Management for Sustainability

The nation’s 90,000 dams and reservoirs help ensure the stability of water and energy supplies and flood risk management. However, reservoir storage capacity, essential to meeting these purposes, has been declining as reservoirs fill with clay, silt, sand, gravel, and cobble sediment.

The National Reservoir Sedimentation and Sustainability Team has developed a series of six, one-hour webinars on topics relating to sedimentation. These webinars were sponsored by the Cooperative Institute for Research in Environmental Sciences (CIRES). Recordings of these webinars can be viewed anytime for free.

- Reservoir Sedimentation Management: Big deal! Why should we even care about it? by George Annandale
- Reservoir Sedimentation Management Options and Data Needs by Greg Morris
- Sedimentation Management for Multi-Purpose Reservoirs: A Federal Perspective by Tim Randle, and Paul Boyd
- Permitting for Reservoir Sedimentation Management by Rollin Hotchkiss and David Olson
- Sedimentation Monitoring by Greg Morris
- Economics of Sustainable Reservoir Sediment Management by Rollin Hotchkiss

The webinars may be accessed from the CIRES web page at https://bit.ly/2ojwSXC.
Construction of Cutoff Walls for Levees and Small Embankment Dams

Tom Brown, Workshop Coordinator

The USSD Committees on Construction and Rehabilitation, Levees, and Tailings Dams organized the workshop. The purpose was to provide an overview of the various types of construction methods that are available for cutoff walls in levee or small dam applications, and the design, investigation, specification preparation, and construction issues typically associated with construction of these cutoffs. The workshop focused on continuously excavated and backfilled walls, and walls constructed in-situ, that are applicable to seepage reduction in constructed embankments and unconsolidated foundations. The use of cutoff walls in coal combustion residual management was also addressed.

The objective of the workshop was to provide engineers and owners involved in or contemplating seepage mitigation of levees and small dams insights on what is involved in getting a reliable cutoff wall in the ground, what can go wrong, and opportunities to improve the potential for a successful project.

The workshop included presentations from 13 individuals specializing in various aspects of cutoff wall construction. Topics addressed included Cutoff Wall Overview (Donald Bruce, Geosystems L.P.), Site investigation and Characterization (Alberto Pujol, GEL), Design (John Rice, Utah State University), Construction Considerations for Excavate and Backfill Walls (Kenneth Andromalos, Geo-Solutions), Construction Considerations for Mix in Place Walls (Charlie Krug, DeWind and David Miller, ADM Consulting), Owner’s Quality Assurance (Richard Millet, AECOM), Cutoff Wall Closure and Repair (Jeffrey Hill, Hayward Baker), Coal Combustion Residual Management (Robert Bachus, Geosyntec), and Cutoff Wall Procurement and Specifications (Panel Discussion). Three case histories included the Herbert Hoover Dike Project (Christopher Papiernik and John Kendall, USACE), Feather River West Levee Project (Nagesh Malyala, AECOM) and the proposed Mosul Dam Cutoff Wall (David Paul, USACE).

Approximately 85 people participated in the workshop, representing AE firms, private and government owners, and construction companies.

Evaluation of Numerical Models and Input Parameters in the Analysis of Concrete Dams

Hillery Venturini, Workshop Coordinator

The USSD Committees on Concrete Dams and Earthquakes organized the workshop, which was attended by more than 50 professionals represented by engineering industry and academia, dam owners, and the dam safety community. The session was a continuation of the workshops held in 2016 and 2017 on aspects related to the structural analysis of concrete dams.

Workshop objectives focused primarily on analysis of a gravity dam, considering various material properties and loads, applying different analysis methods, discussion of accuracy of the numerical analyses solutions, identification of uncertainty and variability of the numerical solutions, the importance in obtaining confidence in analysis, and establishing lists of parameters that warrant additional investigation.

The tallest non-overtopping monolith, with a corresponding foundation width and reservoir, at Pine Flat Dam was selected as a case study. Material properties, and loads were referenced from the extensive studies performed in the 1970s and 1980s at the University of California at Berkeley. Using linear elastic time history method, 8 analysis teams, represented by 5 countries, submitted their solution of the problem formulated by the Workshop Organizing Committee. Output results were collected, summarized, and presented at the workshop in Miami to initiate discussion. Each contributor made a short presentation of key and interesting findings from their perspective.

A moderated group discussion, then focused on various aspects of the results including model effects, methods (i.e., implicit versus explicit time integration, compressible versus incompressible fluids, pressure versus displacement-based fluid elements), variability in parameters and effects (i.e., damping), boundary conditions, and the importance of understanding the frequency and modes of the coupled FE model system. Suggestions from the discussion included: comparison of the FE analysis studies performed at the University of California at Berkeley in 1970s, method investigation for seismic load determination in the FE models, and continued development in validating results.

In general, time history plots of stress and pressures at the heel of the gravity dam showed similar trends with variation in amplitude and phase. More notable differences appeared in the comparison of natural frequencies and hydrodynamic pressures along the height of the gravity dam.

Uncertainties in numerical analysis of concrete dams highlight the need to assess the state-of-practice more closely. Recently, confidence in numerical models has become an area of concern and a point of discussion for dam owners and the engineers performing numerical analyses. While the results of this workshop illustrated trends where variability may initiate, it certainly does not provide an end-all answer. Moving forward, additional workshops may be held to narrow the focus on one of the topics identified in the workshop, as well as continue the benchmark study through USSD and ICOLD involving the international community, in order to continue these discussions on advanced structural assessment of concrete dams and to formulate guidelines of such analyses.
Local Connections, **Global Ideas**

Our clients face tough decisions with limited resources. That’s why we support leading water associations—like USSD—to help make great things possible for our industry.
The U.S. Army Corps of Engineers Levee Safety Program has completed the first summary report of the flood risks and benefits associated with levees that are within the USACE Levee Safety Program. The USACE Levee Portfolio Report is organized around risk (e.g., the flood risk associated with levees) to describe the magnitude of risk, key drivers of risk, sources of uncertainty in the understanding of risk, and distinct factors of risk within the USACE levee portfolio. Assessing, managing and communicating levee-related flood risk to people, property, and the environment is the mission of the USACE Levee Safety Program. The report can be found on the USACE Levee Safety Program website available for download at http://www.usace.army.mil/Missions/Civil-Works/Levee-Safety-Program/.

In 2006, USACE began the task of developing a comprehensive inventory of the nation’s levees and, within our traditional program, inspecting and conducting risk assessments. The USACE levee portfolio (Figure 1) includes about 2,220 levee systems totaling approximately 14,150 miles in length. More than 1,200 levee sponsors operate and maintain roughly 2,000 of these levee systems, spanning roughly 70 percent of the length of the entire portfolio. USACE is in the process of sharing risk assessment information with non-federal sponsors and communities as well as using that information to guide activities within the USACE Levee Safety Program.

Based on an assessment of nearly 2,000 levee systems, this report looks at flood risk and benefits at a portfolio level. USACE conducted this review to better understand the relative importance of factors driving the risks (Figure 2) in order to inform decisions when managing a diverse portfolio of levees. Information in this report is already helping USACE guide decision making in areas such as research, policy, training, analytical methodology, and governance approaches. This report is intended to bring facts to the table and provide a starting point for conversations at all levels. We hope that you will use it to initiate conversations at all levels of governance.

**Figure 1.** USACE portfolio levees represent an unknown portion of the total levees in the United States. There are approximately an equal number of miles of levees in the National Levee Database that are inside the USACE levee portfolio as outside.

**Figure 2.** Levee-related flood risk is a function of hazards, performance, and consequences.
In March 2017, USACE had completed levee risk characterizations and assigned a Levee Safety Action Classification (LSAC) to nearly 73 percent of the portfolio. For the remaining, 27 percent of the portfolio, USACE expects to complete levee risk characterizations and LSAC assignments in the next few years. Thus far, 13 percent of the portfolio consist of levee systems that are Very High, High, or Moderate risk (Table 1) and require interim actions to reduce risk while more long-term and comprehensive risk reduction and risk management solutions are being pursued. These Very High, High, and Moderate risk levees have more than 8 million people that live and/or work behind them. USACE has begun sharing information from risk assessments with sponsors and other community risk managers. USACE will continue to develop approaches and tools to share results of risk assessments with all kinds of risk managers, with a particular focus on training its staff to translate complicated risk information into understandable and actionable information.

USACE considers the full range of flood hazards for a levee, from when water first starts loading the levee to when water starts to flow over the top of a levee. An important flood loading that often impacts risk and indicates when flooding behind the levee starts to occur is the flood loading where water starts to overtop a levee. The likelihood of when water starts flowing over the top of a levee varies considerably across the USACE levee portfolio. Within the USACE portfolio, the annual chance of exceedance (ACE) of the flood loading that reaches the top of the levee ranges from 50 percent to less than 0.02 percent — in colloquial terms, from the 1-in-2 chance to less than the 1-in-5,000 chance of occurring in any given year. The majority of the levee systems within the portfolio begin to overtop at flood levels with an ACE of 0.5 percent (1-in-200 chance) or less. USACE is continuing to invest in collection and assessment of flood hazards through efforts such as the Corps Water Management System and is sharing information with other federal agencies to improve the understanding of hydrologic events.

Table 1. USACE Levee Safety Action Classification Table. *Levee risk is the risk that exists due to the presence of the levee system, and this is the risk used to inform the decision on the LSAC assignment. The information presented in this table does not reflect the overtopping without breach risk associated with the presence or operation of the levee system.

How the levee performs when faced with flood hazards is a factor in levee-related risk. Leveses in the USACE levee portfolio vary widely in age, design and construction practices, and flood regimes (e.g., coastal, river, flashy or long duration). The average age of levees in the USACE portfolio is roughly 50 years old. Leveses constructed by communities and accepted into the portfolio, and levees designed and constructed by USACE in the 1920s–1960s, may be designed and constructed to standards less stringent than current best practices. Risk drivers in levee performance can result from many different mechanisms that can cause the levee to breach. The most common risk driver in levee performance is when the levee is overtopped and breaches (Figure 3). This risk driver impacts over 40
percent of the USACE levee portfolio. Seepage through or beneath the levee is the second most common risk driver, impacting 17 percent of the portfolio. Understanding the uncertainty in how a levee will perform (e.g., well or poor) during flood events is important in managing risk. Monitoring performance, regular inspections, risk assessments, and continuous operation and maintenance are essential for the effective management of risk associated with levees.

Along the way, we have uncovered facts about USACE levee systems that remind us of the importance of understanding benefits associated with levees: they reduce flooding risks to more than 11 million Americans and $1.3 trillion dollars of the economy, including more than 300 colleges and universities, more than 30 sports venues, strategic national industries, and key governmental offices at all levels (Figure 4). The data also shows that these systems are integral with society, with about a mile of USACE levees for every McDonald’s restaurant in the United States.

Flood awareness and emergency preparedness play a key role in risk management for individuals and communities behind levees.

Involved, informed individuals and communities behind levees will be better prepared to take meaningful actions to reduce risks to loss of life (e.g., practicing emergency action plans, warnings and evacuations) or property (e.g., purchasing flood insurance, flood proofing or elevating structures). USACE will continue to support and apply the results of research and knowledge in social science to better understand how warnings are issued and how they spread through communities that experience severe flooding. This research will advance knowledge about the public warning process, help improve how future public warnings and evacuations for any hazard are implemented, enable levee owners to better assess the existing risk posed by their assets, and investigate non-structural risk reduction measures alongside levee upgrades.

Risk information for the USACE portfolio allows decision makers at the federal, state, and local levels to understand the impacts of risk and magnitude of investment needs to address risk. An understanding of investment needs to address levee related risks for the USACE portfolio has not been previously attempted as risk information has not been readily available. However, now that risk assessments are nearing completion, a combined cost estimate to address risks within the portfolio was determined. A portfolio cost estimate does not try to indicate who pays (levee sponsor or federal government) nor does it address other factors that must be considered when making investments such as environmental and community values, but rather informs investment priorities and decisions through the understanding of primary factors that influence costs to address risk and risk management measures that efficiently and effectively reduce risk. USACE will use this portfolio cost information to inform research needs and guidance updates with an eye toward not only reducing risk, but lowering assessment, repair, and mitigation costs.

The cost to address risk in the USACE levee portfolio ranges from $6.5 billion to $38 billion, with an expected cost of about $21 billion (Figure 5). The expected cost of $21 billion is broken down into approximately $13 billion for levee infrastructure improvements to mitigate risk drivers in levee performance before the levee overtops, approximately $8 billion in armorng of levees to mitigate risk drivers in levee performance when the levee overtops, and about $300 million to improve evacuation effectiveness within the leveed area. The estimated cost to improve evacuation effectiveness includes measures such as improved evacuation plans, community outreach, and warning systems. USACE will work with levee sponsors to provide information that can improve evacuation effectiveness, particularly since the cost to improve evacuation effectiveness is significantly less than implementation of levee infrastructure improvements and evacuation effectiveness directly reduces risk to loss of life.
We will update this report periodically. This first report will serve as a baseline for future analysis and allow us to measure the effectiveness of our risk management efforts. It is important to note, however, that USACE levees represent only a fraction of the levees in the nation – the remainder are managed by other federal, state, tribal, regional and local entities. As we continue to conduct a National Levee Inventory and Review on levees outside USACE’s traditional authorities, we will develop a more comprehensive understanding of all of the nation’s levees.

Managing risks associated with levees in the United States will require diligence and cooperation among all levels of government, the private sector and individuals. To be successful in the face of increasing flood hazard and projections of increasing population in flood prone areas, we must all begin to think and act like risk managers.

Figure 5. Estimated costs to reduce key risk drivers associated with the USACE levee portfolio.

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US: ADVOCATE • EDUCATE • COLLABORATE • CULTIVATE   Summer 2018  25
Vienna 2018 Highlights
Sharon Powers, Executive Director, U.S. Society on Dams

More than 1,500 people from 80 member countries came together for the 26th Congress and 86th Annual Meeting in Vienna, Austria, July 1-7. Another reason to celebrate was the 90th year of ICOLD, which formed in 1928. The United States, as a founding national committee, joins in the celebration as USSD also celebrates its 90th birthday!

The week began with technical committee meetings followed by ICOLD Regional Club meetings; USSD is a member of the INCA Regional Club. During the General Assembly, which also functions as the ICOLD business meeting, USSD President Dean B. Durkee (Gannett Fleming) represented the U.S. delegation. We are pleased to announce that past USSD President Michael F. Rogers (Stantec) was selected to serve as ICOLD’s next President. In his acceptance speech, Rogers stressed that he will “continue to work with his colleagues on the Board to proudly represent and strengthen ICOLD around the world, supporting our mission to be the world’s leading professional organization dedicated to the art and science of engineering, safety, and environmental sustainability for dams.” Mike assumed his three-year term immediately following ICOLD 2018. Newly elected Vice Presidents are Michael Abebe (Ethiopia) and Ali Noorzad (Iran).

Former USSD Executive Director Larry Stephens received the ICOLD Honorary Member Award, ICOLD’s highest recognition. In his nomination, Mike Rogers noted that after assuming leadership of USSD in 1985, Stephens led a resurgence of the role of USSD in ICOLD, which prior to his tenure, had been very limited. “Stephens instilled the importance of the critical connection between USSD and ICOLD into the operations of the USSD Board and its membership . . . he is well known and respected around the world for his participation and dedication to USSD and ICOLD, and ICOLD has truly been served by his hard work and dedication.”

A special presentation on the 2017 Oroville Spillway incident was a highly anticipated and well-attended session. John France, leader of the Forensic Team, presented the Team’s findings (see photo at right). The session included several technical presentations covering issues relating to emergency response, geologic and geotechnical issues, H&H considerations, and fast-track recovery design and construction processes for the 2017-2018 flood season. The session was organized by Mike Rogers, with support from the California Department of Water Resources.

ICOLD 2018 also featured the 26th Congress, which is held every three years. Sixteen USSD papers were accepted for the Proceedings, and 11 of these were selected for oral presentation (see page 25).

USSD also took the opportunity to sign a Memorandum of Understanding with the Korean ICOLD National Committee on Large Dams (KNCOLD). A work group will be created to identify projects of mutual benefit. Representatives of USSD and KNCOLD are shown in the photo at right.

Being in Vienna didn’t stop USSD from celebrating the 4th of July. A celebration was held at a local venue (minus fireworks), for U.S. delegates and other invited guests. Thank you to Ballard Marine Construction, Carpi, HDR, Stantec, and Worthington Products for sponsoring this event.

While days at ICOLD 2018 were filled with technical sessions, there was also a plethora of social events interspersed throughout the week that allowed attendees and guests to experience Vienna. From the welcome reception at Vienna City Hall to the evening of music at Wiener Konzerthaus to the farewell dinner complete with Austrian entertainment, ICOLD 2018 was a testament on how 80 countries can come together for a week to exchange best practices and knowledge.

We’ll look forward to ICOLD 2019 in Ottawa, Canada.
With more than 700 people in attendance, the 38th USSD Annual Conference and Exhibition was a big success. Seventy-two organizations showcased their products and services in the exhibition hall, making it USSD’s largest exhibition to date. The six workshops held on Thursday were attended by 350 people, also a record. The 2018 Conference Host was the U.S. Army Corps of Engineers, Jacksonville District, who organized the Thursday and Friday field tours.

Technical Program

The Conference Technical Program began with a Plenary Session on Tuesday morning with several invited presentations that focused on recent extreme events and other topics. Tuesday afternoon and Wednesday featured more than 150 technical presentations in six concurrent sessions. They addressed the conference theme, A Balancing Act: Dams, Levees and Ecosystems, and other topics corresponding to USSD technical committees.

Awards and Recognitions

The 2018 Lifetime Achievement Award was presented to Henry Falvey, recognizing his 50+ years of contributions to the profession. Read more on page 53.

The announcement of the recipient of the Excellence in the Constructed Project Award is eagerly anticipated each year. The 2018 award went to Chilhowee Dam North Embankment Remediation Project, constructed by Barnard Construction Company, Inc. and designed by WSP USA for Brookfield Smoky Mountain Hydropower LLC. For more information about the project, see the article beginning on page 8.

The Outstanding Paper Award was presented to Robert Rinehart and Blake Armstrong, Bureau of Reclamation, for their paper, Soil Strength Measurement over a Range of Strains for Embankment Dam Deformation Modeling. The paper is featured beginning on page 32.

Ali Reza Firoozfar, HDR, received the Outstanding Young Professional Paper Award for Generalized Programmatic Framework for Spillway Inspection and Potential Failure Modes Assessment. Travis Ford, HDR, was given the Outstanding Poster Presentation Award for Optimization of Hydraulic Structure Inspection Intervals Using Data and Artificial Intelligence.

The Public Safety and Security Recognition was given to Tony Bennett, Director of Dam and Public Safety for Ontario Power Generation. Bennett has been with OPG’s Dam Safety Program since its inception in 1985. He is the Chair of ICOLD’s Committee on Public Safety Around Dams and chairs the Canadian Dam Association’s Working Group on Public Safety and Emergency Management.

Scholarships

Four scholarships were presented during the conference:

El Hachemi Bouali, Michigan Technological University – $8,000, Numerical Analysis of Embankment and Berm Settlement based on InSAR Remote Sensing Measurements (see article on page 41 for more information).

Carolyne Bocovich, Colorado School of Mines – $4000, Investigation of Backwards Erosion by Data Driven Modeling.

Johnathan Blanchard, University of Arkansas – $2,000, Relative Humidity Inhibitive Coatings for the Reduction of Degradation Caused by Active Alkali-Aggregate Reactions in Dams.

Sean Salazar, University of Arkansas – $6,000, Satellite Based Radar Remote Sensing for Monitoring of Dams.

5K FUNds Run/Walk

The fourth annual 5K FUNds Run/Walk to support the USSD Scholarship Fund was held on Wednesday, May 2. Eighty-seven runners took part the scenic course along the Miami River. Sean Salazar finished first with a time of 18:35. Thanks to 42 sponsoring organizations, and donations from runners and others, the event raised $9,740 for the USSD scholarship program.

USSD Gives Back

In what has become an annual tradition at each USSD annual meeting, conference participants donated more than $1.320 to Manifezt Foundation, a local non-profit founded in 2015 with the mission of providing free STEM focused education to 8-18 year old students. Manifezt efforts are focused on low-income and disadvantaged communities throughout South Florida.
1 Paul Meeks, Worthington Products, presents $2000 to USSD Scholarship fund on behalf of Tony Bennett, recipient of the Public Safety and Security Recognition. 2 El Hachemi Bouali, Michigan Technological University, receives $8000 scholarship. 3 Ali Reza Firoozfar and Travis Ford, HDR, are all thumbs up after their outstanding paper awards are announced at the Marlins baseball game. 4 Construction equipment at Herbert Hoover Dike, Friday field tour. 5 Michael Crouch, RTI International, with his poster presentation. 6 FUNds Run participants are happy to have reached the finish line.
7 USSD Board Members and Advisors gather after meeting in Miami. 8 USSD President Dean Durkee with recipients of the Excellence in the Constructed Project Brian Krohmer and Kevin Schneider, Barnard; and Mike McCaffrey, WSP. 9 Field tour briefing at Herbert Hoover Dike. 10 Conference attendee adds to the "Share your Story" message board. 11 Herbert Hoover Dike Field Tour. 12 Attendees enjoy the riverside Sunset over Miami reception. 13 Reception in the exhibit hall. 14 John France presents the findings of the Oroville independent forensic team.
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Introduction

Dynamic deformation modeling of embankment dams is often performed to estimate embankment performance during earthquakes. For some cases, extensive deformations occur and large strains accumulate along a failure plane within the embankment or foundation. The behavior of the material located along the failure plane is often a source of uncertainty for cases with large strains. As strain accumulates, the initial peak strength should be reduced to account for strength reduction that occurs from the remolding of material along the failure plane.

This paper presents and discusses the field and lab testing and data analysis methods currently used by Reclamation for measuring soil shear strength across a wide range of strains. Practical techniques for determination of peak, remolded, and residual strengths are presented. Plans for improved testing and modelling are also briefly discussed.

The subject of the present study is an embankment dam located in western Oregon. Constructed by Reclamation in the 1970s, the dam furnishes water for irrigation, municipal, and industrial uses, and provides for wildlife enhancement, recreation and flood control. The dam has operated well since commissioning and is considered to be in sound structural condition. However, due to the significant potential seismicity in the region, the dam is the subject of a Corrective Action Study (CAS) to reduce risk due to seismic-related potential failure modes.

Two fault sources contribute to the seismic risks associated with the embankment – a local fault network that is believed to be able to produce earthquakes with moment magnitude ranging from 5-7 and the Cascadia Subduction Zone believed to be able to produce earthquakes with moment magnitude ranging from 8-9 with long durations of strong shaking. Analytical and numerical modelling indicate that these earthquakes may produce significant movement of embankment slopes leading to large crest settlements. As illustrated in Figure 1, the majority of the shear strains are concentrated in weak foundation layers, underscoring the importance of quantifying material strengths across a wide range of strains.

Extensive field investigations have been carried out as part of the CAS in order to characterize both embankment and foundation material properties. As will be shown, for the soft, slightly overconsolidated fine-grained soils tested here, conventional monotonic testing of intact samples does not reach sufficient strain levels to mimic conditions representative of strains caused by large earthquakes. The results of several testing techniques are taken together to define soil shear strength over a wide range of strains.
**Embarkment and Local Geology**

The stratigraphy of the immediate area surrounding the dam consists of weak, poorly indurated marine sedimentary rocks of upper Eocene age, overlain by residual soil and Quaternary alluvium. This alluvium forms the foundation for most of the embankment, and consists of a thicker, upper fine-grained deposit and a thinner, coarser-grained basal layer. It is likely that the valley fill alluvium deposits are associated with cataclysmic Missoula floods that entered the valley, depositing thick, relatively homogeneous layers of silt, clay, and fine sand in temporary lakes that backed up into the Willamette Valley. The Missoula floods entered the valley at least 22 times through the Lake Oswego gap around the end of the last Ice Age, between 12,700 and 15,300 years ago (Wilson, 1998). The floods were caused by successive breakups of ice dams near Montana’s current border with northern Idaho. The dams on the Clark Fork River backed up large lakes that stretched southeast to near Missoula, Montana. One or more events transported ice-raftered sediments to elevations of 400 feet in the Willamette Valley (Rosenfield, 1992). It is also possible that some of the valley fill alluvial deposits are the result of large ancient landslides that resulted from flooding and rapid draw down as a result of these cataclysmic floods.

As depicted in Figure 1, the dam is a zoned earthfill embankment with a structural height of about 150 feet. The embankment is well constructed, with materials compacted in 6-inch and 12-inch layers (depending on zone and max particle size) using tamping and pneumatic-tired rollers. The upstream face of the dam has a 2.5H:1V slope with a 3-foot thick layer of riprap down to a 20H:1V upstream berm. The downstream face of the dam has a slope of 2.5H:1V from the dam crest to a berm with slope of 5H:1V to the toe of the dam. The downstream face has grass cover which provides a measure of slope protection.

**Drilling and Sampling Program**

Various site investigation methods were employed to aid in determination of embankment and foundation material properties, including Cone Penetrometer Testing (CPT), field Vane Shear Testing (VST), and hollow stem auger drilling to facilitate Standard Penetration Testing (SPT) and collection of intact tube samples. Figure 2 shows selected investigation locations. Intact samples of fine-grained foundation materials were collected with 5-inch outside diameter metal Shelby tubes using a hydraulically activated stationary piston sampler (ASTM D6519).

Previous investigations have shown that the alluvium on the right hand side of the original river channel (looking downstream) is weaker than the alluvium on the left hand side; therefore, investigations were somewhat more concentrated on the right side of the embankment. This paper focusses on the area highlighted in blue in Figure 2b, known as DH-16-7. This area includes CPT, VST, and laboratory testing of intact samples. The area is accessed by a temporary road cut into the downstream face of the dam.

**Lab Testing Program and Results**

As described in the following, samples of foundation alluvium (Qal) were tested for physical properties, compressibility, and shear strength. Several different strength tests were performed to provide design data and model inputs for seismic and post-seismic deformation modeling and slope stability analyses. While triaxial shear tests were performed for embankment material, direct simple shear (DSS) testing was favored for the Qal foundation materials due to the near horizontal orientation of the anticipated failure surfaces through the Qal.

**Physical Properties**

The Qal in the foundation of the embankment varies from sandy silt – s(ML), to elastic silt – MH, to fat clay – CH per the unified soil classification system (USCS) with between 64 and 99% passing the #200 sieve (0.075-mm). The Liquid Limit (LL) ranges from 38 to 63 with an average of 50, while the Plasticity Index (PI) ranges from 7 to 35 with an average of 22. Most samples plot very near the A-line. As shown in Figure 3, the alluvium in the area of the DH-16-7 investigation location, and the subject of this paper, classifies as an Elastic Silt – MH with less than 10% sand, LL varying from 51 to 60 and PI between 22 and 27.
One-Dimensional Consolidation

One-dimensional incremental load consolidation testing was performed according to ASTM D2435 to quantify material compressibility and preconsolidation pressures (over-consolidation ratio, OCR). Two example compression curves are shown in Figure 4. The curves show distinctive breaks from recompression into the virgin compression range. The Sample Quality Designation (SQD) based on the axial strain at the approximate in-situ vertical effective stress indicates medium quality samples (SQD of C, Terzaghi et al., 1996). This is generally corroborated by the change in void ratio divided by initial void ratio approach presented by Lunne et al. (2006) which shows the samples presented in Figure 4 to be of Good to Fair quality (Δe/e₀ = 0.046-0.058). Neither sample exerted swell pressure when inundated with tap water and held at constant volume.

Results showed preconsolidation pressures for the Qal under the mid-slope of the dam ranged from about 6,600 psf to 7,900 psf. This implies that the Qal near DH-16-7 is slightly overconsolidated, with OCR ranging from 1.3 to 1.5. Testing of Qal specimens obtained from the toe of the embankment showed OCR varying from about 2.5 to 5. Based on the coefficient of compression and initial void ratio, the Qal material generally classifies as moderately to highly compressible (Coduto, 2001).

Effective Stress Strengths

DSS testing was performed according to ASTM D6528 across a range of consolidation stresses in order to quantify the peak strength of the Qal material. Specimens were hand trimmed from the 5-inch Shelby tubes. Material was not extruded from the tubes, rather, material was extracted from shorter sections of tubes according to the procedures described by Ladd and DeGroot (2004). Specimens were nominally 2.5-inches in diameter and 0.9-inches tall and were encased in a rubber membrane surrounded by a stack of Teflon coated 0.75-mm tall stainless steel rings. While wire reinforced membranes are also commonly used as an alternative to stacked rings, the stacked ring lateral confinement approach has been shown to give equivalent measures of shear strength and introduce less machine-induced post-peak strain softening (McGuire, 2011).

For tests conducted with vertical consolidation pressure below the preconsolidation pressure (i.e., overconsolidated specimens), the specimen was first loaded to approximately 75% of the preconsolidation pressure and then unloaded to the desired vertical effective stress. Research has shown that this type of consolidation procedure is important, as unrealistically low horizontal stresses are developed during consolidation below about 75% of the preconsolidation stress (Lunne et al., 2006).

Following consolidation, DSS testing can be carried out under drained conditions by applying a constant normal load during shearing — i.e., volume change is allowed. It can also be carried out under undrained conditions by maintaining constant specimen volume. The stacked rings ensure constant cross-sectional area, and the normal load is varied during shearing to maintain a constant height. This constant volume approach is commonly referred to pseudo-undrained testing. The change in normal load is assumed to be equivalent to the excess pore pressure that would have developed in a truly undrained test. Research by Dyvik et al. (1987) has verified the pseudo-undrained assumption is accurate.

The state of stress on the failure plane of DSS specimens is not fully defined since only vertical stress and horizontal stress at the top and bottom of the specimen are measured. Analysis assumes a horizontal failure plane, similar to direct shear testing. Some research suggests that the friction angle from this type of analysis is conservative but that the cohesion is unconservative and should be assumed to be zero (Atkinson and Lau, 1991). Research also indicates that at smaller shear strains (i.e., γ<10-15%) that the effects of the state of stress are likely small and peak undrained strength values are reasonable (Lucks, et al., 1972; DeGroot et al., 1994).
As shown in Figure 5, some specimens of the elastic silt Qal from the DH-16-7 area were sheared to 30% shear strain, while others were sheared to only 10% shear strain. Failure was based on peak shear stress for the two standard tests monotonically sheared to 30% shear strain. Failure was selected at 5% shear strain for the three repeated tests (discussed later). The higher strain specimens were useful to determine the pore pressure response at higher strains, while the lower strain specimens were used for repeated undrained DSS testing described later. Figure 5a presents stress-strain curves from the undrained DSS tests. Failure stresses (indicated with blue dots) were selected from each curve and plotted to determine the peak strength Mohr-Coulomb failure envelope (Figure 5b). As illustrated, the material has an effective stress peak friction angle \( \phi'_{\text{DSS}} \) of 24.9° with no apparent cohesion.

As shown in Figure 5b, the results from the Stark and Hussain (2013) correlation yield an average friction angle of about 17.4°.

**Undrained Strength**

In addition to peak and residual strengths for use in an effective stress framework, it is necessary to determine the undrained strength for use in scenarios where it is assumed that excess pore pressures do not dissipate, for example, seismic deformation analyses where loading is rapid (i.e., loading occurs without any change in water content). It is common to present undrained strengths normalized by the vertical effective stress prior to shearing as the undrained strength ratio \( s_u/\sigma'_{vc} \).

Field vane shear testing (VST) according to ASTM D2573 and cone penetrometer testing (CPT) according to ASTM D5778 were also performed to provide undrained strength data. The DSS and VST results are presented together in Figure 6. The raw VST peak shear strength data was corrected using the method described by Chandler (1988), which takes into account material PI and the anticipated time to failure. Two different types of strength models are also presented. The very simplistic Hockey Stick Model is defined by a constant stress ratio with a minimum value of \( s_u \). The Stress History and Normalized Engineering Properties (SHANSEP) model takes the form:

\[
\frac{s_u}{\sigma'_{vc}} = S(OCR)^m
\]

where:

- \( S \) is the undrained strength ratio \( s_u/\sigma'_{vc} \) for normally consolidated soil (OCR=1), and \( m \) is an exponent quantifying strength gain due to overconsolidation.

The DSS and VST results are presented in two different fashions in Figure 6. In Figure 6a, \( s_u/\sigma'_{vc} \) is plotted as a function of OCR, while in Figure 6b, \( s_u \) is plotted as a function of vertical effective stress. The SHANSEP parameters were selected based on a best fit of the measured DSS data. The slope of the Hockey Stick model was likewise selected based on the best fit of the measured DSS data (and is essentially equivalent to the SHANSEP \( S \) parameter). The \( s_{u,\min} \) values shown were selected to fit the DSS data (in the case of \( s_{u,\min}=1,000 \text{ psf} \)) and to provide a conservative lower limit (in the case of \( s_{u,\min}=500 \text{ psf} \)).

Both models give the same strength ratio for in-situ vertical effective stresses above the approximate preconsolidation stress (i.e., for normally consolidated material). The SHANSEP model appears to provide more realistic strengths, with the Hockey Stick model appearing to be more conservative in general, especially at lower confining
stresses (higher OCRs). It is also interesting to note that the VST strengths, while being comparable to DSS, are generally higher. This is likely due to sample disturbance reflected in the DSS results as well as anisotropy, and indicates that strength models based on lab data could be conservative in this instance.

Figure 7a shows CPT-estimated peak shear strength as a function of depth from the DH-16-7 area. The Qal material is apparent from about 31 to 57 feet from the surface. Peak undrained shear strengths measured from CPT, VST, and DSS are compared in Figure 7b. When analyzing the CPT data, a range of cone factors ($N_{kc}$ values) were assumed from 10 to 14. Typically $N_{kc}$ varies from 10 to 18, with 14 as an average (Robertson and Cabal, 2014). As shown, the VST, CPT, and DSS undrained peak shear strengths are in good agreement.

Cyclic Strength

Cyclic testing was performed to determine the material's response to cyclic loading and to quantify the post-cyclic remolded strength (discussed later). Testing was performed under load (stress) controlled conditions, using a sinusoidal loading waveform at a frequency of 1Hz. Specimens were normally consolidated. Figure 8 presents sample hysteresis loops for Cyclic Stress Ratio (CSR) of 0.19 (Figure 8a), and 0.28 (Figure 8b). Failure under cyclic loading was defined as 3% single amplitude shear strain. Figure 8c presents the number of cycles of 1Hz sinusoidal loading required to reach failure for a range of CSRs.

Results show that the material is quite soft, failing rapidly under moderate CSRs. For example, for a CSR of 0.3, failure occurs at approximately 4 cycles. Results also show that the material softens – i.e., shear modulus decreases – due to increasing pore pressures. The pore pressure ratio (defined as the excess pore pressure as a percentage of the vertical consolidation pressure) at failure was 87-89% for all specimens with exception of the CSR=0.35 specimen which has a pore pressure ratio of 78% at failure. It is also likely that some softening is due to the development of a failure surface and degradation of material structure, but given that the material is already normally consolidated this effect could be minor relative to that of excess pore pressure.

Undrained Residual Strength

It is also important to quantify post-cyclic monotonic strength — that is, the undrained strength available immediately after the cessation of cyclic loading. To this end, cyclic DSS testing was performed using two different methods to degrade specimens to a remolded or residual state before measuring “post-cyclic” undrained strength, $s_{ur}$.

As presented earlier, specimens were subjected to 1Hz stress controlled cyclic loading at various CSRs. Even though
failure was defined as 3% single amplitude cyclic shear strain, loading was continued to 10% single amplitude shear strain. Following cyclic loading, specimen pore water pressure was allowed to equilibrate. Drainage was not allowed during this “rest” stage (specimens were held at constant volume). Once equilibrated, specimens were sheared monotonically to 30% shear strain to measure the post-cyclic residual strength. Results do not show a trend with respect to CSR or pore pressure ratio. The average value of $s_{ur}/\sigma'_{vc}$ was 0.09.

To validate these results, displacement controlled slow cyclic DSS testing was also performed for one set of three specimens (the three specimens that appear to stop at 10% shear strain in Figure 5a). Specimens were loaded at the same rate used in monotonic testing (5% shear strain per hour) with shear strain cycling between +10% and -10%. This equates to a loading frequency of 3.5E-5 Hz. Slow cyclic loading was continued until a stable residual condition was reached. In contrast to the rapid cyclically loaded specimens which were all run in a normally consolidated condition, the slow cyclic specimens were run across a range of normal stresses (and therefore OCRs). Overconsolidated specimens exhibited dilative behavior upon initial loading, but all specimens were contractive in the residual state, with ultimate pore water pressure ratios equaling 75-93%. Results indicated that pore water pressure ratio increased with increasing $\sigma'$, while $s_{ur}/\sigma'_{vc}$ decreased with increasing $\sigma'_{vc}$. The average value of $s_{ur}/\sigma'_{vc}$ from the slow cyclic loading was 0.06. These results imply the post-cyclic undrained strength from the rapid cyclic testing were not at a true residual state, but rather a remolded condition, approaching residual.

Conclusions

Results of a lab testing program to characterize soft foundation material for an embankment dam in Oregon have been presented. Physical property testing showed the material to be a borderline Elastic Silt to Fat Clay. Consolidation testing revealed that the material under the downstream slope of the embankment is slightly overconsolidated. According to both strain-based and void ratio-based criteria, the 5-inch diameter Shelby tube samples were of moderate quality.

DSS testing was preferred over triaxial shear testing given the orientation of the anticipated failure plane. Testing was carried out several different ways, including standard tests for peak strength, load controlled rapid cyclic tests, post-cyclic monotonic tests, displacement controlled slow cyclic tests, and drained repeated tests. Taken together the results of these tests inform the material strength over a wide range of strains and loading conditions.

Discussion and Recommendations

The results presented here have shown that based on current Reclamation laboratory capabilities, several types of tests are required to measure soil strength across the strain range of interest. Of particular interest is the nature of the undrained strength, and while it is relatively simple to determine peak strength and residual strength, it is more convoluted to measure intermediate strengths representing other strain levels. The nature of the softening process in terms of how much strain is required to progress from peak strength to residual strength is also very difficult to quantify using the methods presented here.

Dynamic deformation modeling of earthen embankments requires knowledge of soil strengths over a wide range of strains. Current practice at Reclamation involves using effective stress friction and cohesion strengths (i.e., Mohr-Coulomb parameters) for materials above the water table (embankment phreatic surface). Undrained strengths are used for materials below the water table. Prior to shaking, peak strengths are assumed. Once shaking begins and material yields, reduced strengths informed by post-cyclic monotonic laboratory tests, or remolded strengths from vane shear tests or cone penetration tests are used. At the cessation of shaking, depending on the level of strain predicted and the degree of strain concentration, it may be appropriate to use material strengths that are reduced even further. These residual strengths could be informed from laboratory testing such as repeated direct shear or DSS, or from field vane shear testing.

One potential improvement to this overall methodology would be to enable testing intact specimens in a constant volume (pseudo-undrained) ring shear device which would enable the full stress-strain curve to be presented. This type of testing has been developed and used in analysis of earthquake related slope failures by Stark and Contreras (1996, 1998), and is being pursued by Reclamation.

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References


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Numerical Analysis of Embankment and Berm Settlement based on InSAR Remote Sensing Measurements

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Introduction

Interferometric Synthetic Aperture Radar (InSAR) provides a cost-effective approach for long-term deformation monitoring of dams. This active remote sensing technique can be used to supplement repeat field inspections, identify structures at risk, and incorporate long-term observations into an asset management approach. Asset management, broadly defined as a thorough approach to strategically construct, monitor, maintain, and support infrastructure throughout the life-cycle in a timely and cost-effective manner, has been a goal for many agencies with large asset inventories (Sanford Bernhardt et al. 2003; FHWA 2007; AASHTO 2013). A typical asset management approach includes inventory creation, condition assessment, and long-term asset monitoring. Recently, InSAR has been utilized to aid in the management of a variety of assets, mostly focusing on assets in the transportation corridor (Glendinning et al. 2009; Bouali et al. 2016; Mazzanti et al. 2017). This research describes a similar approach for dam management using satellite-based InSAR as a reliable way to monitor ground deformation across dam and reservoir components (e.g., embankments and berms).

InSAR Background and Data

Persistent Scatterer Interferometry (PSI) is an InSAR stacking technique that uses a minimum of 20 single look complex (SLC) synthetic aperture radar (SAR) images to measure ground deformation on relatively stable targets (Ferretti et al. 2000; Ferretti et al. 2001). Individual persistent scatterers (PS) are identified as a point cloud and measure ground deformation at an accuracy of 1 mm/year (Crosetto et al. 2016). Each PS within the point cloud includes sufficient data to create displacement-time series.

Twenty-three descending ENVISAT radar images were initially acquired by the European Space Agency between September 4, 2005 and January 23, 2010. The ENVISAT Advanced SAR sensor transmitted radar waves at a frequency of 5.313 GHz (5.6 cm wavelength, C-Band) and captured images with a spatial resolution of 20 m, relatively coarse by today’s standards. These data were processed using the PSI technique with the ENVI + SARscape software (Sarmap 2009).

Case Study: Casitas Dam

Casitas Dam is an embankment dam in Ventura County, California, about 100 miles northwest of Los Angeles and is operated by the United States Bureau of Reclamation (USBR 2018). The Ventura River Project authorization bill was proposed to the United States Congress in 1955 and included construction of the Casitas Dam to create a reservoir, Lake Casitas, that would distribute water for agricultural, municipal, and industrial use through 33 mi (53 km) of pipeline. The bill was approved. Construction of Casitas Dam began in July 1956 and concluded in March 1959.

In the late 1990s, the USBR recommended reinforcement construction take place because Casistas Dam was vulnerable to liquefaction if a major earthquake (magnitude > 6.5) occurred in the area (Green 1998). The agreed upon solution was to widen the dam crest and construct a 130-ft berm at the base of the Casitas Dam (Figure 1). The project ended up costing ~$42 million and was completed in 2000 (Surman 2000).

PSI results are shown in Figure 2. Over 100 PS points were obtained on the crest and berm, especially on the southern-facing slopes of the structure. In general, the Casitas Dam was moving in a downward direction (yellow, orange, and red PS) while the dam facilities were moving in an upward direction (blue PS). Since each PS point contains temporal deformation information (e.g., average velocity, displacement at each acquisition date, etc.) and the relatively high-density spatial distribution of PS across the dam allows for multiple deformation measurements, PSI are sufficiently spaced to monitor all significant deformation (Ferretti et al. 2000; Ferretti et al. 2001).
Between 2005 and 2010, the Casitas Dam crest experienced differential deformation. A displacement-time series at four locations along the length of the crest is shown in Figure 2. The displacement-time series shows that, in general, the crest underwent downward deformation of varying degrees: -42 mm at location 2, -16 mm at location 3, -12 mm at location 1, and -5 mm at location 4. There is evidence for two potential causes of dam deformation. The first is the Casitas Dam underwent a general tilting of the dam crest is observed – the north side is relatively stable (location 4) and the south side settled at a rate up to ~10 mm/year (at location 2). Tilting is based entirely on PSI results. The second potential cause incorporates surficial erosion and slumping viewable from aerial photographs (Figure 6.6). Slumping on the crest appears shallow but extends to ~336 ft (~102 m) in two areas, which is measurable using PSI. It is possible the Casitas Dam crest may have undergone both slumping and settlement. Slumping may account for relatively high deformation at location 2 (-42 mm) and settlement may be attributable to deformation at locations 1, 3, and 4, with more slumping in the middle of the crest (-16 mm) and less near the edges (-12 mm on south side; -5 mm on north side near spillway).

Geospatial Kriging interpolation of PSI results is shown in Figure 3. The interpolation underestimates total displacement (mm), but aids in visualization of the spatial distribution of significant deformation. Two areas of significant deformation are enhanced in the interpolation map: (1) linear deformation along length of crest, as discussed with displacement-time series analysis, and (2) deformation on the south side of the berm, which was not easily identifiable with PS points in Figure 2. The berm experienced greater downward deformation – as much as -32 mm in the Kriging interpolation (as compared to -22 mm on the crest). In addition, the berm shows no surficial evidence of deformation. This may be evidence of internal deformation, such as natural surface or foundational settlement, at a scale that is not visible to the human eye and may be below the measurement threshold of in situ instrumentation (e.g., mm-scale).

**Upcoming Research in Numerical Analysis and Modeling**

Embankment and berm settlement is a natural process that occurs over a dam’s lifespan, as the fill material consolidates with time. Settlement may also be a portent indicating leakage or seepage (Sherard & Dunnigan 1985). Dam settlement is heavily monitored and modeled during construction and shortly thereafter (Zhu et al. 2009; Wei & Sun 2010). Dams should also be monitored throughout their life-cycle. The Federal Energy Regulatory Commission (FERC) Division of Dam Safety and Inspections recommend long-term embankment dam monitoring includes, among others, measurements on surface settlement, surface alignment, and foundation movement, which are all deformation variables (FERC 2006). Applications in remote sensing provide a perfect opportunity for long-term, post-construction dam monitoring. InSAR has been successfully used to monitor deformation across many dam structures around the world (Grenerczy & Wegmüller 2011; Chen et al. 2013; Tomás et al. 2013; Di Martire et al. 2014; Emadali et al. 2017). Therefore, the next step is to determine whether the deformation (measured using InSAR) at the Casitas Dam...
in California is attributable to material consolidation or if there is potential risk for future failure.

Future research will focus on assessing the potential for using satellite-based radar imagery toward overall embankment and berm life-cycle monitoring. This includes inverse modeling and numerical analysis of InSAR measurements to help determine whether deformation observed on the Casitas Dam is due to natural settlement or other causes (e.g., foundation movement or internal erosion from piping). Different models will be used to investigate potential causes of deformation:

$$\text{Total Deformation} = \sum (\text{Settlement}, \text{Slope Instability}, \text{Water Level Changes},...)$$

The goal is to delineate between possible sources of embankment and berm deformation, as measured by InSAR, to identify causes of movement at the Casitas Dam and implement an asset management plan.

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References


El Hachemi Bouali is a PhD student at Michigan Technological University. He hopes to continue in academia with a post-doctoral appointment.
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Yakima Basin Integrated Plan

Note: this is the first in a series of articles related to the Integrated Plan.

The Yakima River Basin Integrated Water Resource Management Plan identifies a comprehensive approach to water resources and ecosystem restoration improvements in Washington’s Yakima River basin. The Integrated Plan includes seven key elements to address a variety of water resource and ecosystem problems affecting fish passage and habitat as well as agricultural, municipal, and domestic water supply. The Integrated Plan is a national model for collaborative water resource planning.

The U.S. Department of the Interior Bureau of Reclamation and the Washington State Department of Ecology developed the Integrated Plan in partnership with the Confederated Tribes and Bands of the Yakama Nation. These State and Federal agencies have collaborated with the Yakama Nation to fund and implement this 30-year plan and actively engage many grassroots level entities, such as, irrigation districts, environmental groups, and local and county governments.

Reclamation and Ecology envision 450,000 acre-feet of surface water storage to shore-up existing supply, reservoir fish passage, floodplain and tributary habitat restoration and acquisitions, water conservation, aquifer storage and recovery projects, structural and operational changes and water banking and exchange programs as part of the Integrated Plan. Major infrastructure projects include Cle Elum Dam Fish Passage Facilities and Reintroduction Project, Cle Elum Pool Raise, Kachess Drought Relief Pumping Plant, and Keechelus Reservoir-to-Kachess Reservoir Conveyance.

The Initial Development Phase, 2013 to 2023, advances all seven elements of the Integrated Plan and represents approximately one-third (about $900 million) of the $3 to $5 billion estimated costs (plus annual $10 million for operation and maintenance) for the Integrated Plan.

The Washington State Legislature has affirmed support for the Integrated Plan in statute and has provided $191 million to date. Reclamation and other Federal agencies provide $30 to $50 million annually.

For more information, contact Gwendolyn Christensen, gchristensen@usbr.gov.
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Highlights from the 2018 NDSP Technical Seminar

Bruce Rogers, U.S. Army Corps of Engineers, Philadelphia, Pennsylvania (bruce.r.rogers@usace.army.mil)

Note: Additional summaries will be provided in the next issue of Dams and Leves.

The 2018 National Dam Safety Program Technical Seminar was held in Emmitsburg, Maryland, in February at the Federal Emergency Management Agency Emergency Management Institute. Participants came from all levels of government, owners/operators, engineering firms, and academia. The seminar theme was “Sustaining Public Trust through Effective Emergency Management.”

The following provides summaries of many of the presentations as well as pertinent points made during discussions.

Robert Kagel of the Chester County, Pennsylvania, Department of Emergency Services presented emergency preparedness and roles and responsibilities during emergency response. He stressed building relationships with partner entities prior to actual emergencies. He noted that emergency procurement processes can be invoked in Pennsylvania upon a disaster declaration. He briefed on the National Incident Management System (NIMS), and recovery aspects. Discussion ensued regarding coordination actions between county emergency management entities. It was noted that county emergency management entities and dam owners/operators should establish prior relationships by having dam owners/operators visit the county emergency operations centers (EOCs) and the county personnel visit the dams.

Nicholas Sleptzoff of FEMA presented technical assistance for dam safety preparedness to non-federal governmental entities. Examples of technical assistance include supply chain resilience measures; evacuation and shelter-in-place procedures; and community resilience. He noted that the intent of the assistance is for a single entity to prepare for emergencies due to a single dam, and that FEMA foots the cost of the assistance. Subject matter expert support for the effort is provided by Argonne National Laboratories, the Decision Support System for Water Infrastructure Security (DSS-WISE) process is employed, and a unified consequence analysis process is employed.

Bruce Feinberg of the Bureau of Reclamation (USBR) presented using potentially lethal flood zones (PLFZs) to assess downstream impacts from dam failure (see Figure 1). The idea is to determine PLFZs with depth and velocity modeling, and then concentrate evacuation resources in the PLFZs while instructing people in other downstream areas to shelter-in-place until evacuation resources become available. He noted that this consequence-assessment process is an alternative to life loss assessment, and reduces the uncertainty associated with life loss assessment. During discussion it was noted that the modeling effort can account for high concentrations of people such as hospitals and schools.

Maurice Artis of the Tennessee Valley Authority presented on improving tabletop exercises. He noted that an excellent training source for emergency exercises is the Homeland Security Exercise and Evaluation Program (HSEEP). He covered the differences between discussion-based exercises and operations-based exercises. He discussed roles of the Lead Planner and the internal and external members of the Planning Team. He stated that the conduct of the exercise should start with a quick review of the EAP; then outline the rules for conduct of the exercise; and remind exercise observers that they are not players. He finished by noting that an exercise evaluation form should be prepared in advance for use by participants; that a “hot wash” discussion should immediately follow the exercise; and that an after-action conference should be performed to document all recommendations.

Victor Hom of the National Weather Service (NWS) presented about actionable information to key decision-makers and the public, with the intent being that key information needs to be transmitted to key people in a timely manner. He noted that the information exchange protocol in FEMA Document 64 includes coordination, notification, flood warnings, and communication. He emphasized that information exchange could help pinpoint potentially-
impacted areas, which would allow prioritization of emergency response resources. He pointed out that the DSS-WISE process is already tied to the National Inventory of Dams and the National Levee Database, and that the National Bridge Inventory is being tied in. He noted that EAPs should be provided to the NWS for their planning and response efforts.

John McCain of the South Carolina Department of Health and Environmental Control presented about communication during major events which resulted in failures of low-head dams. Following presentation of the timing of communication with dam owners during Hurricane Joaquin in 2015, he noted that follow-up assessments determined that contact information in 40 percent of EAPs needed updating (including consulting engineers); that few EAPs included standard operating procedures for triggering communication; and that the state was unaware of the CodeRED automated, multi-mode emergency notification system. Following presentation of the timing of communication with dam owners during Tropical Storm Hermine in 2016, he noted that follow-up assessments determined that contact information in 25 percent of EAPs needed updating; that few EAPs included standard operating procedures for triggering communication; and that the state was unaware of the CodeRED automated, multi-mode emergency notification system.

Following presentation of the timing of communication with dam owners during Hurricanes Harvey, Irma, and Maria in 2017 (see Figure 2), he noted that, although the USACE hard-copy mapping shows two inundation scenarios, the modeling includes five inundation scenarios. The importance of multiple inundation scenarios was recognized by the group due to the issues dealt with by decision makers during the Oroville Dam incident where only one inundation scenario had been mapped, but the incident wasn’t compatible with the scenario.

David Schafer of USACE New England District presented about USACE’s updated EAP policy guidance. Peer reviews of the USACE Dam Safety Program had recommended improvements to specific aspects of the EAP guidance. In addition, the guidance update was coordinated with the USACE Levee Safety Program in order to cover both dams and levees with consistent processes. He noted that, in general, the updated guidance is consistent with national guidance developed by FEMA. He also emphasized having in place a process for warning the public in the area immediately downstream of a dam or adjacent to a levee during the time prior to local emergency management personnel receiving the alert and deploying resources to the area to provide warnings or direct evacuations. He described the USACE inundation mapping standards, and how the mapping process was used in real time to advise decision makers during Hurricanes Harvey, Irma, and Maria in 2017 (see Figure 2). He noted that, although the USACE hard-copy mapping shows two inundation scenarios, the modeling includes five inundation scenarios. The importance of multiple inundation scenarios was recognized by the group due to the issues dealt with by decision makers during the Oroville Dam incident where only one inundation scenario had been mapped, but the incident wasn’t compatible with the scenario.

John Sheeley of the U.S. Army Corps of Engineers Modeling, Mapping, and Consequences Production Center presented about USACE’s updated EAP policy guidance. Peer reviews of the USACE Dam Safety Program had recommended improvements to specific aspects of the EAP guidance. In addition, the guidance update was coordinated with the USACE Levee Safety Program in order to cover both dams and levees with consistent processes. He noted that, in general, the updated guidance is consistent with national guidance developed by FEMA. He also emphasized having in place a process for warning the public in the area immediately downstream of a dam or adjacent to a levee during the time prior to local emergency management personnel receiving the alert and deploying resources to the area to provide warnings or direct evacuations. He described the USACE inundation mapping standards, and how the mapping process was used in real time to advise decision makers during Hurricanes Harvey, Irma, and Maria in 2017 (see Figure 2). He noted that, although the USACE hard-copy mapping shows two inundation scenarios, the modeling includes five inundation scenarios. The importance of multiple inundation scenarios was recognized by the group due to the issues dealt with by decision makers during the Oroville Dam incident where only one inundation scenario had been mapped, but the incident wasn’t compatible with the scenario.

Matt Miziorko of the Montgomery County, Maryland, Office of Emergency Management and Homeland Security presented some challenges and lessons learned from incidents. Challenges to effective emergency management include: increased risk due to development and urbanization near waterways; difficulties in dealing with projects that have multiple owners or operators; and lack of warning time prior to an incident. He described the particulars of incidents at Lake Needwood Dam (2006), Wheaton Dam (2014 and 2017), and Burnt Mills Dam (2014). He listed lessons learned from these incidents including: having consistency in emergency declaration levels; knowing the status of designated shelters; using an incident management software such as WebEOC; and using a mass notification software such as Integrated Public Announcement Warning System (IPAWS).
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New Officers, Committee Chairs and Vice Chairs

During its recent meeting in Miami, the USSD Board of Directors elected the following officers:

Vice President — Denise Bunte Bisnett, South Carolina Public Service Authority (Santee Cooper). She most recently served as Secretary-Treasurer and succeeds Manoshree Sundaram.

Secretary-Treasurer — Stuart Harris, Tennessee Valley Authority. He joined the Board in 2017.

Dean Durkee, Gannett Fleming, continues as President.

The Board also approved the following committee chair and vice chair appointments:

ACPA/Website & Social Media — Chair, Yulia Zakrevskaya; YP Vice Chair, Merry Dang

Concrete Dams — Vice Chair, Greg Zamensky; YP Vice Chair, Hillery Venturini

Construction and Rehabilitation — Chair, Rodney Eisenbraun; Vice Chair, Nick Patch; YP Vice Chair, Chris Buller

Earthquakes — YP Vice Chair, Zahra Amini

Public Safety and Security for Dams — YP Vice Chair, Megan Puncke

News of Members

Stephen Benson has joined the new Seattle office of Schnabel Engineering as Principal and Senior Engineer.

Rachael Binsnett has transferred to Stantec’s Charlotte, North Carolina office.

GEOKON, a manufacturer of geotechnical and structural instrumentation, has been certified under ISO 9001:2015 from both ANSI•ANAB, USA and UKAS of Great Britain as of June 1, 2018.

John P. Osterle has been named supervising engineer for water and environment in the Pittsburgh office of WSP USA.

Gerald Roblee, Schnabel Engineering, as been promoted to Principal in the firm’s Greensboro, North Carolina, office.

Falvey Receives USSD Lifetime Achievement Award

Henry T. Falvey received the 2018 USSD Lifetime Achievement Award. He was recognized for his distinguished career in the dams and water power industry spanning six decades. He has made significant contributions to the advancement of technology, especially related to hydraulic structures for dams. He has published more than 40 scholarly works, many of which have become the standard reference for dam engineering professionals. His work on aeration and cavitation on spillways and chutes is widely referenced in the field and his book on labyrinth weirs is also an important contribution.

Following a 27-year career with the Bureau of Reclamation, Dr. Falvey established his own firm, serving as an expert consultant and a peer reviewer for many years. He has consulted or taught in Algeria, Australia, China, Egypt, France, Germany, India, Mexico, Pakistan, Romania, Switzerland, Taiwan, and Turkey. Most recently, Dr. Falvey was a member of the independent forensic team to develop findings and opinions of cause for the Oroville Dam spillway incident.

Dr. Falvey received a BSCE with honors from Georgia Institute of Technology in 1958; an MSCE from California Institute of Technology in 1960; and a Dr.-Ing. from Universität Karlsruhe (Germany) in 1964. He resides in Conifer, Colorado, with his wife of 57 years, Inge.
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