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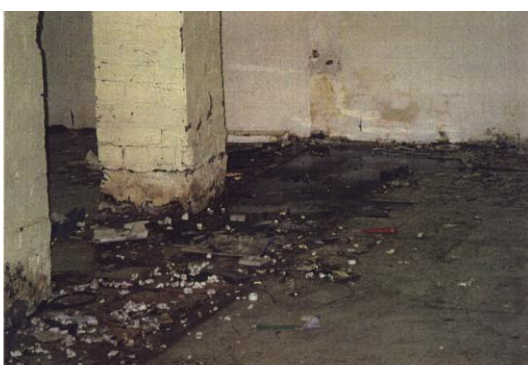

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U.S. Department of the Interior
Bureau of Reclamation

December 2011

This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

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TECHNICAL RESPONSE TEAMS

by Ron Luehring, P.E. – Mid-Pacific Region Dam Safety Program Manager

Abstract

The Bureau of Reclamation developed Technical Response Teams to ensure readiness of the technical staff assigned to each dam and address the recognized concerns of staff mobility, retirement of experienced personnel, coordination between designers and field staff, and lack of experience with dams.

Executive Summary

The Technical Response Team (TRT) for each dam is gathered, at a minimum, every 3 years to conduct dam performance assessment and, when necessary, to address actual anomalous behavior. The teams include dam engineers (structural and geotechnical), instrumentation specialists, geologists, dam tenders and operators, and area and regional office participants. TRT meeting objectives include: (1) perform a focused, comprehensive review of dam operations and performance using a team approach to obtain a broad-based, synergistic look at data, (2) intentionally analyze and discuss visual inspections, instrumentation, and monitoring data to identify successful or unusual behavior or trends in the context of potential failure modes, (3) provide an up-to-date review of dam performance built off previous formal reviews, and (4) ensure the TRT for each dam is equipped to enable an effective, knowledgeable response to technical issues that arise. As important as what the team does, is that in so doing, and personnel newly assigned to the dam learn the unique characteristics of the dam and its past performance.

Background

In 2009, a pilot test of the TRT Periodic Dam Performance Assessment Meeting concept was initiated for 10 Bureau of Reclamation dams, and in 2010, additional testing and development of the concept was performed with respect to another 4 dams. In 2011, Reclamation proceeded with phasing in TRT Periodic Dam Performance Assessment Meetings as a standard part of the dam safety program for all high- and significant-hazard dams. In implementing the TRT Periodic

Dam Performance Assessment Meeting concept, it was decided to link the timing of these meetings to the performance of Periodic Facility Reviews (PFRs), with the TRT meeting occurring just prior to the PFR site examination. By 2012, Reclamation's goal is to fully support and accompany all scheduled PFR examinations that currently number about 40.

The reasons for implementing the TRT assessment on the described interval are twofold:

- It was felt that 3 years is the longest acceptable time period between gatherings of the TRT. A gathering equivalent to a TRT Periodic Dam Performance Assessment Meeting occurs at the initiation of a Comprehensive Facility Review (CFR), so as to conduct the initial CFR meeting and potential failure modes analysis (PFMA). Timing the next regularly scheduled TRT gathering to the PFR site examination provides a 3-year time period between TRT gatherings.

- The TRT discussions can benefit the PFR, both by augmenting the background and knowledge of the engineers that are conducting the PFR, and by providing a convenient means of investigating and documenting any specific issues/conditions at the damsite raised during the TRT discussions (via the PFR site examination and report). Issues and concerns raised during the TRT discussions can result in recommendations included in the completed PFR report where applicable and appropriate. Action Items are also recorded from each TRT meeting for TRT members or dam safety personnel to carry out.

Reclamation's Technical Response Team — Concept Model and Test

The basic dam safety inspection program for Reclamation dams consists of the following:

- **Comprehensive Facility Review (CFR)/Comprehensive Review (CR)**.– Performed every 6 years and led by a Senior Engineer in Reclamation's Technical Service Center (TSC). The CFR includes a potential failure modes assessment; site examination; screening-level risk assessment; review of design, construction, analyses, and monitoring; and a detailed report documenting the work and findings.

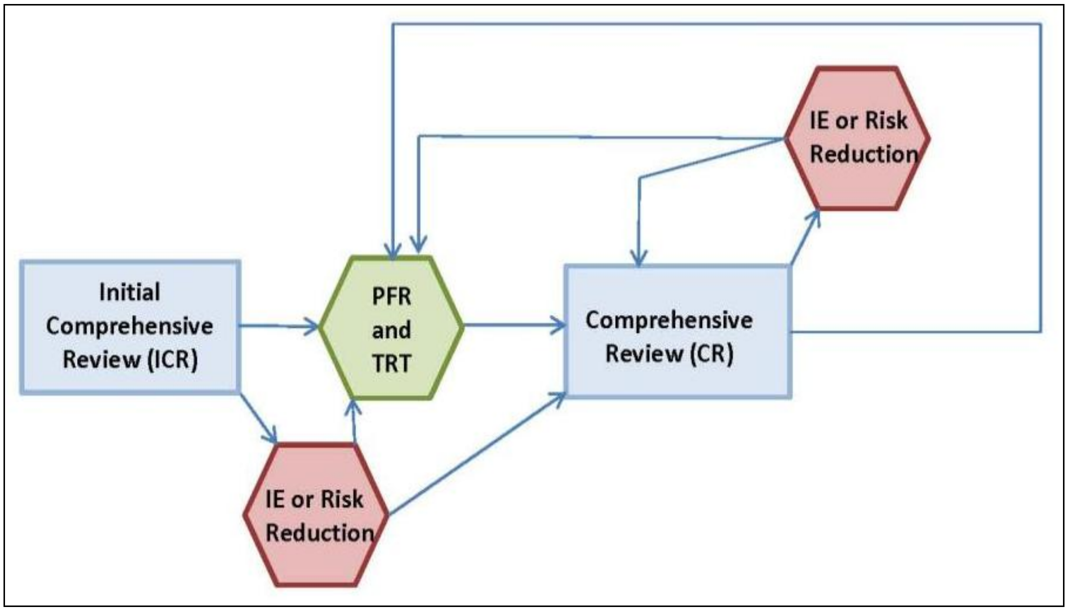

Figure 1.—Overall review process.

- **Periodic Facility Review (PFR)**.–Performed 3 years after the CFR and led by an experienced engineer in the regional office responsible for the dam. The PFR includes a site examination; a thorough review of the dam safety situation, including operations and maintenance for the structure; and a detailed report documenting the effort.

- **Annual Inspections (AI)**.–Performed in years when a CFR or PFR are not performed and led by an experienced engineer in the area office responsible for the dam. AIs are performed by completing a comprehensive inspection/review checklist specifically developed for the facility.

- **Routine Dam Safety Performance Monitoring**.–Performed on an ongoing basis by operating personnel at the dam. Monitoring frequencies and details of the required monitoring efforts are documented on a Schedule for Periodic Monitoring (L-23) and an Ongoing Visual Inspection Checklist (OVIC) that is specifically developed for the dam by PFMA efforts in the CFR. The CFR also includes expected performance limits for all instruments to aid the routine, real-time evaluation of collected instrumentation data.

The composition of the TRT for a dam at Reclamation is as follows:

- Principal Engineer (a geotechnical engineer for an embankment dam and a civil or structural engineer for a concrete dam) – generally from the TSC in Denver

- Geotechnical engineer – from TSC
- Civil engineer (regarding spillway structures, outlet works facilities, etc.) – from TSC
- Principal Geologist – from TSC
- Structural behavior engineer (regarding instrumentation and monitoring activities) – from TSC
- Senior Engineer/Team Leader for the previous CFR – generally from TSC
- Regional office personnel who have knowledge/experience with the dam (civil engineers, geologists, dam safety project managers)
- Dam Safety Program Manager – Dam Safety Office
- Area office personnel who have knowledge/experience with the dam
- Dam operating personnel (may work for Reclamation personnel or for a water district that contracts with Reclamation to operate the dam)

Technical Response Team Periodic Dam Performance Assessment Meetings – Concept

The initial objectives set out for the TRT meetings to address perceived needs can be summarized as follows:

- To complete a focused, comprehensive review of the performance of the dam using a team approach in order to obtain a broad-based, synergistic look at the available data and information
- To intentionally analyze and discuss the visual inspections (as a team), instrumentation data, and other monitoring data on the project in order to identify successful performance or spot any unusual behavior or trends in the context of potential failure modes
- To provide an up-to-date review and analysis of the dam's performance, built off the previous CFR work, the previous PFR, and the current Instrumentation Data Package, for use and consideration during the upcoming PFR

- To ensure the TRT for each project is engaged and mobilized to enable effective, knowledgeable response to technical issues that may arise at the dam (including learning individual team member strengths)

The TRT Periodic Dam Performance Assessment Meeting was not intended to replace or supplant the functions of any of the current key dam safety evaluation activities (noted above), but rather was intended to:

- Fulfill the concept of the performance parameters principle of ongoing utilization of instrumentation and visual monitoring by (1) providing a periodic, focused, multidiscipline review and evaluation of specific monitoring and visual inspection information data keyed to identified potential failure modes and (2) providing an examination of all information (performance, visual monitoring, and instrumentation) to ensure that other potential failure modes are not developing (previously considered or newly identified)

- Support and enhance the accomplishment of the next PFR by providing an intermediate, detailed review of the dam performance information and thereby identify any issues or conditions to be considered and examined during the PFR

There are two key dam performance review elements involved in the TRT Periodic Dam Performance Assessment Meeting:

- Review of the dam performance as evidenced in the instrumentation data and visual monitoring information for the dam

- Review of the dam performance as evidenced in the project operation since the last CFR

The basic TRT process consists of the following steps: (1) the Principal Engineer obtains the relevant, current background reports (most recent CFR, PFR, and Issue Evaluations) and puts them in a "reading room" 2 weeks prior to the meeting and (2) the Instrumentation Specialist provides the historic and current report of the monitoring and instrumentation data to the team members (also hard copy in the reading room).

- Regional and area office personnel are advised of meeting time (and will join by teleconferencing).

- All team members review their "specialty" information and the background material provided in the reading room in advance of meeting (about 2-4 hours preparation time).

- A “fresh eyes” facilitator, who is experienced in dam design and analysis, failure modes, and dam safety reviews the background information on the dam.

- The TRT session of about 2 to 3 hours is carried out.

- Meeting notes are written by the Principal Engineer and peer reviewed by the facilitator and Instrumentation Specialist.

Ensuring that the TRT Meeting is Substantive and not Routine

In order to make sure the TRT meeting concept would be a sustained program and to make sure the TRT meetings were effective and productive for the attendees, careful attention was paid to ensuring that the meetings were not perfunctory. Perfunctory meetings are referred to and thought of as “mechanical,” “automatic,” “obligatory,” and “token.” People come but don’t really expect to get anything out of them. The TRT meeting, by design, is intended to dispel that label. Thus, it is ensured through the efforts of the facilitator, the Principal Engineer, the Instrumentation Specialist, and other team members as applicable that:

- Substantive explanations and discussions of the important characteristics of the dam (any strengths and weakness from design and performance considerations) are included.

- Concise explanations of the most significant potential failure modes are given.

- A review of any key operational aspects that directly related to safe performance of the dam (e.g., spillway gate operations) was performed.

- Understanding was conveyed of what the instrumentation and visual monitoring revealed (or could in the future reveal) about the performance of the dam and the relationship of the monitoring relative to the potential failure modes were incorporated into the meetings and that any action items stemming from these discussions were assigned and recorded.

By paying attention to these aspects of the dam in the TRT meetings, all team members, and especially newly assigned team members and engineers to the organization, gained the type of important information and understanding of the dam that would allow them to be meaningful participants, from the get go, if an actual technical response by the team was called for at some point in the future.

TRT Meeting when an Incident or Unusual Loading Condition Occurs

A very important benefit of the TRT Periodic Dam Performance Assessment Meetings is that, should unusual or emergency conditions develop at the dam site, the TRT can quickly gather, and promptly and efficiently begin to develop, appropriate technical advice based on unusual signs or behavior that could lead to an emergency situation.

A TRT meeting should be convened as soon as possible under the following conditions: (1) upon notice of a developing seepage incident or other significant change in dam behavior associated with a failure mode or potentially serious damage to the structure's integrity, (2) when there is a flood event at the dam that results in reservoir levels above historic highs, and (3) immediately after a significant seismic event.

Obviously, a TRT Assessment Meeting associated with an incident or unusual loading condition will be focusing on the specific situation that triggered the meeting. However, it is beneficial in the meeting to also consider going through the agenda items associated with a TRT Periodic Dam Performance Assessment Meeting if time and circumstances permit. In addition to the agenda items associated with a TRT Periodic Dam Performance Assessment Meeting, the "emergency" meeting should consider the following:

- Discuss emergency management activities with the area office and the need for emergency repair materials, equipment, operators, etc., should potential unsafe conditions develop
- For a flood above the historic high:
    - Review the frequency of instrument readings, documented visual monitoring, surveillance/presence at the dam, and develop review and communication protocols, etc.
    - Ensure data trends as reservoir rises above historic highs are not indicative of developing or pending problems
- Following a significant earthquake:
    - Immediately review data collection frequency
    - Consider if more frequent monitoring is needed during future rising reservoir levels to verify internal damage or changes did not occur

- Discuss the need for special exams (conduit inspections, toe drain video inspections, etc.)

- Upon notification of a seepage incident such as new or increasing seepage:
  - Discuss immediate and long- term operations of the reservoir
  - Discuss the need for emergency repair materials, equipment, operators, etc., should potential unsafe conditions begin to develop further
  - Discuss failure modes the new seepage may be indicative of
  - Review for changes in operations

After the "emergency" meeting, notes can be prepared in a similar fashion as described above for TRT Periodic Dam Performance Assessment Meetings. Follow-on activities are more focused. Lines of communication are solidified. The plans to deal with an incident are made in the most informed manner possible, and the chance of success is greatly enhanced.

Conclusions

Ten notable insights that can be gleaned through the use of the TRT approach are:

- See how things have changed
- See how the dam has responded
- Learn more about the construction and modifications
- Relate failure modes to instrumentation and dam performance
- Understand the flow/piezometric conditions in and between the dam and foundation
- Recognize the physical anomalies
- Reliability of the operations
- Reliability of the monitoring program

- Learn who is on the TRT and who knows what
- Work together to resolve unexpected information

For additional information related to meeting preparation, meeting agenda, and what to include in the meeting notes, refer to the Dam Safety Office Web page that references the Technical Response Teams.

ATTACHMENT 1

Technical Response Team Periodic Dam Performance Assessment Meetings – Preparation

The TRT Periodic Dam Performance Assessment Meeting is set up by a facilitator (eventually this will transition to being set up by the Principal Engineer without use of a facilitator). The following preparatory steps are performed:

- The Structural Behavior Engineer prepares an Instrumentation Data Package that consists of the current instrumentation and visual monitoring data and provides this information to all meeting participants. This data package is to include current and historic piezometric data, plotting of water levels on section views (where applicable), plots of piezometric and seepage data versus reservoir levels (where appropriate), survey monument data, and reservoir operation history over the long term and in recent years. The package is to include adequate information on historic readings to allow the context of current readings to be assessed. Also included are the current Schedule for Periodic Monitoring (L-23) and the current OVIC.

- The Principal Engineer assembles relevant reports, materials, and documentation related to the performance of the dam for use in preparing for the meeting as well as during the meeting. The principle focus is on information developed since the last CFR or PFR. This material would include such items as:

    - The most recent CFR

    - The most recent PFR

    - Annual inspection reports prepared by the area office

    - All Special Inspection Reports completed within the last 3 years, such as toe drain inspection reports, conduit inspection reports, dive inspections of stilling basins, intake structures, inaccessible feature inspections, etc.

    - Any Issue Evaluation reports, technical reports and/or memoranda, etc., completed since last CFR

- The facilitator reviews all background material collected by the Principal Engineer and works with the Principal Engineer with respect to information gaps noted by the facilitator. This review will be the responsibility of a Senior Technical Specialist once the TRT process transitions into a lesser need of a facilitator.
    - The Principal Engineer obtains large-scale drawings for display in the meeting room.
    - Meeting participants that will not be able to attend the meeting in person in Denver, but instead by teleconference, are informed by the facilitator of the materials to be reviewed and discussed during the meeting, including the large-scale drawings that will provided in the meeting room.
    - All TRT members review materials and information related to their respective discipline prior to the meeting.

ATTACHMENT 2

Technical Response Team Periodic Dam Performance Assessment Meetings – Agenda

A typical agenda for a TRT Periodic Dam Performance Assessment Meeting is indicated below:

1. Review of objectives, plan, and scope of the meeting.

2. Review of the character of dam and reservoir operations over the past several years (i.e., low water regime, high water regime, normal water regime, drought, etc.).

3. Review of potential failure modes for the dam (brief discussion of all potential failure modes and identification of the most critical potential failure modes).

4. Discussion of noteworthy issues out of recent reports, evaluations, etc.

5. Discussion of noteworthy recent dam maintenance activities.

6. Review of instrumentation data and performance monitoring information.

7. Review of any performance issues over the last several years, including if and how issues were addressed or discussed.

8. Discussion of instrumentation installations, monitoring data, and indicated dam performance.

9. Review the need to revise the current Schedule for Periodic Monitoring (L-23) and the OVIC.

10. Identification of other conditions or issues that should be raised relative to the dam performance assessment.

11. Review/discussion of potential actions, investigations, etc., or changes regarding routine monitoring/visual inspections that should be considered based on the discussions during the meeting. Review/discuss matters that should be highlighted for attention in the next PFR or CFR. All such items should be captured as “Action Items.”

12. TRT finding relative to continued operation of the dam, including reservoir restrictions, special concerns, etc.

"**Action Items**" developed in the course of the meeting are an important product of the TRT work. They are documented in the meeting notes and are also included in a TRT "Action Item" spreadsheet that documents who, how, when, and proposed funding regarding addressing the "Action Items."

Some topics to discuss in the course of proceeding through the agenda include:

- General description and operation of the facility
    - It has been found useful to excerpt slides from the last CFR presentation to describe the dam, associated facilities, and potential failure modes
    - Typical releases made for irrigation or other purposes
    - Special releases or other changes from normal operation
    - Unusual climatic conditions such as drought or extreme temperature conditions
- Have reservoir operations and levels changed over the past few years?
- Are there any reservoir restrictions in place, and if so, are reservoir operations conforming to those restrictions?
- Were there significant floods, significant seismic activity, fires, or extreme climatic conditions in recent years? If so, what was the response of the structures? (Discuss the possible changes as a result of the these loadings and determine if any special inspections or changes to monitoring programs are needed such as toe drain video inspections, an increase in the frequency of seepage monitoring, etc.).
- Discuss results of previous inspections performed, including special inspections, climb, dive, or closed-circuit television inspections, etc.
- Discuss, brainstorm, and record the possible reasons for any unusual responses of the dam or appurtenances to loading conditions, unusual trends developing, deviations from past responses, or any adverse performance. Failure modes should be central to this discussion.
- Instrumentation data should be explained and presented by the Structural Behavior Engineer.
- The findings from visual monitoring (OVIC) and inspections (annual, special, etc.) should be presented and explained by the Structural Behavior Engineer.

- Each portion of the instrumentation should be reviewed and discussed, considering any unusual behavior or the appearance of any trends or deviations from past performance. Possible explanations, causes, and possible effects or outcomes should also be discussed.

- Determine whether the instrumentation readings and any other specified performance parameters are within the expected limits.

- Evaluate whether performance parameter limits appear to need modification.

- Discuss the need for and rationale for (changed conditions, anomalous readings) modifications to the current instrumentation program (schedule, additional visual inspection or instrumentation, elimination of instruments, etc.)

The TRT's role for all assessments is to review and understand the implications of the performance information and data and identify possible issues and potential actions for implementation by the established processes as appropriate and needed within the organization.

One activity that has recently been added to the TRT Performance Assessment Meeting agenda is to classify the dam at the appropriate level in the Dam Safety Priority Rating System. This is a new system for Reclamation based on their new Public Protection Guidelines for risk management. Discussion of the rating system is beyond the scope of this paper, but it is interesting to note that there is sufficient confidence in the TRT process for the team to perform such an activity that is essential to the needs of Reclamation's Dam Safety Office.

ATTACHMENT 3

Technical Response Team Periodic Dam Performance Assessment Meetings – Meeting Notes

The Principal Engineer is tasked with documenting the TRT Periodic Dam Performance Assessment Meeting in the form of meeting notes. The documentation includes recording the facts of the meeting (who was there, what topics were covered, etc.), but the most important aspect of the documentation is capturing what information was learned by the TRT during the discussions. In other words, what were the major findings and understandings achieved by team members? That information should be presented clearly enough and in enough detail that subsequent team members can pick up the meeting notes and obtain the same knowledge and information garnered by the team during the session. Because of the importance of this aspect of the meeting notes, it is advised that the Principal Engineer draft this "Major Findings and Understandings Section" within a day or two of the meeting.

The meeting notes are to address the following topics:

1. Brief introduction/background information

    - Purpose of meeting
    - General information about the dam
    - List TRT members
    - Year of most recent formal inspection and what the inspection was (CFR or PFR)
    - Time period covered by this TRT meeting (i.e., focus on data since last CFR, but also checking long-term trends)

2. Major findings and understandings

    - Identify each major finding and understanding resulting from the information presented and discussed (i.e., what was learned/ confirmed/pointed out that some on the team were not previously aware of).
    - What potential actions/investigations/instrumentation or monitoring changes or anomalies or operational variations were identified.
        - List Action Items

3. Documents reviewed by the TRT

    - List each document gathered by the Principal Engineer for review by the team even if all members did not review all the documents. For example:

        - Most recent CFR or PFR
        - Inspection reports
        - Instrumentation Data Package
        - Current L-23 and OVIC
        - Annual inspection reports prepared by the area office
        - Special Inspections (toe drains, dives, inaccessible features, etc.)
        - All technical reports completed since last CFR

4. Summary of operations during the past year

    - Summarize the general operation of the facility.

        - Typical releases made for irrigation or other purposes
        - Any special releases or other changes from normal operation
        - Any flooding or seismic activity, drought, fires in area, etc.

    - How did the reservoir level change over the past year?
    - List any changes in seepage conditions.
    - Identify inspections performed, including special inspections, and summarize the general findings of the inspections.

5. Instrumentation and visual monitoring data review

    - Summarize each type of instrumentation reviewed
    - Summarize the visual inspection program results

    - Describe results of detailed reviews, providing detail only where significant differences or important findings were uncovered

    - Describe any potential actions

6. Conclusion

    - Make brief statements about the depth of the review and the relative certainty of the findings.

    - Note whether it is safe to continue operating the dam, including whatever operational restrictions, heightened monitoring requirements, or other activities are required to continue to safely operate the dam.

Shortly after the meeting (within a day or two), the meeting notes should be drafted. Initially, they are provided to the facilitator and the Structural Behavior Engineer for a first level of review. When this review is completed, and the meeting notes have been appropriately edited/modified, then they are transmitted to all participants in the TRT meeting for review and comment (however, this second round of review has not been part of the TRT process at Reclamation as of yet, so the notes get out faster and have been found, nonetheless, to be fully acceptable). Upon completion of this review, the meeting notes are again edited/modified. The finalized meeting notes are transmitted to all participants in the meeting, the Dam Safety Office, records, as well as appropriate management personnel.

ELECTRO-OSMOTIC PULSE BELOW-GRADE DEWATERING SYSTEM PILOT TEST IN TRINITY DAM BONNET CHAMBER

by Daryl Little, Technical Service Center's Materials Engineering Research Laboratory

Electro-osmotic pulse (EOP) technology may be the most effective long-term method to stop water leakage into Bureau of Reclamation (Reclamation) structures. Damage caused by water seeping through concrete and leaks through cracks in a concrete structure or joints can be extensive and expensive to repair. Corrosion of equipment due to the resultant damp environment can also create safety issues due to inoperable equipment (e.g., gate operating motors and pipes). EOP technology has the potential to mitigate many water-related problems from the interior of affected areas without the cost of excavation. The U.S. Army Corps of Engineers (Corps) has utilized this technology on a variety of projects, including the U.S. Treasury Building, as shown on figure 1. Because of EOP's potential to stop water leaks through concrete, a research program was initiated to test the technology at a Reclamation facility.

Figure 1.—U.S. Treasury Building in Washington D.C. showing the conditions before EOP was installed (left) and after it was installed and operating (right).

Introduction

EOP is potentially a long-lasting solution to water intrusion. Results from previous installations performed by the Corps show it has a lower life-cycle cost when compared to grouting or concrete repair alone. EOP prevents structural degradation from water penetrations on rebar. EOP is a technology that uses current and electric fields operated to prevent water from leaking through concrete.

Summary

The EOP pilot test is operating as designed and has reduced the moisture content of the concrete in the test area. This is based on the trend in the collected data that shows the total current has decreased and the resistance increased over time at a constant voltage. The success of the pilot test indicates that this technology does work in this type of application. However, this test section was small. A larger installation should be tested. For the larger test section, EOP should be installed in the bottom 10 feet of the shaft, around its entire circumference. For this test, leaking cracks would be included in the test section. The technology may have application at a number of other Reclamation structures as well.

Test Location

Trinity Dam is near Redding, California, and was chosen as the site for the pilot test. The facility was experiencing water leaks through the bonnet chamber shaft, which lead to several maintenance problems.

The walls of the shaft and bonnet chamber are covered with calcite as shown on figure 2. The calcite has an average deposit thickness of 0.5 to 1 inch as shown on figure 3. Calcite has been measured as thick as 6 inches in some locations. There is standing water on the bonnet chamber floor due to seepage, and corrosion of the air inlet pipe and bonnet cover has occurred. The extent of the calcite deposits is preventing the operation of the door to the chamber as shown on figure 4. If the door cannot be sealed and the gate and bonnet cover fails, then water directly from the reservoir will flow through the door, down into the penstock tunnel, and then out into the powerplant yard.

Figure 2.—Calcite deposits observed on the walls of the bonnet chamber. Excessive seepage over time has resulted in stalactites.

Figure 3.—Calcite on the walls indicates an average thickness of 0.5 to 1 inch.

Figure 4.—Excessive calcite deposits prevent the access door to the chamber from closing and sealing, creating an unsafe condition if the gate fails.

The objective of the first phase was to install EOP in a section of the bonnet chamber at Trinity Dam and monitor the EOP system performance to see if it appeared the concrete was drying in the installation area. The test section was a 12-foot-wide by 6-foot-high wall section opposite the personnel entry tunnel.

Background

An experiment conducted by F.F. Reuss in 1809 showed that when an electric field was applied to a soil, water could be forced to flow through a clay-water system. Flow is initiated using the movement of positively charged ions (cations) in the pore fluid within a porous media like clay or concrete. The water surrounding the cations moves with them. This process is defined as electro-osmosis.

The electrical pulse causes cations (e.g., Ca++), and the associated water molecules they are dissolved into move from the anode, installed on the dry side, towards the cathode, installed on the wet side. This will create a type of barrier and prevent water molecules from entering the concrete. In the case of thick concrete, cathodes can be placed deep in the concrete section.

A commercial system developed to apply EOP technology utilizes the application of a pulsating direct electric field combined with an off-period to reverse the flow of water seepage. A typical pulse wave form sequence consists of a pulse of positive voltage, a pulse of negative voltage, and a period of rest when no voltage is applied. EOP systems require a 120 V_{AC} circuit for the system controller. The total power requirement for a 1,184-square-foot basement is about the same as that for a 100-watt incandescent light bulb. A typical EOP system layout and operation is shown on figure 5.

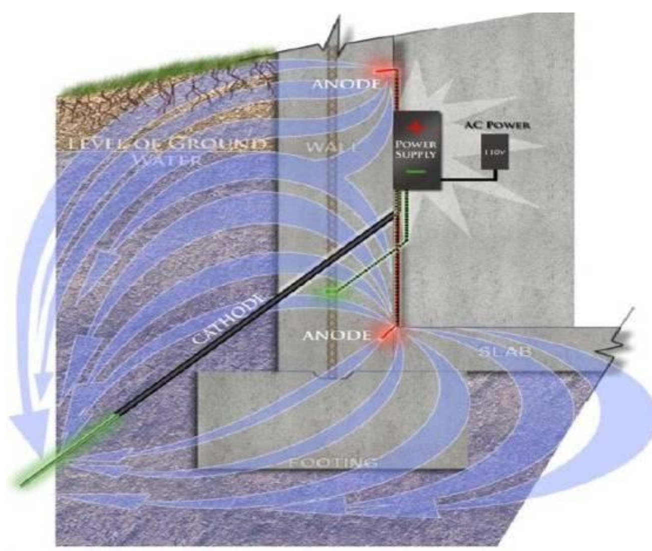

Figure 5.—Typical EOP system layout and operation [1, 2].

Installation

The calcite deposits on the bonnet chamber wall opposite the hatched doorway were removed using a chipping hammer and a grinder. The area cleared off was approximately 12 feet wide and 6 feet high starting from the floor. The calcite deposits on the wall were an average of 0.5 to 1 inch in thickness as shown on figure 3.

Mixed metal oxide-coated titanium mesh strip anodes, 12 feet long and ½ inch wide, and probe-type anodes, 6-7 inches long and ½ inch wide, were installed in the test section. The strip anodes were installed in the wall at the floor joint and 6 feet above the floor in saw cut and chipped out grooves approximately 1 inch wide by 1 inch deep. Six probe anodes were installed in holes approximately 3 feet above the floor and 2 feet apart. The anodes (see figures 6 and 7) were inserted in the grooves and holes and then were filled with a portland cement grout (BASF Masterflow 928). A water drip strip was installed approximately 6 inches above the top anodes to prevent water from the wall above flowing over the test area, which might have lead to erroneous readings.

Figure 6.—Strip anode installed in a groove and then packed with a portland cement grout.

Figure 7.—Probe anode installed in a hole and then packed with a portland cement grout.

Eight mixed metal oxide-coated titanium mesh strip cathodes, ½ inch wide, were installed in the test section. Four cathodes were installed at 1 to 1.5 feet above the floor, and four were installed approximately 4.5 feet above the floor. Cathodes were inserted in the holes, and then the holes were filled with a portland cement grout.

Anode and cathode cables were run through the junction boxes along the wall, and then connected to an anode header cable and a cathode header cable, respectively, in a main junction box. A connection was also made to the rebar to allow the system to supply the rebar with a small amount of protective current and prevent any damage to the rebar due to operation of the system. The main header cables and the cable connected to the rebar were run through conduit to the system controller. The complete installation of all electrodes and junction boxes is shown on figure 8.

Figure 8.—Completed installation with junction boxes and conduit.

Permanent systems only include one junction box and conduit to a control unit, depending on the size of the structure. The anode cables would be embedded in the concrete wall, and the cathode cables would either be embedded in the concrete wall or buried depending on the location of the cathodes and control unit.

To protect the unit from exposure to calcite-saturated water, the cabinet was installed on the wall outside the chamber. The internal components of the control unit are shown on figure 9. The unit was wired into a 120 V_{AC} power source using a series of extension cords to an outlet at the top of the shaft approximately 420 feet away. The unit was programmed to hold a potential of 24 V_{DC} with a current applied to the rebar of approximately 1 – 2 milliamps (mA). Data were collected every 4 hours and stored in an excel spreadsheet file on an SD card.

Figure 9.—The internal components of the control unit.

Test Data

The as-left condition of the wall of the chamber where the test section was located showed a saturated or wet concrete both to sight and touch. After about 2 weeks of operation, the system was evaluated and data collected from the SD card. Figure 10 shows dry areas of concrete after 2 weeks of operation. The humidity in the chamber is nearly 100 percent due to high levels of water and moisture. The weather strip installed to act as a drip tray was full of water and had calcite in it and was not draining as designed, which resulted in water dripping down onto the wall below in some areas.

Figure 10.—Concrete wall at location of installation after 2 weeks of operation. The wall was dry to sight and touch over most of the test section.

The unit collects and saves data to the SD card in an Excel spreadsheet format every 4 hours. Each file contains all the data for a single month. The collected data are then analyzed using Ohms Law, E = IR, where E is the potential (V), I is the current (A), and the R is resistance (ohms). Over time, at a constant applied potential, the current would decrease and the resistance would increase as the moisture level in the concrete decreased in the wall. Figure 11 shows that over the initial first 2 weeks of operation, the measured total current decreased and the calculated resistance increased, indicating that the concrete was drying out. Observations of wall moisture also indicated that the wall was drying (shown on figure 10).

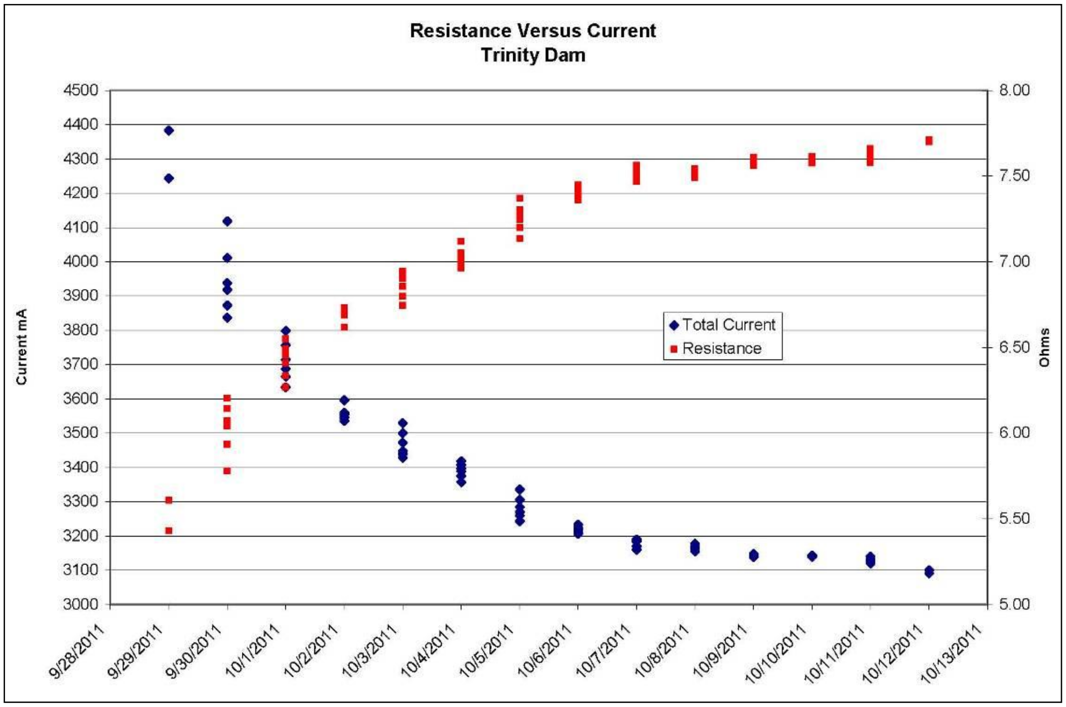

Figure 11.—Data from the first 2 weeks of system operation showing the current and resistance over time. The data show that the moisture content in the concrete was decreasing over time.

Data collected after 4 weeks of operation were analyzed and showed that the total current continued to decrease and the resistance continued to increase. The analyzed data for total current output and resistance is shown on figure 12. This indicates that the system is still operating as planned, and the moisture content of the concrete continues to decrease. The resistance calculated after 4 weeks of operation is nearly double what it was originally.

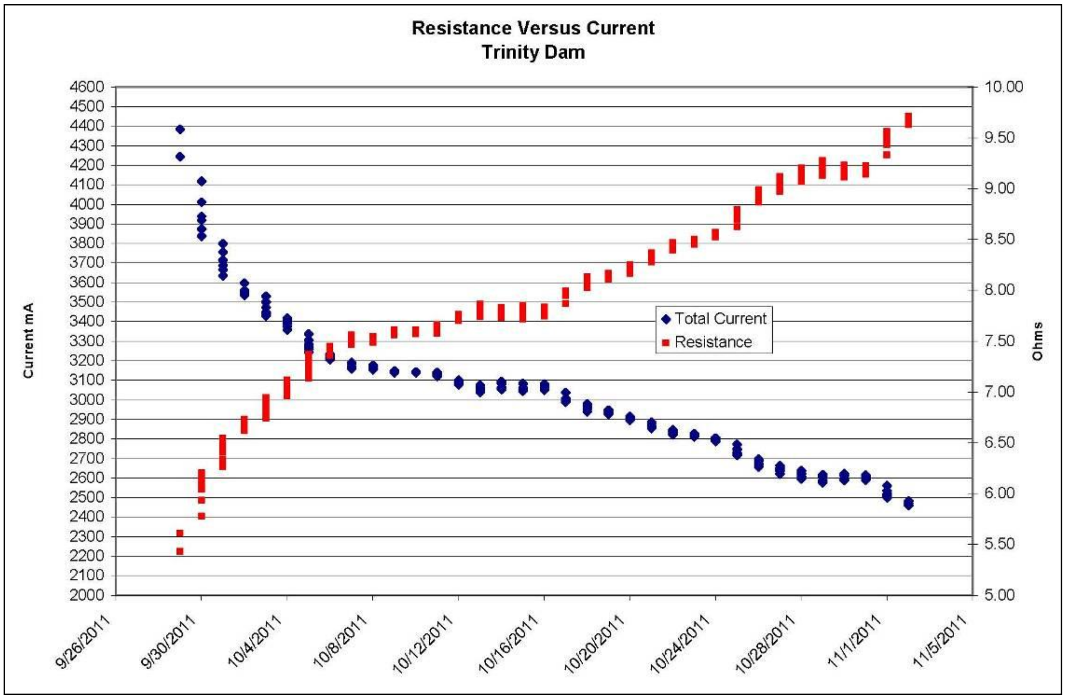

Figure 12.—Data from the first 4 weeks of system operation showing the current and resistance over time. The data show that the moisture content in the concrete was decreasing.

Future Work

The proposed next phase test location contains leaking cracks and a thicker calcite layer. The proposed location is the entire circumference of the bottom 10 feet of the shaft. Cracks are desired in the next test section to determine the effect of leaking cracks on installation and performance of the EOP system.

References

Electro Tech CP LLC, 4972 U.S. Highway 209, Accord, NY 12404.

U.S. Army Corps of Engineers (Corps), Engineer Research and Development Center, Construction Engineering Research Laboratory, 2902 Newmark Drive, Champaign, IL 61822-1076.

Carbon Fiber Reinforced Polymer Repair of Reinforced Concrete Pipe

by Daryl Little, Technical Service Center's Materials Engineering and Laboratory Group

Carbon fiber reinforced polymer (CFRP) lining is a cost-effective repair solution for in-place repairs of concrete pipe. The method requires no excavation and only a short downtime.

The Technical Service Center recently assisted the Pacific Northwest Regional Office by providing advice and specifications and by participating in the quality assurance/quality control inspection for a CFRP installation at Weber Coulee siphon. The new siphon at Weber Coulee is a reinforced cast in-place concrete pipe. Each section has an inside diameter of about 15 feet and is about 25 feet long. Due to consolidation problems with the concrete on four of the new barrel sections, which required extensive concrete repair, the contractor, based on the Bureau of Reclamation's (Reclamation) recommendation, decided to line those sections with CFRP. The CFRP would make the sections watertight and provide long-term serviceability because of the large rock pocket repairs that were made. CFRP has good wear and impact resistance, and can handle the external and internal loads, thus increasing the factor of safety for the barrel section. A completed CFRP-lined section is shown on figure 1.

Figure 1.—Completed CFRP-lined section of the siphon.

Introduction

Some of the barrel sections had a great number of flaws, including full section rock pockets, cold joints, and evidence of voids in and around the reinforcing steel and waterstop. Confidence was low that standard concrete repairs could adequately withstand the high pressures and ensure corrosion protection of the reinforcing steel in the damaged barrel sections for the intended life expectancy.

There was also concern that the repairs to the concrete defects would not be watertight and would be susceptible to leakage, which could affect service life. In addition, the invert of one barrel section was also improperly placed such that the invert was 4 inches thicker than intended and reportedly had consolidation issues during placement.

Installation of a CFRP liner was decided upon in lieu of removing and replacing the defective siphon sections. CFRP repairs are new to Reclamation, but had been successfully used by large municipal water authorities. CFRP has been used to repair concrete pipe quickly and for a potentially smaller cost than steel lining or removing and replacing pipe sections.

CFRP Background

Reclamation's Materials Engineering and Research Laboratory had evaluated the use of CFRP for similar applications through limited research work performed starting in 2005. MERL found it to be a practical repair material for this type of application. Starting in about 1995, San Diego County Water Authority and the Metropolitan Water District of Southern California (MWD) began using CFRP and have had success with their repairs. In phone conversations with MWD, they said the materials and techniques are even better now.

Design of a CFRP system takes into account internal pressure and backpressures and can accommodate a variety of joint and leading edge details as necessary to function as intended by the original pipe design.

Materials are generally readily available, and CFRP rehabilitation can begin soon after repairs to the underlying concrete are completed. Installation can be completed in a short period of time, reducing downtime costs. The pipe can be easily returned to service after a short period for curing of the polymer, which is usually about 3 days. This does not include time required for any needed concrete repairs.

Installation

The CFRP system for the Weber Coulee siphon was designed as a water barrier. Installation of the CFRP included design, ventilation, dehumidification, and temperature control; surface preparation; and installation of the CRFP liner with an epoxy overcoat. The concrete was first repaired in accordance with Reclamation specifications and allowed to cure adequately prior to surface preparation. The concrete surface was prepared in accordance with water cleaning method ASTM D 4258-05, "Standard Practice for Surface Cleaning Concrete for Coating" using high-pressure water cleaning or hydroblasting to remove the laitance and to achieve a concrete surface profile of level 3 in accordance with Guideline No. ICRI 310.2-1997, "Guide for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays." Hydroblasting of the concrete surface is shown on figure 2. Figure 3 shows the surface of the pipe after hydroblasting, including a few of the large concrete repair areas (lighter colored areas). Equipment was then set up to dehumidify the pipe, dry the walls, and ventilate the area.

Figure 2.—High-pressure hydroblasting of concrete pipe surface to remove the laitance.

Figure 3.—Hydroblasted surface showing repaired areas of pipe.

All the epoxies used in the application of the carbon fiber were 100 percent solids, so they contained no solvents or volatile organic compounds. This was important to avoid the need for personal ventilators. All epoxies were mixed outside, in the open air, prior to transport into the pipe. Tyfo® WP (wet-prime) epoxy primer was applied using paint rollers to the concrete surface after it was hydroblasted as shown on figure 4. Tyfo® S (saturation) epoxy was applied to the surface using trowels (figure 5) after the primer was applied, and any final concrete repairs were completed.

Figure 4.—Application of Tyfo® WP epoxy after concrete surface is hydroblasted.

Figure 5.—Application of Tyfo® S epoxy after application of primer and concrete repair.

The carbon fiber fabric, shown on figure 6, had a unidirectional carbon fiber weave. Large rolls of fabric were saturated with Tyfo® S epoxy with a saturation machine (figure 7) and rolled onto plastic pipes. As the fabric was saturated and rolled onto the plastic pipe, it was cut to the appropriate length for installation. The rolls were then wrapped in plastic wrap and transported to the pipe section being repaired.

The rolls of saturated fabric were unrolled onto the surface of the pipe. Three layers of fabric were applied to the pipe: the first layer was applied in the longitudinal direction (shown on figure 8), and the second and third layers were applied in the hoop direction (shown on figure 9). The number of hoop layers required was dependent on the structural requirements of the CFRP repair. Air pockets and wrinkles were smoothed out of the fabric using putty knives and hands as shown on figure 10. After each layer of fabric was applied, Tyfo® S was troweled onto the surface as shown on figure 11.

Figure 6.—Unidirectional carbon fiber fabric.

Figure 7.—Saturation of carbon fiber fabric with epoxy then rolled onto pieces of plastic pipe to length.

Figure 8.—Application of saturated carbon fiber fabric material in longitudinal direction.

Figure 9.—Application of saturated carbon fiber fabric material in hoop direction.

Figure 10.—Smoothing out fabric to remove air pockets and wrinkles.

Figure 11.—Application of Tyfo® S epoxy after application of saturated carbon fiber material.

After the CFRP had cured for 24 hours it was inspected for bubbles, delaminated areas, and fabric tears. It was inspected using a sounding method, and repair areas (figure 12) were identified. The repair method was selected based on the size of the defect. Defects smaller than about 2 to 3 inches in diameter were repaired by using epoxy injection. A hole was drilled in the defect as shown on figure 13, and Tyfo® S epoxy was injected into the defect (figure 14). For defects larger than 2 to 3 inches in diameter, the delaminated layers of CFRP material were removed. Figure 15 shows the removal of a delaminated CFRP layer. Squares of saturated fabric were applied to the surface as shown on figure 16, with one layer of new fabric for each layer removed. The patch applied was larger than the defect such that there was a 4-inch overlap onto the surrounding area, and each additional layer of fabric applied had a 4-inch overlap onto the area surrounding the previous layer. The CFRP will be inspected after 1 year of service and then every 5 years during the required pipe inspection.

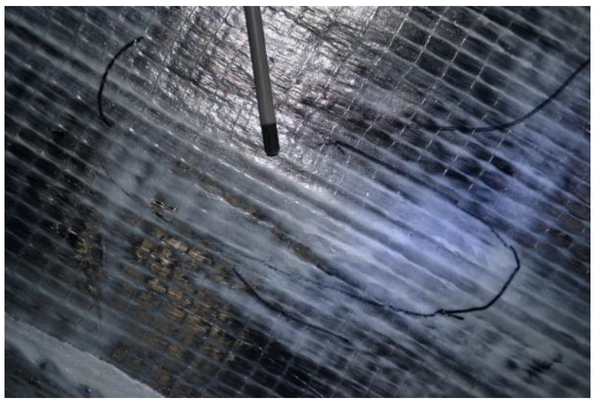

Figure 12.—Delaminated area of CFRP identified for repair.

Figure 13.—Hole being drilled into small delaminated area for epoxy injection repair.

Figure 14.—Epoxy being injected into the small delaminated area.

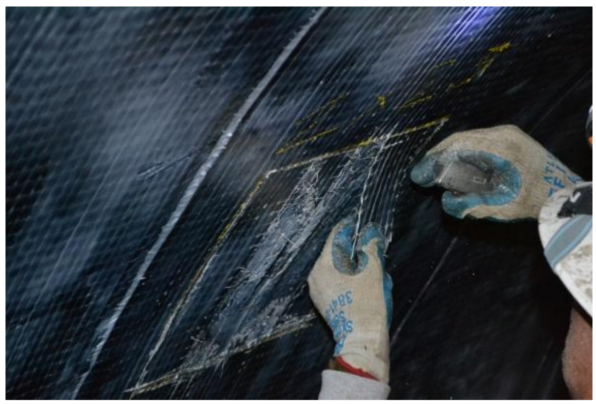

Figure 15.—Cutting out delaminated layers of CFRP to prepare for repair.

Figure 16.—Patch repair of delaminated area of CFRP.

Conclusions

- Lining of the pipe required no excavation and was completed in about 2 weeks after the extensive concrete repair work was completed.

- The installed CFRP liner, with a bond of 400 pounds per square inch to the host pipe's concrete interior surface, is fully capable of resisting the ground water table of 25 feet above the pipe's springline.

- Inclusion of three layers of CFRP material would allow the CFRP liner to act as a long-term impermeable barrier to ensure the water tightness of the barrel sections.

- The CFRP was designed primarily as a water barrier and not for strength purposes; however, the addition of the CFRP liner increases the factor of safety by at least 10 percent for the internal pressure resistance.

- The source of water for the siphon is a canal, and due to the size of the siphon, there was concern for large objects flowing with the water through the siphon and impacting the liner. The CFRP has good wear and impact resistance properties and would handle impact from a car floating down the siphon better than the concrete.

Mission

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