WATER OPERATION AND MAINTENANCE BULLETIN

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UNITED STATES DEPARTMENT OF THE INTERIOR **Bureau of Reclamation**

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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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For further information about the *Water Operation and Maintenance Bulletin,* contact:

Jerry Fischer, Managing Editor

Bureau of Reclamation

Inspections and Emergency Management Group

Code D-8470

PO Box 25007, Denver, Colorado 80225-0007

Telephone: (303) 445-2748

FAX: (303) 445-6381

Email: jfischer@do.usbr.gov

***Cover photograph**: Ladder retention platform with fall arrestor attached.*

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QUIETER IS SAFER – SUCCESSFUL USE OF ENGINEERING CONTROLS FOR NOISE

by Victor Feuerstein[1] and Max Spiker[2]

Hydroelectric powerplants are noisy places where sound levels often exceed the 85 decibel time-weighted exposure threshold. High-intensity noise sources include the movement of water through conduits, gates, valves, and pumps; the turning of turbines and generators; high-speed air movement for cooling; transformers; breakers; other electrical control devices; and maintenance activities. The intensity and distribution of noise are compounded by the transmission of sound and vibration through the structure (concrete and steel) and by noise bouncing around the work spaces (reverberant noise field).

Unprotected exposure to high-intensity noise for extended periods of time can result in permanent hearing loss due to inner ear nerve damage. The effects of noise exposure are exaggerated by extended work shifts. Working in high-intensity noise is known to result in physiological changes in blood pressure and heart rate, fatigue, irritability, an increased tendency to make mistakes, and communication interference. Reducing exposure to high-intensity noise levels makes the work place safer. Controlling exposure to high-intensity noise can be accomplished through the application of engineering controls and the use of personal protective equipment (i.e., ear plugs and ear muffs); however, controlling exposure with protective equipment depends on a relentless dedication to correct usage. Engineering controls can be very effective and offer the advantage of preventing noise exposure.

There are areas at the Estes Park Power Plant where the noise intensity levels exceed the threshold, requiring a hearing conservation program. Periodic monitoring of the noise levels is a component of the Estes Park Power Plant Hearing Conservation Program. The assessment of individual noise exposure is accomplished using Ametek Mark II Audio Dosimeters. Personnel conducting tasks in high-noise areas wear a dosimeter that measures noise intensity throughout a work shift. Dosimetry provides information on an employee's overall noise dose and the level of hearing protection necessary. Area and equipment noise monitoring are conducted utilizing a Quest 1800 Type I Precision Sound Level Meter with an OB-100 Octave Band Analyzer. The data provided by the sound level meter identify noisy areas, equipment, and operations. The Octave Band Analyzer dismantles noise into its sound frequencies.

[1] Industrial Hygienist, Great Plains Regional Office, Billings, Montana.
[2] Power Plant Supervisor for Estes/Marys Lake Power Plant, Estes Park, Colorado.

Knowledge of the predominant noise frequencies and their intensities was used to assess engineering controls available for the type of noise present. This information helped identify feasible engineering controls to reduce the level of noise in specific areas in the Estes Park Power Plant. A number of specific products that would offer a predictable measure of sound control in the targeted areas were identified. Discussions with plant personnel produced an approach that focused on the control of noise in the areas deemed feasible with the highest use by the plant staff. The office areas on the mezzanine, the meeting room adjacent to the control room, and the work areas adjacent to the turbine pit were targeted as starting points. Office staff reported that noise levels interfered with personal and telephone communication. There was a general consensus that the noise made it difficult to conduct meetings. Plant personnel reported that the work and storage areas adjacent to the turbines on the second level were uncomfortably noisy and also interfered with communication.

The range of noise levels recorded over a period of years and different generator unit loading conditions (mezzanine office 74.9 – 85.1 dBA, meeting room 77.4 – 88.3 dBA, turbine level work area 80.6 – 88.4 dBA) and predominant frequencies (31.5 – 2,000 cycles per second) were used to evaluate a number of products. The mathematical reduction in the sound levels based on product information indicated that reductions in the noise in targeted areas of 6 to 9 dBA could be achieved. Since noise intensity doubles for each 3 dBA, the effects of these levels of attenuation would make a substantial difference. The effect of two confounding factors could not be estimated with certainty—whole plant vibration and the effect of the sound that resonates through the concrete and steel present in the plant.

Specially designed sound attenuating doors were installed in the corridor leading to the office areas, the meeting room, and in the doorways separating the turbine pit from the adjacent work areas. Each of the openings where the new doors were installed required the construction of a unique door. The doors were designed and built specifically for the openings, the sound levels, and the predominant frequencies. The manufacturer methodically measured, designed, built, and sealed each door frame assembly on the top, sides, and bottom into each specific opening.

The noise levels throughout the Estes Park Power Plant were reassessed in April 2002 to evaluate the effects of the installation of the sound attenuating doors in separating the high-use noise hazardous areas from the noise sources. The noise reductions were far better than the predicted 6 to 9 dBA. The sound intensity levels measured inside the tightly fitted windowed 4-inch-thick doors were 12 to 17 dBA less than the levels recorded outside. The doors render the mezzanine office area (68 – 73 dBA), meeting room (71 – 76 dBA), and work/storage areas (71 – 76 dBA) adjacent to the turbine pit less than 85 dBA, free of hazardous noise and the need to wear plugs or muffs. The sound level reductions were roughly twice that predicted. The three high-use work areas are noticeably quieter. Plant personnel report the workplace is noticeably quieter and more comfortable. These doors eliminated hazardous noise exposure in these areas and lessened overall exposure of personnel working in the plant. The perceived levels of vibration and resonance through the concrete and steel are noticeably better as well.

Overall, the number of areas in the Estes Park Power Plant where hearing protection must be worn has been reduced. The cost of the doors used at the plant was $23,885; the cost of a single hearing loss claim is between $12,000 and $18,000. Therefore, changes to reduce noise are not only feasible and achievable, but highly cost effective.

The success of installing the sound attenuating doors at the plant has prompted further investigation into controlling other sources of noise in the plant.

Safety Reigns Supreme when it Comes to Ladders

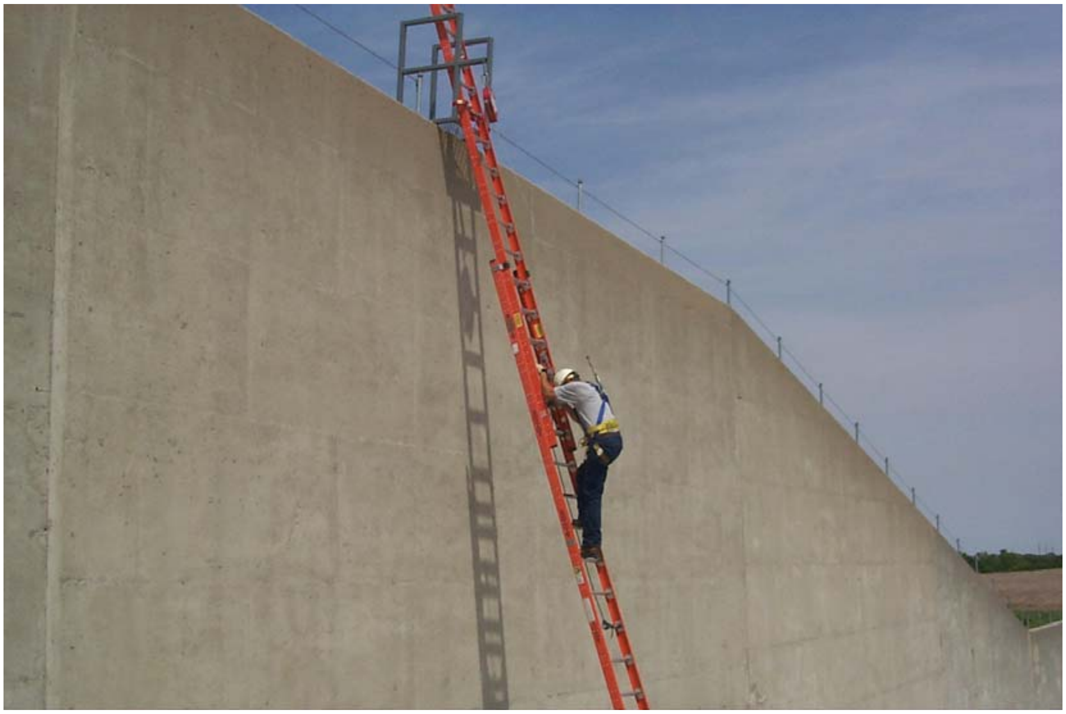
by Nicholas Brown[1]

The McCook Field Office of the Nebraska-Kansas Area Office (NKAO) has implemented an idea to make Comprehensive Facility Reviews (CFRs) a substantially safer operation. Upon inspection of a spillway, a ladder must be placed over the spillway wall and down onto the spillway floor (this may be a distance of more than 30 feet). In compliance with Reclamation Safety and Health Standards Section 13, personnel at the McCook Field Office installed a platform with a fall arrestor attached. The fall arrestor provided a safer and steadier descent onto the spillway floor.

At the McCook Field Office, the platform was installed, the fall arrestor attached, the ladder tied down, and the inspectors outfitted with a full body harness. The inspectors were then hooked up to the fall arrestor and were ready to descend into a valley of immense concrete with massive gates holding back significant amounts of water. All lock-out tag-out procedures were in place so that the spillway gates would not open during the time spent in the spillway. The inspection procedure was a crackerjack operation and went off without a hitch.

The next time a CFR is scheduled for the Nebraska-Kansas area dams, everyone involved will know that safety is the predominant component in all inspections.

[1] Safety Manager, Nebraska-Kansas Area Office, McCook, Nebraska.



CONCRETE REPAIR AND MAINTENANCE

by Kurt Von Fay[1]

Many water systems contain structures built with concrete. Some concrete may last 100 years without any need for repair, while other concrete may need repair as soon as the forms are removed. It is often said (but too often forgotten) that the best material for concrete repair is concrete. New concrete used for repairs will usually be more compatible with the old concrete in strength, thermal expansion, modulus of elasticity, and permeability than other repair materials. Modern, more expensive materials should be used only after it has been determined that ordinary Portland cement concrete will not be an effective repair material; this decision requires knowledge of repair materials and their strengths and limitations.

Concrete Maintenance

This section discusses both concrete repair and concrete maintenance. Proper maintenance can avoid or postpone the need for major concrete repairs. When we think of maintenance, we think of lubricating machinery, painting wood and metal, and replacing worn parts; but, too often, concrete is thought to be maintenance free.

A good maintenance program will involve regularly scheduled inspections. Suspect areas should be monitored. Photographs and notes should be collected and stored to establish a record that can be reviewed at a later date.

Maintenance for concrete typically consists of activities to keep water out of the concrete. Many times, water and some of the dissolved minerals it carries can damage concrete. Usually, some type of coating or overlay is used, but other approaches can also be used.

A frequent cause of concrete deterioration in dams and water conveyance structures is freezing and thawing damage. This is primarily a problem with concrete placed prior to the advent of air-entraining admixtures, which were discovered in the 1940s. These admixtures entrain very small air bubbles in concrete and, if properly distributed in the concrete, protect it in freezing weather. Three factors must be present for freezing and thawing damage to occur: (1) cycles of freezing and thawing temperatures, (2) concrete that is saturated with water, and (3) a concrete that is susceptible to damage (no or improperly entrained air voids). When all three factors are present, water that has entered pores in the concrete freezes and expands about 10 percent as it becomes ice. The expansion causes cracks and forces the concrete apart. During thawing, more water enters and fills the enlarged voids. In the next

[1] Materials Engineering and Research Laboratory, D-8180, Bureau of Reclamation, Denver, Colorado 80225; phone: (303) 445-2399 or e-mail at: kvonfay@do.usbr.gov.

freezing cycle, the concrete is further damaged by water expanding into ice. The resulting damage can range from shallow surface scaling to entire sections of concrete crumbling into rubble.

Freezing and thawing damage can be prevented by eliminating one of the three factors. The most common approach is to reduce the available water by changing operating procedures, by improving drainage, or by using sealers or water repellents on the concrete. During repairs, a more resistant concrete can be used (dense concrete with proper air entrainment). The third option, that is often overlooked, is to reduce the number of cycles of freezing and thawing. This can be done by insulating the concrete or by changing operating procedures to keep critical areas under water (that does not freeze) in cold weather. Varying the depth of water over the years can also avoid concentrating the damage at one elevation.

Another form of concrete maintenance is to prevent structural overloading. Operate gates in the right sequence. Do not exceed bridge load limits. Prevent damage from machinery. Do not drive equipment on slabs designed for pedestrian traffic.

Concrete in contact with high-velocity flowing water has special maintenance needs. Small offsets at joints or small holes in the concrete surface can result in cavitation damage to concrete. The hole or offset causes the flowing water to separate from the concrete surface. This separation causes “bubbles” of negative pressure to form in the flowing water. When these vacuum voids collapse downstream, they exert forces that destroy concrete and most other rigid materials, including high-strength stainless steel. The newly damaged area causes more separation of flowing water, and cavitation damage will occur downstream from the most recently damaged area; this results in a series of damaged areas, each getting larger, downstream from the original offset. Proper concrete maintenance in high-velocity water flow structures includes eliminating offsets and holes and repairing observed cavitation damage before it can enlarge to destroy the entire structure. Since no material will standup to cavitation for a long time, the long-term solution is to manage the flow to avoid flows that will cause cavitation.

Another area of concrete maintenance is preventing abrasion damage. Flowing water, even at velocities too low for cavitation damage, can destroy concrete structures by the impact and grinding action of sand and rock carried in the water. Proper maintenance means reducing the amount of sand and rock in flowing water. Screens or settling areas at inlet structures can help. Retaining walls to protect flowing water from rock slides and fences to keep people from throwing rocks into the water are sometimes needed. Removing material from stilling basins should be a part of routine maintenance.

Concrete Repair

In spite of good maintenance, there will always be some structures requiring concrete repair. There are three choices when deciding on a repair. A permanent repair to attempt to return the structure to its original condition and function is a common approach. In some cases, however, a temporary repair is justified by its lower cost. Temporary repairs are used when a structure will soon be replaced but must serve a few more seasons, or when funding is not available for a permanent repair. The third option of deciding to make no repair is often overlooked. Not all concrete with visible damage needs to be repaired. A spillway floor that has lost a fraction of an inch of concrete due to abrasion over the last 30 years will likely serve another 30 years without repair. In this case the original concrete is of good quality and will likely serve better than any attempted thin repair material.

Before selecting a specific repair method, the cause and extent of concrete damage should be determined.

Cause of Damage

Knowing what caused the damage and reducing or eliminating that cause will make the repair last longer. If no attempt is made to eliminate the original cause of damage, the repair will fail as the original concrete did. Freezing and thawing damage, structural overloading, cavitation damage, and abrasion damage have been discussed above. Sulfate-bearing waters or soils and alkali-aggregate reaction can also attack concrete. Design and construction defects can result in concrete damage due to improperly shaped flow areas, foundation settlement, weak concrete, poor finishing, structural overloading, poor curing, and other causes. Some concrete simply suffers from old age. All construction materials deteriorate eventually. Good design, construction, and maintenance will lengthen service life. Good concrete can last hundreds or thousands of year. Some Roman concrete structures, including the Pantheon and some aqueducts, are still functional after 2,000 years.

Extent of Damage

Knowing the extent of damage is also necessary to planning concrete repair. A shallow surface repair will not be effective if the damage extends deep into the concrete. Knowing the extent of damage will also help in confirming and mitigating the cause. Removing cores from the concrete is an excellent method of determining the extent of damage. Visual examination, petrographic examination, and mechanical testing of the cores can give reliable information on the cause and extent of damage. Coring and testing are expensive and sometimes not justified for small repair jobs. Simple methods such as the rebound hammer, geologist pick, steel rod, and chain drag can frequently be effective in locating weak and delaminated areas of concrete. When major concrete repairs on significant structures are planned, high technology non-destructive methods such as acoustic testing and radar are sometimes used in condition assessment.

Repair Methods

Some basic concrete repair methods are discussed below. For a more extensive list of options and more technical details of repair, consult the most current edition of "Standard Specifications for Repair of Concrete," M-47, Bureau of Reclamation. Also, the "Guide to Concrete Repair" published in 1996 by the Bureau of Reclamation contains good information about maintenance and repair of concrete.

Concrete replacement—replacing a portion of the concrete in a structure without the use of a bonding agent—is one of the most effective concrete repair methods. It is used for large areas that are over 6 inches deep. Repairs of this size and depth usually retain moist curing conditions at the interface between new and old concrete for many weeks and thus develop a good bond. When concrete damage is less that 6 inches deep, it is sometimes still economical to excavate to a depth of 6 inches or more and use the concrete replacement method rather than using thinner repair methods that can be more difficult, more expensive, and less durable.

Dry pack is effective for small, deep repairs with nearly vertical edges such as core holes, form bolt holes, and slots. Dry pack is a mixture of cement, fine sand, and very little water. It is rich in cement, but has little shrinkage because of the low water content. After the hole has been prepared, the dry pack material is pounded into place in thin layers with a wooden rod to ensure complete compaction. Continuous moist curing for at least 14 days is required to ensure that the little water used in the dry pack is not lost and is available for cement hydration.

Mortar replacement is used in areas too wide for dry pack and too shallow for concrete replacement. It is simply Portland cement mortar placed either by hand or pneumatically with shotcrete equipment. This repair works best on new, green concrete (less than 24 hours old) that is still actively hydrating, thus ensuring good bonding between the repair and the base concrete.

Epoxy bonded concrete is used for repairs between 1-1/2 and 6 inches in depth. It is essentially like the concrete replacement method, but because of the shallow depth, an epoxy bonding agent meeting ASTM C-881 requirements is used to ensure good bond to the old concrete.

Epoxy bonded epoxy mortar is used for repairs less than 1-1/2 inches in depth. Epoxy is used both as the bonding agent and as the cementing agent in the mortar. Epoxy mortar contains epoxy and sand. It contains no Portland cement and no water. While epoxy mortar is a strong, durable material, it sometimes disbonds from the substrate concrete when exposed to large temperature changes because its rate of thermal expansion is much different from that for concrete. Thus, if epoxy bonded epoxy mortar is used in an outdoor environment, it will likely become unbonded sometime in the future. Epoxy mortar repairs covering large areas on concrete slabs on grade sometimes trap rising moisture under the repair and then fail when the moisture freezes and expands. Epoxy bonded epoxy mortar repairs should not be used where there will be large temperature changes or where moisture can be trapped under the repair and subjected to freezing.

The above repair techniques give basic repair options for concrete based on the dimensions of the repair area. There are numerous other materials currently used in concrete repair, including polymer concrete, silica fume concrete, and many versions of modified Portland cement concretes. The basic repair principles remain the same. Thicker and more massive repairs reduce the need for bonding agents and increase the chances of a durable repair. Thin repairs need bonding agents, but still have more chance of failure.

Repairing cracks in concrete requires different techniques. Narrow cracks can be repaired by filling with epoxy if the cracks are relatively dry and not moving. With proper technique, the structural integrity of the concrete can be restored. The crack is temporarily sealed along the concrete surface leaving gaps for injection points and for air to exit. An epoxy material meeting requirements of ASTM C-881 is used for the structural repair. On large jobs, two pumps are used, one for each part of the two-part epoxy. The epoxy components are pumped through separate hoses to a mixing head where they mix and exit a single tube. The tube is connected to injection ports installed along the crack. When the crack is completely filled and the epoxy cures, the concrete sections are structurally bonded. On smaller jobs, simpler injection methods can be used (i.e., pressure pots, caulking guns, or squeeze bottles).

It is sometimes necessary to repair concrete cracks without bonding structurally. In tunnels or pipes, cracks are sometimes sealed against water leakage while still allowing for movement due to loading and temperature changes. In recent years, polyurethane materials have been used to inject such cracks. These materials will seal the crack, but they are soft enough to allow significant movements without causing leaks. Injection techniques for polyurethanes differ from those for epoxies, and such work is usually best performed by an experienced specialty contractor.

Conclusions

Large concrete repairs over 6 inches in depth, using Portland cement concrete and no bonding agent, are usually the most durable and, sometimes, the most economical. Thin repairs, while sometimes necessary, often use more expensive materials, more difficult techniques, and result in less durability. It is sometimes economical to over-excavate shallow areas of deterioration to make a deeper, longer-lasting repair. Conventional concrete should be the first choice for concrete repairs. Other materials should be used only where it can be shown that conventional concrete will fail. While good quality original construction concrete is usually superior to any repair, repairs of sufficient quality to greatly extend a structure's life can be made with the techniques discussed.

Information Sources – Concrete and Concrete Repair

Repair: Standard Specifications for Repair of Concrete, M-47, 1996, Bureau of Reclamation (website: <www.usbr.gov/merl/documents/concretespecs.html>).

Repair: Concrete Manual, eighth edition (revised), Bureau of Reclamation, Chapter 7.

Repair: Guide to Concrete Repair (website: <www.usbr.gov/merl/documents.html>).

Mix Proportions for Small Mixes: Concrete Manual, eighth edition (revised), pp. 144, 145, and 232.

Epoxies for Concrete Repair: Buy only products meeting ASTM C-881. Be sure the products are manufactured for your particular application (right temperature range, viscosity, and purpose [fresh concrete to hardened concrete, rack injection, etc.]).

General Concrete Technology:

Concrete Manual, eighth edition (revised).
American Concrete Institute, Manual of Concrete Practice.

When ordering ready mixed concrete, consult the Concrete Manual for the information you need. Be sure to specify air entrainment, 28-day strength, maximum aggregate size, slump, maximum water-cement ratio, and cement type.

Type I cement is the most commonly available. It is for general use where the concrete will not be in contact with sulfate-bearing soils or water. T*ype II cement* has some sulfate resistance and is therefore used for general work above and below ground. For high sulfate conditions, *Type V cement* is necessary. *Type III cement* hardens quickly and gives high early strengths. Some cements meet requirements for more than one type. For example, a cement meeting both *Type II* and *Type III* requirements could be used where the concrete will be below grade in a mild sulfate environment and where fast strength development is needed to put the structure back into service quickly. *Type IV cement* is used when low heat of hydration is needed such as in mass concrete for dam construction. It is rarely used on small repair jobs and may not be available in small quantities.

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

Jerry Fischer, Technical Service Center, ATTN: D-8470, PO Box 25007, Denver, Colorado 80225-0007; (303) 445-2748, FAX (303) 445-6381; email: jfischer@do.usbr.gov

Vicki Hoffman, Pacific Northwest Region, ATTN: PN-3234, 1150 North Curtis Road, Boise, Idaho 83706-1234; (208) 378-5335, FAX (208) 378-5305

Steve Herbst, Mid-Pacific Region, ATTN: MP-430, 2800 Cottage Way, Sacramento, California 95825-1898; (916) 978-5228, FAX (916) 978-5290

Albert Graves, Lower Colorado Region, ATTN: BCOO-4846, PO Box 61470, Boulder City, Nevada 89006-1470; (702) 293-8163, FAX (702) 293-8042

Don Wintch, Upper Colorado Region, ATTN: UC-258, PO Box 11568, Salt Lake City, Utah 84147-0568; (801) 524-3307, FAX (801) 524-5499

Dave Nelson, Great Plains Region, ATTN: GP-2400, PO Box 36900, Billings, Montana 59107-6900; (406) 247-7630, FAX (406) 247-7898