RECLAMATION
Managing Water in the West

Canal Operation and Maintenance:

Concrete Lining and Structures

U.S. Department of the Interior
Bureau of Reclamation
Office of Policy
Technical Service Center
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

Acknowledgements

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Disclaimer

Reclamation developed this manual to provide basic guidance to help canal operators promote effective maintenance and repair of concrete components of canal systems. This information complements—and does not replace—existing Reclamation manuals and standards related to the subject. As each canal system has unique designs and features, these general guidelines cannot be substituted for facility or operating-specific guidance and specifications. Every operating entity is different, and this advice and strategies may not be suitable for all situations.

This is general information useful for typical canal systems for routine concrete related maintenance and repair activities. For non-routine activities, other sources of information should be pursued. Contact local Reclamation Area and Regional office personnel. More in depth information on concrete repair can be found in (von Fay 2015) Reclamation's Guide to Concrete Repair, Second Edition, www.usbr.gov/tsc/techreferences/mands/mands-pdfs/Guide2ConcreteRepair2015_Final.pdf.

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Acronyms and Abbreviations

°F	Degrees Fahrenheit
ACI	American Concrete Institute
ASR	Alkali-Silica Reaction
CAP	Central Arizona Project
HMWM	High Molecular Weight Methacrylic
NRMCA	National Ready Mixed Concrete Association
psi	Pounds per square inch
Reclamation	Bureau of Reclamation
SOP	Standing Operating Procedures
w/cm	water-cementitious materials ratio

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1. Purpose and Scope

This manual is designed to help irrigation districts identify and address routine potential problems related to concrete canal linings and structures that can impact the Bureau of Reclamation's (Reclamation) conveyance system. It also outlines preventive maintenance activities based on routine observations and periodic inspections to discover and treat potential causes of concrete damage, thus prolonging the service life and ensuring water deliveries. This manual will also touch on routine repairs that can be performed by the canal operator and will direct the reader when consultation with an expert is recommended.

The old adage that all concrete cracks—implying that we just need to accept it—is no longer an acceptable approach to managing concrete structures. We need to do everything we can to minimize and control cracking. In the right exposure conditions, quality concrete will last indefinitely and can continue to strengthen over time. However, many exposure and performance conditions can lead to deterioration and damage to the concrete. For concrete in these conditions, proper inspection, routine maintenance, and appropriate repairs will ensure the concrete will perform as intended for as long as possible.

> Reclamation staff are available to provide advice and technical support on Reclamation-owned canals. Contact Reclamation and consider additional engineering support before making modifications to concrete linings or structure. If you determine work outlined in this manual requires more expertise than your staff can provide, please contact Reclamation for technical support at: www.usbr.gov/main/offices.html.

2. How to Identify Concrete Cracking and Deterioration

Many times, concrete is considered maintenance free, but it is not. Concrete structures and canal linings are exposed to harsh conditions as they deliver water. This can result in damage to the concrete. Therefore, diligent monitoring and routine maintenance or repair on concrete structures and canal linings is paramount to keep facilities in good operating conditions. This is critical to ensure continued safe operations and water deliveries. Identifying and resolving issues early can prevent expensive repairs or replacement later.

2.1. Causes of Concrete Damage

Since many repairs will use new concrete, it is important to know a little about the essential steps of making, placing, and curing concrete. Concrete design, construction, and service life exposure determine if the concrete will have a long and successful service life. In most cases, the operating entity maintains existing canal linings and structures, and the original concrete design and construction were probably out of their control. However, concrete design and construction will be discussed later in Section 2.2. *Construction Related Concerns* and Section 6. *Design Considerations for New Concrete* in this manual so operating entities can become familiar with what might affect the concrete and why it is crucial to maintain structures throughout the structure's life.

2.1.1. Function

The structure's function is critical for determining the concrete design requirements of the structure. Knowing the function will help determine the intended exposure, loading conditions, and possible damage mechanisms. Typically, on large projects, different concrete mixes are used, depending on the function of the concrete.

Using the appropriate concrete mix design for its function and exposure conditions ensures the concrete will be durable and have a long service life. For example, in a baffled outlet, the energy of the incoming water jet is dissipated by striking the baffle. This function as an energy dissipater makes the baffle outlet susceptible to abrasion-erosion (Aisenbrey et al. 1974). To counteract potential abrasion-erosion damage, use a high strength concrete.

2.1.2. Thermal Considerations

Concrete that is approximately 2.5 feet thick or larger in all directions is considered mass concrete and needs special consideration. For mass concrete sections, heat generated during hydration of the cement in concrete can lead to high internal temperatures in the concrete element. The concrete can crack if the temperature differential between the interior of the concrete and the external surface gets too high (generally about 35 degrees Fahrenheit [°F]) before the concrete develops sufficient strength (Figure 1).

Figure 1. Thermal crack in a thick section of a concrete wall in a pumping plant. Ground water is leaking through the crack.

These conditions can be even more pronounced when thicker sections are needed with higher early concrete strengths (5,000 pounds per square inch [psi] or greater 28-day strength, or 3,000 psi or greater strength at 3 days). Under these conditions, unless proper precautions are taken, internal concrete temperatures can get very high—nearing 175 °F or higher.

When using mass concrete, the mix design, placement, and curing conditions become critical. Mass concrete mix designs usually have larger aggregate and large replacement volumes of cement with a pozzolan. This will bring down the cement content which will reduce the heat generated in the mix. Special attention to lift heights and insulation of the concrete during the curing phase is also critical. It is best to consult with a concrete engineer when mass concrete is expected on the project.

2.2. Construction-Related Considerations

Properly placing, finishing, and curing concrete can have a big impact on service life. Performing any of these functions improperly can lead to issues, like cracking, that can allow water or other environmental factors to damage the concrete, shortening the life of the structure. The following section will help the reader identify durability issues that can occur during the finishing and curing process.

2.2.1. Early Age Issues

Concrete must be protected until it reaches sufficient strength to avoid damage. The needed strength depends on the early age exposure and loading conditions. For example, in cold weather, the concrete needs to be about 500 psi, which can take about three days to achieve, before it is exposed to freezing weather. If in those same conditions, the concrete is wet, then it may need to be protected much longer to withstand the effects of freezing weather. Cold weather concreting will be discussed further in Section 2.2.2. *Weather Conditions.* Another example is shown in Figure 2 where the paste washed away because the concrete was not protected from moving water before the concrete developed enough strength to withstand erosion from flowing water.

Figure 2. Paste washed from concrete exposed to flowing water before sufficient strength was achieved

2.2.2. Weather Conditions

The American Concrete Institute (ACI) has design guides to follow when placing concrete in hot or cold weather. In hot weather, concrete can set up quickly—making it difficult to finish properly. In addition, if there are high ambient and concrete temperatures, low relative humidity, and high winds, plastic shrinkage cracking can become a problem. Plastic shrinkage cracking occurs while the concrete is still plastic (soft) (Figure 3). After the concrete hardens, drying shrinkage cracks can occur (Figure 4). When these cracks are large enough, they can lead to durability problems. Plastic shrinkage cracks tend to be short and discontinuous, while drying shrinkage cracks can be widespread, continuous, and much longer.

Figure 3. Plastic shrinkage cracking.

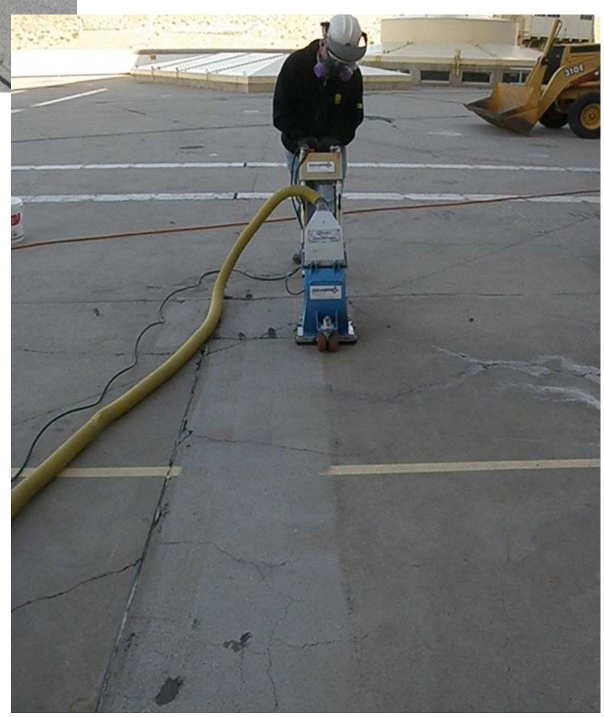

Figure 4. Drying shrinkage cracks on a concrete deck being prepared for a surface sealer.

Placing concrete in cold weather brings along its own issues. As mentioned above, freezing weather can damage the concrete if it freezes too soon after placement. Since cold weather slows down strength gain, the concrete may need to be protected longer. In addition, an air-entraining admixture is required to provide sufficient freeze-thaw durability for concrete subjected to cycles of freezing and thawing weather when it is saturated or nearly saturated. Poor finishing processes can also lead to problems for concrete exposed to cold weather. If bleed water is trapped in the concrete because of premature finishing, a weak and thin top surface is susceptible to freeze-thaw damage. Adding water during the finishing process can do the same thing. If deicing salts are used to melt snow, concrete with a weak surface may see similar results. Figure 5 shows what can happen if this weak layer is created in a freeze-thaw prone environment.

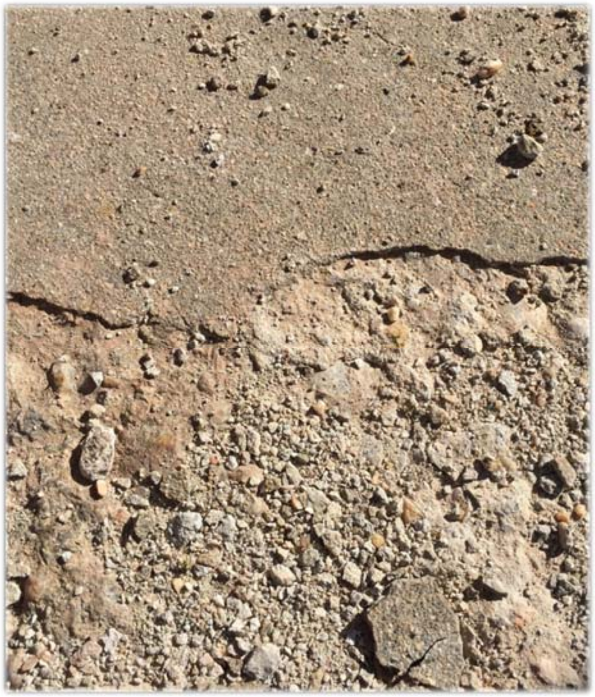

Figure 5. Improperly finished concrete leading to surface damage from cycles of freezing and thawing weather.

3. Concrete Deterioration and Cracking: Identification and Prevention

Three broad types of concrete damage can occur any time during the service life of the structure: chemical and physical deterioration mechanisms and structural overload. These three basic types of damage can be further exacerbated when good concrete practices are not followed. This chapter provides more specifics about the main durability issues that affect water conveyance structures and some steps to prevent them from occurring.

3.1. Chemical Deterioration

Chemical deterioration occurs when there is a chemical attack on the concrete—either from an outside source or when a reaction between the constituents in the concrete occurs.

Sulfate attack. Sulfates found in soils and groundwater react with compounds in the cement paste, creating a byproduct that can soften and expand the paste causing cracking of the hardened concrete (Aisenbrey et al. 1974). Figure 6 shows concrete deterioration of an abutment wall due to sulfate attack.

Figure 6. Sulfate attack on a canal structure.

Prevention. Quality concrete with sulfate resisting cements and certain fly ashes can prevent sulfate attack.

Alkali-Silica Reaction (ASR). This occurs when alkalis in the cement react with siliceous aggregates that were used to make the concrete. The reaction forms a gel that swells in the presence of water and can cause concrete cracking (Aisenbrey 1974). Figure 7 shows extensive ASR damage to a concrete pier.

Figure 7. ASR deterioration.

Prevention. Typical concrete practice now is to use non-reactive aggregates and low-alkali cement to prevent ASR. Using other additives in the concrete can also help prevent ASR.

Corrosion of reinforcing steel (rebar). Normally, the steel is protected by the concrete cover over the steel. However, chlorides in water or on the concrete surface can penetrate into the concrete leading to corrosion. In addition, if there is not enough concrete cover over the rebar, the rebar may start to corrode. As the rebar corrodes, it may crack the concrete and lead to further corrosion (von Fay 2015). Rust staining on the surface of the concrete can indicate there is corrosion of the reinforcing steel (Figure 8).

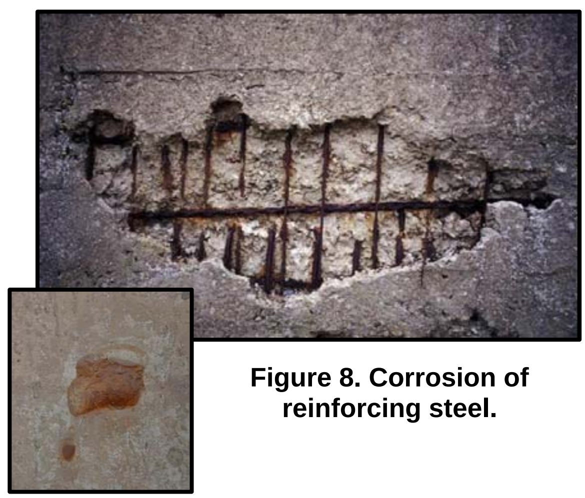

Figure 8. Corrosion of reinforcing steel.

Prevention. Deicing chemicals are a major source of chlorides and attempts should be made to keep them off the concrete if corrosion is suspected or if the rebar is susceptible to corrosion. In some cases, sealers or coatings can help.

3.2. Physical Deterioration

The following forms of deterioration occur from physical mechanisms.

Abrasion-Erosion. This damage results from the grinding action of silt, sand, and rock that impact the water conveyance structure. Figure 9 shows abrasion-erosion damage of concrete.

Prevention. Reduce debris that may cause erosion by:

- Using screens or settling basins at inlet structures.
- Providing retaining walls to protect flowing water from rock slides.
- Providing fences to keep people from throwing rocks and debris into the water.
- Using high strength concrete to improve resistance to abrasion-erosion.

Figure 9. Abrasion-erosion of concrete surface leading to exposed and polished aggregate.

However, exercise care when using heavy machinery to remove debris to avoid damaging the concrete as shown in Figure 10.

Figure 10. A front end loader damaged this concrete liner.

Cavitation. This damage occurs when high velocity water flows encounter rough areas along the flow surface. Cavitation damage starts to become a concern when water flow velocities begin to exceed about 40 feet per second and the flow surface is rough. One major concern with cavitation is that once cavitation begins, more rough areas are formed which can create more extensive cavitation damage. Figure 11 shows some early warning signs that concrete erosion, and possibly cavitation, have begun.

Figure 11. The early stages of concrete erosion and possible cavitation.

Prevention. Proper concrete maintenance in high velocity flowing water structures includes eliminating offsets in joints and holes in concrete surface, and repairing observed cavitation damage before it can enlarge to cause more damage (von Fay et al. 2015).

Cycles of freezing and thawing weather. This damage occurs in concrete that does not have proper air entrainment and that is saturated or nearly saturated. As the water freezes in the concrete, it expands and can crack the concrete. Each new crack can hold additional moisture, leading to further cracking during the next freeze cycle. Figure 12 shows freeze-thaw damage to a concrete flume.

Figure 12. Freeze-thaw damage to concrete flume.

Prevention. Modern concrete used in exposures with freezing weather are made with air-entraining admixtures, which create an air void system in the concrete to protect it when it freezes. Air voids in properly air-entrained concrete relieve the pressure caused by the freezing water, which prevents cracking of the concrete.

Preventing or minimizing freeze-thaw damage in existing structures may be possible in some cases by varying the water level to avoid concentrating the damage in one location as shown in Figure 13. Other options include using weatherproofing treatments with concrete sealers and coating systems. However, these treatments need to be carefully designed, or they will not work and could potentially lead to further damage.

Figure 13. Freeze-thaw damage that could have been reduced by changing the structure's operations.

3.3. Structural Overloading on Concrete Structures

Structural overloading is the other main category of damage to concrete. Cracks from structural overloads usually have a distinctive appearance and typically do not look like cracking from deterioration. As shown in Figure 14, cracks from the structural damage are usually distinct and occur in one area of the structure. For most Reclamation structures, structural overloads are a rare occurrence, and usually only result from an accident, flooding, or an earthquake.

Figure 14. Structural damage from a collapsed roadway that impacted a support pier of a siphon. The road was undercut by flooding and then collapsed against the pier.

3.4. Structural Overloading on Concrete Canal Lining

When canal linings have cracks or leaking joints, water under the lining can lead to a host of problems in the canal. When a concrete canal lining cracks, it is usually because of some type of structural overload—from improper foundation support due to poor preparation, soil erosion, settlement, expansion or excess hydrostatic load. This is because concrete is relatively weak in tension, and concrete canal linings are rarely reinforced. When the linings experience a tensile load, they can easily crack. The section below describes some of the issues that can occur in concrete canal linings due to leaks from cracks or failing joints.

Cracks may form in the concrete liner from a number of mechanisms discussed in this document. Cracks or leaking joints allow seepage under the liner exacerbating the damage. Water beneath the lining can then lead to soil erosion (voids), subsidence of the foundation, and uplift and cracking of canal linings (Figure 15).

Figure 15. A crack in the canal allowed water to erode the soil beneath the liner.

Prevention. Canal lining maintenance requires prompt repairs of cracks and leaking joints. See Section 5.7.2 *Canal Lining Leaking Cracks and Joints* for suggestions on how to repair leaking joints and cracks.

Voids under the concrete lining can occur due to seepage and soil erosion, subsidence, solutioning of soluble soil material, or animal burrows. Water which seeps through cracks or open joints often cause voids to form on the interior embankment slopes and/or the canal invert.

Concrete linings can suffer significant damage if the voids are large enough so that the lining is no longer properly supported. Concrete linings are typically thin and unreinforced, and thus have little capacity to “bridge” voids. Figure 16 shows the damage that can occur when voids under concrete liners are allowed to continue to erode the foundation.

Figure 16. Voids under canal linings.

Prevention. The first step to repairing voids is to repair any leaking to prevent voids from getting worse from infiltrating water. After repairing any leaks, proper void repair depends on the nature of the void. Repair options include various backfill grouts, including cementitious and chemical grouts, and controlled low strength materials (a special type of concrete which is usually proportioned to be flowable). Careful consideration is needed before filling voids beneath the lining. Grout pressures of just a few psi can lift the canal lining and cause additional damage. In addition, some canals may have drains (scupper drains) or other features under them, and void filling operations need to be monitored to ensure those features are not impacted.

Control animal burrows as discussed in Reclamation’s Canal Operation and Maintenance manuals (Reclamation 2017 [Animals]).

Subsidence can occur if the soil below the concrete liner is not sufficiently compacted, collapses upon wetting, or contains minerals subject to solutioning. Once the void becomes large enough, the lining will deform and crack. The compromised lining then allows more water beneath the lining and subsidence worsens.Figure 17 shows extensive damage of concrete linings due to subsidence.

Figure 17. Subsidence of several canal linings.

Prevention. Use the same methods as preventing voids.

Blowouts can occur when the canal water surface is drawn down too quickly (Reclamation, 1967). During extended operations, hydrostatic pressure develop on both sides of the canal lining as the supporting soils become saturated. When the canal water is removed, the hydrostatic pressure behind the lining is no longer offset by the water in the canal. The differential hydrostatic pressure can cause the canal lining to buckle outwards or separate from adjacent linings. Figure 18 shows damage to a concrete liner where hydrostatic pressure overloaded the concrete liner.

Figure 18. Hydrostatic pressure behind the lining ruptured the canal lining.

Prevention. In general, lowering the canal water surface slowly will prevent blowouts. Avoid lowering the canal water surface by more than 1 to 2 feet per day. Follow the site-specific Standing Operating Procedures (SOP) for canal drawdown procedures.

Figure 19. Hydrostatic pressure from ground water cracking a concrete canal lining.

In some cases, ground water from other sources can exert similar pressures on canal linings and lead to cracking and possibly failure, as shown in Figure 19. In these cases, special drainage features (such as scupper drains near the canal invert) may be needed to relieve the pressure. This may be common in northern climates where canals are un-watered in the winter.

Uplift of the canal lining can occur when expansive soils are present in the foundation or were used to construct the embankment. Highly expansive soils can cause large uplift pressures on the underside of the canal lining. These pressures can also cause the lining to buckle outwards or separate from adjacent linings.

Figure 20. Uplift of the concrete lining.

Nearby woody vegetation with root systems that extend beneath the canal lining can cause uplift or similar damage. Figure 20 shows uplift of a concrete liner.

Prevention. Where expansive soils are known to be causing uplift and damage, take every effort to limit the amount of water seeping from the canal. This might include regular crack and joint sealing and/or the addition of a geomembrane liner. Sometimes the soil can be treated with cement or lime to limit the swell potential. The type of treatment should be designed by a geotechnical engineer. *In-situ* soil treatment can be very expensive. Other solutions may require over-excavation and replacement with a more suitable backfill material.

For new canals, geotechnical investigations should be completed to identify whether there are expansive soils along the alignment and to design preventative measures.

Control vegetation as discussed in in Reclamation's Canal Operation and Maintenance manuals (Reclamation 2017 [Vegetation]).

Buckling of the canal lining can occur when there is an insufficient number of expansion joints. As the concrete expands, the concrete liner will buckle outward similar to uplift of the linings (Figure 21). Buckling of the linings will happen at every joint, whereas uplift will only occur at one location. If buckling is due to heat expansion, then typically joints only on one side of the canal (the side with direct exposure to the sun) will be impacted.

Figure 21. Buckling of canal lining where joint material is being squeezed out.

Prevention. The location and spacing of expansion joints should be carefully considered during the design phase. Additional expansion joints can be added after construction by saw cutting. An engineer should be consulted prior to adding additional joints.

4. Develop a Concrete Inspection, Maintenance, and Repair Program

Rather than jumping to the questions: “How do we repair this and how much will it cost?” it is better to follow a proactive and systematic approach in identifying, monitoring, and repairing concrete structures. To properly monitor the condition of concrete structures and canal linings, establish a formal inspection program. Focus on finding and observing signs of concrete damage. Make records of observed damage and store these in an easy-to-access location. These records can be compared over time to determine if damage is getting worse, how fast the damage is progressing, or if it is remaining stable. Inspection, maintenance, and repair plans should discuss:

- **Monitoring concrete structures for damage.** Perform regular, routine inspections. Develop maps and/or drawings of all concrete structures in the canal system, and note any problem areas on the maps/drawings. Photograph and monitor these areas regularly. Appendix A: *Maintenance Checklist for Concrete Canal Structures and Linings* is a checklist that can be used during the inspection.

- **Determining the cause(s) of damage.** Addressing the underlying causes of the damage is the only way to prevent further damage from that same cause. Damage from a one-time event, like an accident or an earthquake, is unlikely to occur again. But other forms of concrete damage can stem from recurring damage mechanisms and can combine into multiple causes. Fixing the damage without understanding what caused the problem in the first place will likely mean that the repair will be damaged in the same way. Moreover, it is important to do a thorough investigation of cause and extent before performing any repairs, because the wrong repair could unintentionally cause more damage.

- **Evaluating the extent of damage.** Determine how much concrete has been damaged (how long, how wide, how deep, and how much of the structure or lining is involved). How will this damage affect the serviceability of the structure or lining? Monitor to help predict how quickly the damage is occurring and how the damage is likely to proceed. This step may require obtaining samples of concrete to help answer these questions or to conduct other forensic investigations.

- **Planning response to damage**. Most concrete damage progresses slowly, and several options are usually available if the deterioration is detected early. Early detection allows time for planning and budgeting for repairs, and in some cases, can allow for changes in operation to prevent or minimize further damage. Determine:

- *What can be done to prevent or minimize further damage?* A combination of repair and maintenance procedures or operational changes may help slow or stop the rate of deterioration.

- *Does the damage need to be repaired and if so, when?* Consider many factors before deciding to repair the concrete. Repairs are needed if the damage affects operations and safety or will likely do so in the future if the deterioration progresses.

- *How should the damage be repaired?* There are many standard repair and maintenance methods described in Reclamation's Guide to Concrete Repair (von Fay 2015). In general:

  - Select the repair method and material
  - Prepare the existing concrete for repair
  - Apply the repair method
  - Cure the repair properly

- **Monitor after a repair.** Periodically visit the repair site to check the performance of the concrete repair. If the original source of the damage was not removed, the damage or deterioration could come back or propagate to areas that were previously unharmed. The same could happen if an inappropriate repair material was used.

Failing to monitor and address problems promptly could result in more expensive repairs or replacement later.

Table 1 indicates the type of damage that each structure in the canal system might experience. Use this table when developing a maintenance and repair program to pay special attention to each kind of deterioration or damage and where it might occur.

Reclamation can be consulted with preparing a good monitoring program.

While operating entity staff can handle routine and small repairs, it is best to consult with Reclamation's Area Office to determine the best method to handle larger repairs. Contact local Reclamation O&M engineers. They or Reclamation's Technical Service Center (TSC) can provide technical assistance with unique or tough repairs and challenges as well as the latest recommendations on materials, methods of mixing, application, curing, and precautions to be exercised during placement.

Table 1. Types of Concrete Damage by Structure Type

	Structure Types	Sulfate Attack	ASR	Corrosion of Reinf. Steel	Abrasion-Erosion	Cavitation	Freeze Thaw	Structural Overload	Foundation Voids	Soil Erosion	Subsi-dence	Lining Blowout	Canal Lining Uplift	Buckling
Conveyance Structures	Canal Linings	x	x	x	x		x	x	x	x	x	x	x	x
	Inverted Siphons	x	x	x	x			x	x	x	x			
	Bench Flumes	x	x	x	x		x	x	x	x	x			
	Elevated Flumes	x[1]	x	x	x		x	x		x	x			
	Road Crossings	x	x	x	x		x	x	x	x	x		x	
	Drops	x	x	x	x		x	x	x	x	x			
	Chutes	x	x	x	x		x	x	x	x	x	x		
Regulating Structures	Checks	x	x	x	x		x	x	x		x			
	Check-drops	x	x	x	x		x	x	x	x	x			
	Turnouts	x	x	x			x	x	x	x	x			
	Diversion Structures	x	x	x	x		x	x	x	x	x			
	Check and Pipe Inlets	x	x	x	x	x	x	x	x		x			
Protective Structures	Wasteways	x	x	x			x	x	x	x	x	x	x	
	Culverts	x	x	x	x		x	x	x	x	x		x	
	Overchutes	x	x	x	x		x	x			x			
	Drain Inlets	x	x	x	x		x	x	x	x	x			
Water Measure-ment Structures	Parshall Flumes	x	x	x	x		x	x			x	x	x	
	Stilling Well	x	x	x	x		x	x			x			
	Weirs	x	x	x	x		x	x	x	x	x			
	Weir Boxes	x	x	x	x		x	x		x	x			
	Open-flow Meters			x			x	x						

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	Structure Types	Sulfate Attack	ASR	Corrosion of Reinf. Steel	Abrasion-Erosion	Cavitation	Freeze Thaw	Structural Overload	Foundation Voids	Soil Erosion	Subsi-dence	Lining Blowout	Canal Lining Uplift	Buckling
Energy Dissipators	Baffled Apron Drops	x	x	x	x	x	x	x	x	x	x			
	Baffled Outlets	x	x	x	x	x	x	x	x	x	x			
	Vertical Sleeve Valve Stilling Wells	x	x	x	x	x	x	x	x	x	x			
Transitions and Erosion Protection	Transitions	x	x	x	x		x	x	x	x	x	x		
	Erosion Protection							x	x	x	x			
Pipe and Pipe Appurt-enances	Pipe			x	x	x		x	x	x	x			
	Pipe Appurtenances			x		x		x	x	x	x			

[1] Will only occur if sulfates in the water because the structure is elevated from the soil.

5. Repairs

5.1. Prioritize Repairs

With the exception of erosion damage, cracking is the leading indicator of many types of damage to concrete canal linings. The size, type, cause, and location of cracking can have a big impact on deciding whether repairs are needed and when. Many times, observation and careful consideration are needed to make that determination. Other times, it can be pretty obvious that repairs are needed and needed soon. In most cases, repairs on large cracks are required as soon as these cracks are observed. For concrete canal linings, the decision to make repairs to cracks or joint leaks depends on foundation material conditions or whether the canal section is in “fill.” Environmental conditions can also make simple crack repairs a much larger repair project.

For concrete structures other than canal linings, determining when to repair cracked and deteriorated concrete can be more difficult and may require more investigation, planning, and budgeting. The decision should be based on exposure conditions, the cause of the cracks, and the potential for additional damage caused by the cracking. For concrete structures undergoing some type of deterioration, repairing cracks is usually futile. For example, repairing cracks caused by ASR will not work if the concrete is still deteriorating because the concrete will just crack again. When possible, remove concrete undergoing deterioration, and replace it with concrete designed to handle the conditions. Sometimes, special sealers and coatings may slow down the deterioration if time is needed before repairs can be done. However, this solution is only a stop-gap measure—do not rely on this solution to last more than a few years, if that. In addition, the sealers can be expensive and properly applying them can be labor intensive.

After an inspection of the concrete structure has been performed and a repair plan has been made, it’s time to think about what repairs the water district can perform and what repairs require experts or expert advice. A quick reference guide for possible short-term and long-term solutions is in Table 2 at the end of this section.

5.2. Sulfate Attack, Alkali-Silica Reaction (ASR)

Properly diagnosing these specific forms of deterioration usually requires laboratory testing. This may be a prudent expenditure because it can help provide information for a sound repair or maintenance plan.

For example, if the cause of deterioration is sulfate attack, then sulfate-resisting concrete or repair mortar materials are needed to ensure that the repairs will last. These repair materials are readily available or can be easily proportioned when they are needed.

Repairs to concrete that has undergone sulfate attack or ASR deterioration normally require complete replacement of the structural element.

The Guide to Concrete Repair (von Fay 2015) details temporary fixes to slow the deterioration from sulfate attack: applying a coating (per Section D.1.d) or a concrete sealing compound (per Section D.1.a through D.1.c). The Guide also explains that low viscosity epoxies (Section D.1.b of Guide to Concrete Repair) and high molecular weight methacrylic (HMWM) sealing compounds (Section D.1.a of Guide to Concrete Repair), when applied as “healer-sealers,” can sometimes slow the rate of deterioration in concrete undergoing ASR. The decision to use these materials should not be taken lightly. They can be expensive, require special surface preparation, usually only work in specific exposure conditions, and their service life could be relatively short.

5.3. Corrosion

If it is known that the concrete will be exposed to deicing salts, then some sealers can slow down the intrusion of chlorides. In addition, special additives to the concrete can help protect the rebar from corrosion.

When making repairs to concrete that is suffering from deterioration due to rebar corrosion, take special care or the corrosion can accelerate or can start to occur at a location very near the repairs. Many times, additional concrete will need to be removed to eliminate all chloride contaminated concrete and additional corroded steel may need to be removed. Refer to Reclamation’s *Standard Protocol to Evaluate the Performance of Corrosion Mitigation Technologies in Concrete Repairs* (M-82; Reclamation 2014) for determining the best repair material options to mitigate corroded steel in concrete. A structural engineer should be consulted to determine if the structure’s strength has been compromised.

5.4. Abrasion-Erosion Repair

Abrasion-erosion is best repaired with a high strength concrete. As outlined in the Guide to Concrete Repair, silica fume concrete (Section D.3.d) or polymer concrete (Section D.2.d) are the best materials for repairing concrete that will continue to sustain abrasion-erosion damage (von Fay 2015).

5.5. Cavitation Repair

Repairs to cavitation damage can be difficult. In some cases, cavitation damage can be repaired using polymer concrete or epoxy mortar (Section D.2.d of the Guide to Concrete Repair). In other cases, it may be necessary to use a packaged cementitious or chemical repair mortar (Section D.2.f of the Guide to Concrete Repair). Reclamation has not found consistent performance with these types of materials, so materials must be carefully considered. Work with an expert to determine an appropriate product. Hydraulic engineers should be consulted for design and operations changes to prevent cavitation from continuing.

5.6. Freeze-Thaw Repair

Keeping concrete that is susceptible to freezing and thawing deterioration (typically older concrete placed before or about 1950) dry can prevent deterioration. For many water conveyance structures, keeping this concrete dry can be difficult or impossible. Certain portions of exposed concrete structures are more vulnerable than others to deterioration from weathering in freezing climates: exposed surfaces of the top of walls, piers, posts, handrails, and parapets; all curbs, sills, ledges, copings, cornices, and corners; and surfaces in contact with spray or water at frequently changing levels during freezing weather. When performing repairs to this type of concrete, it is important to use materials that are durable in a freeze/thaw environment and that won't trap moisture under the repair material bond line.

In other cases, it may be possible to apply weatherproofing treatments with concrete sealing compounds as described in the Guide to Concrete Repair (Section D.1.a through D.1.c) to surfaces that are especially susceptible to freeze-thaw (von Fay 2015). Concrete sealing compounds may provide some protection of the concrete. However, their use needs to be carefully considered, or these compounds will not work or could even potentially lead to further damage.

5.7. Crack Repair

5.7.1. Concrete Structures

Repairing cracking due to structural overload may require the assistance of a structural engineer to help determine the cause of the cracking and to design a fix. If the structural overload resulted in yielding of the steel reinforcement, the reinforcement will need to be replaced.

For cracking that is not resulting from some form of deterioration (for example, cracks from drying shrinkage, thermal, or plastic shrinkage), cracks as large as 0.004 inches wide can self-heal (plug) in certain conditions. In other cases, cracks as small as 0.002 inches wide may need to be repaired. For example, if the crack will allow water that contains various salts to come in contact with reinforcing steel, then the crack may need to be repaired using a suitable chemical grout (epoxy for example) to prevent corrosion of the reinforcing steel.

5.7.2. Canal Lining Leaking Cracks and Joints

Keeping canal linings from moving requires prompt repairs of cracks that are full depth and joints that may be open. If water gets under the linings, then a host of problems can occur as described earlier.

The general guidelines for repairing cracks or damaged joints to existing (not new) canal linings are:

- For linings with cracks or joints with offset or displaced edges, larger than 0.50-inches, replace the lining or part of a lining.

- For linings with cracks or joints with offset or displaced edges smaller than 0.50-inches that are leaking, repair using a chemical grout or suitable spray applied polyurea. Not all chemical grouts or polyureas are appropriate for repairing leaking cracks or joints in concrete canal linings. Care is needed when selecting materials for leak repairs. In addition, using these repair materials can be expensive, so it may be more economical to simply replace the lining.

- Cracks less than 0.04-inches wide and not full depth (not leaking): Monitor crack.

- Cracks between 0.04-inches and 0.20-inches that may be leaking: Repair using routing (cutting a small channel in the concrete to hold the sealant) and sealing is an option. It may be prudent to do nothing and monitor the crack. If routing and sealing is selected, then:

  - Route a minimum 0.25-inches wide and 0.50-inches deep with chamfered edges

  - Use a non-sag polyurethane sealant

  - Completely fill the routed groove with sealant

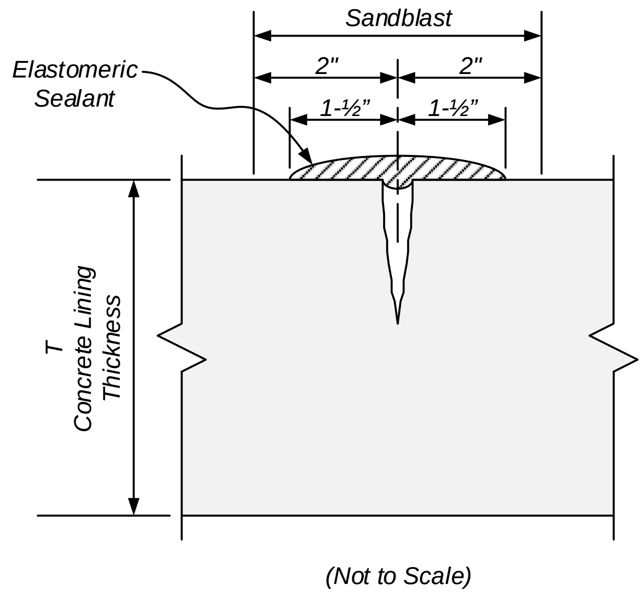

Figure 22. Cap seal for random cracks.

- Another option for smaller cracks and offset joints or edges less than 0.04 inches is the cap and seal method (Figure 22). However, surface preparation is critical, and it may be difficult to monitor the crack once it is capped. In addition, this type of repair may not last long.

These are general guidelines and may not be suitable for all cracks and joints. Repairs to leaking joints and leaking cracks that show signs of movement (for example, offset edges) require relatively flexible materials or the repair will likely fail prematurely. A suitable chemical grout or spray-applied polyurea should be considered. Again, care is needed when selecting materials for leaking crack or joint repairs.

For cracks that extend full depth and do not appear to be moving, more rigid repair materials can be used, including some epoxies and rigid polyurethanes.

If seepage flows are observed in adjacent embankments, or especially if water is observed to be "flowing" through lining cracks or joints, examinations and repairs should be conducted immediately. As seepage increases, the possibility of piping embankment materials and failing foundations or embankments becomes significant.

Sealing joint leaks and cracks in canal linings has been a critical issue for Reclamation because in the past, performing the repair required dewatering and shutting off service for extended periods of time. However, some recent research conducted by Reclamation's TSC Concrete, Geotechnical, and Structural Laboratory has found that some chemical grouts can be injected underwater with the support of a commercial diver to seal seepage cracks. A field demonstration of this repair was conducted on a crack on a Central Arizona Project (CAP) canal lining outside of Casa Grande, Arizona (Harrell and Klein 2015 and 2016). and Figure 24 show the final product of the chemical grouts after they were injected underwater and cured for 24 hours. Further work is being considered to examine methods to deliver these materials without the aid of divers.

Figure 23. Chemical grout product A with 120 °F pre-mixed injection water.

Figure 24. Chemical grout product B with no mix water.

5.8. Repairing Shotcrete

Shotcrete, sometimes called gunite, is an application method for concrete. Typically, the concrete materials are selected and proportioned to make application effective. Shotcrete is defined as “mortar or concrete pneumatically projected at high speed onto a surface” (ACI Committee 2016). There are two basic types of shotcrete: dry mix and wet mix. In dry mix shotcrete, the dry cement, sand, and coarse aggregate (if used) are pre-mixed with only sufficient water to reduce dusting. This mixture is then forced through the delivery line to the nozzle by compressed air. At the nozzle, sufficient water is added to the moving stream to meet the requirements of cement hydration. For wet mix shotcrete, the cement, sand, and coarse aggregate are first conventionally mixed with water, and the resulting concrete is then pumped to the nozzle, where compressed air propels the wet mixture onto the desired surface.

Because shotcrete is concrete, it can suffer from all the damage mechanisms described above. Repairs to shotcrete should be conducted according to the guidelines presented here and other referenced sources. In addition, shotcrete can be repaired with shotcrete, if that is the most appropriate method selected after following the necessary steps to arrive at a sound decision.

5.9. Reinforced Concrete Pipe Repairs

Repairs to damaged reinforced concrete pipe can become complicated, depending on the extent of the damage. If there is only minor damage to the cover on the rebar, the concrete can potentially be repaired with a repair mortar. If there is damage to the rebar, an entire section of pipe may need to be replaced (depending on whether the pipe is prestressed or not). Structural engineers should be consulted immediately if any damage to pipe is detected. Repairs should not be attempted without first consulting a structural and materials engineer.

Table 2. Solution Matrix to Service Life Issues

Issue	Type of Deterioration or Damage	Short-term Solution	Long-term Solution	Repair performed in the dry	Repair can be performed underwater	Notes
Sulfate Attack	Chemical	Apply a coating or sealer.	Replace affected concrete.	Likely	Unlikely	Repairs may be short lived if all the affected concrete is not replaced. Sealers only slow the rate of the deterioration.
Alkali-Silica Reaction	Chemical	Apply a low viscosity epoxy or a high molecular weight methacrylate (HMWM) as a "healer-sealer."	Replace affected concrete.	Likely	Unlikely	Repairs may be short lived if all the affected concrete is not replaced. Sealers only slow the rate of the expansion.
Corrosion of Reinforcing Steel	Chemical	Apply a topical corrosion inhibitor.	Remove and replace all damaged concrete and corroded steel.	Likely	Unlikely	Corrosion of steel may extend beyond the extent of damaged concrete. When repairing concrete damaged by corrosion of steel careful planning is essential.
Abrasion-Erosion	Physical	Remove excessive debris from water.	Repair concrete with a high strength repair material. Repair with a silica fume concrete.	Likely	Unlikely	If silica fume concrete (SFC) will be used for repairs, consult with a concrete materials expert. Trial placements with SFC are encouraged.
Cavitation	Physical	Apply coatings. Grind protrusions. Fill voids with a high strength material.	Structural modification to entrain air in the flow or reduce flow velocities.	Likely	Unlikely	No known material will withstand cavitation indefinitely.

Issue	Type of Deterioration or Damage	Short-term Solution	Long-term Solution	Repair performed in the dry	Repair can be performed underwater	Notes
Freeze-Thaw	Physical	Apply a coating or sealer. Adjust operations of the canal to limit exposure of concrete to water during freezing periods.	Replace or repair concrete.	Likely	Unlikely	The repair must be thick enough to reduce freezing and thawing of underlying concrete.
Overload of the Structure	Structural	Alter loadings. Repair cracks with epoxy injection. Replace damaged concrete. Shore or brace.	Alter loadings. Repair cracks with epoxy injection. Replace damaged concrete. Replace or strengthen structure.	Likely	Unlikely	Consult with a Structural Engineer.
Voids	Structural	Fill void with low pressure grout or by sluicing sand to support the canal lining.	Remove the lining and reconstruct the subgrade of the affected area. Use low pressure grout to fill void(s) and support the canal lining.	Possibly	Yes, but may be very expensive (grouting) relative to other options	Consult with Reclamation to develop a grouting program. Excess grout pressures can cause additional damage to the embankment and lining.
Subsidence	Structural	Add steel bracing to limit further liner movement. Cover area with an anchored geomembrane to minimize seepage losses.	Remove and reconstruct the lining and subgrade in the affected area.	Likely	Unlikely	Conduct an investigation to understand the cause and extent of the subsidence. Consult with Reclamation to develop an appropriate design.
Blowouts	Structural	Seal cracks to minimize seepage losses. Remove or fill lining offsets that might affect canal hydraulics.	Replace damaged canal linings. Modify operations to prevent future blowouts.	Likely	Unlikely	Refer to SOP for drawdown rates. Consider the addition of weep holes and scupper drains.

Canal Operation and Maintenance: Concrete

Issue	Type of Deterioration or Damage	Short-term Solution	Long-term Solution	Repair performed in the dry	Repair can be performed underwater	Notes
Uplift of Liners	Structural	Seal cracks to minimize seepage loss. Remove or fill lining offsets that might affect canal hydraulics.	Replace damaged lining panels. Replace expansive soil with a non-expansive foundation material.	Likely	Unlikely	Over excavate foundation materials and compact fill prior to lining replacement. Consider lime or other chemical additives to limit future swelling soils.
Buckling	Structural	Sawcut additional expansion joints.	Sawcut additional expansion joints. Replace linings that include proper expansion joints.	Likely	Unlikely	
Leaking Cracks and Joints in canal linings	Structural	Repair the crack or fill the joint with a flexible surface seal or injection material.	Replace the lining. Inject the crack or joint with a flexible material.	Possibly	Possibly	Depending on the repair material selected, dewatering may be required.
Soil Erosion	Structural	Modify local drainage paths. Fill voids with soil to prevent worsening condition.	Channelize surface runoff by using berms, ditches and armored swales. Construct a concrete curb and gutter system. Add drainage inlet and culverts as needed.	Likely	N/A	The canal should be inspected for surface erosion after each major storm. The affected areas should be repaired as soon as possible as they will worsen from subsidence rainfall events.

Notes:
1. For more information, please refer to the Reclamation's Guide to Concrete Repair Second Edition (von Fay 2015).
2. Consult an Engineer prior to performing any repairs.

6. Design Considerations for New or Replacement Concrete

If replacement concrete is required to repair a structure, consider these factors while working with experts and before ordering concrete.

6.1. Concrete Mixture Design

Many considerations go into specifying concrete, including:

- What kind of weather or soil conditions will the concrete be exposed to?
- Will the concrete be in contact with water?
- Is the concrete exposed to chemicals that may require the rebar to have extra protection?

One of the most important considerations when designing a concrete mix is to know the concrete's service and exposure conditions. For many Reclamation concrete structures, the exposure conditions dictate the concrete requirements rather than the structural loads.

American Concrete Institute (ACI) standard ACI 318-14 requires the designer to determine the exposure category and class (i.e., severity of the exposure) for each type of concrete placement. This standard specifies mix requirements for four exposure categories:

- **Freezing and Thawing (F)**. Freeze-thaw exposure will determine if the concrete mix needs to be air entrained. The concrete will likely be affected by freeze-thaw damage if the concrete undergoes cycles of freezing and thawing temperatures while the concrete is saturated or nearly saturated with water and does not contain an adequate air void system. Properly adding air entrainment will provide the required air void system.
- **Sulfate (S).** The concentration of sulfates in the water or soil in contact with the concrete will determine what type of cement is required. High levels of sulfate content may require using supplementary cementitious material to increase sulfate resistance of the concrete. Many areas of the Western U.S. have soils and water that contain sulfates high enough to damage improperly proportioned concrete. If sulfate levels are not known, samples of the soil and water should be tested.
- **In Contact with Water (WA).** Concrete in contact with water should have low permeability. For this reason, the concrete mix is required to have a low water-cementitious materials ratio (w/cm).

- **Corrosion Protection of Reinforcement (C).** Corrosion protection of reinforcement is considered when the concrete will be exposed to moisture and chlorides (for example, de-icing chemicals or seawater). Exposure to chlorides and moisture will require a limit on the chloride content from the concrete making materials (aggregates, cementitious materials, mixing water, and admixtures). There are also additional requirements on the concrete cover on the reinforcement.

Use a minimum 4,000 psi 28-day strength mix if the concrete will be exposed to freeze-thaw cycles with limited exposure to water, low sulfate exposure, and no exposure to external sources of chlorides (such as deicing chemicals). If the concrete will be in an area with freeze-thaw cycles and frequent exposure to water, high sulfate exposure, or exposure to external sources of chlorides, the minimum compressive strength should be 4,500 psi at 28-day strength. For more severe exposure, the compressive strength may need to be 5,000 psi at 28 days' age. In abrasive environments, strengths over 10,000 psi at 28 days' age may be needed. An air-entraining admixture should be used in all exterior concrete exposed to cycles of freezing and thawing weather.

6.2. Construction Practices

As can be seen from Section 2.2. *Construction-Related Problems*, many of the concrete deterioration issues can result from poor concrete construction practices. Follow these good concreting practices when placing concrete.

6.2.1. Batching, Mixing, and Placing

It is recommended that a National Ready Mixed Concrete Association (NRMCA) certified batch plant be used to supply the concrete mix if available in the area. The concrete should be manufactured and delivered in accordance with American Society for Testing and Materials (ASTM) C94. Typically, the concrete should be placed within 90 minutes of batching, but if the location is remote and the truck cannot get there in time, an extended set control admixture can be used. Concrete temperature at placement shall not exceed 90 °F.

6.2.2. Consolidation

Poor consolidation (compaction) can create honeycombing as a result of using improper or faulty vibrators, improper placement procedures, poor vibration procedures, inappropriate concrete mixtures, or congested reinforcement.

Consolidation using vibrators is a process that is mastered with experience. Over-vibrating the concrete can lead to segregation and loss of entrained air. Under-vibrating can result in rock pockets and poor consolidation around rebar.

6.2.3. Curing

Adequate curing will increase the strength, water tightness, abrasion resistance, freeze-thaw resistance, and volume stability. There are several methods for curing:

- Sprinkling or fog spraying: entire surface is kept wet during the curing period.

- Wet burlap or mats: materials are kept wet during the entire curing period.

- Membrane forming curing compounds: waxes and resins that seal the moisture in.

One of these methods should be used on all new concrete placements. Curing should last a minimum of 3 to 7 days—longer is almost always better. The temperature of the concrete should be between 50° and 100° F, but may be higher. If a curing compound is used, it should be applied as soon as the bleed water has dissipated and finishing operations have ceased.

6.2.4. Hot and Cold Weather

Special precautions should be taken for certain weather conditions.

- **Hot weather.** Placing concrete in hot weather conditions can lead to lower 28-day strengths, more thermal, plastic shrinkage, and drying shrinkage cracking, and difficulty controlling air entrainment during placement. Hot weather conditions occur with high ambient heat, high concrete temperatures, low relative humidity, wind, and solar radiation exposure. Plan for hot weather by monitoring weather reports and placing at cooler times of the day. Use adequately sized crews so that the concrete can be placed quickly. When possible, use enclosures to provide shade and shield the concrete from wind exposure.

- **Cold weather.** Placing concrete under cold weather conditions can lead to slower setting times and slower strength gain, lower 28-day strengths and permanent damage if the concrete freezes, and plastic shrinkage cracking. When placing concrete under cold weather conditions, protect the concrete from freezing until the concrete reaches 500 psi by providing insulating or heating blankets. In some conditions, protection may be needed until the concrete reaches a higher strength. Air-entrain concrete for exterior use. Do not perform any finishing operations while water is present on the surface. Do not use steel trowels, which will seal the surface, trap bleed water, and create a weak layer below the surface. Do not place concrete on frozen ground, snow, or ice.

ACI has several guides related to Hot (ACI 305R) and Cold (ACI 306R) Weather Concreting.

7. References

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Appendix A: Maintenance Checklist for Concrete Canal Structures and Linings

This Maintenance Checklist for Concrete Canal Structures and Liningss based on von Fay, K. F. Guide to Concrete Repair, Second Ed., Denver, Colorado: U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, 2015. https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/Guide2ConcreteRepair2015_Final.pdf

Bureau of Reclamation
Maintenance Checklist for Concrete Canal Structures and Linings

Project Name:	____________________
Project Location:	____________________
Date of Inspection:	____________________
Name of Inspector:	____________________
Other Attendees:	____________________
	____________________
	____________________
	____________________
Notes:	

Refer to Canal Maintenance: Mechanical, Section 6, *Safety* for procedures prior to starting the inspection.

Bureau of Reclamation
Maintenance Checklist for Concrete Canal Structures and Linings

Voids/Subsidence/Blowouts/Uplift/Buckling								
Item #	Structure Type	Station/Location	Description	V/S/BL/ U/BU	Photo Location*	A	M	IA
EX:1	Canal Lining	Sta. 15.00	4'-0" wide	V				X
1								
2								
3								
4								
5								
6								
7								
8								
Notes:								

V: Void S: Subsidence BL: Blowout U: Uplift BU: Buckling
A: Acceptable M: Monitor IA: Needs Immediate Attention
*Directory or file location where photos are stored

Bureau of Reclamation
Maintenance Checklist for Concrete Canal Structures and Linings

Cracks/Joints								
Item #	**Structure Type**	**Station/Location**	**Width**	**Length**	**Photo Location***	**A**	**M**	**IA**
EX:1	Canal Lining	Sta. 15.00	0.03 inches	4'-0"		X		
1								
2								
3								
4								
5								
6								
7								
8								
Notes:								

A: Acceptable M: Monitor IA: Needs Immediate Attention
*Directory or file location where photos are stored
For more information refer to Guide to Concrete Repair Second Edition- Part I- Section C.11.

Abrasion-erosion/Cavitaion/Freeze-thaw

Item #	Structure Type	Station/Location	Description	AE/ C/FT	Photo Location*	A	M	IA
EX:1	Canal Lining	Sta. 15.00 4 ft from top of lining	2'-0" x 3'-0"	FT			X	
1								
2								
3								
4								
5								
6								
7								
8								

Notes:

AE: Abrasion-Erosion C: Cavitation FT: Freeze-Thaw

A: Acceptable M: Monitor IA: Needs Immediate Attention

*Directory or file location where photos are stored

For more information refer to Guide to Concrete Repair Second Edition- Part I- Section C.6, C.7, and C.8.

Bureau of Reclamation
Maintenance Checklist for Concrete Canal Structures and Linings

Corrosion

Item #	Structure Type	Station/Location	Description	Photo Location*	A	M	IA
EX:1	Canal Lining	Sta. 15.00	2'-0" x 3'-0" delamination in area				X
1							
2							
3							
4							
5							
6							
7							
8							

Notes:

A: Acceptable M: Monitor IA: Needs Immediate Attention
*Directory or file location where photos are stored
For more information refer to Guide to Concrete Repair Second Edition- Part I- Section C.9.

Bureau of Reclamation
Maintenance Checklist for Concrete Canal Structures and Linings

Sulfate Attack/ Alkali-Silica Reaction (ASR)							
Item #	**Structure Type**	**Station/Location**	**Size**	**Photo Location***	**A**	**M**	**IA**
EX:1	Canal Lining	Sta. 4+15.00	2'-0" x 3'-0"			X	
1							
2							
3							
4							
5							
6							
7							
8							
Notes:							

A: Acceptable   M: Monitor   IA: Needs Immediate Attention
*Directory or file location where photos are stored
For more information refer to Guide to Concrete Repair Second Edition- Part I- Section C.4 and C.5.