BUREAU OF RECLAMATION

Investigating the Need for Corrosion Protection of Steel Reinforcements in Concrete at Reclamation

Science and Technology Program
Research and Development Office
Final Report No. ST-2024-24002-01
Technical Memorandum No. 8540-2024-45

U.S. Department of the Interior September 2024

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
13-09-2024	Research	November 2023–September 2024

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Investigating the Need for Corrosion Protection of Steel Reinforcements in Concrete at Reclamation	24XR0680A1-RY15412024WI24002 / X4002
	5b. GRANT NUMBER N/A
	5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. AUTHOR(S) Grace Weber, Materials Engineer, gweber@usbr.gov	5d. PROJECT NUMBER Final Report ST-2024-24002-01
	5e. TASK NUMBER N/A
	5f. WORK UNIT NUMBER 86-68540
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Materials and Corrosion Laboratory Technical Service Center Bureau of Reclamation U.S. Department of the Interior PO Box 25077, Denver Federal Center Denver CO 80225-0007	8. PERFORMING ORGANIZATION REPORT NUMBER TM No. 8540-2024-45
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Science and Technology Program Research and Development Office Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007	10. SPONSOR/MONITOR'S ACRONYM(S) R&D: Research and Development Office Reclamation: Bureau of Reclamation DOI: U.S. Department of the Interior 11. SPONSOR/MONITOR'S REPORT NUMBER(S) Final Report ST-2024-24002-01

12. DISTRIBUTION/AVAILABILITY STATEMENT

Final Report may be downloaded from https://www.usbr.gov/research/projects/index.html

13. SUPPLEMENTARY NOTES

None

14. ABSTRACT

This research sought to investigate whether concrete corrosion is a significant issue at Reclamation facilities and determine if further implementation of corrosion protection methods is warranted for Reclamation structures. This was accomplished through review of Reclamation Asset Management resources and outreach to field contacts. Findings from the data collection indicated that, at this time, there is not sufficient need or benefit to begin widespread implementation of corrosion protection techniques for Reclamation's reinforced concrete infrastructure. However, targeted implementation may still be useful if corrosion of the reinforcing steel can be definitively shown to be the primary factor in concrete deterioration.

15. SUBJECT TERMS

Aging infrastructure, cathodic protection, concrete rebar, corrosion mitigation, reinforced concrete

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
				30	Grace Weber
a. REPORT	b. ABSTRACT	THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
U	U	U			303-445-2327

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Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research.

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Cover photograph: Exposed reinforcing steel on the underside of a concrete bridge structure (Photo credit: Reclamation).

Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology Program

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Acronyms and Abbreviations

AMD	Asset Management Division
AMPP	Association for Materials Protection and Performance
ASR	Alkali-silica reaction
DSIS	Dam Safety Information System
FHWA	Federal Highway Administration
MB	Missouri Basin
NACE	National Association of Corrosion Engineers
Reclamation	Bureau of Reclamation
VDOT	Virginia Department of Transportation

Contents

Executive Summary

This research sought to investigate whether concrete corrosion is a significant issue at Bureau of Reclamation facilities and determine if further implementation of corrosion protection methods is warranted for Reclamation structures. This was accomplished through review of Bureau of Reclamation Asset Management resources and outreach to field contacts.

Findings from the data collection indicated that, at this time, there is not sufficient need or benefit to begin widespread implementation of additional corrosion protection techniques for Reclamation's reinforced concrete infrastructure other than those already utilized (e.g., adequate cover).

However, targeted implementation may still be useful if corrosion of the reinforcing steel can be definitively shown to be the primary factor in concrete deterioration, or a significant secondary effect due to adverse exposure conditions. This could be further investigated or verified through future work, such as:

- Conducting broader field outreach or data searches to reach more Bureau of Reclamation offices.

- Use of online resources such as Web Soil Survey to cross-reference geographic regions of high chloride levels with the data search.

- Demonstration project to perform half-cell potential surveys on concrete structures with high corrosion risk to definitively determine if concrete corrosion is occurring.

- Further communication with Bureau of Reclamation bridge program to discuss the possibility of corrosion protection on roadway structures identified as having concrete corrosion issues.

1. Introduction

Reinforced concrete is a widespread material in Bureau of Reclamation (Reclamation) infrastructure. The reinforcing steel is generally protected from corrosion by the alkaline (high pH) environment within the concrete which aids in forming a stable passive oxide layer on the steel. Two issues which can cause the breakdown of this passive layer, however, are a decrease in the pH of the concrete or the presence of chlorides in the concrete. Carbonation naturally occurs in the presence of carbon dioxide and its reaction with calcium in the cement, lowering concrete pH over time and breaking down the passive layer. Chloride contamination can cause pitting corrosion of the reinforcing steel. Once corrosion begins, it is typically accelerated as the reinforcing steel becomes increasingly exposed to moisture or chlorides due to worsening cracks or spalling of the concrete.

Concrete patch repairs are one way to cover reinforcing steel and keep a cracked or spalled concrete structure in service. However, if the bulk concrete structure is already chloride-contaminated, the fresh concrete patch can introduce a corrosion gradient that accelerates steel corrosion at the interface of the existing and new concrete. Over time, this can cause need for additional patches around the original patch, often referred to as "patch-accelerated corrosion" or the "halo effect." This is why all corrosion issues must first be addressed before repairing concrete.

Concrete corrosion protection techniques are not novel. However, these methods are not commonly used at Reclamation facilities. For example, corrosion inhibitors have not been specified at Reclamation in over 10 years. Reclamation's aging concrete structures require increasing levels of maintenance and repairs to extend service life. This research sought to investigate whether the use of corrosion protection could help to prevent the need for expanding, repeated repair.

1.1. Corrosion Protection of Reinforced Concrete

Some methods of corrosion protection for reinforced concrete are briefly described in the following subsections.

1.1.1 Corrosion Inhibitors

Corrosion inhibitors are admixtures added to fresh concrete during the batching process. These chemicals generally serve as an anodic inhibitor by creating a protective layer on the steel surface. Some have an additional benefit of reducing chloride permeability of the hardened concrete. There are also surface-applied corrosion inhibitors which can be applied to new or existing structures.

1.1.2 Protective Coatings

Epoxy-based coatings are a corrosion protection method for steel reinforcements, depending on the service conditions. Epoxy coatings provide a barrier to impinging moisture and chlorides, while also providing electrical insulation from corrosion current. Alternative organic or metallic (e.g., stainless cladding or galvanizing) coatings can also be used to inhibit corrosion in reinforced concrete, although this is based on exposure environment, and cost may be a factor.

Opinions on the use of this technique vary within the corrosion industry, as there is risk of highly localized corrosion at coating defects, which could outweigh the benefits of the technique. Findings from the Virginia Department of Transportation (VDOT) show that it is not cost-effective in concrete bridge decks [1]. As of September 1, 2010, use of epoxy coated reinforcing steel is no longer allowed on VDOT projects, with corrosion-resistant reinforcement used instead, where appropriate [2].

1.1.3 Cathodic Protection and Cathodic Prevention

Cathodic protection uses anodes embedded within or attached to the surface of the concrete or concrete repair, and electrically connected to the reinforcing steel. This drives the electrochemical reaction such that the steel is the cathode, or the part of the electrochemical cell that is not consumed. The two types of cathodic protection are:

- **Galvanic (sacrificial)** – anode is consumed; protection is provided by the inherent difference in electric potential between anode and structure.
- **Impressed current** – anode is inert and consumed very slowly; protection is provided by using an external power supply to supply current.

The appropriate type to use depends on the situation. With both, there is an initial “charging” of the steel to re-passivate, drive out chlorides, and build up hydroxyl ion, and then a maintenance stage to maintain passivity. NACE International (now AMPP, the Association for Materials Protection and Performance) published a 2020 revised report that included detail on the different types of galvanic anode cathodic protection that are commonly used with reinforced concrete [3].

For new construction, cathodic protection is also known as cathodic prevention. Cathodic prevention is specific to situations where chlorides have not yet reached the steel and is used to prevent chloride migration and depassivation from occurring in the first place [4].

Research by the Federal Highway Administration (FHWA) has shown cathodic protection to be the only technique that can mitigate corrosion in concrete bridge decks regardless of chloride levels in the concrete [5].

1.1.4 Test Method M-82 for Evaluation of Corrosion Mitigation Performance

Test method M-82, Standard Protocol to Evaluate the Performance of Corrosion Mitigation Technologies in Concrete Repairs, was published in 2014 out of the Reclamation Technical Service Center [6]. Development of the test method was externally funded, and the work was done by Tourney Consulting Group. With the many options existing for concrete repair, this document provides test protocols to evaluate the success of each repair method when corroded reinforcing bars are present. This is a useful reference to provide technical information in determining concrete repair performance. There is ongoing discussion on revising the M-82 to incorporate updated results into the document.

Further work by Reclamation and non-Reclamation team members developed a test protocol specifically for sacrificial anodes in patch repairs, as informed by the M-82 document. The work was titled "Test Protocol to Evaluate the Effectiveness of Embedded Sacrificial Anodes in Reinforced Concrete," and was presented at the 2016 CORROSION conference held by the National Association of Corrosion Engineers (NACE, now AMPP) [7].

1.2. Research Objectives

This research sought to investigate whether concrete corrosion is a significant issue at Reclamation facilities and whether further investigation is warranted into corrosion protection methods that should be implemented for Reclamation structures. This was accomplished through review of Reclamation Asset Management Division (AMD) resources and outreach to field contacts.

2. Data Collection

To determine the breadth of concrete corrosion issues at Reclamation, the team surveyed Reclamation resources to find potential cases of steel reinforcement corrosion.

2.1 DSIS Search

The Dam Safety Information System (DSIS) is a database where recommended corrective actions for Reclamation facilities can be documented. Entries can include information such as the recommendation year, category, type, source, status, estimated cost, scheduled completion date, and general notes on the situation.

Researchers used a download of the DSIS report from December 15, 2023 to search for recommendations that could potentially have corrosion of reinforcing steel as a factor contributing to concrete deterioration. This was accomplished through successive keyword searches of the recommendation notes. The total number of recommendations after each phase of the keyword search is listed below:

- 41,580 – total recommendations prior to keyword searches
- 4,315 – include keyword "concrete"
- 322 – include keywords "concrete" <u>and</u> "rebar" or "reinforcing"
- 101 – include keywords "concrete" <u>and</u> "rebar" or "reinforcing" <u>and</u> "spall"
- 24 – same as above <u>and</u> work status is "incomplete"

The final list included 24 recommendations of interest, listed by Reclamation region in Table 1.

Table 1.—Number of DSIS Recommendations of Interest Identified in Each Reclamation Region

Reclamation Region	Identified Recommendations
California-Great Basin	6
Columbia-Pacific Northwest	1
Lower Colorado Basin	3
Missouri Basin	8
Upper Colorado Basin	6
Total	**24**

Research team members reached out to field contacts at some of the offices identified by the DSIS search to request more information, review available inspection or maintenance reports and photographs, and to try and determine if corrosion protection would be a viable or effective solution to help mitigate the issues being experienced. Some of the information gathered is included in Appendix A. Findings showed that in most cases, concrete corrosion could not be conclusively shown to be the primary factor in causing concrete deterioration, but was typically a secondary factor resulting in faster deterioration. Commonly, alkali-silica reaction (ASR) or other factors were more of a primary concern, and it could not be determined if concrete corrosion began before or after the reinforcing steel became exposed.

2.2 Bridge Inventory Search

Since the outreach to the DSIS search facilities did not result in many structures primarily experiencing concrete corrosion, researchers pursued a second avenue for data collection using the Reclamation bridges inventory. Bridges and roadway structures are often susceptible to corrosion issues due to presence of chlorides (deicing salts) and other contaminants and additional cyclic stresses.

For these bridges and roadways, concrete service life models are often based on the time to corrosion of rebar, which considers concrete cover (typically 2–4 inches), chloride surface concentration, and chloride ion diffusion coefficient (varies between concrete mixtures). With these factors, it is possible to calculate the time for sufficient chlorides to build up at the reinforcing steel to cause corrosion. This is critical for bridges and pavement due to the prevalence of deicing salts. Reclamation typically has closer to 4-inch rebar cover and less exposure to deicing salts.

Reclamation AMD maintains a database of all bridge and roadway structures owned or operated by Reclamation. The database includes information on factors such as age, material type and design, average daily traffic, design load, and length, with an approximate total of 8,000 bridges. AMD staff provided a download of the Bridges Inventory that was pulled on February 2, 2024.

In the bridge search, researchers focused on Type 1 bridges, which are roadways, making them more likely to have deicing salts applied in the winter. This narrowed the list to roughly 400 structures, and researchers further narrowed by focusing only on concrete deck bridges. The final list of results included 5 structures in the Missouri Basin (MB) region. Some photographs and information obtained from outreach to MB bridge contacts are listed in Appendix B. In discussions, regional contacts indicated that there was not great need for corrosion protection on MB bridges and roadways at this time.

3. Conclusions and Future Work

Conclusions are listed below:

- Field outreach from the DSIS search did not come back with any definitive concrete corrosion examples.
    - More often, concrete corrosion was a secondary issue that began only after a primary issue, such as alkali-silica reactivity.
    - However, field outreach was very limited and may not accurately reflect the circumstances across all of Reclamation.
- Roadway structures from the bridge search showed greater likelihood of experiencing concrete corrosion than Reclamation's other concrete structures.

These findings indicate that, at this time, there is not sufficient need or benefit to begin widespread implementation of additional corrosion protection techniques for Reclamation's reinforced concrete infrastructure other than those already utilized (e.g., adequate cover).

However, targeted implementation may still be useful if corrosion of the reinforcing steel can be definitively shown to be the primary factor in concrete deterioration, or a significant secondary effect due to adverse exposure conditions. This could be further investigated or verified through future work, such as:

- Conducting broader field outreach or data searches to reach more Reclamation offices.
- Use of online resources such as Web Soil Survey to cross-reference geographic regions of high chloride levels with the data search.
- Demonstration project to perform half-cell potential surveys and ground penetration radar surveys on concrete structures with a high probability for corrosion risk to definitively determine if concrete corrosion is occurring.
- Continued communication with Reclamation bridge program to discuss the possibility of corrosion protection on roadway structures identified as having concrete corrosion issues.

4. References

[1] FHWA/VTRC 06-R29, "Summary Report on the Performance of Epoxy-Coated Reinforcing Steel in Virginia" (Charlottesville, VA: Virginia Transportation Research Council, 2006). Available: http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-r29.pdf

[2] FHWA/VCTIR 11-R21, "Acceptance Procedures for New and Quality Control Procedures or Existing Types of Corrosion-Resistant Reinforcing Steel" (Charlottesville, VA: Virginia Center for Transportation Innovation and Research, 2011). Available: http://www.virginiadot.org/vtrc/main/online_reports/pdf/11-r21.pdf

[3] NACE TR01105-2020, "Sacrificial Cathodic Protection of Reinforced Concrete Elements—A State-of-the-Art Report" (Houston, TX: NACE).

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[6] M-82, "Standard Protocol to Evaluate the Performance of Corrosion Mitigation Technologies in Concrete Repairs" (Washington, DC: U.S. Bureau of Reclamation, 2014). Available: https://www.usbr.gov/tsc/techreferences/mands/manuals.html

[7] N.S. Berke, D. Little, B.E. Bucher, K.F. Von Fay, "Test Protocol to Evaluate the Effectiveness of Embedded Sacrificial Anodes in Reinforced Concrete," CORROSION 2016 paper no. 7524 (Houston, TX: NACE International, 2016).

5. Supporting Data Sets

Additional files associated with this research are stored on the Reclamation Technical Service Center network (internal only) as described below:

- **File Path.**—\\bor\do\TSC\Jobs\DO_NonFeature\Science and Technology\2023-PRG-Investigating Corrosion Protection of Steel Reinforcements in Concrete
- **Point of Contact.**—Grace Weber, gweber@usbr.gov, 303-445-2327
- **Short Description of Data.—**Files primarily include: photographs, data, and emails from data search; documents associated with literature review; and project management files.
- **Keywords.—**aging infrastructure, cathodic protection, concrete rebar, corrosion mitigation, reinforced concrete.
- **Approximate Total File Size.**—698 MB, 216 files, 27 folders

Appendix A – Photographs of Structures Identified from DSIS Search

Figure A-1.—Exposed rebar along a bridge crossing over a canal. The bridge is a roadway that has deicing salts applied in the winter. It has not required previous repairs and it is unknown whether concrete corrosion caused the initial concrete deterioration.

Figure A-2.—Deteriorated concrete with exposed reinforcing steel that has required multiple repairs at the same location. The suspected cause is ASR and subsequent freeze-thaw. Notes on other structures from the same region: roadways that are treated with deicing salts in the winter have not experienced major spalling or delamination, just minor cracking and a few popouts.

Figure A-3.—Spalling pedestal with exposed reinforcing steel. The initial cause of the concrete deterioration is unknown.

Figure A-4.—This structure has documented issues with ASR. Left: deteriorated concrete due to ASR. Right: Old concrete removed from around reinforcing steel prior to repair.

Figure A-5.—Spalling and exposed rebar on underside of stair treads on the spiral staircase between the upper and middle galleries. Rebar corrosion and concrete damage likely due to inadequate cover.

Figure A-6.—Deteriorated concrete on a walkway.

Figure A-7.—Concrete damage, possibly due to ASR. Generally, no corrosion staining is visible, except some possible corrosion staining at the wall on the lower right corner of the image.

Figure A-8.—Cracking along a parapet wall due to freezing and thawing.

Figure A-9.— Concrete slabs exhibiting widespread horizontal cracking with relatively narrow widths. The source of the cracking is likely due to freezing and thawing.

Appendix B – Photographs of Structures Identified from Bridge Inventory Search

Figure B-1.—Type 1 bridge. Location noted as having deterioration, cracking, efflorescence, rust staining, spall, and exposed rebar with corrosion.

Figure B-2.—Type 1 bridge. Location noted as having deterioration, cracking, efflorescence, spall, and water staining. Corrosion was not noted as an issue.

Figure B-3.—Type 1 bridge. Location noted as having cracking, spalling, and one instance of exposed rebar. Corrosion is not explicitly mentioned in inspection reports.

Figure B-4.—Type 1 bridge. Location noted as having exposed rebar. Corrosion is not explicitly mentioned in the inspection reports, but the rebar corrosion and concrete damage may be due to inadequate cover.