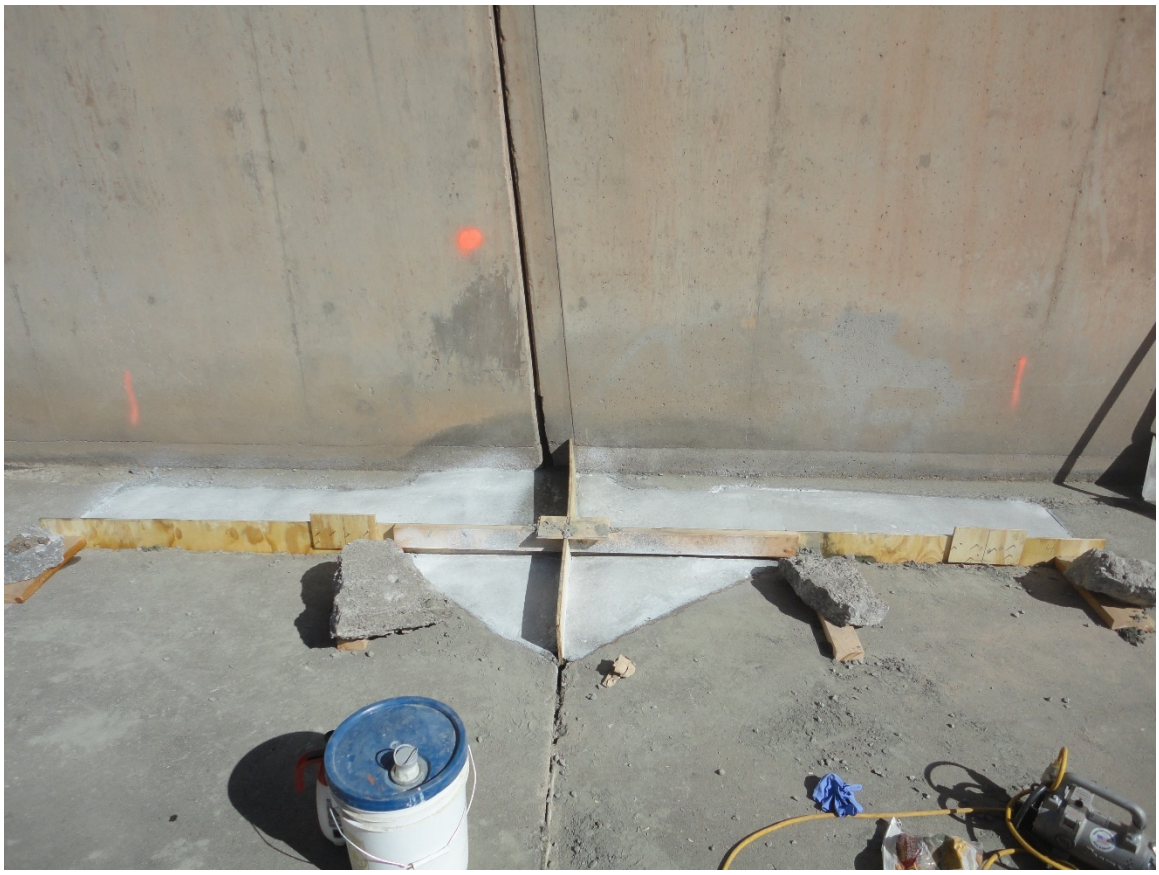
RECLAMATION

Managing Water in the West

Permeability Compatibility Between Concrete Repair Material and Concrete Substrate – Scoping Study

Research and Development Office
Science and Technology Program
Final Report ST-2018-1863-01 (8530-2018-58)



U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

September 2018

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 Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
T1. REPORT DATE: SEPTEMBER 2018	**T2. REPORT TYPE:** RESEARCH		**T3. DATES COVERED**
T4. TITLE AND SUBTITLE Permeability Compatibility Between Concrete Repair Material and Concrete Substrate - Scoping Study			**5a. CONTRACT NUMBER** 18XR0680A1-RY15412018WI31863
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. AUTHOR(S) Shannon Harrell, P.E. sharrell@usbr.gov 303-445-2370			**5d. PROJECT NUMBER** ST-2018-1863-01
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER 86-68530
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Shannon Harrell, P.E. Bureau of Reclamation Technical Services Center Concrete, Geotechnical, and Structural Laboratory			**8. PERFORMING ORGANIZATION REPORT NUMBER** 8530-2018-58
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research and Development Office U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007			**10. SPONSOR/MONITOR'S ACRONYM(S)** **R&D:** Research and Development Office **BOR/USBR:** Bureau of Reclamation DOI: Department of the Interior
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) ST-2018-1863-01
12. DISTRIBUTION / AVAILABILITY STATEMENT **Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/**			
13. SUPPLEMENTARY NOTES			
14. ABSTRACT The primary objective of this report is to develop a robust research program and to highlight the importance of research related to freeze-thaw durability and repair material compatibility with existing concrete substrates. This report will identify several organizations in the concrete industry that have identified better concrete durability as a key goal.			
15. SUBJECT TERMS Concrete repair, freeze thaw, compatibility			
16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT** U
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	

18. NUMBER OF PAGES	**19a. NAME OF RESPONSIBLE PERSON**
15	Shannon Harrell
	19b. TELEPHONE NUMBER 303-445-2370

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

BUREAU OF RECLAMATION

Research and Development Office
Science and Technology Program

Concrete, Geotechnical, and Structural Laboratory, 86-68530

Final Report ST-2018-1863-01 (8530-2018-58)

Permeability Compatibility Between Concrete Repair Material and Concrete Substrate - Scoping Study

SHANNON HARRELL
Digitally signed by SHANNON HARRELL
Date: 2018.09.25 10:15:34 -06'00'

Prepared/Technical Approval by: Shannon Harrell, P.E.
Civil Engineer, Concrete, Geotechnical, and Structural Laboratory Group, 86-68530

Checked by: Katie Bartojay, P.E.
Civil Engineer, Concrete, Geotechnical, and Structural Laboratory Group, 86-68530

WESTIN JOY
Digitally signed by WESTIN JOY
Date: 2018.09.25 10:29:34 -06'00'

Peer Review: Westin Joy, P.E.
Civil Engineer, Concrete, Geotechnical, and Structural Laboratory Group, 86-68530

Acronyms and Abbreviations

ACI	American Concrete Institute
ARPA-E	Advanced Research Projects Agency-Energy
ASTM	ASTM International
DOE	Department of Energy
ICRI	International Concrete Repair Institute
SDC	Strategic Development Council

Executive Summary

The discussion of repair material compatibility with the existing concrete substrate has been a topic of discussion between concrete repair experts for many years. Most of the compatibility discussions have been focused on dimensional compatibility between repair materials and existing substrates, but there has not been much emphasis on permeability compatibility. When permeability has been investigated, most studies looked at the repair material itself and not the composite system. Many researchers have studied freeze-thaw durability of repair materials using ASTM C666 [1], or the permeability as it relates to chloride ion penetration using ASTM C1202 [2], which relates more to corrosion of embedded steel. There is one example of issues with permeability between the concrete substrate and the repair material that has been cited in several references. However, there is limited research into how a low permeability repair material placed over a highly permeable concrete substrate will affect the long-term durability of the repair in cold weather environments.

Water vapor transmission is the key compatibility issue that will be discussed in this report. Water vapor transmission becomes an issue when a low permeability repair material placed over an existing concrete substrate allows the transport of water vapor to the interface between the repair material and the existing concrete substrate. If the repair is thin, the water vapor may freeze and hydraulic pressure may cause the repair to disbond from the existing concrete, leading to failure of the repair [3].

This scoping study came to the following conclusions:

- Concrete durability is one of the topics leading experts find important for the development of the concrete industry.
    - Both SDC and ARPA-E list concrete durability as goals for the concrete industry.
- There is limited guidance by ICRI for specifying concrete repair overlays that may be subject to water vapor transmission passing through the existing concrete substrate.
- There has been little research on freeze-thaw durability of the composite system. Most studies have looked only at freeze-thaw durability of the repair material.
- Typical guidance for specifying permeability of concrete repair materials has been to specify a low permeability material because of its resistance to chloride penetration and carbonation of the concrete.
- More applied research in the laboratory is recommended.

Contents

Figures

Abstract

The primary objective of this report is to develop a robust research program and to highlight the importance of research related to freeze-thaw durability and repair material compatibility with existing concrete substrates. This report will identify several organizations in the concrete industry that have identified better concrete durability as a key goal.

Background

The discussion of repair material compatibility with the existing concrete substrate has been a topic of discussion between concrete repair experts for many years. Most of the compatibility discussions have been focused on dimensional compatibility between repair materials and existing substrates, but there has not been much emphasis on permeability compatibility. When permeability has been investigated, most studies looked at the repair material itself and not the composite system. Many researchers have studied freeze-thaw durability of repair materials using ASTM C666 [1], or the permeability as it relates to chloride ion penetration using ASTM C1202 [2], which relates more to corrosion of embedded steel. There is one example of issues with permeability between the concrete substrate and the repair material that has been cited in several references. However, there is limited research into how a low permeability repair material placed over a highly permeable concrete substrate will affect the long-term durability of the repair in cold weather environments.

Water vapor transmission is the key compatibility issue that will be discussed in this report. Water vapor transmission becomes an issue when a low permeability repair material placed over an existing concrete substrate allows the transport of water vapor to the interface between the repair material and the existing concrete substrate. If the repair is thin, the water vapor may freeze and hydraulic pressure may cause the repair to disbond from the existing concrete, leading to failure of the repair [3].

Previous Work

In 2017, the Bureau of Reclamation's (Reclamation) Research and Development office through the Science and Technology program funded the scoping study report number ST-2017-7103-01, *Development of Practical Guidelines to Achieve Compatibility in Concrete Repairs and Overlays- Scoping Study*. Through that project, the Concrete, Geotechnical, and Structural Laboratory (CGSL) identified permeability as a concrete repair material compatibility issue that required further investigation. There has been very little research focus on permeability as it relates to water vapor transmission and bond failure between repair materials and existing concrete substrates [4].

Reclamation's involvement with the concept of concrete repair compatibility was started with the Materials Engineering and Research Laboratory (MERL) report number MERL-2014-87, *Compatibility Issues in Design and Implementation of Concrete Repairs and Overlays* which was also funded by Reclamation's Research and Development office through the Science and

Technology program. The report identified 5 compatibility issues that require further study; dimensional, permeability, electrochemical, chemical, and aesthetic compatibility [5].

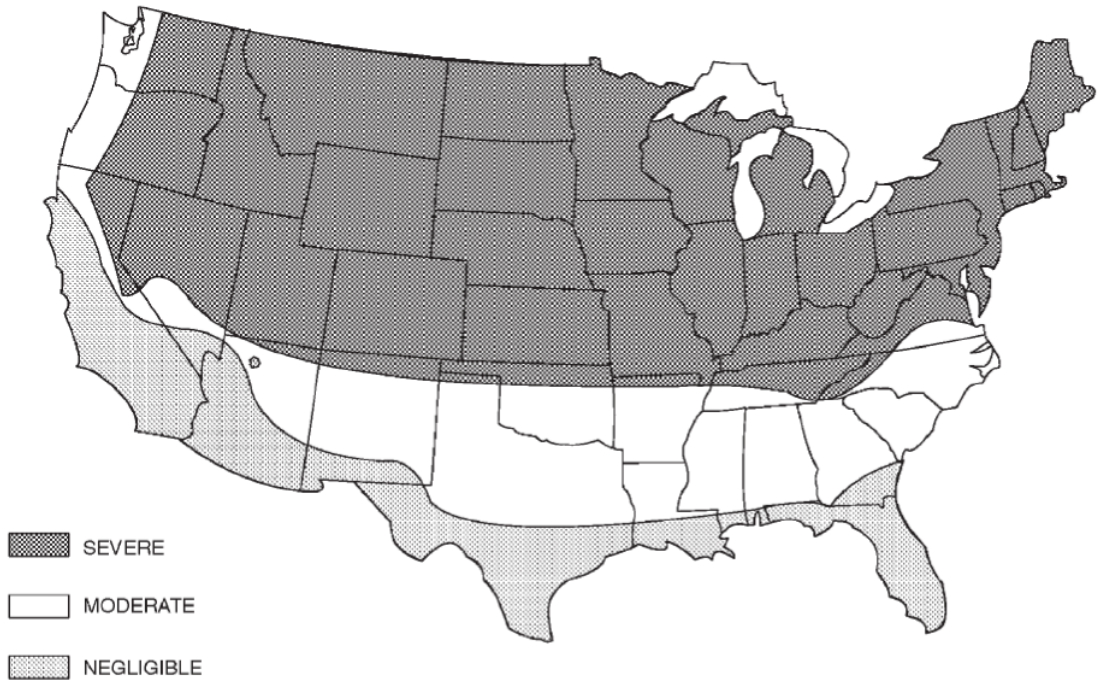
MERL report number MERL-2014-87, referenced Vaysburd and Emmons [6] which discusses the potential of encapsulating concrete through protective vapor barriers. The vapor barrier traps moisture below the impermeable coating and can lead to freeze-thaw damage of the concrete. MERL-2014-87 referenced Vaysburd, noting that further studies should be conducted to determine what degree of permeability should be recommended for repair materials. The question was raised: “Is a very low permeability or matching (with the existing concrete) permeability more effective?” [5] [7].

Conclusions

- Concrete durability is one of the topics leading experts find important for the development of the concrete industry.
    - Both SDC and ARPA-E list concrete durability as goals for the concrete industry.
- There is limited guidance by ICRI for specifying concrete repair overlays that may be subject to water vapor transmission passing through the existing concrete substrate.
- There has been little research on freeze-thaw durability of the composite system. Most studies have looked only at freeze-thaw durability of the repair material.
- Typical guidance for specifying permeability of concrete repair materials has been to specify a low permeability material because of its resistance to chloride penetration and carbonation of the concrete.
- More applied research in the laboratory is recommended.

Discussion

The following literature review has been provided to highlight the lack of guidance as it pertains to concrete repair material permeability. There has been very limited guidance on how to handle specifying a concrete repair overlay in a concrete structure where the existing concrete may be saturated prior to repair or may have a means of water vapor transmission through the existing concrete. In general, the guidance is simply to consider that a low permeability repair material may not be appropriate. The literature review also reinforces the author’s view that durability is an issue throughout the concrete industry. Although dimensional, chemical, electrochemical, and chemical compatibility are important to long lasting concrete repairs, permeability is just as important in cold weather climates and should not be ignored. Many Reclamation projects fall in this F/T affected exposure classification. Figure 1 below shows that many of Reclamation facilities are in “severe weathering probability” zones.



a. Alaska and Hawaii are classified as severe and negligible, respectively.
b. Lines defining areas are approximate only. Local conditions may be more or less severe than indicated by region classification. A severe classification is where weather conditions result in significant snowfall combined with extended periods during which there is little or no natural thawing causing deicing salts to be used extensively.

FIGURE R301.2(3)
WEATHERING PROBABILITY MAP FOR CONCRETE

Figure 1. Freeze-thaw probability map from International Residential Code 2009 [8].

Literature Review

ICRI Recommendation [3]

The International Concrete Repair Institute (ICRI) has numerous technical guides to educate the concrete repair industry on specifying repair materials, appropriate surface conditions and preparation of the existing concrete substrate, concrete removal and repair material application methods, and many more. One of these technical guides, Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces (Guideline No. 320.2R-2009) [3] discusses the properties that should be specified as it relates to a durable repair. However, when it comes to permeability, the recommendation in section 3.3.1 is a low permeability repair material to resist chloride ion penetration and carbonation of the concrete. There is no discussion as to how a low permeability repair material placed over a highly permeable and saturated concrete substrate may affect freeze-thaw damage potential.

Freezing and thawing resistance is also discussed in ICRI Guideline No. 320.2R-2009 [3] in section 3.3.3, but the recommendation is based on freeze-thaw resistance of the repair material and not necessarily the composite section.

Water vapor transmission through the repair material is discussed in the ICRI Guideline No. 320.2R-2009 [3] as being an issue if water vapor is transmitted through the substrate and trapped below a low permeability repair material. ASTM E96 [9] is the recommended test method to determine the water vapor transmission of the material. However, many major repair material manufacturers either do not test their products using ASTM E96 [9] or do not publish the results in their technical data sheets. In addition, Guideline No. 320.3R-2012 [10], Guideline for Inorganic Repair Material Data Sheet Protocol, does not recommend ASTM E96 [9] as a test method that should be conducted or reported by the repair material manufacturers [10]. Without the publication of this information by the manufacturer, it is difficult to know if the repair material will be compatible with the existing substrate when it comes to water vapor transmission. Furthermore, there is uncertainty in what the range of values ASTM E96 [9] gives and what limits truly affect the bond.

Strategic Development Council (SDC) [11]

The Strategic Development Council (SDC) is a council of the ACI Foundation which was formed to facilitate and accelerate the acceptance of new technologies. SDC has developed a Concrete 2029 initiative where one of their goals is durability roadmapping. SDC has been holding numerous Concrete 2029 workshops during the biannual technology forums. The 2017 Spring workshop held in Dallas, TX focused the discussion on durability design and what improvements need to be made in the U.S. to achieve better concrete durability in the future.

An overview of International codes and how they approach durability was highlighted. The biggest takeaway was the emphasis on expected design service life. The Japan Society of Civil Engineers have a chapter on verification of durability to determine if steel corrosion, freeze-thaw damage, or chemical attack will affect the required performance of the structure. ACI 318 has no reference to design service life [12].

ARPA-E Workshop [13]

Advanced Research Projects Agency-Energy (ARPA-E) was established as an advanced research project agency within the Department of Energy (DOE) to “identify the most urgent challenges the U.S. faces in maintaining leadership in key areas of science and technology.” ARPA-E funds research on energy technologies to foster the United States’ economic and energy security.

In April 2018, ARPA-E held an *Extremely Durable Cementitious Materials Workshop* which brought together leading experts in the concrete industry. The workshop included representatives from government, academic, and private sector industries. The purpose of the workshop was to “identify innovation which significantly improves durability, lowers its energy footprint, and results in next generation, cost-effective materials to address our current infrastructure challenges.”

One of the themes that routinely arose during the discussions was the need for more durable concrete. These discussions also focused on the gaps in the industry for long term durability and how the U.S. has fallen behind in defining exposure conditions and requiring that durability be a focus during design. This was also highlighted in the SDC workshop discussed above.

The workshop challenged the attendees to have an open discussion about the following goals and how they could be achieved:

1. Double concrete durability with two times longer service life.
2. Halve O&M expenses.
3. Use of existing facilities.
4. Lower concrete costs.

Reclamation was a part of this workshop to bring to the table how concrete durability (or lack thereof) affects our infrastructure. We discussed the importance of durable concrete due to our mission of reliably delivering water and power to the 17 western states.

Recommendations for Next Steps

Laboratory Research Strategy

Laboratory research should be conducted to answer the following questions:

1. Will a low permeability repair material placed over a highly permeable and saturated existing concrete substrate lead to *bond failure* of the concrete after cycles of freezing and thawing due to trapping water vapor below the concrete repair material?
2. Will a low permeability repair material placed over a highly permeable and saturated existing concrete substrate lead to an *acceleration of freeze-thaw deterioration* of the existing concrete substrate due to trapping water vapor below the concrete repair material?

Bond Failure Investigation

Investigation of the bond failure between a low permeability repair material and highly permeable and saturated existing concrete substrate will be tested in the lab by first casting specimens that are highly permeable. The slabs will be saturated to different levels to determine if there is a degree of saturation at or beyond which bond failure is likely to occur. A low permeability repair material will be cast on top of the highly permeable specimens. Bond testing of the specimens utilizing the pull-off test per ASTM C1583 [14] will be used to set a baseline of the bond strength that is expected for each degree of saturation. The specimens will then be subjected to freeze-thaw testing per ASTM C666 [1] and retested for bond strength per ASTM C1583 [14] at the completion of the ASTM C666 procedure. Figure 2 shows the configuration of the concrete specimens for the bond failure investigation.

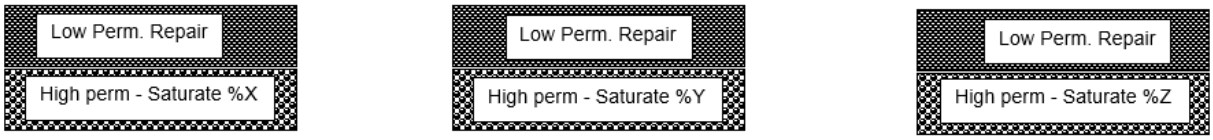


Figure 2. Concrete specimens used for bond failure investigation.

Acceleration of Freeze-thaw Deterioration Investigation

Highly permeable concrete specimens without low permeability concrete overlays will be cast at the same time as the specimens for the bond failure investigation. The specimens will be subjected to freeze-thaw testing per ASTM C666 [1] at the same time as the bond failure specimens.

At the end of testing, a petrographic examination will be conducted to compare the degree of deterioration of highly permeable specimens with low permeability concrete overlays to highly permeable specimens without an overlay. Figure 3 shows the two different specimens that will be used for this portion of the investigation.

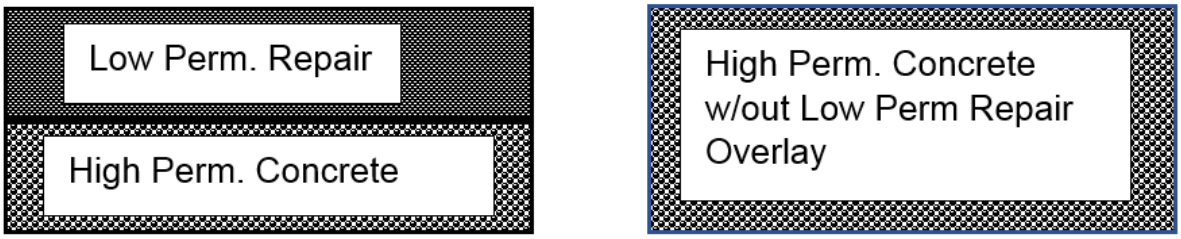


Figure 3. Concrete specimens used for accelerated freeze-thaw deterioration investigation.

Further Studies

Successful outcomes from the laboratory research outlined above could lead to the following additional investigations:

- Field study to determine if results are similar to those observed in the laboratory study.
- Development of guidance for specifying concrete repair overlays in freeze-thaw prone locations.

References

[1] ASTM, *ASTM C666/C666M - Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing,* West Conshohocken, PA: ASTM International, 2015.

[2] ASTM, *ASTM C1202 - Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration,* West Conshohocken, PA: ASTM International, 2017.

[3] International Concrete Repair Institute (ICRI), "Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces (Guideline No. 320.2R-2009)," International Concrete Repair Institute, Des Plaines, IL, May 2009.

[4] S. Harrell, "Development of Practical Guidelines to Achieve Compatibility in Concrete Repairs and Overlays - Scoping Study," Bureau of Reclamation, Research and Development Office, Denver, CO, 2017.

[5] A. M. Vaysburd, B. Bissonnette and K. F. von Fay, "Compatibility Issues in Design and Implementation of Concrete Repairs and Overlays- MERL-2014-87," U.S. Department of the Interior, Bureau of Reclamation, Denver, CO, 2014.

[6] P. H. Emmons and A. M. Vaysburd, "Factors Affecting Durability of Concrete Repair - The Contractor's Viewpoint.," in *Proceedings of the Fifth International Conference on Structural Faults and Repair, 253-268,* Edinburgh, UK, 1993.

[7] A. M. Vaysburd, "Holistic System Approach to Design and Implementation of Concrete Repairs," *Cement and Concrete Composites,* vol. 28, no. 8, pp. 671-678, 2006.

[8] International Code Council, International Residential Code, Country Club Hills, IL: International Code Council, Inc., 2009.

[9] ASTM, *ASTM E96 - Standard Test Method for Water Vapor Transmission of Materials,* West Conshohocken, PA: ASTM International, 2016.

[10] International Concrete Repair Institute (ICRI), "Guideline for Inorganic Repair Material Data Sheet Protocol (Guideline No. 320.3R-2012)," International Concrete Repair Institute, Rosemont, IL, 2012.

[11] ACI Foundation Strategic Development Council (SDC), "Concrete 2029," Dallas, TX, 2017.

[12] T. D. Marcotte, "Durability Design International Codes," in *SDC Technology Forum #41*, Dallas, TX, 2017.

[13] ARPA-E, "Extremely Durable Cementitious Materials," Dallas, 2018.

[14] ASTM, *ASTM C1583 - Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direction Tension (Pull-off Method),* West Conshohocken, PA: ASTM International, 2013.

Data Sets that Support the Final Report

If there are any data sets with your research, please note:

Share Drive folder name and path where data are stored: \\bor\do\ENGRLAB\MERL\Science and Technology\FY18\Harrell\Permeability\references

Point of Contact name, email, and phone: Shannon Harrell, sharrell@usbr.gov, 303-445-2370

Short description of the data: Literature references used in this study.

Keywords: ASTM, Concrete repair, compatibility.

Approximate total size of all files:13.5MB (folder size)