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Special and Unique: Lessons Learned from the Implementation of Pull-Off Testing as Part of Project Quality Assurance and Quality Control at Operating Nuclear Power Plants

Jeffrey M. Owad, PE, PMP
Engineering Manager
structural TECHNOLOGIES

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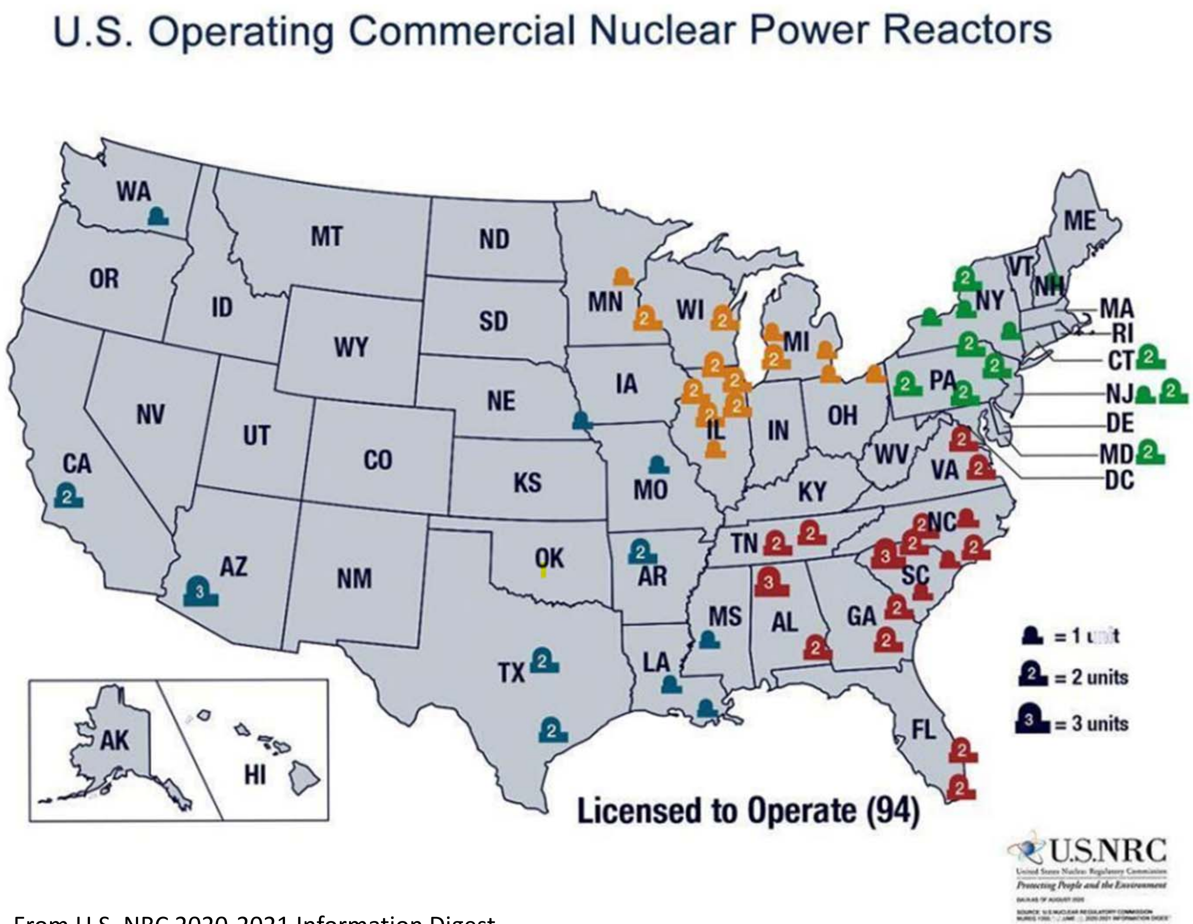
Agenda

- America's Aging Nuclear Fleet
- U.S. NRC Quality Requirements for Licensees
- What is Pull-Off Testing?
- Pull-Off Testing Acceptance Criteria
- Lessons Learned
- Questions?

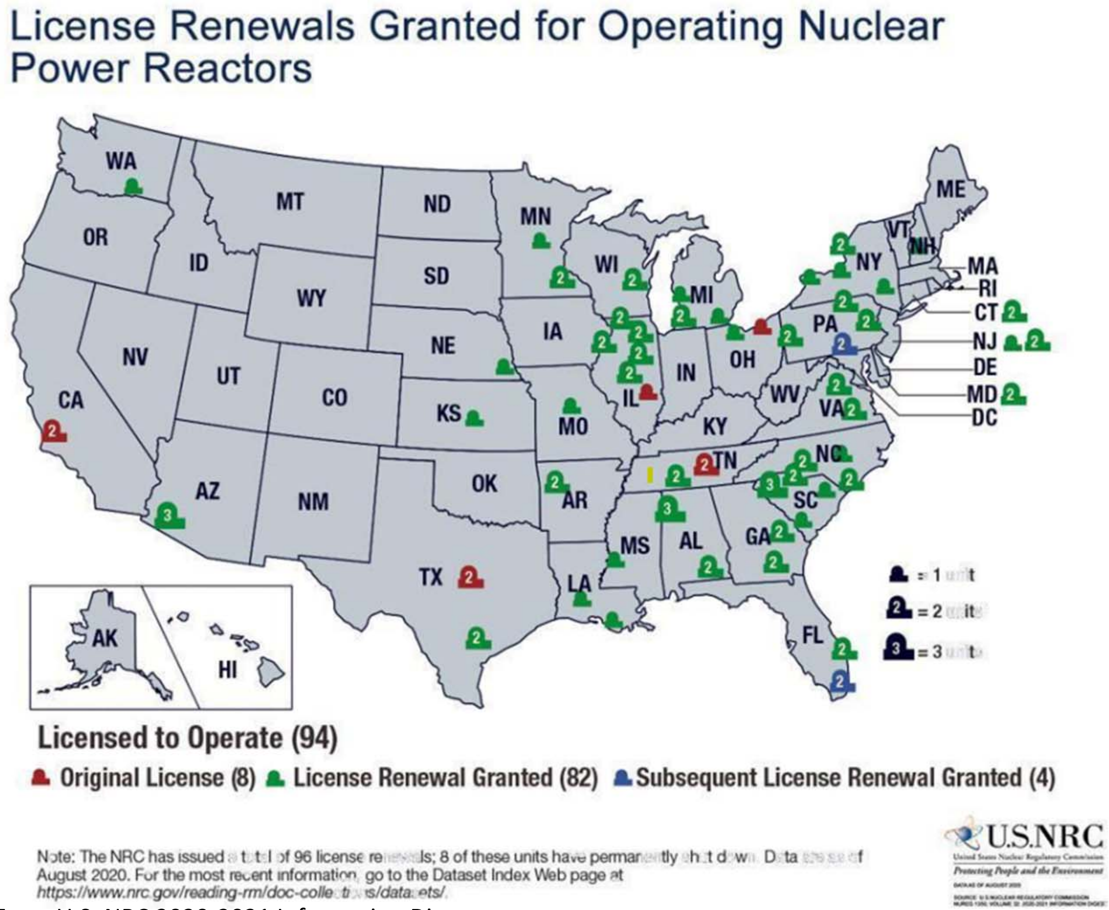
America's Aging Nuclear Fleet



From U.S. NRC 2020-2021 Information Digest

- America's operating nuclear generation fleet is responsible for ~20% of the United States' electrical use
- U.S. NRC regulates the operation of (94) licensed commercial nuclear power reactors

America’s Aging Nuclear Fleet

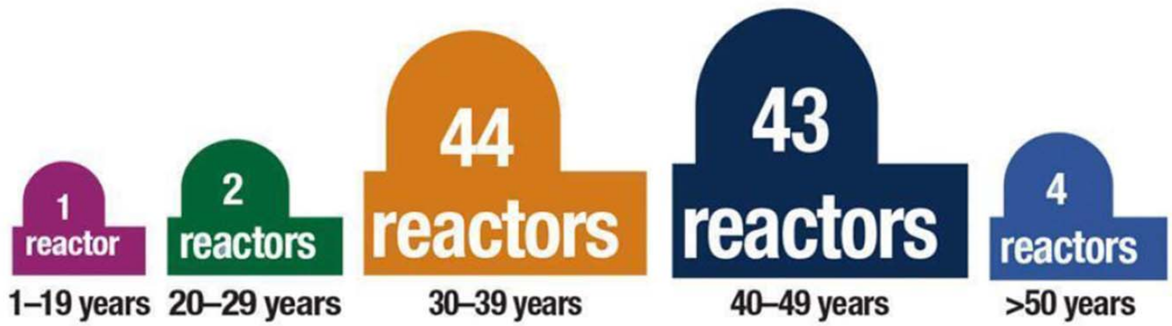


From U.S. NRC 2020-2021 Information Digest

- Each reactor is initially licensed for 40 years
- U.S. NRC has granted (86) of the (94) licensed commercial nuclear power reactors 20-year license extensions
  - (4) have been granted a 2nd 20-year license extension

America's Aging Nuclear Fleet

U.S. Commercial Nuclear Power Reactors
—Years of Operation by the End of 2020



Note: Ages are based on operating license issued date and have been rounded up to the end of the year. For the most recent information, go to the Dataset Index Web page at *https://www.nrc.gov/reading-rm/doc-collections/datasets/*.

From U.S. NRC 2020-2021 Information Digest

NRC Quality Requirements for Licensees

Appendix B to 10 CFR Part 50 establishes the Quality Assurance Criteria for Nuclear Power Plants and states:

> *"**Nuclear power plants and fuel reprocessing plants include structures, systems, and components that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public.** This appendix establishes quality assurance requirements for the design, manufacture, construction, and operation of those structures, systems, and components. The pertinent requirements of this appendix **apply to all activities** affecting the safety-related functions of those structures, systems, and components; these activities include **designing, purchasing**, fabricating, handling, **shipping, storing**, cleaning, **erecting, installing, inspecting, testing,** operating, maintaining, **repairing,** refueling, and modifying."*

NRC Quality Requirements for Licensees

Typical Set of Project Documents for a project at a Nuclear Power Plant and the responsible party

- Engineering Change Package (Utility)
- Plant Procedures (Utility)
- Work Order (Utility)
- Project Specifications / Criteria Documents (Utility/Contractor)
- Quality Plan (Utility/Contractor)
- Project Execution Plan (Contractor)
- Inspection and Test Plans (Contractor)

How does one successfully perform pull-off testing as part of a project quality plan at a nuclear power plant?

What is Pull-Off Testing?

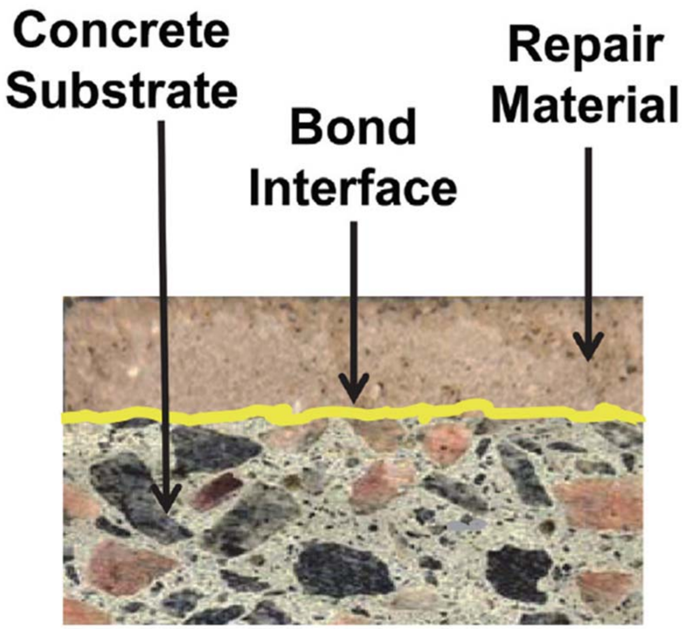


Fig. 1.1: Components of a composite overlay/ repair system

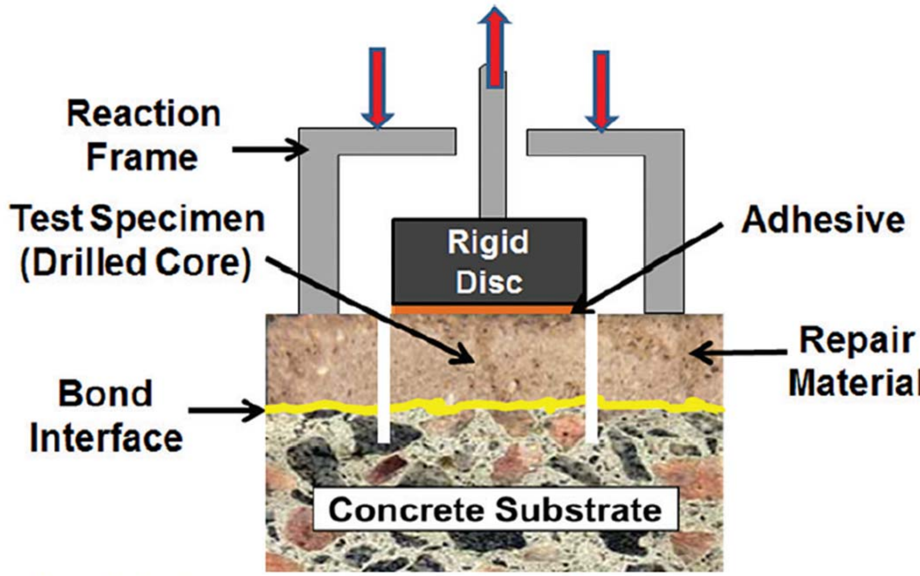


Fig. 3.3: Specimen preparation and test setup (composite system)

Figures from ICRI Technical Guideline No. 210.3R-2013

Acceptance Criteria and Test Plans

- No generally accepted pull-off test criteria
- Criteria should be determined based on experience
- Concrete is a variable material
- Results can be reviewed and evaluated by a competent individual to determine if acceptable

Acceptance Criteria and Test Plans

In nuclear power industry, acceptance criteria, in general, are:

- Specific
- Rigid
- Not Open for Interpretation

Testing and acceptance criteria need to be well documented and vetted prior to being put in use via:

- Documented performer training and qualifications
- Written test procedures
- Written test plans

Lesson Learned #1: Substrate Surface Preparation

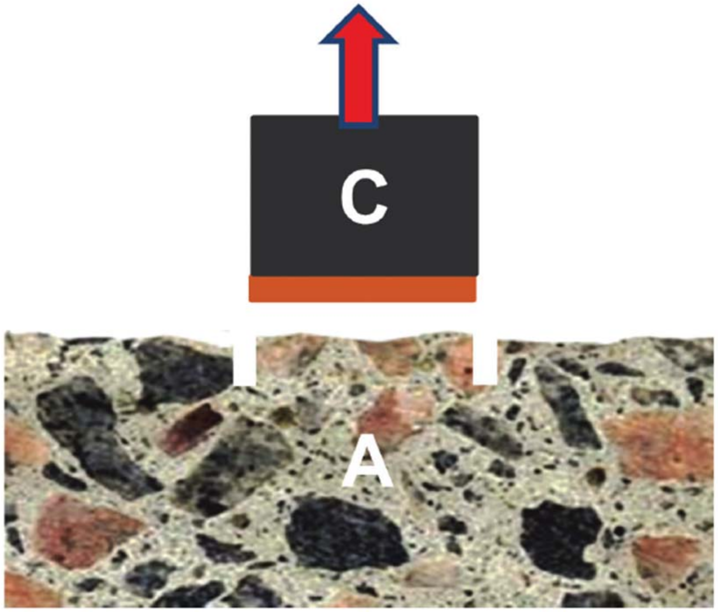


Fig. 3.9.a: Concrete substrate test: Failure Mode S1

Nuclear Industry "error trap":

Work orders & specific sequence of tasks

Figure from ICRI Technical Guideline No. 210.3R-2013

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Lesson Learned #1: Substrate Surface Preparation

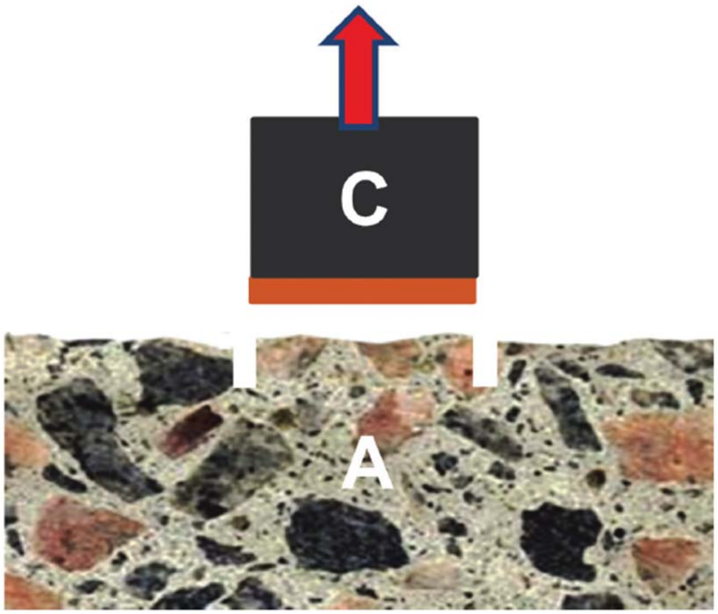

Fig. 3.9.a: Concrete substrate test: Failure Mode S1

Core ID	Bond Strength (PSI)	Failure Mode
NL7A2C1	72.9	S2
NL7A2C2	70.9	S1
NL7A2C3	175.2	S1
NL7A2C4	91.6	S1
NL7A2C5	88.9	S1
NL8A3C1	47.1	S1
NL8A3C2	263	S1
NL8A3C3	143.1	S1
NL8A3C4	216.9	S1
NL8A3C5	183.9	S1
NL9A2C1	185.7	S1
NL9A2C3	30	S1
NL9A2C4	200.8	S1
NL9A2C6	102.8	S1

Figure from ICRI Technical Guideline No. 210.3R-2013

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Lesson Learned #1: Substrate Surface Preparation

Core ID	Bond Strength (PSI)	Failure Mode
NL7A2C1	72.9	S2
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NL8A3C5	183.9	S1
NL9A2C1	185.7	S1
NL9A2C3	30	S1
NL9A2C4	200.8	S1
NL9A2C6	102.8	S1

Lesson Learned #1: Substrate Surface Preparation

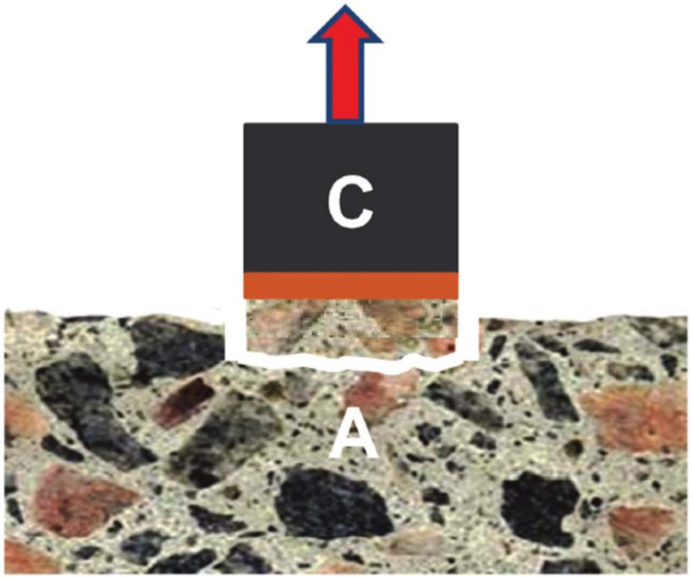
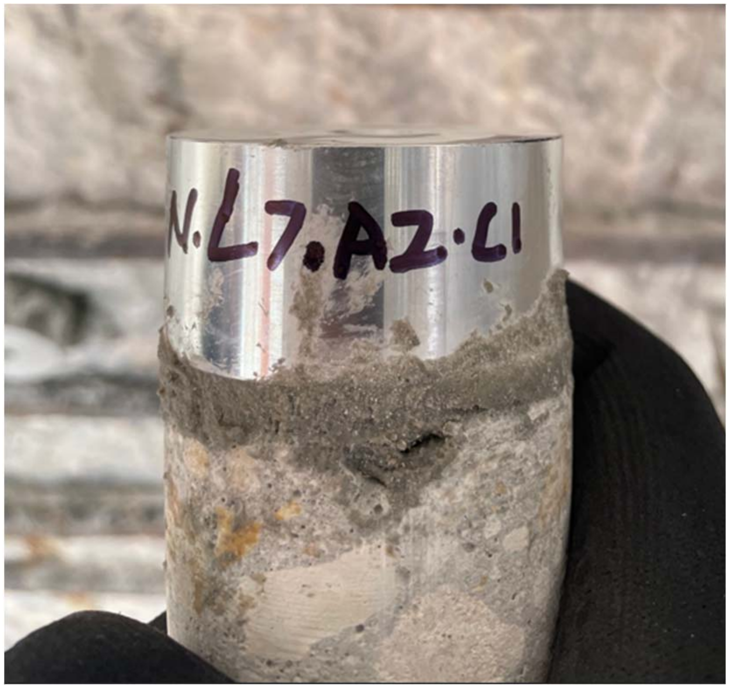


Fig. 3.9.b: Concrete substrate test: Failure Mode S2

Core ID	Bond Strength (PSI)	Failure Mode
NL7A2C1	72.9	S2
NL7A2C2	70.9	S1
NL7A2C3	175.2	S1
NL7A2C4	91.6	S1
NL7A2C5	88.9	S1
NL8A3C1	47.1	S1
NL8A3C2	263	S1
NL8A3C3	143.1	S1
NL8A3C4	216.9	S1
NL8A3C5	183.9	S1
NL9A2C1	185.7	S1
NL9A2C3	30	S1
NL9A2C4	200.8	S1
NL9A2C6	102.8	S1

Figure from ICRI Technical Guideline No. 210.3R-2013

Lesson Learned #1: Substrate Surface Preparation



Core ID	Bond Strength (PSI)	Failure Mode
NL7A2C1	72.9	S2
NL7A2C2	70.9	S1
NL7A2C3	175.2	S1
NL7A2C4	91.6	S1
NL7A2C5	88.9	S1
NL8A3C1	47.1	S1
NL8A3C2	263	S1
NL8A3C3	143.1	S1
NL8A3C4	216.9	S1
NL8A3C5	183.9	S1
NL9A2C1	185.7	S1
NL9A2C3	30	S1
NL9A2C4	200.8	S1
NL9A2C6	102.8	S1

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Lesson Learned #1: Substrate Surface Preparation

How did this happen:

- Lack of understanding of project execution steps by external stakeholders
- Overconfidence of internal stakeholders that work order was identical to previous project on adjacent unit

Changes moving forward:

- Quality Plan enhancements: In-process quality check list for field leaders and quality engineer developed
- All project documents reviewed and updated to remove potential error traps/ambiguous language
- Work Order was revised to list all tasks in the proper order

Lesson Learned #2: Depth of Core into Substrate

Imprecisely tracking & underestimating drill depth

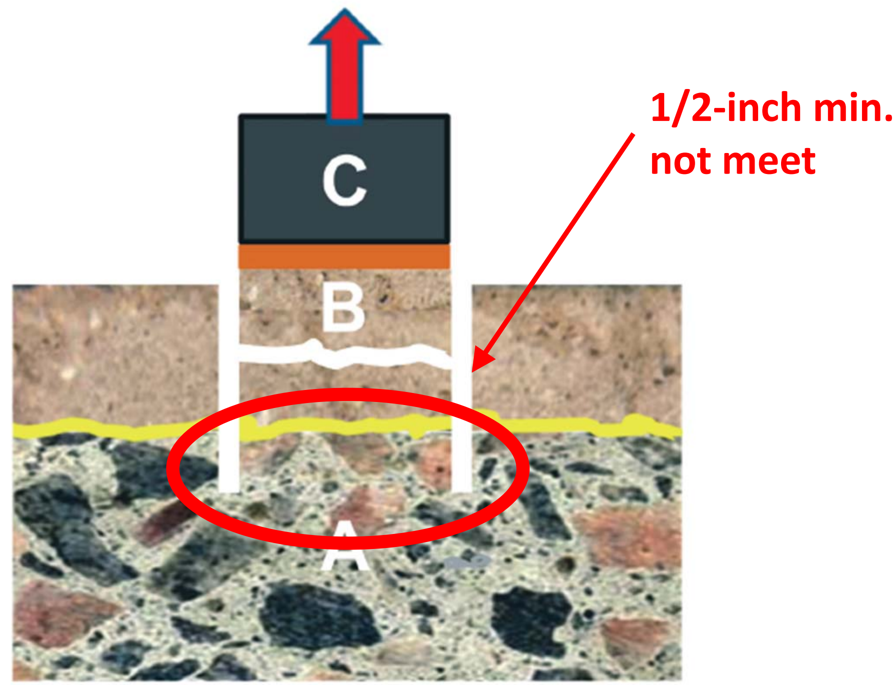

Fig. 3.9.d: Composite repair test: Failure Mode R2

Figure from ICRI Technical Guideline No. 210.3R-2013

Lesson Learned #2: Depth of Core into Substrate

How did this happen:

- Core depths were average over 1 ft x 1 ft grid along repair area.
- The testing lead reduced target drill depth from 1.5 inch to 1.0 inch

	QUANTITIES & DEMOLITION DEPTH (INCH)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	4.5	4	3.75	4.25	3.25	3.75	4.25	3.75	3.5	3	3	3.5	3.75	4.25	4	4.75	4.75	5.75	5.25	4.5
2	3.25	3.5	4	4	4.25	4.25	3.5	4.25	2.5	2.75	3.5	2.75	2.5	3.25	3.5	4	4.25	4.2	5	4.5
3	3															3.25	2.75	2.75	5.5	3.75
4																				

Lesson Learned #2: Depth of Core into Substrate

Changes moving forward:

- Project specification document was updated.
- Pre locating Composite Pull-off test locations
- Project Quality meeting to review incident
- More rigorous pre-job brief

Impact to project: pull-off testing paused for 2 months!

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Lesson Learned #3: Interpretation and Communication of Test Results.

Compressive strength was implied as a contributing cause to low pull-off test results

Core Id	Bond Strength (psi)	Failure Mode
1	151	R5
2	143	R5
3	127	R3
4	229	R6
5	302	R5
6	175	R3
7	350	R3
8	92	R5
9	Invalid test result	
10	64	R5
11	207	R5
12	63.6	R5
13	183	R5
14	159	R5

Mode R5 and Mode R6= failure in the substrate, Mode R3= failure at the bond surface

Lesson Learned #3: Interpretation and Communication of Test Results.

Definition: Operability

- A system, subsystem, train, component, or device shall be **OPERABLE** or have **OPERABILITY** when it is capable of performing its specified safety function(s), and when all necessary attendant instrumentation, controls, normal or emergency electrical power, cooling and seal water, lubrication and other auxiliary equipment that are required for the system, subsystem, train, component, or device to perform its specified safety function(s) are also capable of performing their related support function(s).

From U.S. NRC Inspection Manual Chapter 0326 – Operability Determinations

Lesson Learned #3: Interpretation and Communication of Test Results.

How did this happen:

- Project specifications were not detailed enough to address unsatisfactory results
- Contractor did not understand the potential negative impact of an unsatisfactory result and could not properly explain the technical basis for the test and how to properly interpret the results
- Owner's Engineer did not understand the what the test results meant prior to accepting this test as part of the project quality plan and made conservative assumptions when unsure

Lesson Learned #3: Interpretation and Communication of Test Results.

Changes moving forward:

- Prepared a white paper was prepared outlining the entire pull-off test process
- Prepared a formal written procedure for performing pull-off tests.
- Retrained project team
- Prepared a "Pull-Off Test Validation and Implementation Plan"
  - Acceptance criteria was changed from "The minimum tensile bond strength for the repair concrete is 150 psi or failure within the substrate" to…

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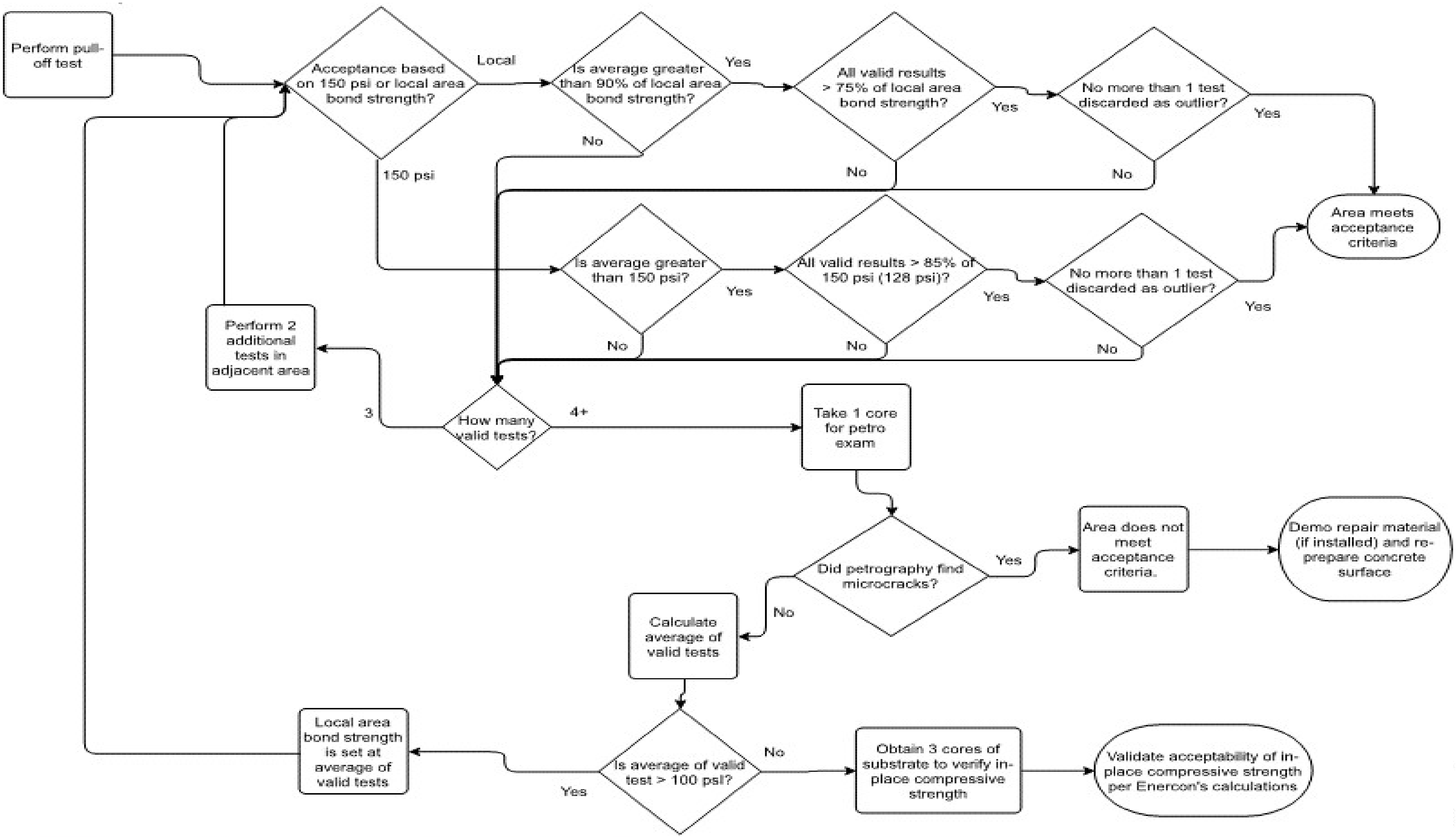
Perform pull-off test
Acceptance based on 150 psi or local area bond strength?
Local
150 psi
Is average greater than 90% of local area bond strength?
Yes
No
All valid results > 75% of local area bond strength?
Yes
No
No more than 1 test discarded as outlier?
Yes
No
Area meets acceptance criteria
Is average greater than 150 psi?
Yes
No
All valid results > 85% of 150 psi (128 psi)?
Yes
No
No more than 1 test discarded as outlier?
Yes
No
Perform 2 additional tests in adjacent area
How many valid tests?
3
4+
Take 1 core for petro exam
Did petrography find microcracks?
Yes
No
Area does not meet acceptance criteria.
Demo repair material (if installed) and re-prepare concrete surface
Calculate average of valid tests
Is average of valid test > 100 psi?
Yes
No
Local area bond strength is set at average of valid tests
Obtain 3 cores of substrate to verify in-place compressive strength
Validate acceptability of in-place compressive strength per Enercon's calculations

Questions?

Jeffrey M. Owad, PE, PMP
Engineering Manager

jowad@structuraltec.com
www.structuraltechnologies.com

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