Title	REACTOR BUILDING DELAMINATION REPAIR- PHASE 3 CONCRETE REMOVAL
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EC Folder Utilities (Rev 7)					Help
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A.1 EC Folder Contents

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A.2 List of Hard Copy Only Pages

Section/Pages which have blank page place holders for hard copy only originals: None

A.3 Revision Summary

Original Revision.

A.4 Problem Statement

Per AR 358724, during the hydro-demolition of the Reactor Building Containment Wall in preparation for Steam Generator Replacement, gaps were exposed between adjacent hoop (i.e. horizontal) tendons within the boundaries of the temporary access opening. The gaps are generally in a vertical plane between the tendon sleeves and extend for an indeterminate length. This engineering change is part of an overall strategy that will evaluate and accept methods for returning the Reactor Building Containment Wall to its original design base configuration.

A.5 Solution Statement

The goal of this EC and interfacing ECs is to ensure the final configuration of the Reactor Building Containment Wall is as good as the original design base configuration. Final analysis of the structure will be based on a new Finite Element model being developed by MPR Associates, Inc. The repaired wall shall be able to withstand all applicable design conditions, normal and accident.

This EC is the third phase in a multi-phased approach to perform these repairs as follows.

1) Crack Arrest (EC 75000) – A series of cuts will be provided into the delaminated concrete. These cuts will provide a path of stress relief during the detensioning process. Two horizontal cuts will be made, one above and one below, the steam generator replacement opening. The length of the cuts will not exceed the area of construction opening. In addition to horizontal cuts, vertical cuts will also be installed above and below the contstruction opening at Azimuth 150°. The cuts will run between the currently detensioned vertical tendons at a depth only to cut embedded rebar. This is to minimize cutting active hoop tendons which exist above and below the current containment opening.

2) Detensioning (EC 75218) – A Finite Element model developed by MPR Associates, Inc. shall be completed to show the necessary detensioning and re-tensioning sequence as well as compliance with the appropriate bases. The detensioning implemented by this phase will ensure adequate prestress can be returned to the Reactor Building structure.

3) **Concrete Removal** (EC 75219) – This EC will address the removal of the existing delaminated concrete. Method will include a combination of hydro demolition as well as mechanical removal/saw cutting methods. Contract vendor SGT will be providing the implementation of the removal. This EC shall also review the depth of removal, rebar removal requirements, and necessary work platforms associated to perform the work. Consideration shall be given to any stabilization required to support the delaminated concrete during removal activities.

4) Concrete Placement (EC 75220) – This EC will address the replacement of the delaminated concrete with new concrete. Mix and installation shall consider criteria evaluated per EC 63016 to originally restore the containment opening. Critical concrete characteristics such as creep, aggregate type, testing requirements, etc. shall also be considered as a part of this phase.

5) Re-tensioning (EC 75221) – This EC will address the final re-tensioning sequence to restore prestress back into the concrete containment shell once the replaced concrete has adequately cured. Final MPR FE analysis results shall be incorporated to ensure the applicable design and licensing bases requirements have been met.

A.6 Operating Experience

A search for Hydrodemolition and Concrete Removal under Operating Experience at INPO's website yielded the following items of interest to this EC:

OE 14720 – Davis-Besse - Hydrodemolition – Safety Concern:

Description: A Contract Worker was stationed in the annulus area between the containment vessel and the concrete shield building and was present to monitor any leakage into the annulus. The Contract Worker was installing a sump pump behind the backstop in the Auxiliary Building Annulus Wall when the hydrodemolition commenced operations. The noise & water from the hydrodemolition startled the Contract Worker. He dove to the scaffolding decking and, crawled to the ladder. The Contract Worker injured both knees during this action. Radio communication had been established to inform all personnel involved when the machine was to start. This communication did not occur to prepare the worker in the annulus. As other utilities may consider using the hydrodemolition process, it is essential for personnel safety to have a rigid protocol of effective communications.

Causes: There were two causes that contributed to this event. The worker was new to the project and was not aware of what to expect in regards to noise level and slight water intrusion. Primarily however, the supervisor failed to contact the worker in the annulus prior to the hydrodemolition starting. The supervisor, having been involved for several days of hydrodemolition prior to the specific date of the incident, became lax in attention to detail.

How the issue is addressed by this EC:
A note will be added in the precautions and limitations section of the Installation Instructions that the containment coordinator is to be informed prior to starting the hydrodemolition machine. The coordinator must then inform all personnel in the immediate area of the opening that hydrodemolition activities are about to start and noise levels will increase dramatically.

OE 29756 – LaSalle – Hydrodemolition Hose Rupture

Description: During hydrolazing of a floor drain header in the reactor building on 08/27/09, the pressure regulating valve return hose to the water reservoir tank ruptured at a local fitting. Water is routed through the return hose when the trigger on the wand is released. MC (clean and cycle condensate) water accumulated on hydrolazer skid for approximately 15 seconds until power to hydrolazer was secured. An RP (radiation protection) technician was on the scene when leak occurred and the spill was immediately cleaned up without further incident. No injuries to personnel occurred.

Causes: Lack of a preventive maintenance program for the hydrolazer. The hydrolazer recirculation hose failed due to aging.

How the issue is addressed by this EC: While this OE most likely relates to hand operated hydrolazer, the maintenance implication still applies to any hydrodemolition equipment. A note will be added in the precautions and limitations section of the Installation Instructions that the hydrodemolition equipment is properly inspected prior to use.

OE 14942 – Wolf Creek – Concrete Cutting

Description: As described in OE 14942, used concrete saw blades may develop cracks over time/usage. Continual usage of the crack blades can cause catastrophic failure and project shrapnel that may cause severe injury to personnel.

Causes: Lack of inspection of saw blades prior to their usage in the field.

How the issue is addressed by this EC: All concrete cutting saw blades shall be thoroughly inspected prior to use to prevent a similar event. Additionally, any activities which cut/bore into the CR3 containment structure have the potential to irreversibly damage the underlying post-tensioning system. As noted in NCR 364655, potential tendon damage occurred during core boring activities associated with condition assessment. As such consideration should be given to this NCR during pre-job briefing activities prior to commencing any work in the field.

Lesson Learned – EC 63016 – OTSG Replacement

NCR 358636, Storm Drain Cover Removed – A storm drain cover was removed from a storm drain on the southwest corner of the berm. Some wastewater resulting from hydrodemolition activities that was pooled up over the storm drain was released. Only Qualified or designated personnel are allowed to remove storm drain covers.

NCR 358653, Hydrodemolition Waste Water Release to Intake Canal – During Hydrodemolition activity at 0500, wastewater discharge became plugged with concrete debris which cause the chute to back up and allow water to overflow onto the southwest bermed area. Water flowed to a nearby storm crain which was covered with a protective mat which was placed there for oil spill prevention measures. Water pooled up around the storm drain and a worker in the area lifted the mat which allowed approximately 500 gallons of this wastewater to enter the storm drain. The storm drain is connected to an outfall at the CR3 intake canal. Verbal and written notification of release was made to PEF environmental services. A call was then made by EHSS to the FDEP southwest district office at 0955. Contractor was instructed to place a small sump pump in the area of the storm drain to prevent on-going pooling of water in the area. The water was pumped to a drum which was then pumped to the hydrodemolition catch basin.

B.1 Design Specification

The details of the design change are specified below:

B.2 Scope Description

This EC is the third phase in a series of five ECs in development for the repair of the CR3 RB Containment building delamination.

To facilitate the repair of the CR3 Reactor Building containment delaminated concrete removal will occur between RB Buttresses #3 and #4 located at the 120° and 180° azimuths. Removal of concrete will occur during plant no mode. Tendons will be detensioned as prescribed by EC 75218 prior to the removal of the concrete.

Removal of the delaminated concrete will require the removal of the rebar within the boundaries of the delaminated region. Rebar shall be discarded. Sufficient rebar will remain to allow for splicing of the original near face reinforcement and/or additional reinforcement required for final replacement concrete strength as required by interfacing EC 75220.

Based on requirements of the interfacing EC 75220, depth of removal and surface preparation requirements shall also be specified by this EC. The design evaluation will consider both cut and hydrodemolition removal methods.

B.3 References

1. <u>Industry Standards:</u>

1.1. ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWA, IWE, and IWL of the 2001 edition through the 2003 Addenda, as amended by 10CFR50.55a.
1.2. ASME Boiler and Pressure Vessel Code, Section III, Division 2, Code for Concrete Containments, 2001 edition through the 2003 Addenda
1.3. ANSI N45.2.11-1974, Quality Assurance Requirements for the Design of Nuclear Power Plants
1.4. ASME Boiler & Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, 1965 Ed
1.5. ASME Boiler & Pressure Vessel Code, Section III, Nuclear Vessels, 1965 Ed
1.6. ASME Boiler and Pressure Vessel Code, Section III, Division 2, Appendix F, Rules for Evaluation of Service Loadings with Level D Service Limits, 1995 Ed
1.7. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NE, 1995 Ed
1.8. ICRI 03730 (#310.1R), "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Corrosion" (Note: ACI 515.1R referenced in this document has been withdrawn on 1/1/1979)
1.9. ICRI 03732 (#310.2), "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays"
1.10. ICRI 03737 (#310.3), "Guide for the Preparation of Concrete Surface for Repair Using Hydrodemolition Methods"
1.11. ICRI 03739 (#210.3), "Guide for Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials"
1.12. ASTM D4580, "Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding"
1.13. ACI 503R, "Use of Epoxy Compounds with Concrete"
1.14. ACI 546R, "Concrete Repair Guide"
1.15. ACI/ICRI Concrete Repair Manual, Third Edition, Volume 1

1.16. ACI 318-63, "Building Code Requirements for Reinforced Concrete"
1.17. ASTM A421-65/98a, "Standard Specification for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete"

2. Design Basis Documents:
2.1. DBD11, Design Basis Document for the Containment, Revision 7 (Tab 1/1)
2.2. DBD13, Design Basis Document for Major Class I Structures, Revision 5 (Tab 1/3)

3. Specifications:
3.1. SP-5209, Revision 0, CR-3 Seismic Qualification
3.2. RO 3040, Requirement Outline, Pre-stressing System Tendon Conduit, Date 06/12/1970
3.3. SP-5583, Dated 09/18/1968, Specification, Tendon and Associated Conduit, RB
3.4. GAI Specification SP-5844, Dated 10/21/1970, Specification, Installation of Pre-stressing System Tendon Conduit and Embedded anchorage
3.5. GAI Specification SP-5646, Fabrication and Delivery of Reinforcing Steel, Dated 04/25/1969
3.6. GAI Specification SP-5566, RB Liner and Penetrations and Personnel Access Locks, Dated 3/18/1981
3.7. CR3-C-0003, Rev. 5, "Concrete Work for Restoration of the SGR Opening in the Containment Shell"

4. Drawings:
4.1. 421-043, Revision 7, RB Equipment Access Shield Structure
4.2. 421-031, Revision 4, RB Exterior Wall – Concrete Outline
4.3. 421-032, Revision 8, RB Stretch-Out of Exterior Wall Buttress #2, #3, #4 and #5
4.4. 421-033, Revision 8, RB Stretch-Out of Exterior Wall Buttress #5, #6, #1 and #2
4.5. 421-036, Revision 10, RB Exterior Wall – Sections and Details
4.6. 421-039, Revision 5, RB Exterior Wall – Equipment Access Opening Reinforcement Details
4.7. 421-041, Revision 5, RB Ring Girder – Concrete Outline – Plan And Sections
4.8. 421-001, Revision 4, RB Tendon Access Gallery – Plan, Sections and Details
4.9. Prescon Drawings Series 5EX7-003, (CR3 Dwg Key #S-26 series and S1542 thru S1596)

5. Calculations:
5.1. I89-0013, Revision 8, "Containment Air Temperature Loop Accuracy"
5.2. S10-0001, Revision 0, "Tendon Tension Calculation"
5.3. S10-0002, Revision 0, "Finite Element Model Description"
5.4. S10-0003, Revision 0, "Conduit Local Stress Analysis"
5.5. S10-0004, Revision 0, "Detensioning"
5.6. S10-0005, Revision 0, "Bending Tension Interaction Diagrams for Selected Sections"
5.7. S10-0006, Revision 0, "Seismic, Wind, and Tornado Evaluation and Delamination Depth Evaluation for Detensioned State"

6. Nuclear Generating Group (NGG) Procedures:
6.1. EGR-NGGC-0003, Rev. 10, "Design Review Requirements"
6.2. EGR-NGGC-0005, Rev. 29, "Engineering Change"
6.3. EGR-NGGC-0011, Rev. 13, "Engineering Product Quality"
6.4. EGR-NGGC-0154, Rev. 5, "Single Failure Analysis"

6.5. EGR-NGGC-0204, Rev. 6, "Evaluation and Selection of Material for Plant Components"
6.6. MNT-NGGC-0004, Rev. 11, "Scaffolding Control"
6.7. EGR-NGGC-0015, Rev. 3, "Containment Inspection Program"
6.8. FIR-NGGC-0003, Rev. 4, "Hot Work Permit"
6.9. CHE-NGGC-0045, Rev.14, "NGG Chemical Control Program"

7. <u>Plant Procedures:</u>
7.1. AI-1803, Revision 21, "Safety Standards for Ladders & Scaffolds"
7.2. SP-178, Revision 30, "Containment Leakage Test – Type 'A' Including Liner Plate"
7.3. AI-1000, Revision 42, "Housekeeping/Material Condition Program"
7.4. AI-2200, Revision 13, Guidelines for Handling, Use, and Control of Transient Combustibles
7.5. SP-300, Revision 219, "Operating Daily Surveillance Log"
7.6. ISIIWE, Rev 3, "Inservice Inspection Program/Containment Inspection Program - IWE/IWL"
7.7. SP-736K, Rev. 0, "Reactor Building Hydrodemolition Release to the Settling Ponds"
7.8. OP-417, Rev. 111, "Containment Operating Procedure"
7.9. AI-1820, Rev. 3, "Hazardous and Non-Hazardous Waste Management"
7.10. AI-1816, Rev. 3, "Industrial Safety Signs and Tags"

8. <u>Plant Change Documents:</u>
8.1. EC 63016, Revision 31, "Containment Opening"
8.2. EC 74801, Revision 8, "Containment Structure – Extent of Condition Core Bores"
8.3. EC 75000, Revision 0, "CR3 Containment Delamination Repair, Phase 1 Crack Arrest"
8.4. EC 75218, Revision 0, "Reactor Building Delamination Repair Phase 2 – Detensioning (In Development)
8.5. EC 75220, Revision 0, "Reactor Building Delamination Repair Phase 4 – Concrete Placement (In Development)
8.6. EC 75221, Revision 0, "Reactor Building Delamination Repair Phase 5 – Retension/Test (In Development)
8.7. EC 63020, Revision 9, "SG replacement – Outside Erection Crane and Inside Auxiliary Crane"
8.8. EC 75497, Revision 0, "Containment Delamination Electrical Interference Removal"
8.9. EC 59400, Revision 0, "Identify the Source and Limitations for CRS Water Supply and Discharge for OTSG Outage RFO-16"
8.10. EC 63022, Revision 31, "Steam Generator Rigging and Transport"
8.11. EC 63021, Revision 11, "Temporary Material and Personnel Hoist Outside RB"
8.12. EC 70377, Revision 1, "Temporary Power outside the RB for SGR Project and Containment Repair"

9. <u>Regulatory Documents:</u>
9.1. FSAR, Revision 31.3
9.2. Improved Technical Specifications (Through Amendment 239 and Improved Technical Specifications Bases Revision 81)

10. <u>Other References:</u>
10.1. AR 00358724, Exposed Cracks During Hydro-Demolition
10.2. AR 00372472, 50.59 Screen for EC 75219
10.3. AR 00370853, Small Cracks Found Parallel to Liner

10.4. AR 00358636, Storm Drain Cover Removed
10.5. AR 00358653, Hydrodcemolition Wastewater Release to Intake Canal
10.6. SAF-SUBS-00029, Rev. 3, "General Machine Guarding"
10.7. SAF-SUBS-00030, Rev. 3, "Hand and Power Tool Safety"
10.8. SAF-NGGC-2172, Rev. 12, "Industrial Safety"
10.9. EVC-CRNF-00002, "Crystal River Nuclear Plant Site-Specific Environmental Policies, Permits, Registrations, Certifications, and Plans"
10.10. State of Florida, Industrial Wastewater Facility Permit Number FLA16960, Crystal River Energy Complex
10.11. EVC-SUBS-00008, Rev. 5, "DOT Hazardous Materials"
10.12. EVC-SUBS-00016, Rev. 8, "Hazardous Waste Management"

B.4 Design Inputs

Following is a list of applicable *design inputs* specified to meet the requirements of ANSI N45.2.11.

1. Basic Functions of Each Structure, System and Component:

   Reactor Building Containment Structure:

   The containment is a Class I Structure as described in the FSAR Sections 5.1.1.1 and 5.2.1 and the Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1). The primary function of the reactor containment building and its steel liner is to house the primary nuclear system and to provide biological shielding from the fission products that could become airborne under accident conditions. Its failure could result in the uncontrolled release of radioactivity and its integrity is vital for the safe shutdown and isolation of the reactor. Containment integrity is required in Modes 1, 2, 3, and 4, Ref. 9.5 (TS 3.6). There are no Improved Technical Specification (ITS) Limiting Conditions for Operation (LCOs) for containment integrity during Modes 5, 6 and defueled (TS 3.6.1). The installation of this EC shall occur during No Mode. During No Mode there are no TS requirements for containment integrity or TS Actions that require containment closure, however the containment should not have catastrophic failure during the applicable design basis loads

   Basis: Design Basis Document for the Containment (Ref. 2.1, Tab 1/1),
   ITS Sections 3.6 and 3.9,
   FSAR Sections 5.1 and 5.2

2. Performance Requirements such as Capacity, Rating, and System Output:

   The reactor containment building is a Class I Structure designed as a passive barrier that is required to maintain its structural integrity during a design basis accident and for all normal and accident load cases and load combination. It was designed for an internal pressure of 55 psig and a temperature of 281 degrees F (accident condition); an internal pressure (external pressure drop) of 3 psig during a tornado; and an external pressure (internal pressure drop) of 2.5 psig during normal operation of the plant. Total suction pressure on interior of Containment of -6.0 psig is also considered. Additional consideration was given to the dead load, live load, temperature gradients, and effects of penetrations at accident and working conditions.

Basis: Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1)
FSAR, Section 5.2.1

3. Codes, Standards, and Regulatory Requirements:

The post tensioned, reinforced concrete reactor containment building is designated as a Class I Structure (FSAR Section 5.1.1.1 and Ref. 2.1) and by definition is therefore nuclear safety-related. Its design and construction predated the establishment of a concrete pressure vessel code. The primary design code for the concrete, tendons and steel reinforcement was ACI 318-63, Parts IV-B and Part V. The tendons conformed to the applicable portions of ASTM A421-65 for low relaxation wire (FSAR Section 5.2.2.3.2). The liner plate conformed in all respects to the applicable Sections of ASA N 6.2-1965 "Safety Standard for Design, Fabrication and Maintenance of Steel Containment Structures for Stationary Nuclear Power Reactors".

Basis: Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1)
FSAR Section 5.1.1

4. Design Conditions such as Pressure, Temperature, Fluid Chemistry and Voltage:

Pressures:
Normal Operation: +1 to -1 psig
Accident pressure inside containment resulting from worst case LOCA: 55 psig
Accidental RB Spray Actuation: -2.5 psig on interior of containment
Total suction pressure (suction on interior of containment: -6.0 psig)
Tornado differential pressure (suction on outside of containment): -3 psig

Temperatures:
Operating temperature inside containment: 60 to 115°F
Operating temperature outside containment: 25 to 100°F
Accident temperature: 281°F

Note: While the DBD is the document which describes design operating temperature, SP-300 and TS Section 3.6.1 require operating temperatures below 115°F during Modes 1-4. Based on SP-300 and Calculation I89-0013, temperatures have routinely exceeded limit as described by the DBD and may approach 130°F.

Basis: Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1)
FSAR Section 5.2
ITS Sections 3.6 and 3.9
SP-300
Calculation I89-0013
OP-417

5. Loads such as Seismic, Wind, Thermal, and Dynamic:

Loads to be considered in verifying the structural integrity of the containment building include both forces resulting from natural phenomena such as earthquake, tornado, wind, and hurricane in addition to those resulting from design basis accident conditions, material dead and live loads and forces resulting from tendon stressing. Also to be considered are loads associated with the hydrodemolition process and its interaction with the structure itself. Thermal gradients across the exposed unreinforced concrete section due to delamination removal shall also be considered and monitored to maintain acceptable value as outlined in MPR Analyses (CR3 Calc # S10-0001 thru S10-0006).

Basis: Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1),
ACI 318-63, Parts IV-B and Part V
S10-0001 thru S10-0006

6. Environmental Conditions:

Water requirements:

Concrete removal with hydrodemolition will require large amounts of clean water that must be delivered to the hydrodemolition equipment. Water specimens must be obtained to verify baseline chemical and radiological testing of the water prior to the start of any hydrodemolition. This shall be performed by CR3 chemistry. The resulting waste water and concrete debris that are generated must be disposed of in an environmentally acceptable manner.

Waste water disposal requirements:

Samples for radiological testing and analysis shall be taken at the collection bins and tested at the on-site RP/Chemistry laboratory in accordance with existing site procedures. Discharge of the water and rubble may continue uninterrupted while samples are being tested and analyzed.

The implementation vendor, SGT, is responsible for water delivery and the means of piping it to and from the containment and is outside the scope of this EC. They are also responsible for determining if the settling ponds have adequate storage for expected waste water. CR3 Chemistry will provide testing of necessary samples. Adjustment of pH will be via temporary storage of hydrochloric acid as required. Water shall not be discharged to the setting ponds until these samples are cleared by Chemistry and RP. On-site tank storage is to be provided as required by Progress Energy. The details for water supply and disposal for concrete removal shall be included and approved per the associated Work Order Task.

Basis: Offsite Dose Calculation Manual
Industrial Waste Water Permit (IWWP)
Chemical Control CHE-NGGC-0045
EC 63016

7. Interface Requirements:

This EC interfaces with the following ECs:

1. EC 63016, Containment Opening
2. EC 74801, Containment Structure – Extent of Condition Core Bores

3. EC 75000, CR3 Reactor Building Delamination Repair, Phase 1, Crack Arrest
4. EC 75218, Reactor Building Delamination Repair Phase 2 – Detensioning (In Development)
5. EC 75220, Reactor Building Delamination Repair Phase 4 – Concrete Replacement (In Development)
6. EC 75221, Reactor Building Delamination Repair Phase 5 – Retension/Test (In Development)
7. EC 63020, SG replacement – Outside Erection Crane and Inside Auxiliary Crane (for safe load path usage)
8. EC 75497, Containment Delamination Electrical Interference Removal

Basis: NCR 358724

8. Material Requirements:

Not Applicable

9. Mechanical Requirements:

Tendon Gallery Sumps shall be tagged and protected during the hydrodemolition process to prevent damage to the pumps from laitance/debris that will be transported through the empty tendon sheaths to the gallery.

Basis: EC 63016

10. Structural Requirements:

This EC will provide for the removal of the delaminated concrete in the Reactor Building exterior wall. Tendons shall be removed at the discretion of SGT using ram detensioning, coiled, and have identification clearly attached. Spare tendons should be ordered to replace any tendon that is damaged during hydrodemolition. These spares shall account for those tendons which may be located in a flexible tendon sheath. Remaining tendon sleeves are to be inspected and repaired prior to containment restoration. The final configuration (reduced wall cross-section) shall be evaluated to show the structure meets all applicable design loads as identified in B.4.5 including but not limited to deadweight, thermal, seismic, and hydrodemolition.

Basis: Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1)
FSAR Sections 5.1 through 5.2
Scope of EC

11. Hydraulic Requirements:
The pumps and associated piping supplied for the hydrodemolition operation must be capable of providing and recovering the water needed for operation of the hydrodemolition equipment.

Basis: Scope of EC

12. Chemistry Requirements:

Water requirements for hydrodemolition:

Clean water must be available for any hydrodemolition activities and must be supplied at a rate which meets the equipment requirements. Water specimens must be obtained to verify baseline chemical and radiological testing of the water prior to the start of hydrodemolition.

Waste water requirements:
Waste water from the hydrodemolition process will be tested before discharge to ensure it meets Plant and the State of Florida permit requirements including the Industrial Waste Water Permit (IWWP). Wastewater release shall be in accordance with SP-736K. Refer to Section B.6.6 for an evaluation of the water requirements. The details for water supply and disposal for concrete removal shall be included and approved per the associated Work Order Task.

Basis: Industrial Waste Water Permit
Chemical Control per CHE-NGGC-0045
SP-736K

13. Electrical Requirements:

Conduit running just above the equipment hatch shall be relocated temporarily to allow for complete removal of the delaminated concrete.

Basis: EC 75497, Scope of this EC

14. Layout and Arrangement Requirements:

The location of removal shall be between Buttresses #3 and #4. Removal shall be such that sufficient rebar ties remain in place so code splice will be developed between the new rebar and the bars in the undisturbed concrete per concrete placement EC 75220. ACI 318 requires a minimum of 7" for cut #8 rebar. Rebar cuts shall consider future splices around horizontal tendon ducts and adjacent rebar (#11 near the equipment hatch, #18 near ring girder, #9 from Buttresses). EC 75220 shall be referenced for rebar replacement requirements prior to making any rebar cuts to ensure the design requirements are not invalidated. Depth and final surface preparation shall be such that placement conditions are optimized.

Basis: Scope of this EC
ACI 318
Dwg. 421-032
Dwg. 421-036
EC 75220

15. Operational Requirements Under Various Conditions:

Removal shall only commence during the no mode condition so as to maintain the plant in a safe condition. Thermal gradients across the remaining unreinforced concrete wall shall be monitored and controlled based on a 7-day average differential to prevent adverse stress levels within the concrete.

Basis: Scope of EC, OP-417, MPR Analyses S10-0001 thru S10-0005, EC 75218

16. Instrument and Control Requirements:

Thermal gradients shall be monitored across the reduced concrete cross-section following removal. This shall be accomplished with remote instrumentation as required.

Basis: S10-0001 thru S10-0006

17. Access and Administrative Control for Plant Security:

Conduit running just above the equipment hatch shall be relocated temporarily to allow for complete removal of the delaminated concrete. This conduit provides power for plant security lighting. Temporary changes shall not adversely impact site security features.

Basis: EC 75497, Scope of this EC

18. Redundancy, Diversity, and Separation Requirements of Structures, Systems, and Components:

Not Applicable

19. Failure Effects on Requirements of Structures, Systems, and Components:

The primary function of the reactor containment building and its steel liner is to house the primary nuclear system and to provide biological shielding from the fission products that could become airborne under accident conditions. Its failure could result in the uncontrollable release of radioactivity and its integrity is vital for the safe shutdown and isolation of the reactor. Repair of the delamination will occur during no mode operation during which time containment Operability is not required (TS 3.6.1). The partially detensioned containment could possibly pose a threat to the adjacent Auxiliary Building (due to the presence of the spent fuel pools), during a seismic or tornado event (II/I relationship).

Basis: Improved Technical Specifications 3.6, 3.9
FSAR Section 5.0

20. Test Requirements:

Surface preparation of removed concrete shall be such that new concrete can adequately bond to the existing concrete. Surface preparation testing shall use ACI 503R, Appendix A as a guideline. Additional subsurface testing shall be performed in accordance with ICRI 03739.

Basis: ACI 503R-93 (Reapproved 2008)
ICRI 03739

21. Accessibility, Maintenance, Repair, and ISI Requirements:

Not Applicable

22. Personnel Requirements and Limitations:

Not Applicable

23. Transportability Requirements:

    Not Applicable

24. Fire Protection or Resistance Requirements:

    Not Applicable

25. Handling, Storage, and Shipping Requirements:

    Not Applicable

26. Other Requirements to Prevent Undue Risk to the Health and Safety of the Public:

    Safe load paths shall be considered to offset potential load drop scenarios during movement of any required equipment over vital plant components.

    Basis: EC 63020

27. Materials, Processes, Parts, and Equipment Suitability for Application:

    Not Applicable

28. Safety Requirements for Preventing Personnel Injury:

    The removal process should utilize properly qualified mobile or suspended platforms and/or scaffolding as required. Hydrodemolition equipment should utilize enclosures which are capable of capturing all loose debris (i.e. high strength netting) in order to prevent falling objects on personnel or plant equipment below.

    The project safety interface should ensure that proper and sufficient consideration is made of the requirements for fall protection and of the dangers involved in working at heights.

    Pre-Job briefs shall incorporate any relevant OE prior to commencing work in the field. Consideration should be given the dangers associated with utilizing concrete cutting equipment.

    Basis: OSHA requirements
    SAF-NGGC-2172, "Industrial Safety" or SGT Equal
    AI-1803, "Safety Standards for Ladders & Scaffolds"
    OE 14942, "Circular Concrete Saw Blade Cracking May Cause Personnel Injury"

29. (CR3) Circuits for systems with Improved Technical Specifications testing requirements:

    Not Applicable

30. (CR3) Emergency Diesel Generator Loading Impact Assessment:

    Not Applicable

B.5 Assumptions

None

B.6 Evaluation

1. Basic Functions of Each Structure, System and Component:

Reactor Building Containment Structure:
The CR3 Reactor Building is similar in design to the containment buildings for the Three Mile Island Nuclear Station Unit 1, the Turkey Point Plant, the Palisades Plant, the Point Beach Plant, and the Oconee Nuclear Station.

The containment is a concrete structure with a cylindrical wall, a flat foundation mat, and a shallow dome roof. The foundation slab is reinforced with conventional mild-steel reinforcing. The cylinder wall is prestressed with a post-tensioning system in the vertical and horizontal directions. The dome roof is prestressed utilizing a three-way post-tensioning system. The inside surface of the reactor building is lined with a carbon steel liner to ensure a high degree of leak tightness during operating and accident conditions. Nominal liner plate thickness is 3/8 inch for the cylinder and dome and 1/4 inch for the base.

The foundation mat is bearing on competent bearing material and is 12-½ feet thick with a 2 feet thick concrete slab above the bottom liner plate. The cylinder portion has an inside diameter of 130 feet, wall thickness of 3 feet 6 inches, and a height of 157 feet from the top of the foundation mat to the spring line. The shallow dome roof has a large radius of 110 feet, a transition radius of 20 feet 6 inches, and a thickness of 3 feet. The containment has been designed to limit the leakage rate to 0.25% by weight of contained atmosphere in 24 hours at the design pressure and temperature.

Per Section 5.2 of the FSAR and Ref. 2.1 the design of the containment building is based on:

- The containment of radioactive material which might be released from the reactor core following a Design Basis Loss-Of-Coolant-Accident (LOCA).
- Temperature and pressure generated from the LOCA, i.e. 281 degrees F and 55 psig. (The design pressure is 55 psig but the DBA pressure is 54.2 psig (Ref. FSAR Section 14.2.2.5.9 and TS B 3.6.1).
- Operational and Safe Shutdown Earthquakes
- Severe weather phenomena, i.e. hurricane winds, tornado and tornado missile

The post-tensioned, reinforced concrete containment building was designed by the ultimate strength methods in accordance with ACI 318-63, Part IV-B and Part V, Chapter 26 "Prestressed Concrete". The load capacity of members was reduced by a capacity reduction factor Φ=0.90 for flexure in accordance with Section 1504 of ACI 318-63 (FSAR Section 5.2.3.3.1).

Based on the no mode state of the plant during the removal of delaminated concrete, the normal design base requirements do not apply. The delaminated region will be removed and repaired prior to final start-up, as such, the Reactor Building containment is not adversely affected.

2. Performance Requirements such as Capacity, Rating, and System Output:

Since the reactor containment building acts as a passive barrier, it must be verified for all applicable Design Basis loads and load combinations, including all loads resulting from any necessary repair activities, to ensure its structural integrity during restoration and through end of plant life. Its failure could result in the uncontrollable release of radioactivity and its integrity is vital for the safe shutdown and isolation of the reactor. Since the containment is essentially returned to its original configuration after all phases of repair, there will be no changes to any performance requirement for capacity, rating or system output.

The delaminated concrete removal scope does not adversely impact the performance requirements of the current state of the Reactor Building containment in terms of the total repair methodology to restore design base function. This process will be credited as a repair aid only to allow new concrete placement and retensioning activities as described in EC 75220 and 75221, respectively. Refer to Sections B.6.5 and B.6.10 for review of concrete removal process.

3. Codes, Standards, and Regulatory Requirements:

At the completion of all repair activities, the post tensioned, reinforced concrete containment building will comply with all applicable design basis loads, load combinations, codes and standards. Final Finite Element Model analysis will ensure the containment maintains this requirement before being returned to service.

4. Design Conditions such as Pressure, Temperature, Fluid Chemistry and Voltage:

Removal of the delaminated region of the containment building wall will not change any of the design conditions for containment. The extent of repairs of all 5 interfacing ECs is to ensure the final configuration of the containment meets its original design base requirements. Concrete removal is being credited only for preparing the degraded region for the final design repair only. As such, the removal is merely an aid in restoring the containment to its intended configuration.

5. Loads such as Seismic, Wind, Thermal, and Dynamic:

The purpose of this EC is to remove the delaminated concrete in the CR3 RB containment as identified in NCR 358724. This delaminated region is located between buttresses #3 and #4 in a relatively symmetric hourglass shape surrounding the SGR construction opening created by EC 63016. The depth of the delamination varies from a few inches to an observed 11" as shown on SK-72519-C001. Removal of all unsound concrete is the only feasible method to ultimately restore the containment structure back to its design base condition.

Historically delamination had occurred during initial construction of the plant within a large portion of the containment dome. Similar to this EC, the delaminated region was removed via mechanical means, the surface prepared, radial rebar installed, and the concrete replaced. The latter portion of the repair approach shall be addressed in interfacing EC

75220. This evaluation will focus primarily on the removal shape, the method of removal, surface preparation, and the interim condition of the containment structure prior to concrete replacement.

Both the American Concrete Institute and the International Concrete Repair Institute provide methods and guidelines for repairing degraded concrete structures. A review of ICRI 03730, Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion (Attachment Z01), shows that the basic shape for any removal should encompass any area of delamination in the most basic, rectangular shape possible. Additional consideration should be given to all edges ensuring they are straight, square, and free of feathered edges. Based on the above, a stepped approach will be utilized as shown on SK-72519-C001 to remove the delamination. Only rectangular type joints will be utilized during removal to meet the ICRI guidelines. The depth of the removal is dictated by both existing MPR finite element analyses S10-0001 thru S10-0005 and ACI 318 code requirements for clear distance behind newly placed reinforcement. The analyses assume a uniform delamination between buttresses #3 and #4 of an average of 10". To prevent invalidation of this analysis, the typical removal depth shall be 10" (the centerline of the hoop tendons). It is understood that localized areas may need to be removed deeper than the 10" as the delamination extends deeper in some areas, particularly above the construction opening. To ensure the average of 10" used in the MPR analyses is not invalidated, localized areas exceeded the 10" were examined and deemed acceptable for the purpose of this removal EC (Reference S10-0006). Based on AREVA design engineering input, ACI 318 code requirements dictate that a minimum of 8½" of delamination be removed to provide adequate bond development length for the proposed radial reinforcement ties being installed per EC 75220. The 10" removal depth bounds this requirement. To minimize a slight stepping approach, removal will allow a typical 10" of removal with localized areas exceeding slightly further.

Further review of ACI and ICRI documents reveals methods most associated with concrete removal. It should be noted that concrete removal directly impacts surface preparation techniques. Methods described by these documents include grinding, abrasive blasting, water jetting, milling, scarifying, needle scaling, and flame blasting. Based on previous installer work experience, hydrodemolition provides the fastest, most uniform method of removal. ICRI 03732 (Attachment Z00), Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays, describes a series of recommended surface profile finishes as well as methods to attain those finishes. Furthermore ICRI 03737, Guide for the Preparation of Concrete Surfaces for Repair Using Hydrodemolition Methods, describes the expected surface profile as a result of hydrodemolition removal. Based on both ICRI 03732 and ICRI 03737, a surface profile of at least CSP-6 could be expected but can approach CSP-9, levels which provide a good level of surface irregularity ideal for creating a mechanical bond. Based on ICRI 03732, only water jetting, milling, flame blasting, needle scaling, and scabbling provide surface profiles suitable to concrete replacement. It should be noted that mechanical impact methods have the highest tendency to create micro-cracking within the concrete surface. Therefore, based on the guidelines produced by ICRI, hydrodemolition is the preferred acceptable method for concrete removal. Further localized removal may occur with manual hydrodemolition or less invasive mechanical methods as described in ICRI 03732 and ICRI 03730. An exception should be noted that only hydrodemolition and saw cutting shall be permitted in the edge areas. This is to ensure no feathered edges occur at these critical construction joints.

Once the majority of concrete has been removed and after ensuring that sound concrete exists beyond the removed concrete final surface finishing can commence. Guidelines require surfaces to be cleaned and free of loose aggregate. Particular attention is required for hydrodemolition as the removed slurry can harden on the concrete surface and interfere with creating an adequate mechanical bond. Consistent with ACI 546R, Concrete Repair Guide, and ACI 503R (Appendix A, Attachment Z03), Use of Epoxy Compounds with Concrete, a simplified field test for surface soundness will be implemented to ensure the surface is adequately prepared for the placement of new concrete. A small aluminum t-bar will be affixed to the concrete surface with epoxy and pulled off. The pull off force will be recorded via a dynamometer and compared to the design base document tensile stress value of 200 psi. This will ensure that any portion of the concrete is just as likely to crack as the newly formed bond. Frequency of the testing will be performed as per those guidelines per ACI 503R at the rate of 1 test per every 100 ft^2 of prepared concrete surface. Should testing consistently show adequate preparation, the frequency of testing may be reduced at the discretion of the responsible civil engineer. It should be noted that radial rebar will be installed as part of the EC 75220 scope that alone will be capable of withstanding design stress across the repair interface; however, concrete preparation as outlined above will ensure that complete reliance on this radial rebar is minimized. To further ensure all delamination has been removed, concrete sounding techniques as described in ASTM D4580 (Attachment Z02) will ensure proper consideration is given to driving out all areas of loose concrete.

It should be noted that the root cause has not yet fully refuted the hydrodemolition process with respect to the creation of subsurface micro-cracking and induced vibrations in the concrete surface. However, surface preparation requirements dictate only a few methods will create the surface required for new concrete placement. Based on best industry practices hydrodemolition is the most highly recommended for both removal and surface preparation. Other alternate methods which would provide the required surface profile such as shotblasting or scarifying have a higher tendency to create surface and subsurface micro-cracking. Therefore, in order to minimize the likelihood of micro-cracking, hydrodemolition is the most feasible method of removal as noted above. To ensure significant damage has not been sustained in the structure, in-situ pullout testing of the subsurface will show the necessary strength remains in the concrete subsurface. This testing will be in accordance with ICRI 03739 (Attachment Z07). This requires a core to be drilled and a metal disc affixed to the top of the core. The core is then pulled similarly as outlined above and the tensile stress recorded. While the primary intent of this test is to ensure a good bond between adjacent materials, it can also show whether or not micro-cracking has been created to the extent which allow additional delamination to propagate through the sound concrete sub-surface. The acceptance criteria would also be 200 psi as outlined above. Per the ICRI recommendations testing should occur at a frequency of 3 per 5000 ft^2 of repair area. The devised pullout testing rig used for examining adequacy of the surface prep may be adjusted for this similar usage. The above testing techniques and adherence to the guidelines of the ACI/ICRI repair guidelines will ensure minimal adverse impact will occur to the containment structure. Additionally, the use of hydrodemolition may or may not induce vibrations through the delaminated surface which are capable of propagating the crack further into buttresses #3 and #4. To mitigate this risk as much as possible, a saw cut will be placed around the general removal area before hydrodemolition commences. This cut line will be offset 6" from the buttresses and top of the equipment hatch doghouse haunch. The cut will be a minimum of 1½" or as deep as reasonable achievable to as to prevent the cutting of underlying rebar. This cut will allow a weakened path for any potential propagation while minimizing the likelihood of propagation into the buttresses or equipment hatch concrete. Any further required removal would be limited to less invasive hand chipping techniques as required. It should be noted that possible strategies were discussed with Root Cause team in order to alleviate some of the concerns regarding micro-cracking/crack propagation; however, the available condition assessment data and experience dictated this design as the best approach and the risk of potential crack propagation was accepted and mitigated as best as reasonable achievable. Furthermore, the intent of this EC is based on best, sound engineering judgment with industry guidance to minimize the likelihood of crack propagating into the buttresses, equipment hatch, and ring girder concrete.

Based on the previous usage of hydrodemolition during the creation of the construction opening, the water jets will impart a load on the reactor building containment wall. Communication with the OTSG replacement Responsible Engineer indicates that these loads are minor based on industry guidelines, on the order of 500 lbs in a localized area. When comparing those loads with the magnitude of the deadweight of the affected critical section as well as the design wind loads, it can be seen that the load is bounded and well within the design strength of the structure. It should be noted, however, that the Delamination Root Cause Evaluation team is examining specific failure modes associated with the hydrodemolition itself related to Induced Vibration, excessive jet pressure, excessive blasting rate, and fine micro-cracking. Those failures modes have yet to be completely refuted and thus hydrodemolition cannot be used without the aforementioned testing criteria to ensure the best achievable concrete preparation is achieved.

MPR analyses S10-0001 thru S10-0006 bound the interim condition of the CR3 RB containment structure in the no mode condition. In the interim condition, the structure is not required to meet design base requirements as the reactor is defueled. The assumption of the 10" loss of wall section will be maintained as described in those analyses so as not to create a condition that is outside the bounds of those calculations. Localized removal areas past 10" will only be allowed at the discretion of the responsible civil engineer. This is described in the work installation instructions. Load conditions which may have an impact on the containment shell, dome, liner plate and base mat have been accounted for through element self weight in the MPR finite element models and associated ANSYS models as evaluated below.

Wind Loads:
While defueled there are no TS requirements for containment integrity or TS Actions that require containment closure, therefore, design basis wind loads are not applicable. While the containment is defueled and partially detensioned it could possibly pose a II/I hazard to the adjacent Auxiliary Building due to the presence of the spent fuel pools. However, containment repair will occur prior to the start of hurricane season which normally starts in June, therefore, hurricane wind loads are not evaluated. It should be noted that the tornado wind load analysis bounds the normal and hurricane wind loading scenarios.

Tornado Wind Loads:
While defueled there are no TS requirements for containment integrity or TS Actions that require containment closure. Therefore, design basis requirements for Tornado Load are not applicable. However, while the containment is defueled it could possibly pose a II/I (collapse) hazard to the adjacent Auxiliary Building due to the presence of the spent fuel pools. Accordingly, calculation S10-0006 has conservatively evaluated the partially detensioned containment shell for design basis tornado wind loads, with the delaminated

concrete removed, for a tornado wind velocity of 300 mph and an external pressure drop of 3 psig (Ref. 2.1, 5.7 & Section 5.2.1.2.6 of the FSAR)

Seismic Loads:
The appropriate seismic loads have been applied to the containment ANSYS finite element model generated by MPR and evaluated in Calculation S10-0006.

Per the Containment DBD (Ref. 2.1), and Section 5.2.1.2.9 of the FSAR, the design basis seismic parameters are as follows:

- Operating Basis Earthquake (OBE)
  0.05 g, maximum horizontal ground motion acceleration
  0.033, 0.033g, maximum vertical ground motion acceleration
- Safe Shutdown Earthquake (SSE)
  0.1 g, 0.1 g maximum horizontal ground motion acceleration
  0.067, 0.067 g, maximum vertical ground motion acceleration

While defueled there are no TS requirements for containment integrity or TS Actions that require containment closure. However, while the containment is defueled it could possibly pose a seismic II/I hazard to the adjacent Auxiliary Building due to the presence of the spent fuel pools. MPR evaluated the effects of seismic loads on the partially detensioned containment shell with the delaminated concrete removed and concluded that the containment shell had sufficient strength to preclude any possible collapse mechanism (Ref. calculation S10-0006).

Thermal Loads:

As outlined in the MPR analyses, temperature monitoring will have a significant role in the overall stability of the structure in the interim condition. Based on analysis, a thermal gradient differential between the interior and exterior faces of the containment wall could result in stresses that create and/or propagate cracks within the remaining unreinforced concrete cross-section.

The effects of thermal loads on the containment shell while detensioned have been evaluated for the following three items:

- Thermal loads due to restrained expansion of containment liner
- Axial (average cross-sectional) temperature within the concrete
- Temperature gradient through the thickness of the concrete sections

Temperature inside containment during removal will be controlled by Operations so that the inside temperature does not vary from the outside temperature by more than 10° F. Operations will use the RB ventilation cooling, heating and purge system per OP-417 making daily adjustments as required to maintain the delta as close to zero as possible based on a 7 day rolling average. Temperature Monitoring Requirements are outlined in B.6.16.

Polar Crane Loads:

The partially detensioned containment shell, with the delaminated concrete removed, has been evaluated by MPR (Refer to Calc. S10-0004) for the dead weight of the polar crane only. The polar crane cannot be used for any lifts prior to the completion of analysis as documented in EC 75220.

Pressure Loads:
During No Mode there are no accident pressure loads that need be evaluated.

6. Environmental Conditions:

Radiation decontamination of the concrete rubble and waste water, and any associated anchorage components may be required before disposal. Discharge of the water and rubble may continue uninterrupted while samples are being tested and analyzed. After the concrete rubble has been released by RP it will be hauled offsite to a landfill.

Implementation vendor, SGT, is responsible for water delivery, storage and the means of piping it to and from the containment and is outside the scope of this EC. They are also responsible for determining if the settling ponds have adequate storage for the expected waste water from hydrodemolition.

The details for water supply and disposal for concrete removal are outside the scope of this EC and will be included and approved per the associated Work Order Task.

Water requirements:.

EC 63016 and ECED 59400 identified the possible source of this water as the well fields located to the east of CR3, operated and maintained by the fossil group at Crystal River South (CRS). Well water could be diverted through existing CRS plant piping or temporary piping to one of the existing abandoned oil storage tanks (Cap. 8,000,000 gallons) which have been successfully used in the past by CRS and CR3 to satisfy requirements for bulk water storage for other high water demand projects. Water from this storage tank could then be pumped either via temporary piping to the hydrodemolition equipment located at the containment.

Water supplied to the hydrodemolition contractor should have total suspended solids of less than 45ppm and must undergo laboratory analysis to baseline radio nuclides and other chemical parameters as determined by RP and the chemistry department. Again, the details for water supply and disposal for concrete removal are outside the scope of this EC and will be included and approved per the associated Work Order Task.

Waste water disposal:
Samples for radiological testing and analysis shall be taken and tested at the on-site RP/Chemistry laboratory in accordance with existing site procedures. Discharge of the water and rubble may continue uninterrupted while samples are being tested and analyzed. Specific details developed on radiological sampling and analysis of the waste generated during hydrodemolition will be addressed by the associated work package.

As per EC 63016 and communication with the Sr. Environmental Specialist, waste water could be discharged to the south percolation ponds which have been determined (by CR3 and corporate environmental) to be within the current definition of wastewaters under the Plant Industrial Waste Water Permit. Therefore, sending the pre-tested (Refer to B.6.12 for testing requirements) waste water to the ponds is currently allowed. However, no discharge shall take place until both site chemistry and RP have cleared samples as acceptable for discharge. Hydrodemoltion may continue provided all the waste is collected in temporary basins or tanks. Refer to ECED 59400 for an evaluation of the risks associated with using the percolating ponds for effluent disposal. The source and storage of supply water, the use of the existing plant piping/facilities, use of the percolating ponds, and the erection/support of temporary piping for the disposal of the waste water is outside the scope of this EC and will be addressed by the relevant work orders.

Additionally, based on the previous use of Mac & Mac as outlined in EC 63016, wastewater would need to be treated via a skid mounted treatment facility. The purpose of this facility is to capture suspended material (grease, oil, concrete, etc.) and provide pH adjustment prior to discharge. This facility would require the temporary storage of up to 1600 gallons of 17% hydrochloric acid. This is acceptable as reviewed in Attachment Z63 of EC 63016 without further review based on its previous usage.

7. Interface Requirements:

This EC repair will coordinate final design repair with EC 63016, Containment Opening, EC 74801, Containment Structure – Extent of condition Core Bores, EC 75218 – Reactor Building Delamination Repair Phase 2 – Detensioning (In Development), EC 75219 - Reactor Building Delamination Repair Phase 3 – Concrete Removal (In Development), EC 75220 - Reactor Building Delamination Repair Phase 4 – Concrete Placement (In Development), and EC 75221 - Reactor Building Delamination Repair Phase 5 – Retension/Test (In Development).

Safe load paths shall be considered per EC 63020, particularly when using the Manitowoc 2250 crane. Installation of any hydrodemolition equipment would require strict adherence to the safe load paths as identified in that EC.

8. Material Requirements:

There is no evaluation required for this Design Input.

9. Mechanical Requirements:

During hydrodemolition of the concrete containment wall, water will drain down the exposed vertical tendon sheaths into the tendons gallery where it shall be collected in 55 gallon drums. However, it is expected that considerable overflow could occur (based on previous SGR experience) which will be collected in the tendon gallery sump. Since this waste water contains dissolved concrete (cement, sand and larger aggregate) it must be kept out of the plants waste water system. SGT mechanical workers shall establish sufficient boundaries or barriers that will prevent the concrete waste water from reaching tendon sump. The station gallery sumps, SDP-3A and SDP-3B will remain in normal operation. Sump pumps will be installed inside of the barrier, which will pump the waste water that collects in the sump to the portable water treatment plant located outside the protected area. Prior to the beginning of hydrodemolition activities, steps must be taken to confirm the proper operation and discharge volume of the temporary sump pump they supply. In the unlikely event that some water from the hydro-demolition process leaks past the barriers, it would be processed from the tendon gallery sump to the Turbine Building sump. This water would then be processed out with the normal station release process contained in OP-407N, Liquid Releases from the Secondary Plant. There is no need for additional testing the water that drains into the tendon gallery if the gallery is classified as being outside the RCA. If the gallery is classified as being inside the RCA then additional sampling is required by RP.

10. Structural Requirements:

Please reference B.6.5 for formal evaluation of the concrete removal.

11. Hydraulic Requirements:

Based on previous experience, the water requirements for the hydrodemolition activities are approximately 2,000,000 gallons of clean water and must be supplied at the rate of up to 360gpm.

12. Chemistry Requirements:

Water requirements for hydrodemolition:
ECED 59400 identified the possible source of this water (approximately 2,000,000 gallons) as the well fields located to the east of CR3, operated and maintained by the fossil group at Crystal River South (CRS). RP/Chemistry laboratory baseline testing of the water before it is delivered to the hydrodemolition contractor for radio nuclides and other chemical parameters is required to verify that TSS is within the vendor requirements.

Chemical requirements for discharging the waste water are within the scope of this EC and are discussed below under "Waste Water'. The implementation vendor, SGT, is responsible for water delivery, storage and the means of piping it to and from the containment and is outside the scope of this EC. They are also responsible for determining if the settling ponds have adequate storage for the expected waste water generated from hydrodemolition.

The details for supply and disposal of the water for concrete hydrodemolition will be included and approved per the associated Work Order Task.

Waste water:
Samples for radiological testing and analysis shall be taken and tested at the on-site RP/Chemistry laboratory in accordance with SP-736K. Discharge of the water and rubble may continue uninterrupted while samples are being tested and analyzed.

Per EC 63016, the environmental/chemistry groups evaluated the current requirements of the Plant Industrial Waste Water Permit (IWWP) and concluded that waste water (non-radiological) treatment is required as a pre-requisite before discharging the water. The following waste water (non-radiological) tests will be performed as a pre-requisite for discharge:

- Only pH sampling will need to be performed as a pre-requisite for discharge. Contractor should strive to keep the pH between 6.0 and 9.0. Periodic sampling of pH will be needed. A "stop job" limit shall be established at pH less than or equal to 2, or pH greater than or equal to 12.5.

13. Electrical Requirements:

Temporary EC 75497 evaluates the necessary requirements for moving the interfering conduits located directly above the equipment hatch. More specific details concerning the temporary layout and/or necessary security compensatory actions will be found within that document. Please reference EC 75497 for additional details. EC 70377 addresses the availability of temporary power for work associated with the repair ECs.

14. Layout and Arrangement Requirements:

The shape of removal as shown on SK-72519-C001 is within best industry guidelines for concrete repair. The squared corners and minimization of feathered edges as recommended in ICRI 03730 (Attachment Z01) and ICRI 03737 are incorporated into the repair methodology. Coupled with proper surface preparation techniques and consideration for rebar splices/staggering, the layout will allow for successful concrete placement per EC 75220.

15. Operational Requirements Under Various Conditions:

As stated in the design input, the work shall only commence during shut down conditions. This is to minimize potential adverse impact to the structure. Thermal gradients requirements and evaluation are as described in B.6.5.

16. Instrument and Control Requirements:

Temperature Monitoring Requirements:
Calculation S10-0004 has included a 10° F thermal gradient in the ANSYS FEM when evaluating the containment shell for reduced prestress and reduced concrete thickness.

The surface temperature of the liner plate will be measured using thermocouples (As in Attachment Z06 or similar devices that can measure surface temperature) attached to the surface of the liner plate at a minimum of two representative locations. Similar devices will be attached to the inside surface of existing core bores located in the general vicinity of buttresses 3 and 4 as required to obtain representative internal concrete temperatures. These devices will be placed so that they can measure internal bore surface temperature at 3 approximate depths; 4" inside the core bore, at mid-point and at the base of the core bore or at least 12". The temperature measuring instruments for the various depths may be combined in a single core bore or spread among adjacent core bores as determined practical during installation. Once mounted, the core bore should be plugged with at least 2"-3" of insulating material at the outer face. In addition, two thermocouples will record ambient air temperature outside containment. The temperature devices shall be capable of recording temperatures at a sampling frequency of at least once every 10 minutes. If capability exists, the temperatures will be made available on the CR3 business network for display on OSI PI.

At a minimum, the rolling 7 day average temperature will be trended and recorded for the inner liner surface and 4" concrete depth (in PI if available). It is desired to have indication from all devices in PI. The seven day average is listed because of the latent affect that temperature has on a 42" thick (or 32" thick after delaminated concrete is removed) concrete wall.

Thermal measuring devices are not attached to the outside face of the containment wall since un-conservatively high temperatures would be recorded if the measurements were taken at the surface of the containment wall due to solar radiation, i.e. the surface temperature is directly affected by the sun and would not be representative of the average temperature 2"-3" inside the wall (Reference Attachment Z29R0 of EC 75218).

The thermal gradient that will be managed will be the difference between the average of the two thermocouples attached to the liner and the average of the two thermocouples 4 inches from the face of the outside containment wall inside the core bores. Operations will use the RB ventilation cooling, heating and purge system per OP-417 making daily adjustments as required to maintain the delta as close to zero as possible based on a 7 day rolling average. The limit on the ambient temperature inside containment is 60 degrees. If the delta between the thermocouples inside containment and 4 inches from outside face of containment inside the core bores reaches 8 degrees F, engineering will evaluate if additional actions need to be taken outside containment by SGT to increase the concrete temperature. These actions may include tents, blankets, heaters, and moisture. Based on a review of the stresses in the unreinforced section of concrete during the detensioned condition, the extent of protection outside containment is expected to be limited to an area about 10 feet beyond the perimeter of the steam generator opening.

Summary: Temperature gradient (4 inches subsurface to inner liner) will be managed as close to zero as practical based on a seven day rolling average. When the thermal gradient reaches 8 degrees F, an evaluation will be made by engineering with the intent of determining if forecasted temperatures could result in a sustained temperature gradient greater than 10 degrees F. If such a gradient is judged possible then appropriate actions will be taken. The action is to preclude a temperature gradient of 10 degrees taken as a 7 day rolling average.

17. <u>Access and Administrative Control for Plant Security:</u>

Temporary EC 75497 evaluates the necessary requirements for moving the interfering conduits located directly above the equipment hatch. More specific details concerning the temporary layout and/or necessary security compensatory actions will be found within that document. Please reference EC 75497 for additional details.

18. <u>Redundancy, Diversity, and Separation Requirements of Structures, Systems, and Components:</u>

There is no evaluation required for this Design Input.

19. <u>Failure Effects on Requirements of Structures, Systems, and Components:</u>

The overall concrete removal will not adversely affect the final design base configuration of the Reactor Building Containment. This is due to the fact that the removed condition is not required to be credited for final design loading conditions as the repaired containment would need to meet. Based on the evaluation in B.6.5, the adjacent Auxiliary Building will remain unaffected as a result of the removal and the reduced section is stable for the applicable loading conditions. Subsequent interfacing ECs will restore the containment to meet its design base requirements.

20. <u>Test Requirements:</u>

The surface preparation testing requirements are in line with industry best practice standards. The testing as described in Appendix A of ACI 503R are easy to replicate on a large scale and will quickly discriminate between an adequately cleaned and prepared surface and an unacceptable surface for future bonded concrete. Based on its simplicity and its recommendation as a best industry practice, this testing is considered both prudent and acceptable for surface examination prior to concrete placement. Simple subsurface testing per ICRI 03739 will show if micro cracking has developed to a point at which would impact the structure. This testing is minimally invasive and requires only 3 points per 5000 ft^2 of repair area. Any other required ASME Section XI, Subsections IWE/IWL as well as ASME Section III inspections and testing shall be implemented under interfacing ECs 75218, 75220, and 75221.

21. Accessibility, Maintenance, Repair, and ISI Requirements:

    There is no evaluation required for this Design Input.

22. Personnel Requirements and Limitations:

    There is no evaluation required for this Design Input.

23. Transportability Requirements:

    There is no evaluation required for this Design Input.

24. Fire Protection or Resistance Requirements:

    There is no evaluation required for this Design Input.

25. Handling, Storage, and Shipping Requirements:

    There is no evaluation required for this Design Input.

26. Other Requirements to Prevent Undue Risk to the Health and Safety of the Public:

    Safe load paths as described in EC 63020 shall be considered to minimize the likelihood of damaging critical plant equipment during any necessary rigging activities. No further evaluation is required for this design input.

27. Materials, Processes, Parts, and Equipment Suitability for Application:

    There is no evaluation required for this Design Input.

28. Safety Requirements for Preventing Personnel Injury:

    The concrete removal process will utilize properly qualified mobile or suspended platforms as used for the tendon activities being performed during Refueling Outage 16 and/or scaffolding as required. The project safety interface must ensure that proper and sufficient consideration is made of the requirements for fall protection and of the dangers involved in working at heights as well as falling objects and dropped items. Future revisions may be used to incorporate any other platform needs as they are determined by the SGT project team.

29. (CR3) Circuits for systems with Improved Technical Specifications testing requirements:

    There is no evaluation required for this Design Input.

30. (CR3) Emergency Diesel Generator Loading Impact Assessment:

    There is no evaluation required for this Design Input.

B.7 Interfaces

Progress Energy EC Project Team and Interfaces

- Aaron Mallner – Responsible Engineer, CR3 Containment Design Base Analysis Team
- Ron Knott – CR3 Containment Design Base Analysis Team
- Rick Pepin – CR3 Containment Repair Team Lead
- Paul Fagan – CR3 Containment Condition Assessment and Engineering Team Lead
- Charles Williams – CR3 Containment Root Cause Analysis Team Lead
- C. Glenn Pugh – RE EC 75220
- Sid Powell – Licensing Support
- John Holliday – Contract SGR EC 63016, Containment Opening RE
- Keith Allen – CR3 Design Superintendent
- Rick Portmann – CR3 Containment IWE/IWL Program Owner
- Paul Gosselin, SGT – Planner
- Glen Maxwell, Ron Dufresne, Jim Clayborne, SGT – Installer
- Scot Stewart – Scot Stewart
- Casaba Ranganath – Lead Design Verification
- Ron Tyrie – Operations
- ALARA – Ken Young
- Craig Miller – CR3 Containment Root Cause Team

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Thomas J. Rowe, S.E.
Wiss, Janney, Elstner Associates, Inc.
Principal Engineer
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B.8 Quality Class Determination

Quality class of individual components and materials required for this EC are as follows:

1. The containment building is a **Class I Structure (Safety Related)** as described in the FSAR Sections 5.1.1.1 and 5.2.1 and the Design Basis Document for the Containment, (Ref. 2.1, Tab 1/1). The primary function of the reactor containment building and its steel liner is to house the primary nuclear system and to provide biological shielding

from the fission products that could become airborne under accident conditions. Its failure could result in the uncontrollable release of radioactivity and its integrity is vital for the safe shutdown and isolation of the reactor.

2. Tendons, tendon anchorage including stressing washers, shims and tendon grease are all **Safety Related.** These items ensure the structural integrity of the containment building.

Therefore, the overall quality classification of this EC shall be Safety Related.

C.1 Document/Drawing and Equipment Database Mark-Ups

Controlled documents requiring revision are listed on the EC Affected Document List (ADL). Drawings required for turnover are designated with the “OpSVc” flag on the ADL. Document changes may be indicated by document mark-ups or by "Description Of Change" provided in the tables below.

C.2 Updates of Controlled Documents/Drawings

There are no design records that require updating as a result of this modification. Any evaluation or removal sketch shall be within the body of this EC.

Doc. Type	Document Number	Sht	Description Of Change or Reference to Mark-Up
			NONE

C.3 Other Required Updates

Item	Description Of Change or Reference to Mark-Up	Rq'd for T/O?	AR Number?
	NONE		

C.4 Equipment Parameter Notes

CAUTION

Parameter Notes are placed under Revision Tracking & Control beginning with the V10.0.4 upgrade of PassPort (installed on December 10, 2006). Prior to V10.0.4, special rules were required for processing EDB Parameter Notes. Prior to V10.0.4, since parameter notes are not part of the EC PassPort report which becomes a QA record, a parameter note with a pending change should be captured in the table below to preserve the QA record. Changes to parameter notes created after V10.0.4 should be processed in the same manner as any other EDB change under Revision Tracking & Control, and are not required to be captured in the table below.

(Select Table/Select/Table, copy Ctrl-C, and paste Ctrl-V the following table as many times as necessary.)

U	System	Tag # or Equipment #	Parameter
Pending Minor Revision		NONE	

C.5 Equipment Document References

Equipment document references in the Equipment database are not under PassPort revision tracking and control. They should be listed below (Title is optional):

Unit	System	Tag # or Equipment #			
		NONE			
Doc. Type	Sub-Type	Document Number	Sht	Add or Delete	Title

D.1 Installation Package

The following information is used to specify installation requirements to be used for planning the *work package*. Installation sketches are provided in the sketch section of the EC.

D.2 Installation Requirements

Prerequisites and Precautions

1. Pre-job brief shall be conducted prior to commencing project in the field. Topics should include OE 14720, OE 29756, and Hydrodemolition Lessons Learned documented in NCRs 358636 and 358653.
2. Contact WCC prior to beginning work in the field.
3. Control of transient combustibles is to be maintained in accordance with AI-2200.
4. Housekeeping of the work areas shall be maintained in accordance with AI-1000 or approved SGT equivalent.
5. Erect any required scaffold in accordance with MNT-NGGC-0004 or approved SGT equivalent.
6. Any hazardous waste that is produced by activities implemented per this EC shall be handled and shipped in accordance with Procedures EVC-SUBS-00016, EVC-SUBS-00008 and AI-1820.
7. Any non-hazardous waste that is produced by activities implemented per this EC shall be handled and shipped in accordance with Procedure AI-1820.
8. Strain gauges have been installed by WO 1636782-04 and are functional.
9. Perform Hot Work in accordance with FIR-NGGC-0003.
10. Verify all detensioning work associated with EC 75218 has been completed prior to concrete removal.
11. Installer to verify dosimetry requirements with Radiation Protection prior to commencing work in the field.
12. Sensing Systems has verified that the original plant strain gauges, which are attached to the embedded reinforcement, are not functioning. They shall be removed as they are uncovered during the demolition process. Strain gauges installed for monitoring during detensioning shall be removed under the direction of Sensing Systems as the wall being prepared for removal.
13. Lesson Learned concerning hydrodemolition runoff as documented in NCRs 358636 and 358653 shall be reviewed prior to start of work. Only qualified or designated personnel are allowed to remove storm drain covers to adjust the flow of pooling water runoff.
14. All hydrodemolition equipments shall be tested prior to start of work.
15. A safety net or other similar device shall be erected around the hydrodemolition equipment to prevent debris from falling and injuring personnel
16. Discharge of hydrodemolition into settling ponds may not commence until both site chemistry and RP have cleared samples as being acceptable to do so. Hydrodemolition may continue provided wastewater and rubble are collected in temporary bins/tanks until they can be cleared. Activities shall be in accordance with EVC-CRNF-0002.
17. Use of chemicals for this activity are subject to the requirements of CHE-NGGC-0045, NGG Chemical Control Program.
18. Dikes shall be installed around equipment, especially chemical storage, in accordance with WP-106, "Storm Water Discharge from Diked Petroleum, Chemical,

and Equipment Storage Areas." **Barriers shall be specifically installed around tendon gallery sumps SDP-3A and SDP-3B to prevent potential hydrodemolition runoff from the tendon sheaths from entering into the pumps. The pumps shall be tagged out at the discretion of site operations.** Temporary sump pumps shall be installed to remove any runoff in the tendon gallery and carry to a portable collection facility. Water shall be examined by site chemistry and RP prior to disposal and/or discharge. Additional precaution shall be noted for the potentially open equipment hatch. Should the equipment hatch still be open, barriers shall be installed by SGT so as to prevent water and/or concrete slurry from entering into the CR3 RB during hydrodemolition activities.

19. The CR3 RB containment coordinator or project lead should be notified prior to the start of hydrodemolition activities. This person shall inform all personnel within containment in the immediate area that hydrodemolition activities will commence and noise levels may drastically increase.

Removal of Concrete

1. Overview of concrete removal is shown on SK-75219-C001. Additional concrete may be removed as required to assure complete delamination removal. The sketch is to serve as a starting point for removal. The intent is for hydrodemolition to remove the general area while knocking loose any of the delaminated concrete. The hydrodemolition process should cease as the centerline of the hoop tendons is reached. Greater depths may be removed under the direction of the responsible PGN civil engineer under the guidance of the ACI concrete repair manual. In certain circumstances, hydrodemolition shall be discontinued and certain hand removal methods shall be used such as pneumatic or hydraulic impact breakers, needle guns, lance hydrolazing, or equivalent. The use of those tools and depths exceeding 10" shall be reviewed and approved by the PGN responsible civil engineer prior to their usage for localized removal.

2. Hydrodemolition shall be the primary method of concrete removal. No single pass of hydrodemolition shall remove more than 4" of delaminated concrete. Pressure shall be reduced as the depth of delamination is approached to minimize jets spraying the hoop tendon sheaths as well as sound concrete behind the delamination. Hydrodemolition may be used at the reduced pressure to clean the surface and obtain the desired surface profile on the sound concrete but should not be used to significantly remove the concrete past the centerline of the horizontal hoop tendons.

3. The maximum depth of removal shall be a typical 10". This is the centerline of the hoop tendons. Spalling of localized areas behind the hoop tendons is expected. Delamination extending beyond hoop tendons shall have a minimum of 2" excavation around the tendon to ensure a good bond when the concrete is replaced. All obviously loose pieces of concrete shall be removed. When spalled areas pass beyond the 10" depth, refer to note 1 as hand methods may be required to complete the removal of unsound concrete. As before, all loose concrete shall be removed from the containment wall. Areas that require localized attention to provide further removal shall utilize a less invasive method which may include but is not limited to mechanical or hydraulic impact breakers, needle guns, or lance hydrolazing. The usage of alternate removal tools shall be approved by PGN civil engineering prior to their usage on the wall past 10".

4. Rebar should be cut using saw-cut method only for those rebar that will utilize a lap or mechanical splice. Flame cutting is permissible to advance removal work in the field provided that cut is made no closer than 6" to the prepared end. The heat affected zone shall be removed before any final splicing/coupling takes place. Rebar shall be discarded and is not to be reused for work associated with EC 75220. Any original plant construction aids may be removed as needed by SGT by any safe, reasonable method. Tailings for the embedded #8 rebar of a minimum 9" for an approved mechanical coupler shall remain for tie-in of new rebar as shown on SK-75219-C001. Splices shall be planned around horizontal tendon ducts and adjacent rebar as required by EC 75220. Final lengths may be more than 9" so as to develop alternate code splice requirements and staggering requirements (Within 36 to 80 bar diameters may be cut to utilize a lap splice). Rebar coming up from the equipment hatch (#11 bars) as shown on Drawings 421-032/ 421-040 and rebar projecting downward from the ring girder (#18 x 24'-0" long) as shown on Drawing 421-036 **SHALL NOT** be cut unless prior authorization is obtained. Additional #9 hooked bars as shown on 421-036 extending from the buttresses **shall** also be preserved. If rebar other than the identified #8 requires cutting, stop work and notify Progress Energy design engineering to provide design review and requirements at that time. Should interferences prevent the use of saw cutting in some areas, SGT should contact PGN civil engineering for acceptable alternative on a case by case basis. The resolution shall not impact the ability to install necessary mechanical couplers as described in EC 75220, if needed.

Preparation of Concrete Surface

1. Concrete surface shall have a minimum surface profile of CSP-6 or greater as described by ICRI 03732 in Attachment Z00. Based on ICRI 03732 and ICRI 03737, hydrodemolition methods achieve this minimum surface profile. Other methods may be used at the discretion of the PGN civil design engineering in accordance with the Concrete Repair Manual, Third Edition, to remove localized areas of unsound/delaminated concrete. Methods which have a high tendency to produce micro-cracking will not be allowed.

2. Prepare **all** edges as described in ICRI 03730 (page 7 of Attachment Z01) as applicable. Saw cut a minimum 1½ along cut line as shown on SK-75219-C001, however, cut shall be made as deep as reasonably achievable without cutting remaining rebar tailings. The use of mechanical impact breakers shall not be allowed to prepare the edges to minimize micro-cracking in these locations. Remove all feathered edges.

3. After all cutting/hydrodemolition the surface shall be cleaned of all dirt, oil, grease, laitance, slurry, and loosely bonded aggregates. As noted in ICRI 03730 and ICRI 03737, if hydrodemolition is used, cement and particulate slurry shall be removed before drying and hardening.

4. Concrete sounding shall be performed in all removed area locations using ASTM D 4580 as a guide (Reference Procedure B, Attachment Z02). All unsound concrete shall be removed. A typical grid spacing of 12"x12" (+3"/-6") should be utilized for sounding. A 16 oz ball peen hammer or long threaded rod is recommended for the

sounding process. The sounding object should be struck against the concrete surface at the predetermined spacing. The personnel performing the sounding should listen to and note the resulting "ringing" sound. A tone change more like a dull "thump" or "thud" would be indicative of a delaminated section of concrete. Those delaminated regions should be removed with less intrusive hand methods such as a needle gun or equivalent.

5. Any noticeable cracking at the surface should be mapped. PGN design engineering shall examine this mapping and as well as the concrete surface in order to communicate acceptance criteria for leaving, removing, or repairing. If the crack is unable to be removed or is determined to be left as-is, EC 75220 shall provide the repair and/or acceptance criteria for leaving the crack untouched. This includes those areas particularly around the area of the liner stiffeners as identified in NCR 370873. Any specific area of interest should be documented and captured as part of the mapping process to ensure it is correctly addressed. It should be noted that cracking is expected to form above and below the construction opening as a result of detensioning activities (reference EC 75218). Particular attention should be given to those areas during surface preparation in order to identify those cracks.

6. A cursory review of any remaining reinforcement shall be performed by the PGN responsible civil engineer to note any significant degradation/damage to the rebar prior to the implementation of EC 75220 to prevent any significant delay in the work schedule.

Surface Testing Considerations:

Testing for adequate surface preparation shall be implemented by SGT field engineering under the direction of the PGN civil design engineering using ACI 503R, Appendix A as a guide (See Attachment Z03, Pages 27 and 28).

1. Cut 1" Aluminum T-bar into segments so as to create 1 in^2 bonding surface area on the flange.

2. Drill a hole in the web portion of the T-bar for subsequent tension pull attachment

3. Abrade flange of T-bar with Crocus Cloth or equivalent

4. Using a fast setting epoxy, affix the T-Bar to the surface of the prepared concrete. Epoxy strength should meet or exceed the strength of the concrete, or 5000 psi compressive strength and 200 psi tensile strength

5. Score around the edge of the flange to ensure only 1 in^2 of bonding surface area.

6. Allow epoxy to set per manufacturer's recommendations

7. Fabricate testing rig as shown in figure A.5 of Attachment Z03. Dillion Dynamometer may be substituted with equivalent tension type dynamometer with capacity of 500 lbs minimum. Resolution shall be such that values can be recorded in 10 lb increments. Hardware may be substituted as required to allow fit up to bonded aluminum T-bars.

a. Load bonded T-Bars at a uniform rate. Record the force value at which the T-bar debonds and note the type of failure on the Attachment Z04 data sheet.
b. Concrete bond strength should meet or exceed 200 psi.
c. Repeat steps 1 through 7 at a rate of 1 test for every 100 sq. feet of prepared concrete surface or as best as reasonably achievable. Tests shall be re-conducted for areas where inadequate bonding strength is determined. Additional surface preparation may be required to obtain surface with adequate bonding strength.
d. **Testing may be terminated at the discretion of PGN civil engineer if results show consistent adequate bond strength or testing is shown to not be practical.**

Subsurface Micro-Cracking Test Considerations:

Testing for adequate subsurface strength shall be implemented by SGT field engineering under the direction of PGN civil design engeering using ICRI 03739 as a guide (See Attachment Z07).

1. Drill 2"corebores a minimum of 6" deep at 3 random locations throughout the prepared surface area.

2. Affix a metal disc as described in Attachment Z07 with the same epoxy used to affix the aluminum T-Bar above and allow to set per manufacturer's recommendation.

3. Using skill of the craft attach the rigid disc to the pullout rig created for the above testing.

4. Apply a load at a uniform rate and record the load at which the core breaks. Stress levels should meet or exceed 200 psi. Additional surface preparation/excavation may be required if testing shows inadequate strength.

5. Repeat the test as described in ICRI 03739 a minimum of three locations at the discretion of the PGN civil engineer. **Testing may be terminated if conditions prove impractical.**

Monitoring for Excessive Thermal Gradients across the Unreinforced Containment Wall

Based on review of the MPR analysis S10-0004, a 10° F shall be accounted for and maintained during and after the concrete removal process.

1. Thermocouples per Attachment Z06 (or equivalent) shall be attached to the RB containment liner and exterior concrete wall at the discretion of CR3 operations and the CR3 Containment Design Basis Analysis team.

2. A rolling 7 day rolling average shall be observed by operations. The delta temperature difference between internal containment temperature to exterior temperature shall be maintained at less than 10° F by using OP-417. The limit on the ambient temperature inside containment is 60° F.

3. If the thermal gradient approaches 8° F, an evaluation will be made by engineering to determine if forecasted temperatures could result in a sustained gradient greater

than 10° F. If such a gradient is judged possible then appropriate actions shall be taken and the affected organizations shall be notified at this time.

4. Internal containment temperature shall be maintained by site operations utilizing OP-417. Scaffold and sheeting shall be erected as needed to maintain temperature on the exterior surface. SGT shall be responsible for supplying heaters to maintain the temperature on the external surface within the "tented" area.

D.3 Label Requests

Labels requiring change as a result of this EC include: NONE

D.4 EC Parts List

Parts or other materials required by this EC are tabulated below. Any unique or long lead procurement actions are indicated in the description.

Installation					Design			
Item No.	Qty/ Units	PO Number	PE Request	Catalog ID	Description (If available, include Manufacturer, Model, and Version)	Spec or CGI	Q Status	
							Buy	Use
1	TBD/ Feet				T-BAR, 1” Aluminum, MFR. STD., Length as Required		QL-4	QL-4
2	TBD/ Each				Epoxy, Fast-set, MFR, STD., Min bond strength = 200 psi and minimum compressive strength = 5,000 psi		QL-4	QL-4
					TBD = To be determined			

E.1 Testing Requirements

Unique Prerequisites, Precautions, Limitations, Initial Conditions, and Outage Requirements:

In-situ surface preparation testing will be required prior to concrete placement per EC 75220. Surveillance may be required for to monitor surface final bonding surface conditions prior to concrete placement. Refer to Attachments Z00 and Z01 for industry guidance on surface preparation. Other required ASME Section XI, Subsections IWE/IWL as well as ASME Section III inspections and testing shall be implemented under interfacing ECs 75218, 75220, and 75221.

Test and Acceptance Criteria:

Design Input/ Parameter/ Function	Test Procedure Or Method	Acceptance Criteria	Required for T/O Y/N?
Bonding surface preparation	**ACI 503R-93 (Reapproved 2008)** **Reference Installation Instructions and Attachment Z03, Pg 27-28.**	**Bond strength meets or exceeds 200 psi. 200 psi is the minimum design tensile strength of the concrete as described by DBD for the Containment. At that stress level the concrete anywhere in the structure is just as likely to crack as the bond interface between existing and new concrete.**	**N**
Subsurface in-situ strength test	**ICRI 03739**	**Core strength meets or exceeds 200 psi. 200 psi is the minimum design tensile strength of the concrete as described by DBD for the Containment. At that stress level the concrete anywhere in the structure is just as likely to crack as the bond interface between existing and new concrete.**	**N**

F.1 Turnover/Closeout Summary

Based on a review of Section 9.3.4 of EGR-NGGC-0005 and the scope of this Engineering Change, turnover to operations SHALL NOT be required based on the following:

- No Priority 0 documents are affected
- No POM procedures are affected
- No impact to electronic equipment data
- No Tech Spec Change is required
- No impact to surveillance test schedules
- No impact to Clearance software
- No impact to Technical Specification tracking software
- No training requirements
- No testing requiring Engineering review of results identified
- No labeling requirements

Closeout Summary

All Work Order Tasks are status FINISHED or COMPLETED

Assure AR's are COMPLETED or CLOSED

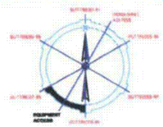
Prior to EC Closure, a "Post-Job Brief" will be held after EC 75000 has been installed to discuss and evaluate the various aspects of the EC. This briefing will be chaired by the Responsible Engineer or his designee and will be attended by representatives of the organizations with insights into how well the job was accomplished. The attendees will be determined by the RE based on input needed and availability of appropriate individuals. Reference AR 365187.

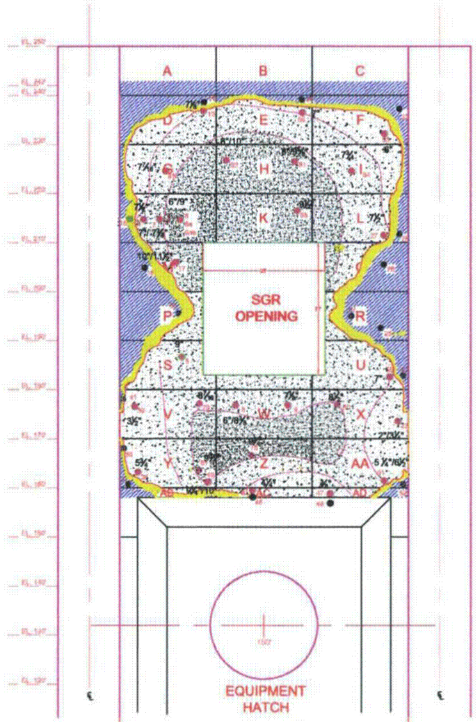
Catalog and Bill of Materials Impact

BOM Manufacturer:	**Model:**	**Version:**		
	NONE			
Manufacturer's Part Number	**Catalog ID**	**Add or Delete**	**Q Status**	**Proposed Stocking Quantity**

G.1 Installation Sketches

Sketch Number	Sht	Rev	Title
SK-75219-C001	1	A	Delaminated Concrete Removal Details
SK-			
SK-			
SK-			
SK-			
SK-			
SK-			

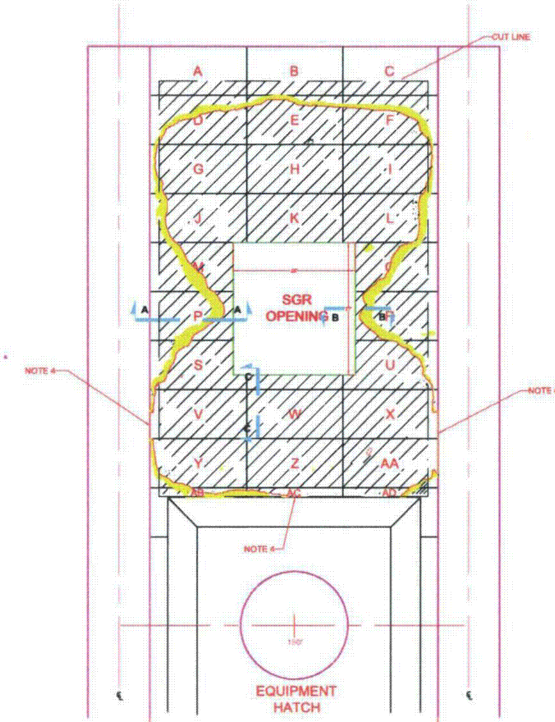




RBCN-0015

CRACK DEPTH MAP

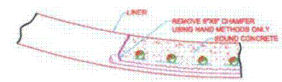
LEGEND
- CORE BORE WITH DELAMINATION
- CORE BORE NOT DELAMINATED
- 8.5"+ DEPTH OF DELAMINATION
- 7" - 8.5" DEPTH OF DELAMINATION
- 3" - 7" DEPTH OF DELAMINATION
- XX/XX - NEAR FACE / FAR FACE DELAMINATION



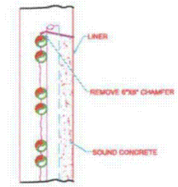
RBCN-0015

ALLOWED AREA OF REMOVAL
DEPTH=CENTERLINE OF HOOP TENDONS (10" TYPICAL)

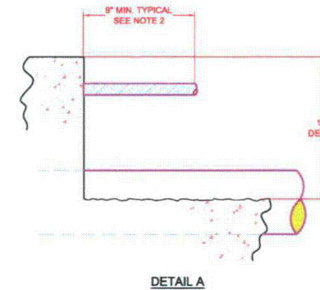
LEGEND
- GENERAL AREA OF REMOVAL



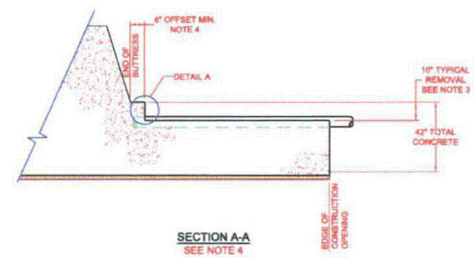
CONSTRUCTION OPENING SECTION B-B
PLAN VIEW



CONSTRUCTION OPENING SECTION C-C
ELEVATION VIEW



DETAIL A



SECTION A-A
SEE NOTE 4

NOTES:

1. DRAWING IS PROVIDED AS A STARTING REFERENCE FOR REMOVAL OF DELAMINATION. CONCRETE MAY BE REMOVED TO CENTERLINE OF HOOP TENDONS PROVIDED SURFACE AND EDGE PREPARATION IS CONSISTENT WITH ICRI 03732, ICRI 03730 AND ACI 546R.

2. 9" MIN REBAR TAILS ARE REQUIRED FOR SPLICING NEW #8 REBAR, VERTICAL AND HORIZONTAL, AS SHOWN ON DWG. 421-032. SPLICES SHALL BE PLANNED AROUND HORIZONTAL TENDON DUCTS AND ADJACENT REBAR. #11 REBAR PROJECTING UPWARD FROM THE EQUIPMENT HATCH AND #18 REBAR PROJECTING DOWNWARD FROM THE RING GIRDER **SHALL NOT BE CUT.** ADDITIONAL #9A546 @ 13" PROJECTING FROM BUTTRESS #3 AND #4 AS SHOWN ON DWG. 421-036 SHALL ALSO BE PRESERVED. IF REBAR OTHER THAN #8 REQUIRES CUTTING, STOP WORK AND NOTIFY PROGRESS ENERGY DESIGN ENGINEERING.

3. LOCALIZED AREAS OF REMOVAL MAY EXCEED 10" AT THE DISCRETION OF THE PGN RESPONSIBLE ENGINEER IN ACCORDANCE WITH MPR ANALYSIS S10-0006.

4. 6" MINIMUM OFFSET AT EDGES REQUIRED TO MINIMIZE HYDRODEMOLITION DAMAGE TO BUTTRESSES #3 + #4, AND THE EQUIPMENT HATCH. PANELS WHERE THE DELAMINATION EXTENDS TO THOSE EDGES (V,X,Y,X,AA,AB,AC + AD) SHOULD HAVE ANY REMAINING CONCRETE REMOVED WITH LESS AGGRESSIVE MECHANICAL METHODS AT THE DISCRETION OF RESPONSIBLE CIVIL ENGINEER.

5. THE CONCRETE SURFACE AT THE TOP OF THE REMOVED SECTION SHALL BE SLOPED UP TOWARDS THE WALL EXTERIOR TO FACILITATE THE ESCAPE OF AIR.

NO.	DESCRIPTION	DRAWN
A	ISSUED PER EC 75219 R0	

REVISIONS

Progress Energy

NUCLEAR ENGINEERING

CRYSTAL RIVER UNIT 3

DELAMINATED CONCRETE REMOVAL DETAILS

DRAWN	CHKD.	APPVD.	DATE	SCALE
-	-	-	X	N.T.S.

DISCP.	SHEET	DWG.	REV.
	SH-001	SK-75219-C001	A

FILE:

H.1 Risk Management

Scope of Work:
EC 75219 is the third phase in a multi-phased approach in the repair of the CR3 RB containment building identified per NCR 358724 as follows: 1) Crack Arrest (EC 75000) – A series of cuts will be provided into the delaminated concrete. These cuts will provide a path of stress relief during the detensioning process. Two horizontal cuts will be made, one above and one below, the steam generator replacement opening. The length of the cuts will not exceed the area of construction opening. In addition to horizontal cuts, vertical cuts will also be installed above and below the contstruction opening at Azimuth 150°. The cuts will run between the currently detensioned vertical tendons at a depth only to cut embedded rebar. This is to minimize cutting active hoop tendons which exist above and below the current containment opening. 2) Detensioning (EC 75218) – A Finite Element model developed by MPR Associates, Inc. shall be completed to show the necessary detensioning and re-tensioning sequence as well as compliance with the appropriate bases. The detensioning implemented by this phase will ensure adequate prestress can be returned to the Reactor Building structure. 3) **Concrete Removal (EC 75219)** – This EC will address the removal of the existing delaminated concrete. This is to facilitate the placement of new concrete per EC 75220. The removal of the delamination will require the detensioning of vertical and horizontal tendons within the affected region as prescribed in EC 75218. All steel reinforcement (rebar) exposed within the opening must be cut and discarded. Once the delaminated region is removed, phase 4 EC 75220 may be implemented. Removal will be accomplished via a combination of hydrolazer and/or mechanical methods (chipping). 4) Concrete Placement (EC 75220) – This EC will address the replacement of the delaminated concrete with new concrete. Mix and installation shall consider criteria evaluated per EC 63016 to originally restore the containment opening. Critical concrete characteristics such as creep, aggregate type, testing requirements, etc. shall also be considered as a part of this phase. 5) Re-tensioning (EC 75221) – This EC will address the final re-tensioning sequence to restore prestress back into the concrete containment shell once the replaced concrete has adequately cured. Final MPR FE analysis results shall be incorporated to ensure the applicable design and licensing bases requirements have been met.
Risk Critical Evolution(s) and Associated Risk Parameter(s):
As noted above, this EC will address removal of the concrete only. Based on the available methods of removal, hydrolazing and mechanical chipping, risk of damage to the underlying reinforcement and tendon sheaths exists. While the conventional reinforcement will be removed as a result of this EC and ultimately replaced, damage to the tendons is possible and must be minimized, particularly to the flexible conduits in the region around the equipment hatch. Additionally, due to the scale of the removal, consideration must be given to all the personnel safety risks associate with removing such a large volume of concrete. It should be noted that this Risk Worksheet is preliminary awaiting final resolution of the Root Cause, particularly. Work shall be performed during plant No Mode to prevent adversely affecting the integrity of the structure while the removal takes place.

Risk Assessment:	Risk Screen Level:
Probability: ☐ 1 ☐ 2 ☒ 3	☐ H ☒ M ☐ L

Consequence: ☒ 1 ☐ 2 ☐ 3	

Basis for Probability and Consequence:

The activity mitigation/avoidance strategies as well as the basis for probability have been documented below. Each item as individually screened as medium risk or low risk, therefore, the overall risk of this EC shall be medium in accordance with EGR-NGGC-0011.

Risk Response Planning

Risk Parameter:	Risk Response:	Risk Response Action:
Infrequently performed task related to concrete removal of RB containment wall.	☐ Avoidance ☐ Acceptance ☑ Mitigation	Design and Construction Engineering Oversight - Using hydrodemolition and other large scale equipment to create an opening in the RB wall is an activity that is infrequently performed at CR3. However, using hydrodemolition equipment to create such an opening has been successfully employed at numerous other nuclear plants in support of their SGRs and reactor vessel closure head replacement projects. A majority of the CR3 Delamination repair team, both engineering and construction personnel have extensive prior experience working on SGRs and (RVHRs) and are cognizant of the potential problems associated with hydrodemolition and mechanical demolition. Final Root cause determination will be considered before proceeding with any one removal option. Previous Experience - The vendor performing the hydrodemolition (Mac and Mac, **EXPECTED**), has been in the business of hydrodemolition for over 30 years and will be responsible for operating the equipment. Installation Instruction Precautions: The installation instructions will contain a precaution for the hydrodemolition contractor to reduce water pressure as needed before exposing the underlying tendons. This is to reduce the risk of penetrating the sheath. The consequences of further damage during the removal process are considered high, however, this phase of work is merely to allow the final repairs to occur. Proper engineering oversight during the removal process will ensure removal is done in a safe, efficient manner. Additionally, damage that could occur during the removal will be evaluated and repairs made during the subsequent interfacing EC 75220. As such the likelihood of irreversibly damaging the structure is considered extremely low. Therefore this risk parameter is considered medium.
Personnel safety due to large volume of concrete removed and associated working at heights.	☐ Avoidance ☑ Acceptance ☐ Mitigation	Concrete removal and handling of associated equipment will involve the dangers of working at heights. Personnel access to the various scaffolds and work platforms must be limited to those individuals that have a need to actually be on the platforms. The pre-job brief should also emphasize the potential danger from dropped objects, especially considering the heights involved when working on the containment building roof or suspended on the work platforms. Adherence to Vendor Procedures and Training is critical. Incorporation of relevant OE shall also be incorporated into necessary pre-job briefs. Adherence to CR3 Procedures - All work performed relating to this EC will be in accordance with SAF-NGGC-2172, "Industrial Safety" or

		SGT equivalent. All appropriate safety equipment is to be employed during the performance of this modification (e.g. eye, face, hearing, hand, foot protection, fall prevention / protection, respirators). Personnel working on scaffolding must be familiar with the requirements for working at heights. All work controlled areas will be marked and tagged per AI-1816, "Industrial Safety Signs and Tags" or by equivalent SGT process. While the consequences of the injury are high related to the removal work, the probability is considered extremely low provided all Site procedures are appropriately adhered to. As such this risk parameter is considered medium.
Accelerated schedule could allow for approval prior to final root cause determination	☑ Avoidance ☐ Acceptance ☐ Mitigation	The various phases of the delamination repair project are ongoing in parallel to the root cause investigations. There are significant consequences if the repair techniques would make the crack larger or not even solve whatever crack initiating event caused the delamination. Surface preparation requirements dictate only a few methods will create the surface required for new concrete placement. Best industry practices shall determine the recommended technique for both removal and surface preparation. The least invasive method which would damage the structure shall be considered. To ensure significant damage has not been sustained in the structure, in-situ pullout testing of the subsurface will show the necessary strength remains in the concrete subsurface. This testing will be in accordance with ICRI 03739. While the consequences of procedding without final root cause may be high, probability is considered extremely low as any additional areas of damage sustained during removal may be repaired before final concrete placement. Therefore this risk parameter is considered medium.
Multiple parties involved such that errors may be introduced via communication channels	☐ Avoidance ☐ Acceptance ☑ Mitigation	The containment team consists of both design and implementation individuals. These individuals are required to interact during pre-job and kick off meetings. Final EC review by members of both parties would prevent approval of product. Therefore, the consequences of an overlooked design item may be high, however the constant review process would make it an unlikely occurrence. Therefore this risk parameter is considered medium.

H.2 Validation Plan

The Responsible Supervisor should complete the following validation plan with the Responsible Engineer at the initiation of the EC (see EGR-NGGC-0011).

Product/EC Stage	Process/Tool	Outsourced EC[1, 2, 3] ☐	Internal EC[1, 2, 3] ☑	All other Engr Products[3] ☐	To Be Implemented?[4]
At Initiation	Validation Plan	R	R	O	☑
	Risk Determination	R	R	O	☑
	Risk Response Planning	R[7]	R[7]	O	☐
	Project kick-off meeting	X	O	O	☑
	Pre-job briefing	R	R	NA	☑
	Formation of an EC Team	X[5]	X[5]	NA	☐
	Scheduling/Work Management	X	X	O	☑
Development Phase	In-process review – 0% Design Challenge	X	X[5]	O	**Waived**
	In-process review – 30% Design Challenge	X	X[5]	O	☑
	In-process review – 70% Design Challenge	X	X[5]	O	**Waived**
	In-process review – Final Design Challenge	X	X[5]	O	**Waived**
	Source review	O	NA	NA	☐
	Owner review	X	NA	NA	☐
	Error Prevention Tools (STAR, SAFE, OAQ-3, etc)	O	O	O	☑
	Design Review Board – Conceptual	X	X	O	**Waived**
	Design Review Board - Final	X	X	O	☑
	Engineering change checklist	R	R	O	☑
	Outsource management checklist	R	O	O	☐
	Procurement vendor oversight checklist	O	O	O	☐
	Supervisor EC Approval Checklist	R	R	NA	☑
	EC Implementation Checklist	O	O	NA	☐
Post Implementation	Post-job briefing[6]	X	X	O	☑
	Post-job critique[6]	O	O	O	☐

Risk Level[4]: ○ H ◉ M ○ L

Waiver Basis:

This EC is considered medium risk as discussed in the Risk Management Section. A significant amount of work completed under EC 63016 will be reviewed an incorporated as applicable. This EC is one of several smaller EC's as a result of the containment delaminated repair plan. This EC is formed in part by taking information from EC 63016 and reusing it where possible as well as building upon EC 75000 for crack arrest. The EC scope will be reviewed by plant personnel in a Final DRB. Management has requested additional oversight by scheduling a 30% challenge with design team participants to ensure all technical requirements for the delamination removal are addressed. The final DRB is sufficient to address technical and plant concerns so the 100% Design Challenge will also be waived. Concurrence of the risk assessment and this validation plan will be performed by CR3 Design Superintendent, Keith Allen. Post Job Brief will be performed under NTM AR 377697.

Notes:

1. Required use of processes/tools per this procedure apply to PCHG-DESG, PCHG-ALTR and TCHG-DESG ECs (except child ECs) only. These tools are optional for all other EC types
2. Outsourced ECs are ECs which are developed by vendors. Internal ECs are ECs developed in-house.
3. O – Optional, X – Required (unless waived and waiver basis documented), R - Required.
4. Design Superintendent approval is required for ECs screened as high risk or for waiving DRB not previously waived for this application.
5. For ECs determined to be high risk level.
6. Initiate an NTM for scheduling purposes when the validation plan is approved.
7. For ECs determined to be medium or high risk level.

H.3 Reviewer Comments

Select, copy, and paste the table below into a WORD file and e-mail message to reviewers. Select (Table/Select/Table), copy (Ctrl-C) and paste (Ctrl-V) tables from reviewer's responses below. Have reviewer sign EC milestone when comments are resolved.

Discipline/Program Review		**Scope of Review**	
IWE/IWL	EC 75219 30% Design Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
R. Portmann	IWE/IWL	12/28/09	No

Item	**Comment**	**Resolution**
1	Section A.5. 1). & Section H.1. 1). – Consider generalizing these paragraphs to eliminate future revision of this EC due to potential changes in EC 75000.	The sections have been simplified.
2	Section B.2, 2nd para. – Delete "within the boundaries of the delaminated region"	Removed.
3	? Cutting of rebar to be included in this EC?	Rebar will be cut and removed as described in scope. Rebar tails will remain as required for replacement.
4	? Inspection of the cut rebars to be included in EC75220?	Inspection of the rebar is not to be part of this EC scope
5	? Hydrodemolition and/or concrete chipping equipment set-up and tie in to site structures to be included in this EC?	Equipment set-up shall be included in either this EC or another EC based on availability of info and status of potential EC.
6	Section E.1 Testing Requirements – Add a statement that the ASME Section XI, Sub-section IWA and IWL and the ASME Section III inspection and testing requirements are to be addressed under EC's 75218, 75220 and 75221.	Added.
7		

Discipline/Program Review		**Scope of Review**	
RP	30%		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Ken Young	ALARA	01/06/10	

Item	**Comment**	**Resolution**
1	RCA entries at hole will require EDs / TLDs but no frisking should be required. RCA should be posted for dose rates	Prerequisite added to installation section to require craft to verify dosimetry requirements prior to commencing work

	only. This would require a sign-in and sign-out process only.	in the field.
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Discipline/Program Review	Scope of Review		
Operations	30% design review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Ron Tyrie	Operations SRO	01/06/10	No

Item	Comment	Resolution
1	A – Incorporate CR3 LL from recent experience	LL incorporated into A.6.
2	B – In the RB design discussion, consider listing the imposed lower temperature limit of 60° F for interior areas during shutdown conditions.	Incorporated
3	B – Page 5 item 5 – in the discussion of thermal gradient, we must not just consider but monitor and control within design limits as determined by the analysis for unreinforced concrete.	Added additional wording and bases
4	B – page 7 item 16 – consider adding the temporary local temperature monitoring instrumentation to be added (2 inside, 2 outside) with remote monitoring capability.	Added additional wording and corresponding evaluation in B.6.16
5	B – page 8 item 26 – Consider mentioning the dropped load evaluations to ensure RW flume capability (SF Pool cooling) is not lost during this EC execution	Added additional wording and corresponding evaluation in B.6.26
6	D – Nothing here?	Added during completion of final product.
7	J – engineering checklist has not been completed	Engineering Checklist to be completed prior to issuance for final review.

Discipline/Program Review	Scope of Review		
Procurement Engineering	30% Design Challenge		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Rick Curry x4215	Mechanical	1/6/10	

Item	Comment	Resolution
1	Section D.5, EC Parts List, recommend adding "none" or "none required".	Added parts based on surface testing

2	Need to add Procurement Engineering as a milestone signoff.	So added.

Discipline/Program Review	Scope of Review		
Licensing	'30% Design Challenge		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Sid Powell		1/6/10	no

Item	Comment	Resolution
1	EC 63020 should be included as reference for applicability of using the mobile crane for lifts and the associated loading calculations	Added.
2	References 9.2 – the current numbers are 235 for the License Amendment and 81 for the Bases revision. The bases revision will change on Jan 15, 2010	Incorporated.
3	Design Inputs 1. – in describing the containment the language that is used in the FSAR is 'uncontrolled release' vs. 'uncontrollable'	Incorporated
4	Design Inputs 19 – you include references to modes 5 and 6 and LODHR. Throughout this EC we will remain in no Mode and there can be no LODHR event involving the containment.	Removed statement describing LODHR
5		

Discipline/Program Review	Scope of Review		
Maintenance	30% Design Challenge		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Pepin		1/6/10	

Item	Comment	Resolution
1	Incorporate Interfacing Conduit Removal EC	EC 75429 has been added and described in design input 17
2	Is monitoring required during removal?	Based on discussion, monitoring does not add an significant value to the de-stressed (detensioned) structure in the region of removal.
3		
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Discipline/Program Review	Scope of Review		
Installer/SGT	30% Design Challenge		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Bill Alumbaugh		1/6/10	

Item	Comment	Resolution
1	Section B.2, 3rd Para, 2nd Sent. Rebar will be removed and disposed, not reused.	Scope states rebar will be discarded.

	Recommend revise to agree with Section H.1.3 which states that the rebar will be discarded.	
2	Section B.4.1, Last Para in section. Recommend rewording of sentence beginning "The function of the containment ..." to "The design function of the containment building will not be adversely affected and all code requirements and design margins will be maintained during the delamination removal and repair."	Reworded.
3	Section B.4.5, 1st Para, 5th Line. Loads associated with hydrodemolition are considered. Hydrodemolition is to be used in the removal of the delaminated area. Do current analyses envelope the use of the same process in the MPR analyses?	Hydrodemolition loads are considered as a result of evaluation in EC 63016/EC 75000 and are minor with respect to the overall strength to the structure.
4	Section B.4.5, 1st Para, 5th Line. Thermal gradients generate the higher stresses in no mode with detensioning. Identify the design parameters and controlling construction provisions.	The monitoring parameters have been discussed in B.6.16.
5	Section B.4.6, Water Requirements, 3rd Line. Clarify that SGT will provide access and water sample will be obtained and test performed by CR3.	B.4.6 has been reworded to clarify responibilites.
6	Section B.4.6, Waste Water, 1st Para. 1st Line. Same comment as No. 5	B.4.6 has been reworded to clarify responibilites.
7	Section B.4.6, Waste Water, 2nd Para. , 1st Line, Progress Energy provides water tanks for storage. SGT provides piping for delivery from wells to tank and from tank to work site.	B.4.6 has been reworded to clarify responibilites.
8	Section B.4.10, 1st Para, 2nd Line. "No additional damage." Crack arrest, chosen demolition method was selected because it was determined not to be a contributing cause, and inspections will be performed before and after demolition to assure that the delamination has be been removed. But there is the potential that additional delamination may be encountered which would make this phrase incorrect. Recommend deleting sentence, previous sentence states that the crack is removed should be sufficient.	Removed.
9	Section B.4.10, 1st Para, 3rd Line. "Cutting of tendon sheaths..." Flex	Reworded.

	tendon sleeves will most probably be damaged by hydrodemolition and with demolition there is always the possibility a sleeve will be damaged. Recommend rewording and mention that tendons will be removed from known sleeves containing flexible sections to minimize damage potential to the tendon. Remaining tendon sleeves are to be inspected and repaired prior to containment restoration.	
10	Section B14. 1st Sentence. Boundaries of the section to be removed is to be identified to width, length and depth or as described on a drawing.	Drawing SK-72519-C001 shows the removal area.
11	Section B14. 2nd Sentence. Rebar will be excavated by hydrodemolition then cut to length to leave a tail. If configuration requires a shorter length or in the even the cut is adjacent to a splice where the bar is removed by demolition then drill and grout may be required. 2nd sentence needs to be generalized stating that a code splice will be developed between the new rebar and the bars in the undisturbed concrete.	Added wording.
12	Section B4.19, 6th line. Recommend deleting the phrase "While defueled," The Containment structure creates the II/I condition. If the containment meets code loading conditions, including seismic, with the tendons detensioned then it remains seismic cat 1 in the degraded state. IF it does not then RG 1.29 and 1.206 is going to drive a II/I evaluation because of the adjacent Cat. 1 structures. Defueled state just means there are no Cat 1 components inside containment. Based upon previous statements the containment with detensioning is code qualified to dead + Live + seismic + wind/tornado/hurricane as applicable. Pressure is eliminated (no fuel) which is the controlling load for the containment.	So deleted.

Discipline/Program Review	Scope of Review		
Procurement Engineering	Final Comments		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Rick Curry x4215	Mechanical	1/27/10	

Item	Comment	Resolution
1	Section D.5, EC Parts List, see table below for comments.	Incorporated

Installation					Design			
Item No.	Qty/ Units	PO Number	PE Request	Catalog ID	Description (If available, include Manufacturer, Model, and Version)	Spec or CGI	Q Status Buy	Q Status Use
1	TBD/ Feet				T-BAR, 1" Aluminum, MFR. STD., Length as Required		QL-4	QL-4
2	TBD/ Each				Epoxy, Fast-set, MFR, STD., Min bond strength = 200 psi and minimum compressive strength = 5,000 psi.		QL-4	QL-4
					TBD = To be determined.			

Discipline/Program Review	Scope of Review		
Environmental			
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Ron Johnson/Lloyd Tardif	Environmental Permits	1/27/10	

Item	Comment	Resolution
1	Section A.6; Operating Experience. We might want to add references CR3 NCRs 358636 and 358653, related to a release of industrial waste water to the canal associated with the SGR hydro-demolition activity.	Lessons Learned added to A.6 and references added to Section B. Additional prerequisite added to installation section.
2	Section B.3.6, NGG Procedures, add: CHE-NGGC-0045, "NGG Chemical Control Program".	Added
3	Section B.3.7, Plant Procedures, add reference to SP-736K, "Reactor Building Hydro Demolition Release to the Settling Ponds"; this procedure was developed for SGR and should be used again.	Added

4	Section B.3.10, Other References: add documents: EVC-CRNF-0002, "Crystal River Nuclear Plant Site-Specific Environmental Policies, Permits, Registrations, Certifications and Plans"; also add FLA016960, "CREC Industrial Waste Water Permit";	Added
5	B4.12, I would reword section on waste water requirements to include reference to existing procedure SP-736K, "Reactor Building Hydro Demolition Release to the Settling Ponds".	Included
6	B.6.5. typo on page 14; 2nd paragraph, 5th line down, change "10" will only be allowed only at the", to "10" will only be allowed at the"	Corrected
7	Sections B.4.6 and B.6.6 (2 sections), it needs to be clarified in both locations that "discharge" of the water cannot go to the settling ponds until samples are cleared by RP. Prior to clearance, hydro-demolition can proceed as long as the water and rubble are collected in temporary basins / tanks etc. (This is the same approach used during the SGR hydro-demolition.)	Incorporated and added additional installation prerequisite step
8	Section B.6.6, under "Water requirements"; 2nd sentence; revise: "have been successfully used in the past by CRS to satisfy.." to "have been successfully used in the past by CRS and CR3 to satisfy..". Same section and paragraph, 3rd sentence: During the SGR hydro-demolition, no existing plant piping was utilized, due to reliability concerns. I suggest removing this option since the temporary piping option was very successful.	Corrected Corrected
9	D.2, Installation Requirements, Prerequisites, suggest adding the following: "Use of chemicals for this activity are subject to the requirements of CHE-NGGC-0045, NGG Chemical Control Program."	Added
10	Add a prerequisite to ensure that proper dikes are setup around equipment, especially chemical storage in accordance with WP-106, "Storm Water	Added

	Discharge from Diked Petroleum, Chemical, and Equipment Storage Areas"	

Discipline/Program Review	Scope of Review		
Licensing	Pre-DRB Design Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Sid Powell		1/28/10	no

Item	Comment	Resolution
1	B.4.1 – Discussion should focus on remaining in No Mode during this activity. References to LCOs and Required Actions are unnecessary.	Reworded B.4.1

Discipline/Program Review	Scope of Review		
System Engineering	EC 75219 Final Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Scot Stewart	Penetration Sys Engineer	1/29/10	No

Item	Comment	Resolution
1	Drawing SK-75219-C001 – Typo in Note 3, "AMY" should be "MAY" Typos in Note 4, 1. Hydrodemolitiondamage should be Hydrodemolition damage. 2. Responsiblecivil should be responsible civil 3. "edces" should be "edges" 4. "descetion" should be "discretion"	Drawing SK-75219-C001 has been revised, please see latest revision.

Discipline/Program Review	Scope of Review		
IWE/IWL	EC 75219 Final Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
R. Portmann	IWE/IWL	1/29/10	No

Item	Comment	Resolution
1	Need to add the addition of temporary Tendon Gallery Sump Pumps and to tag out SDP-3A & SDP-3B during hydrodemolition activities	Sump pumps SDP-3A and SDP-3B have been addressed as well as the need for temporary sumps in the tendon gallery.
2	Section B, B.4.10 – States that cutting of tendon sheaths in not allowed. Be prepared to revise the EC during hydrodemolition if it occurs. It also states to remove tendons from known flexible sheaths, this I believe is a risk that needs to be discussed and decided in work	Design Input B.4.10 reworded.

	order space. May want to consider deleting it from the EC since we are ordering spare tendons.	
3	Various locations reference ACI 503R for surface conditioning, have we validated the surface condition requirements of Spec CR3-C-0003?	THE ACI and ICRI requirements for surface preparation meet or exceed the original requirements as outlined in Section 3.3 of CR3-C-0003. An additional note 5 was added to SK-75219-C001 to slope the top of the removal area to allow the escape of air as described in 3.3.4 during placement. The reference has been added to Section B.
4	The IWL Repair/Replacement plan does not reference ACI 503R or ICRI 03739 for use in the repair. Have we made these required documents? If so then the IWL RPE needs to authorize this via the R&R Plan in EC 75218.	These documents are above and beyond normal IWL requirements. Additional testing as described by this documents would merely give additional assurance of sound repair without adversely impacting the information contained within the IWL repair plan.
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Discipline/Program Review	**Scope of Review**		
Operations	EC 75219 100% review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
R. Tyrie	Operations SRO	01/30/10	No

Item	**Comment**	**Resolution**
1	Section B, Page 7 – States to remove tendons from known flexible sheaths, I have been lead to believe that they may be left in place at risk and that spare tendons have been ordered.	Design Input B.4.10 reworded.
2	Section B, Page 15 / 18 – in the discussion on thermal monitoring, the information to be gathered was revised by the PE engineering team. The existing criteria is for continuous monitoring of 2" subsurface and the inner liner temperature. These are the locations that the 7 day rolling average are based. Other locations (outside air temperature, 6" and 12") are monitored for use in evaluating changing conditions and other capability for measurement will be in place for local determination of internal concrete temperature as needed. Redundancy is incorporated into this plan to allow continuous monitoring with potential instrument malfunction or	Section B.6.16 has been rewritten to incorporate the latest monitoring plan as described by EC 75218.

	physical damage during EC activities.	
3	Z05R0 – This text is an early exchange of monitoring and control ideas / plans that should be updated per the note above. An accurate description can be copied from EC 75218	Attachment Z05 was made intentionally blank. Requirements for monitoring are described in evaluation section, reference to attachment Z05 has been removed.
4	Z060R0 – The test instruments originally proposed are not being used. I would consider deleting this attachment and just refer in section B to a methodology as approved by PE engineering within the bounds described.	The thermal monitoring has been rewritten in Section B.6.16. It assumes that this thermocouple or another similar device may be used. To prevent affecting readability of the entire document, the attachment will remain as the evaluation assumes any other device may be used at the discretion of engineering.
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Discipline/Program Review	Scope of Review		
Design Basis Analysis	EC 75219 100% review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
John Holliday	Civil/Structural	01/30/10	No

Item	Comment	Resolution
1	Section B.2, 2nd paragraph: Change EC 72518 to EC 75218.	Paragraph correctly references EC 75218 as prescribing the detensioning requirements.
2	Section B.4.10: State those tendons that have to be removed must be ram detensioned, coiled, and identification clearly attached to the tendon. Are these tendons going to PSC for refurbishment? Where is the repair detail for the tendon ducts? Has material been ordered for the repair? Will PSC have sufficient grease if additional tendons are removed? Have we ordered replacement anchor heads?	Input B.4.10 reworded. The intent is for SGT to leave tendons in sheaths and perform removal. Spares have been ordered, so any damage to a flexible sheath would require the tendon be removed and replaced vs. removing a much larger number of tendons which may or may not be damaged. Repair details for tendons, grease, anchor heads, etc. are outside the scope of this Engineering Change.
3	B.4.14: The EC should state what the splice length is for the #8's. Are the splices going to be staggered, if so adjust the cut lines for the existing #8s accordingly.	B.4.14 reworded. Minimum Splice is mentioned as 7". Installation sketch will require a minimum of 9" with no maximum which will allow for either lap splicing or splicing under the direction of EC 75220.
4	B.4.15: The thermal gradient will be monitored so as to maintain the delta as close to zero as possible based on a rolling 7 day average. Delete reference to the controlling within 10 degrees.	Deleted
5	B.4.28: State that the hydrodemolition equipment must be enclosed within an	Incorporated

	enclosure that is designed to capture all loose debris resulting from hydrodemolition, i.e. high strength netting.	
6	Is the equipment hatch going to be installed during hydrodemolition. If not, what precautions are going to be taken to prevent water from going into containment?	Additional precautions were added into installation section along with the tagging of the tendon gallery sumps.
7	B.4.12: Discuss requirement for adding hydrochloric acid. Refer to EC 63016. (Evaluated effects on control room habitability). Has sufficient acid been ordered?	Added requirement and evaluation if B.4.6 and B.6.6 as was captured in EC 63016. Hydrodemolition vendor has not yet been finalized (Mac & Mac is still under negotiation). Acid would have to be ordered at the discretion of SGT once all contracts are completed.
8	Page 15, Thermal Loads: Delete all reference to historical records and 60 and 70 degree temperatures. State that "Operations will use the RB ventilation cooling, heating and purge system per OP-417 making daily adjustments as required to maintain the delta as close to zero as possible based on a 7 day rolling average".	Incorporated.
9	B.6.16, Temperature Monitoring: 1st sentence, delete "based on an inside temp of 70 and an outside temp of 60. Re-write the rest of this section based on EC 75218 Section B.6.10.	B.6.16 has been rewritten based on the latest revision of EC 75218.
10	D.2, Removal of concrete, #4: Are you going to use standard lap splices? If so, need to re-word this paragraph.	Paragraph has been reworded based on the known requirements of EC 75220 at this time. A minimum of 9" tails are required with no maximum to allow for staggering as based on splice details per EC 75220.
11	D.2, Thermal gradient monitoring: Re-write as described in EC 75218. Delete reference to 10 degree delta. Monitoring is to maintain a delta as close to zero as possible. Contact engineering is it is 8 degrees.	Thermal gradient monitoring has been reworded based on the write up in EC 75218.
12	Parts list: Tendon grease, anchor heads, shims, longer cans, contingency for tendons to be removed due to flex conduit, or will this be addressed in concrete placement EC?	This as a whole will be addressed in EC 75220. This EC requires SGT to consider potential damage to tendons that could result from excavating through flexible tendon sheaths.
13	Add a Caveat that work cannot begin until the root cause (PII) has established whether hydrodemolition was a	A caveat was in place, however the decision was made to remove this caveat after discussion with PII and engineering

	contributor to the original delamination. If it is, this EC must be revised to address any concern raised by PII.	lead (P. Fagan). It is understood that the portion of the root cause dealing with micro-cracking was reintroduced. However, after careful discussion, PII acknowledged that methods for surface preparation other than hydrodemolition could also cause micro-cracking at a much higher frequency. Based on the necessity for surface preparation, hydrodemolition was left in as the least likely to produce adverse affects. A root cause review was added to the EC package to ensure all additional requirements before releasing hydrodemolition for work.
14	I believe there is a strong possibility that the crack may propagate due to vibration at the perimeter of the delamination if hydrodemolition is allowed within several feet of the outer edge of the delamination. Once the hydrodemolition is past the #8 rebar cage, this problem is probably greatly reduced due to the condition of the concrete (badly fractured and broken). I was under the impression that PII was going to address this during their root cause evaluation, it now appears that this may not be so. If hydrodemolition is allowed to progress to the edge of the delamination then there should be a discussion in the EC concerning the associated risks, i.e crack propagation.	Additional wording was added to B.6.5 about possible risks of propagating crack into buttresses and equipment hatch concrete. Description of saw cutting was added as one mitigating strategy. Additional wording concerning risk acceptance based on best engineering judgment using industry guidance was also added.
15	Add requirement to map cracks around the opening that result from tendon detensioning as required in EC 75218	Mapping activities added to surface preparation section of installation section.

Discipline/Program Review	Scope of Review		
Installer/Planner	EC 75219 Final Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Glen Maxwell	SGT Installer	1/29/10	No

Item	Comment	Resolution
1	B10 – Remove tendons that have flexible duct. Can we distress the tendon, leave it in the sleeve, remove the concrete, then evaluate the sleeve? The depth of the concrete removed will vary. The removal of the tendon afterwards will not be a	Section B.4.10 has been reworded to say removal of tendons is now at the discretion of SGT. Damaged sleeves will require replacement (not in the scope of this EC) as needed. Spare tendons may be used or the tendon sent for

	problem if it is damaged. For reuse of the tendon even if done prior to demolition, it would have to be sent to PSC for reconditioning. (Jim Clayborn 208-680-6592)	reconditioning again at SGT discretion.
2	D2 – Removal of concrete. 2. States 4" max on demo – Note that delamination sections may come out larger than 4". (Jim Clayborn 208-680-6592)	It is understood that some sections may "chunk" and separate out
3	This EC does not speak very much about cutting reinforcing or the need for staggered mechanical or welded rebar splices. During the course of concrete demolition it would be prudent to consider that some reinforcing will have to be cut, especially in tightly congested places at the bottom and top of the affected area. (Jim Clayborn 208-680-6592)	The installation instructions now account for this based on the requirements of interfacing EC 75220. Per our discussion, a note was added to notify PGN design engineering of the need to cut any rebar other than the #8 for further evaluation and disposition.
4	Section B: 5. The 10" depth removal maximum limit has some conflicting requirements. Should give acceptable amount past the 10" limit. 5. Should have method to address wind loading if it goes into hurricane season. 26. Does EC 63020 cover all de-tensioning work? (Larry Davis 704-618-2568)	Acceptable amount depends on the underlying surface conditions. This is why sounding is required with a hammer, etc. as described by ASTM 4580. Any degraded concrete shall be removed at the discretion of the responsible PGN Civil Engineer. This is specifically described in the Installation Section.
5	Section D: Same comment as above for 10" removal limit. SGT will need to be prepared for required 10° Delta-T contingency (heaters within tented area). (Larry Davis 704-618-2568)	See resolution above. The preparedness of SGT for potential actions required for thermal gradients is at their discretion and outside of the scope of this EC the monitoring of the 7-day average temperature is already being performed. Operations is required to adjust the containment interior temperature under OP-417.
6	50.59 Screen: 11a discusses stress relief cuts, should also address including concrete/rebar removal. (Larry Davis 704-618-2568)	Please reference REG AR 377913 for final 50.59 Screen. Draft has been removed from EC folder.
7	Z05: Acceptance criteria given is 5° F, EC gives limit as 10°F. (Larry Davis 704-618-2568)	Attachment Z05 is now intentionally left blank. The monitoring requirements were updated in the evaluation section as was required in EC 75218. The installation section also incorporates the latest monitoring plan.
8	SK-75219-C001, Rev A: See comments above for acceptable	Please see revised Sketch in Section G01.

	depth. Drawing notes centerline of hoop tendon. Drawing needs to specify removal area from specific reference points so that cut lines can be laid out by SGT Field Engineers. Recommend extraneous information be deleted from drawing for clarity. Should provide contour requirements at top to allow concrete pour. This may also apply to containment opening. Reference dimensions need to be specified. (Larry Davis 704-618-2568)	
9	Sketch G01R0 SK-75219-C001 << Typos in Notes 2, 3, and 4 >>	Please see revised Sketch in Section G01.
10	Note: Testing requirements throughout EC are beyond the typical requirements that SGT performs regularly. Extra time will be needed for planning, mock-up, implementation, etc.	Any necessary mock-ups may be completed at the discretion of SGT
11	ASTM D 4580 is not applicable to this project. The sounding equipment and grid layout cannot be achieved through rebar for obvious reasons. (Paul Gosselin xt 1824)	Procedure B of ASTM 4580 is quite applicable. The intent is to use the instructions contained in the standard <u>as a guide</u> for using a hammer to sound concrete after the major delamination is removed. This will ensure no secondary pockets of delamination remain in the wall before concrete replacement.

Discipline/Program Review	Scope of Review		
Civil/Structural/RE	EC 75219, Revision 0, final review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
C. Glenn Pugh	Civil/Structural/RE	01/28/10	N

Item	Comment	Resolution
1	PassPort Screen has "outage" checked no. It should be checked yes	The outage checkbox is grayed out and will not allow to be checked. This is the same as EC 75000.
2	Under Section B.3.8 add EC 63020 for Safe Load Paths	Added
3	Under Section B.4.7 add EC 63020 for Safe Load Path when using the Manitowoc 2250 crane	Added
4	Section B.5 has no assumptions or caveats noted. However, the Risk assessment, Section B.6.5 and other sections indicated the root cause needs to be completed prior to start of work. Need to indicate this in the Assumptions	A caveat was in place, however the decision was made to remove this caveat after discussion with PII and engineering lead (P. Fagan). It is understood that the portion of the root cause dealing with micro-cracking was reintroduced.

	section, check the caveat box on the PassPort screen. Agree, that hydro-demolition needs to be ruled out as a contributing cause, or at least justifiy that no further cracking into the buttresses is expected due this method of removal.	However, after careful discussion, PII acknowledged that methods for surface preparation other than hydrodemolition could also cause micro-cracking at a much higher frequency. Based on the necessity for surface preparation, hydrodemolition was left in as the least likely to produce adverse affects. At this time the additional testing for subsurface microcracking was included. A root cause review was added to the EC package to ensure all additional requirements before releasing hydrodemolition for work.
5	Under Section B.6.7 add EC 63020 for Safe Load Path when using the Manitowoc 2250 crane. This would apply if a chipping platform is reinstalled. Also would apply for hydro	Added
6	Section B.7 needs to be revised to show current project team and interfaces as outlined in Aaron Mallner's email dated 1/26 and as amended by Emin Ortalan's email dated 1/27/10	Updated
7	A comment from 30% challenge was to consider the need to pull back the tendons from the flexible tendon sleeves because of possible damage from the hydro-demolition process. There are no instructions in the EC to do this.	B.4.10 was updated to leave the removal of tendons at the discretion of SGT based on various comments. They shall be responsible for ordering replacements as required for this at risk activity.
8	Currently Section D.2 and the sketch says to cut all #8 bars leaving an 8" (+/- 1") tail. Conversations with installers indicate they would like an option of leaving more of a tail if possible to do lap splices instead of mechanical splices. Need to have an option of 8" or 40" (40db) See AREVA comments below for further information on this	Rebar Tail is now specified as 9" minimum based on Scott Mawhinney's input. No maximum is provided as cuts are to be made with respect to interfacing EC 75220 with consideration given adjacent rebar, tendons. Lengths are specifically called out as potentially needing longer than 9" based on staggering and code splice requirements.
9	It appears the "Subsurface Mirco-Cracking Test" per ICRI 3739 is a pullout test for repaired concrete. Should this test be in EC 75220 instead of this one?	Based on conversation with PII, it was determined a test should show whether significant micro-cracking would occur in the subsurface. This test would require pullout of in-situ cores. It is understood that this intent of the test is to normally test across the layers of repair, but this EC implements it a little differently to check the soundness of the underlying concrete. The instructions for use are the same as it would be for checking a repaired surface and is cleaner than

		creating a new test. It may also be implemented in EC 75220 for further evaluation of the repaired conditions.
10	Section E.1 has the in-situ strength test which is the same as above. Same question, should this be in 75220 instead.	See above resolution
11	30% Comment 11 from Bill Alumbaugh is similar to comment 8 above and is not included in Section D.2	See Comment #8 resolution
12	Consider deleting Sections J.3 and J.4. Not used	Deleted
13	The ACI 503R-93 included as an attachment has no EC, Attachment, or page number identification required for an EC attachment.	The document has been scanned in again and appropriate header added.

Discipline/Program Review	Scope of Review		
AREVA Engineering (EC 75220)	EC 75219, Revision 0, 100% review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Scott Mawhinney (AREVA Engineering)	Civil/Structural	01/28/10	N

Item	Comment	Resolution
General comment on SK 75219-C001		
1	Line weight in color do not print as a hard solid line	Drawing SK-75219-C001 has been revised, please see latest revision.
2	Why is the first elevation call Fig. 3 when the second elevation has no Fig. identification?	Drawing SK-75219-C001 has been revised, please see latest revision.
3	No ledged for concrete removal limits	Drawing SK-75219-C001 has been revised, please see latest revision.
4	Hatch pattern comes all the way to the buttress; it should stop 6" before buttress.	Drawing SK-75219-C001 has been revised, please see latest revision.
5	Extraneous delamination information should be removed from the second elevation view and the hatch pattern should cove the entire area (less dense pattern).	Drawing SK-75219-C001 has been revised, please see latest revision.
6	The "construction opening section should be called B-B and shown on the elevation view; also a 90 degree cut should show a similar detail.	Drawing SK-75219-C001 has been revised, please see latest revision.
7	The 8" plus or minus 1" is not generous enough, the book says 7" min for # 8, I would say 9" min and add a note to say that	Drawing SK-75219-C001 has been revised, please see latest revision.

	splice must be planned around obstructions such as horizontal tendon ducts, length will vary. Also it is my understanding that near the "dog house" the #8 @12" transition to #11 @ 9". Therefore, # 11 will require more than the minimum 7".	
8	Section A-A should not say 10" max removal, it should say 10" typical, see note 3	Drawing SK-75219-C001 has been revised, please see latest revision.
9	Section A-A please show center line of buttress for clarity and the buttress itself is not drafted in the proper proportion.	Drawing SK-75219-C001 has been revised, please see latest revision.
10	Detail A, I thought 10" deep was to the centerline of hoop tendon, it is not show that way. Also surfaces should be shown rough and delineated "see EC 75220 D.2 "preparation of concrete surface"	Drawing SK-75219-C001 has been revised, please see latest revision.
Section D Comments		
13	In Section D.2 add: *13. Conduct survey before detensioning , after detensioning, and establish construction control so that formwork can be properly placed so as to verify required minimal membrane thickness as well as the alignment of reinforcing steel.*	If a survey is required prior to and just after detensioning it needs to be included in EC 75218 which implements work around the detensioning schedule. This EC assumes all that work is completed and work is ready to commence on the removal. Please contact Ken McEwan to incorporate this EC comment as needed into EC 75218.
14	<u>Removal of concrete</u> ***[below is also note 1 on drawing C001]*** 1. SK-75219-C001 depicts the approximate limits and depths of delaminated concrete, limits of unsound concrete will vary, however, limits of concrete removal are expressly shown. When unsound concrete is discovered beyond the limits of removal the Responsible Engineer shall be contacted prior to its removal. In certain areas/circumstances hydrodemolition shall be discontinued and hand methods of removal shall used with chipping tools less than 60 pounds in weight. ***[see note 4 on drawing C001]***	Additional wording was added to step, however, no specific tool weight shall be specified based on the variety of potential circumstances which may arise. ICRI documents recommend no greater than 30 lb equipment to prevent micr-cracking. As such it is left at the discretion of the RE using the Concrete repair manual as a guide.
	2. [last part of section], add the word "horizontal" hoop tendon	Added
	3. when spalled areas pass beyond the 10" depth, refer to note 1 and	Added

	hand methods may be required to complete the removal of unsound concrete. 4. Within 36 & 80 bar diameters of the concrete removal limit reinforcement may be cut to utilize a lap splice [alternate splices] or the bar May be trimmed no closer than 9" from the edge of demolition for the use of an approved mechanical coupler. The saw cut/friction blade reinforcement removal is the only recommended preparation for the mechanical coupler installation. However, for safety reasons, flame cutting within 6" of a prepared end is permissible. The only reinforcement that may be cut and spliced are #11 reinforcement and smaller. Also only # 8 reinforcement and smaller may utilize a lap splice of a minimum of 36 bar diameters. ***[Revise note 2 on drawing C001]***	Reworded.. Holdpoint was incorporated to prevent cutting of rebar greater than #8 without prior approval to ensure proper lengths will remain in place. Reference to EC 75220 is also added.
15	<u>Preparation of Concrete Surface</u> 1. I would suggest saw cut between 1" and 1 ½" deep, they should saw cut vertically 6" away from edge of 6" 2. no comment 3. no comment 4. this should go in the category below 5. rebar inspection and preparation of the splice should either be its own section or omitted from EC 75219 and placed in 75220	 Saw cut is only prescribed method now. Drawing shows 6" offset No resolution req'd No resolution req'd Cleaning is part of the surface preparation and is acceptable in the current section. Testing will not commence until all surface prep is completed This inspection is a cursory review by site engineering to ensure any significant issues are identified up front before IWL inspections take place per EC 75220. This is above and beyond what is required and is able to commence while the civil engineer is already up on necessary work platforms overseeing sounding/surface prep.
16	<u>Surface test</u> 1. no comment [N/C 2. N/C	 No resolution req'd No resolution req'd

	3. N/C 4. Call out the epoxy brand [General comment: this test should be performed now to make sure it is successful, due to the relative lack of tensile strength of this concrete (aggregate) as compared to other mix designs you may want to verify the test is achievable]	No resolution req'd Epoxy procured is at the discretion of SGT. It was left open with the BOM requiring minimum characteristics so whatever was quickly attainable could be ordered. Mock-ups are at the discretion of SGT. This testing is again above and beyond what is required by IWL for concrete surface preparation and may be discontinued at the discretion of the responsible civil engineer based on circumstance.

Discipline/Program Review	Scope of Review		
Mech. Maint.	EC 75219 Final Review		
Reviewer	**Discipline**	**Date**	**Turnover Required?**
Rick Pepin		1/30/10	No

Item	Comment	Resolution
1	Section D.2, #4 – remove AI-1000, SGT is not using this procedure, they have their own procedure (say IAW approved procedure)	Added "or approved SGT equivalent" to ensure traceability of any potential procedure usage, even potentially outside of SGT's current scope of work.
2	D.2, #5 - Scaffold is IAW approved procedure	Added "or approved SGT equivalent" to ensure traceability of any potential procedure usage, even potentially outside of SGT's current scope of work.
3	Removal of Concrete, #4 - Rebar cannot be saw cut in many areas, do not use this restriction, we are guessing by drawings on the rest of this line and we cannot put the "shall not" in here because we may have issues, leave more should and as allowable and not "shall not	Saw cutting is required for using the mechanical couplers based on discussion with the EC 75220 responsible engineer. Added wording to say to contact PGN civil engineering for acceptable alternative methods within the bounds of EC 75220 (in-development) so as not to invalidate the rebar replacement design.
4	Preparation of surface, #1 - I think the "responsible Engineer" making all the field decisions is a hold that we are setting ourselves up for. The RE will not be here round the clock. Field Engineers will be. We need to be careful of titles so when we go round the clock I am sitting on my hands waiting for the next dayshift.	Wording changed to PGN civil design engineering. Civil engineering will be staffed on dayshift/nightshift with mandatory turnovers once work has commenced. There will be no "sitting on hands" while waiting for the morning. At least one civil engineer will have received turnover about the previous shifts work and can direct work in the field as required.
5	Preparation of surface, #5 - Sounding will be done by "who and who will make this contract, is this team around the clock	There seems to be a general misunderstanding of the sounding process. Sounding in this case refers to

	group that can support a restart of a unit that is off line. Is this group properly staffed to do this work in a schedule basis?	hitting the wall with a hammer or other long metallic object and listening to a tone change. The tone change indicates an area of delamination that needs to be removed. The intent is to remove secondary delamination that is not visible to the naked eye. ASTM 4580 was added to provide guidance on how this works (See procedure B, ASTM 4580). No special equipment or personnel is required.
6	Section B.6.6 Water requirements The samples for radioactivity are clear to us. The base line chemical requirements to us are not clear for what is required for hydro blasting. We need to ensure disposal requirements and waste water but on up front requirements that are not real clear here. Waste water requirements I believe we can deal with.	These requirements and associated evaluation are exactly as per EC 63016 when Mac & Mac provided the hydrodemolition services. If Mac & Mac is again the hydrodemolition vendor, then they would best know what works with their equipment. This EC was generalized based on the final hydrodemolition vendor being unknown (Be it Mac & Mac or American Hydro). More specific requirements can be included if and when they are required as determined by the vendor. As noted in the EC the details for the water supply are outside the scope of this EC and may be processed in the associated WO task as was the case with EC 63016.
7	Surface Testing Considerations: Pre statement. "Testing will be implemented under the direction of the RE." How do I schedule that? 1. If this testing is a standard procedure I suggest referencing We can go a long ways doing this testing without putting in concrete, This section is not able to schedule or deliver to the vendor the extent of what is going to be done, somehow we have to better define what we are looking for here, "...To ensure significant damage has not been sustained..."	Wording changed to under the direction of PGN civil design engineering. EC's do not prescribe how work is to be scheduled, they merely provide the **design requirements** for any given project and why they are acceptable. Attachments Z03 and Z07 give step by step instructions on how to perform the testing. A brief overview was written in the installation instructions so as to prevent rewriting the ICRI documents in the installation section. For the surface testing, assuming 50 tests are conducted scheduling would be the time it takes to "glue" 50 1in^2 aluminum T-bars to the wall and pull them off. Once the pull of rig is developed it will not take more than a few minutes to conduct a test at each location plus the time to access those locations. The frequency now includes a practicality statement, however 50 would be the most one should expect. As for the subsurface

		testing a maximum of three 2" cores at least 6" deep spaced evenly over the entire repair area would be needed" those cores stay in place during testing and again pull as before on the cores. As noted above, PGN civil engineering will be working day/nightshift to support any and all work in the field. Mock-up testing can and should be scheduled/performed at the discretion of SGT. There would also be PGN civil support as required during that time.
8	No less than two and no greater than 12.5, the rest of this needs to go <u>Only pH sampling will need to be performed as a pre-requisite for discharge</u>. Contractor should strive to keep the pH between 6.0 and 9.0. Periodic sampling of pH will be needed. A "stop job" limit shall be established at pH less than or equal to 2, or pH greater than or equal to 12.5.	Again, these are the requirements directly related to hydrodemolition work performed under EC 63016 by Mac & Mac. The requirements states the contractor "should strive" for those limits based on previous SGR experience. Merely asserting that the contractor should strive for those limits does not prevent the job from being implemented. As such, the requirement will remain as written as changing the wording does not prevent work in the field.
9	The surface prep is pretty unique and might end up being a huge point of discussion, the manual referenced notes no embedded materials in the technical guidelines for in-situ testing referenced, there are many construction aids in our wall that might prevent us getting good samples, not sure how we are going to meet this lab testing requirements on the wall.	As noted, these are in-situ tests meaning it is field testing, not lab testing. It is understood there are a number of construction aids, but the vast majority of the testing is at the surface on a very localized area < $2in^2$. The instructions allow for testing to be ceased based on practicality or if the results show consistent meaningful data. Reference comment #7 resolution.
10	There is a lot of detail that is based on lab testing and lab practices referenced that will most likely not apply to work that is taking place on the wall. The pull off test and the surface requirements and amount of detail for lab testing may not be applicable on most places on the containment. The amount of steel down by the doghouse and the bottom of the delamination will preclude most of this testing.	Review comment #7 and #9 resolutions. A practicality statement was added to the installation instructions for such cases as was described. A statement allowing termination of testing
11		
12		
13		
14		

I.1 Design Verification

(Select, copy, and paste the table below into a WORD file and e-mail to Lead DV. Select, copy and paste table from DV response below. Have Lead DV agree that all comments are resolved prior to advancing EC status to H/APPR.)

The signature of the Lead Reviewer records that:

- the review indicated below has been performed by the Lead Reviewer;
- appropriate reviews were performed and errors/deficiencies (for all reviews performed) have been resolved and these records are included in the design package;
- the review was performed in accordance with EGR-NGGC-0003.

Design Verification Review	X	**Engineering Review**		**Owner's Review**	
Design Review	X	**Scope of Review**			
Alternate Calculation		EC 75219, Rev.0			
Qualification Testing					
Special Engineering Review					

Reviewer	**Discipline**	**Date**
Casaba Ranganath	Civil/Structural	1/29/10

Item	Comment	Resolution
1	Section A.5, Page 3: Concrete Removal (EC 75219): In the scope it indicates that this EC will review the necessary work platforms associated to perform the work. There is no discussion in the EC in Section B or Section D about the work platforms. Need to provide information on the work platforms. Also in the last sentence under this title change "slab" to "delaminated concrete".	Work platform usage has yet to be finalized. Once all necessary platforms are identified they may be included in a revision to either this EC or EC 75000 under the direction of Paul Fagan. Changed wording as noted. Currently, only the tendon platforms are identified as being used for repair activities which were qualified previously for work per EC 63016.
2	Section A.6, Page4: OE 14720: It is mentioned that a note will be added in precautions and limitations that the containment coordinator to inform all personnel in the immediate area about the start of hydro-demolition. This instruction is not in Section D00.	Included as a requirement of the pre-job brief
3	Section A.6, Page 5: OE 29756: Under how the issue is addressed in this EC, it is mentioned a note will be added in precautions and limitations installation instructions regarding proper inspection of the hydro-demolition equipment, however it is not mentioned in D00 Section Precautions and Limitations.	Included as a requirement of the pre-job brief
4	Section B.2, Page 1: in the second paragraph 72518 should be 75218. In the fourth paragraph add concrete after depth of.	Sentence correctly reads "75218"
5	Section B.3, Page 1: References ICRI	

	03730, 03732, 03737, and 03739 are now called as # 310.1R, # 310.2, # 310.3, and #210.3. I do not have the revised copies. I do not know if any information has changed. Suggest adding these numbers in parenthesis. Also note that ACI 515.1R referenced in ICRI 03732 has been withdrawn on Jan 01, 1979. Reference 1.11: Change 'to" to "for" and "Bon' to "Bond" Reference 1.14: parenthesis missing before Concrete. Reference 9.2: Change Amendment #229 to 235 and Revision 73 to 81.	Incorporated as noted.
6	Section B.3: Add the following additional references: ACI 318-63, ASTM 421-65 and 98a, CHE-NGGC-0045, SP-736K, AI -1816, OP-417, AI-1820, EVC-SUBS-00008, EVC-SUBS-00016, EC ED 59400, EC 75497, EVC-SUBS-00107, EVC-CRNF-00002 and FLAO 16960 at the respective locations. The above references are used in the body of the EC at different places.	References Added
7	Section B.3, Page 3, Reference 9.2 change Amendment 229 to 239 and Revision 73 to 81.	Revision Level Updated
8	Section B.4.1, Page 4: Delete the LCO requirements and rest of the paragraph suggest changing it to state that "during No Mode there are no TS requirements for containment integrity or TS Actions that require containment closure, however the containment should not have catastrophic failure during the applicable design basis loads".	Design Input reworded and simplified
9	Section B.4.3, Page 4: add FSAR Section 5.1.1 under Basis.	Added Basis
10	Section B.4.4, Page 5: Add OP-417 under Basis. OP-417 mentions that the optimum average temperature during full power operation is approximately 115^0 F (Page 8). In lieu of this should we use 115^{0}F instead of 130^0 F.	OP-417 added. Note was left about the maximum temperature approaching 130°F based on input from system engineer. However normal limit was changed to 60-115°F.
11	Section B.4.6, Page 6: The last sentence in the second paragraph mentions the details for water supply and disposal for concrete removal shall be included and approved per the associated Work Order Task and references EC 63016 WO	WO was providing reference/basis so new WO could be completed. To prevent confusion, WO order was removed and Basis just references EC 63016.

	1165094-03 under basis. Note that this work order is closed under EC 63016. Need to develop new work order task for this work.	
12	Section B.4.7, Page 6: Add EC 75497.	Added interfacing EC
13	Section B.4.11, Page 7: Discuss about pumps and piping for hydro-demolition process as mentioned in EC 63016 Section B.4.11.	Added as per EC 63016
14	Section B.4.19, Page 8: Add 3.9 to Improved Technical Specifications under Basis.	Added
15	Section B.4.26, Page 9: Change "of" to "under" in the second line and add EC 63016 under Basis.	Basis added. Reworded to read more clearly.
16	Section B.4.28, Page 9: Need to discuss about prevention of debris falling on personnel during concrete cutting or hydro-demolition.	Added discussion
17	Section B.6.1, Page 11: In the first line in this page change "installation of the cuts" to "removal of delaminated concrete" and add after removed in the second line "and repaired"	Corrected
18	Section B.6.2, Page 11: In the second paragraph first line add after "The" "delaminated concrete" and change describe to described in the last sentence and change cut installation in the last line to removal process.	Corrected
19	Section B.6.5, Page 12: It is mentioned that 8 ½" minimum delamination should be removed to get adequate bond development length as per ACI 316. The development length is dependent upon concrete strength and bar diameter. Without the radial reinforcement design, how is the 8 ½" length determined. Is ACI 316 the right code number, should it be 318, Verify. It is also mentioned in the same paragraph that ACI 316 requirements for clear distance behind newly placed reinforcement should be followed. This clear distance should in front of newly placed reinforcement and also the code ACI 316 should be 318.	This was based on Input from AREVA design engineering in regards to the proposed radial reinforcement. ACI 316 was corrected to read 318. Paragraph was reworded to say this was based on AREVA design engineering input (Scott Mawhinney). The removal depth is now stated as a 10" typical removal which encompasses those design requirements.
20	Section B.6.5, Page 13: First line revise as follows: Once the majority of concrete has been removed and after ensuring that sound concrete exists beyond the	Reworded

	removed concrete final surface finishing can commence. In the fourth sentence add after affixed "to the concrete surface". Delete separate after bond. After guidelines add as per ACI 503R in the next sentence. In the second paragraph in the line after (Attachment Z07) change end to top.	 Reworded
21	Section B.6.5, Page 14: Delete the second "only" in the line that says 10" will only be allowed only	Corrected
22	Section B.6.5, Page 14: Wind Loads: A sentence can be added here to say that the wind load is enveloped by the Tornado Wind Loads.	Note added.
23	Section B 6.5, Page 14: Tornado Wind Loads: The reference to Calculation S10-0004 is not correct, it should be S10-0006. Calculation S10-0004 evaluates delaminated and detensioned concrete for dead load including equipment and thermal loads. It is also mentioned in this calculation (Page 6) that at the final detensioned state, some tensile and shear stresses around the opening exceed the stress acceptance criteria. This calculation also states that justification of these high-stress areas is outside the scope of this calculation. Where is this justification provided and this should be referenced to indicate that the containment structure meets the acceptance criteria for thermal loads.	As described in EC 75218, those areas are acknowledged to have those high stress levels and cracking is expected and considered acceptable. As a result of that EC mapping of those cracks in required particularly above and below the construction opening. That mapping requirement was added into the installation section. Additionally, EC 75218 requires that those cracks be repaired with grouting per EC 75220.
24	Section B.6.5, Page 14: Seismic Loads: Seismic loads are addressed in Calculation S10-0006 and not in S10-0004. Revise accordingly in two locations.	Corrected
25	Section B.6.5, Page 15: Pressure Loads: Change "Defueled " to "During No mode" since during defueled, it is required to consider LODHR pressure loads.	Revised
26	Section B.6.12, Page 17: Waste Water: Reference Procedure SP-736K for Waste Water removal requirements.	So referenced
27	Section B.6.16, Page 18: In the first sentence after prestress add "and reduced concrete thickness" and add ° F after 70. In the second paragraph it is mentioned	Reworded entire section based on aligning monitoring requirements as written in EC 75218. The temperature is already being

	that device should be placed 2"-3" inside the core bore, this may interfere with 2"-3" of polystyrene that will be used to plug the core bore, consider changing the dimension to 3"-4". In the last paragraph, one sentence before the last sentence add after "outside containment" "temperature greater than 50°F and less than 60°F". In the last line add after "Removal" "of concrete can start and"	recorded in this fashion without any difficulty. Changing it would describe the measurement in a way it is not taking place.
28	Section B.6.26, Page 20: After EC 63020 add EC 63016. Since EC 63016 covers safe load paths for movement of platforms.	All safe load paths from 63016 were included in latest rev of 63020 per E. Ortalan.
29	Section B.6.28, Page 20: Add after may in the last sentence "be".	Added.
30	Section D.2, Page 1: Suggest adding the following additional Prerequisites and Precautions: a) Test all hydrodemoltion equipment before start of work. b) A safety net or other devices must be erected around the hydrdemolition equipment to prevent debris from falling and injuring personnel c) Ensure that all applicable environmental permits are obtained and in place before implementation of activities associated with this EC. d) Ensure that activities associated with this EC are in accordance with the applicable portions of EVC-CRNF-0002, "Use of Crystal River Nuclear Plant Site Specific Environmental Compliance Manual" e) All chemicals and other consumables shall be approved and properly labeled per CHE-NGGC-0045. f) The containment coordinator is to be informed prior to start of hydro-demolition equipment. The coordinator must inform all personnel in the immediate area that the hydro-demolition activities will start and noise levels will increase dramatically.	Additional prerequisites added.

31	Section D.2, Page 1: The work order listed in Item 8 under Prerequisites and Precautions is not identified in X-ref.	Added.
32	Section D.2, Page 3: In item 7.b. delete exceed after should. In Item 3 under Subsurface Micro-Cracking Test Considerations, delete "to" after craft and in Item 5 minimum of three times should be three locations, clarify. In Item 1 under Monitoring ... add after attached "to".	Incorporated
33	File G01- SK-75219-C001: Editorial Note 1: Change 1CR1 to ICRI and AC1 to ACI. Note 3: Change AMY to MAY and DISECRETION to DESECRTION. Note 4: Provide space between HYDRDEMOLITION and DAMAGE. Change C to G in third line and provide space after RESPONSIBLE and change DSCETION to DESCRETION in the fourth line. Drawing 421-032 referenced in Note 2 should be 421-351 verify. Some locations that are shown to have delamination depths not greater than 8.5" under LEGEND have depths greater than 8.5" verify.	Drawing has been revised. Drawing 421-032 is the proper drawing and references the layout of the #8 bars. Legend and Delamination depth is a general guide prepared by the condition assessment team. A noted in the installation instructions, the drawing is to provide a guideline/starting point. Sounding will ensure any are which may exceed the limits shown on that figure are properly removed.
34	Section H.1, Page 1: Under EC 75219 scope, delete "and removal" after detensioning in the third line.	Deleted
35	Section H.2, Page 4: the fifth line requires some rewording. Should this be plant personnel and Final DRB.	Reworded
36	Section J.1, Page 1: Job Objectives: Last sentence change This to The. Page 2: Under Error Precursor, suggest checking Repetitive actions, Unexpected equip conditions, Adverse physical conditions, illness and under Error Prevention Techniques "Tests".	Incorporated
37	Attachment Z02: Does not have header and footer.	Header was added
38	Attachment Z05, Page 1: change removal to removed in the third line under Purpose. Page 2: Item 6, delete r from strand in the first line.	Attachment Z05 is now intentionally left blank based on it containing outdated monitoring requirements. This was based on review comments by Operations.

Note: The Lead Reviewer signature on the EC DV milestone panel signifies that a lead review has been performed in accordance with EGR-NGGC-0003 and that errors/deficiencies (for all reviews performed) have been resolved and included in the EC package.

J.1 Engineering Pre-Job Briefing

Responsible Engineer: Aaron Mallner Date: 12/23/09

Job Objectives: *(Clearly define the task and what the task entails (scope). Discuss how the scope of the task was validated.)*

The main objective of this EC is to remove the delaminated concrete as documented in AR 358724. This will be accomplished via hydro demolition and/or mechanical removal/cutting. Underlying traditional reinforcements will be cut and removed as a result of this EC. Removal method will be such that tendon sheaths sustain minimal damage so their reuse is possible. The end state of this EC shall provide necessary input into the interfacing EC 75220 for concrete placement.

Job Expectations: *(Clearly define Roles and Responsibilities (performer, preparer, checker, independence of verifier, project coordinator, corporate, Non Station Personnel, etc.).*

Aaron Mallner will act as Responsible Engineers for this EC. A specific verifier, third party reviewer, etc. have not been identified at this time. Careful interface and oversight by RE and Supervision will be required since this EC will also involve many consultants, contractors, and in-house engineering staff. Other plant personnel from the Root Cause team, Maintenance, Radiation Protection, etc will have an opportunity to review and comment on the EC package.

Other Expectations include:

- Perform evaluations and analysis of acceptable repair options.
- Follow applicable procedures.
- Maintain communication with assigned personnel.
- Review and incorporate applicable OE.
- Effectively communicate issues that impact success of product or established schedule.
- Notify supervision if conditions change that alter the scope of this pre-job brief or the validation planning. Maintain focus on risk planning established in validation plan.
- Target date for EC approval to meet project schedule needs.

Skill Sets Required (including impacted organization reviewers): *(Review personnel qualifications. Establish appropriate mentoring and oversight if appropriate.)*

This is a civil/structural design modification. Civil/Structural design engineer qualifications are required. All anticipated personnel assigned to this modification are experienced and do not require mentoring. CR3 Design engineering supervision and management will provide oversight on the EC.

Specific skill set requirements include:

- Knowledge of the ACI Building Code and Concrete Design techniques.
- Knowledge of CR3 Design and Licensing Basis
- Knowledge of finite element plate and beam analysis, and seismic analysis techniques.
- Coordination with team members to evaluate ongoing activities
- Remain cognizant of plant personnel safety during concrete placement.
- Knowledge of heavy load lifting activities

Error Precursors (TWIN analysis)

Task Demands	*Work Environment*	*Individual Capabilities*	*Human Nature*
☑ Time/Schedule Pressure	☑ Distractions	☑ Unfamiliarity with task	☑ Stress – Work/ Home
☑ High Workload	☑ Changes from routine	☐ Lack of knowledge	☐ Health patterns
☑ Multiple simultaneous tasks	☐ Confusing displays/Controls	☑ New techniques not used before	☑ Assumptions
☑ Repetitive actions/monotony	☐ Workarounds/OOS equipment	☐ Lack of proficiency	☑ Complacence
☑ Unrecoverable / Irreversible actions	☐ Hidden system responses	☐ Unsystematic problem solving skills	☐ Overconfidence
☐ Interpretation requirements	☑ Unexpected equip conditions	☐ "Unsafe" attitude for critical tasks	☐ Mind Set
☑ Unclear goals, roles, responsibilities	☑ Adverse physical conditions	☐ Illness/ Fatigue/ General Health	☐ Inaccurate risk perceptions
☐ Lack of/or unclear standards	☐ Vague or incorrect guidance		☐ Mental shortcuts
☐ Activity inputs inadequate			☐ Limited short term memory
			☐ Apparent emotional health
			☐ First day back from days off
			☑ First time evolution

Error Prevention Techniques

☑ Self Check / STAR	☑ Checklists
☑ Peer Check	☐ 5 Step Problem Solving Process
☐ OAQ-3 Pass (Att. 13)	☑ Communication
☐ Mentoring	☐ Task Planning Review
☑ Procedure adherence	☑ Tests
☑ Reviews	☐ SAFER
☐ Time out	

Prioritization/Budget Required ☐ Yes ☑ No

☐ Sponsor identified	☐ Parts identified
☐ Project prioritized & budgeted	☐ Elements for estimate identified
☐ Capital/ O&M	
☐ Maintenance to implement	
☐ Contractor to implement	

Additional Checklist Items

Roles/Responsibilities/Reviews

- [x] Work assignment made, roles defined, key interfaces identified
- [x] Required internal reviews (including an independent verifier), Required third party reviews
- [x] Expectations and makeup of EC Teams and DRB
- [x] Individual accountability made clear

Plant Interface

- [x] Plant Walkdown needs
- [ ] ALARA
- [x] Personal safety (heat stress, electrical, safety equipment)
- [x] Review plant scheduling and plant interface considerations

Product Quality Considerations

- [x] Risk management worksheet and Validation plan completed, mitigating strategies discussed
- [x] Utilize the Product Quality Checklists
- [ ] Formalized design inputs (for Outsourced products and vendor supplied inputs)
- [ ] Need for a formal FMEA
- [ ] For digital upgrades, consider EGR-NGGC-0157 requirements
- [x] Design basis and margin considerations identified
- [x] Validating assumptions

Human Performance Tools

- [x] Lessons learned / OE items – Include feedback on recent product quality concerns from CAP roll-up, EPR, EC, Team implementation roll-up and EC reviews [Significant NCR 105197]
    - For EC (Permanent Design/Commercial Change, Alternate Replacements and Temporary Design/Commercial Change) reviews: Review the last 6 months of NCRs related to Engineering Change by running a text search report using "Engineering Change" or "EC."
- [x] Methods of communicating and coordinating actions
- [x] Emphasis on doing the job right vs. schedule

Miscellaneous

- [ ] Review appropriate programs/ procedures to be used
- [x] Schedule of milestones (design inputs, reviews, etc.)
- [ ] Implementation of work management tool to schedule reviews
- [ ] Implementation of project management tools (including need for a project plan) per NGGM-PM-0018

Comments:

J.2 Engineering Change Checklist

The following engineering change checklists address the design specification, administrative items, implementation, and testing. Use this checklist to ensure all important aspects of the engineering change have been captured.

	Administrative/PASSPORT Considerations	Y	NA
1	Problem statement is adequately documented in the Contents section of the EC.	[x]	[ ]
2	Solution statement is adequately documented in the Contents section of the EC. Options are evaluated and the reasons for selection and elimination have been provided.	[x]	[ ]
3	The history/root cause of the issue that has necessitated the EC has been provided. Applicable NCRs and OE have been incorporated.	[x]	[ ]
4	EC Team members are listed in the Contents section. An NIT SME has been included on the EC team for plant	[ ]	[x]

	Administrative/PASSPORT Considerations	Y	NA
	digital SSC-related products.		
5	If EC is a Commercial Change, the Commercial Change Screening Criteria (Attachment 1 of EGR-NGGC-0005) has been completed.	☐	☑
6	The revision levels of applicable documents utilized to develop the EC have been verified.	☑	☐
7	The accuracy of the Table of Contents has been verified. Ensure page numbers in the Table of Contents match the page numbers in the sections.	☑	☐
8	"Track changes", if used, has been set to display revision bars only.	☐	☑
9	Validation plan is included in the review section of the EC package (if required).	☑	☐
10	DRB comments/resolutions are included in the review section of the EC package	☑	☐
11	All information is legible so that QA records can be made.	☑	☐
12	EGR-NGGC-0005, Attachment 7 screening criteria has been used to determine required reviews.	☑	☐
13	The required discipline inputs and outputs have been design verified or engineering reviewed as required. Lead reviews and concurrent reviews have been completed.	☑	☐
14	The applicable Discipline, Program, and 50.59 reviewers are qualified in PQD.	☑	☐
15	If EC is a Master, the Master EC field is checked. If EC is a Child, Child is in the KW4 field and the Master EC is on the Xref panel.	☐	☑
16	For concurrent modifications, the Adv Wk Appvd field is checked.	☐	☑
17	"Cavet Outst" field is checked if caveats or exclusions (future details, missing documentation, vendor outputs, etc.) are identified in the scope of the EC.	☐	☑
18	ADL is complete. All affected documents are included. Reviewed field is checked. If a Turnover is required to Operations, the "Ops Svc" field is checked for each document that is required to be updated prior to turnover. Compare ADL to Section C (Markup) to ensure affected document lists match.	☐	☑
19	For temporary changes, the appropriate incorporation code has been identified for documents on the ADL.	☐	☑
20	AEL is complete. All affected tags are included. Minor revisions have been initiated and reviewed.	☐	☑
21	Reason for Revision attribute has been added and completed if EC is being revised	☐	☑
22	"VALIDATION PLAN APPROVED" and "50.59 APPROVED AND ON XREF" attributes have been added and completed if applicable. Document Validation Plan approvals in notes.	☑	☐
23	The correct quality class has been included on the Attributes Panel in accordance with EDB and the Quality Classification of Section B.	☑	☐
24	Turnover to Operations is checked Y or N on the Attributes panel (and agrees with Turnover/Closeout Summary and Testing requirements).	☑	☐
25	All required reviews and approval signoffs have been included on the Milestone Panel.	☑	☐
26	For EC's that require turnover, the 'RE T/O RELEASE' and 'OPS T/O ACCEPT' milestones are included. These milestones are not included for EC's not requiring turnover (including Master EC's). The 'DOC REV RELEASE' milestone is not included for Master EC's.	☐	☑
27	For Child EC's, the NO50.59 IMPACT1 and NO50.59 IMPACT2 milestones are included.	☐	☑
28	Work Orders (required for turnover), Action Requests (NCR, OPEX, REG, NTM, etc.) are included in the Xref Panel. Delete Work Package and Work Request references. Ensure no WO tasks are on Xref panel for Master EC's.	☑	☐
29	An NTM AR has been initiated if a post-job briefing and/or post-job critique has been specified on the validation plan	☑	☐
30	A.1.1. The basis for the initial risk level has been re-evaluated during the Engineering product development process when new information is available, and for modified or new scope.	☑	☐

	Design Section	Y	NA
1	Design Specification scope is clearly defined with specific detail and for software applications meets EGR-NGGC-0157 requirements. Caveats or exclusions that will be included in a future EC revision (e.g. future details, missing documentation, vendor outputs, etc.) are identified.	☑	☐
2	Codes, specifications and standards applicable to the design are consistent with the plant commitments (e.g. UFSAR).	☑	☐
3	All design inputs identified in EGR-NGGC-0005, Attachment 2 and EGR-NGGC-0157, Attachment 6 have been reviewed for applicability.	☑	☐
4	Design inputs indicate the basis and source of each input.	☑	☐
5	Design inputs are in accordance with the sources identified in Attachment 2 of EGR-NGGC-0005.	☑	☐
6	Design inputs clearly address required operating conditions for equipment (normal, transient, and accidents) and the expected performance requirements under these conditions.	☑	☐
7	Interfaces with other SSCs are clearly identified in design inputs.	☑	☐
8	All assumptions are clearly identified and bases for assumptions (or method of validation) are provided.	☐	☑
9	Evaluation considers and dispositions each identified design input. Evaluations are provided in the "Evaluation" section, and not in the "Design Inputs" section.	☑	☐
10	Impacts on PSA modes, assumptions and success criteria are identified.	☐	☑
11	Relative internal (plant specific) and external (nuclear and non-nuclear) operating experience is considered in the design and is evaluated.	☑	☐
12	Evaluation includes a failure modes and effect discussion for new and modified equipment.	☑	☐
13	Evaluation identifies changes to margins and considers mitigation for reduced margins.	☑	☐
14	Evaluation considers in-process Engineering Changes to interfacing SSCs. Potential impacts based on possible cumulative effects are evaluated. Required sequencing of implementation and document updates is considered.	☑	☐
15	Vendor-supplied technical data has been validated against design inputs.	☑	☐
16	Individuals/Vendors who provided input (excluding EC Team members) are identified in the Interfaces section.	☑	☐
17	The applicable quality classifications are identified based on EC scope and boundaries are established.	☑	☐
18	Constructability walkdowns have been completed, if possible, to verify actual plant configuration and constructability of the design. Where constructability walkdowns are not possible, the modification clearly identifies the possible risk that field changes based on actual as-builts may be required.	☑	☐
19	Modifications that involve interface agreements have responsibilities (including engineer of record) and testing requirements defined by responsible groups.	☑	☐
20	The impact to Preventive Maintenance program has been considered and reviewed. This includes: • establishing or revising the scope of PM activities, including material requirement changes (Note: Model Work Order may have staged Material Requests that require revision) (PM Planner) • establishing or revising the frequency of PM performance (System Engineer or Program Engineer) • planning to reset schedule for PM performance based on modification activities (PM Program Manager)	☑	☐
21	Software and databases used meet the benchmarking and verification procedural requirements.	☐	☑
22	Increased rigor used when modifying daisy-chained electrical circuits. (CAPR 292232)	☐	☑
23	Wire segment numbers are changed wherever a discontinuity is introduced or recognized within a control circuit. (CAPR 292232)	☐	☑

	Document/Database Impact Considerations	Y	NA
1	Design record document (Drawings, Calculations, DBD's, Specifications, etc.) impacts have been identified.	☐	☑

	Document/Database Impact Considerations	Y	NA
2	Non-Design record document (POM Procedures, System Descriptions, Operator Aids, etc.) impacts have been identified.	☐	☑
3	Vendor Manual changes for addition or deletion of information have been identified.	☐	☑
4	EDB change information is clearly identified. Review EDB requirements for affected or new equipment tags and ensure Maintenance Rule and ZTEF codes have been entered. Minimum required data fields for new equipment tags have been included per EGR-NGGC-0012. A Manufacturer Model Version (MMV) has been identified for any procured component subject to maintenance. For calibrated devices, setpoint parameters have been identified. If installing new equipment, consider if an EDB tag number(s) should be assigned. Ensure software components receive EDB tag numbers, when required by EGR-NGGC-0157.	☐	☑
5	Electrical cable management impact has been identified and input provided by the cable management coordinator if wires, cables or conduits are added, removed or spared.	☐	☑
6	The applicable load lists in Operations procedures are considered for impact if adding, removing, or modifying electrical characteristics of a component fed from an electrical panel, bus or MCC.	☐	☑
7	Markups are provided for each impacted document or a precise description of the impact to each document is provided. Consider preparation of a sketch list to aid in document update, particularly for large projects and when multiple sketches impact the same drawing.	☐	☑
8	Other tracking items (PMR AR's, NTM AR's, etc.) are identified.	☐	☑
9	If the EC is a Master, no minor revisions are created.	☐	☑
10	Changes potentially impacting a regulatory commitment (BNP RRIL, RG 1.97, EP, ISI, ASSD, SBO, T/S, etc.) are adequately reviewed for updating of the calibration program (Ref. BNP procedure ENP-33.4) [BNP only]	☐	☑

	Implementation Section	Y	NA
1	A succinct description of the EC implementation instructions has been included in the "Installation" section.	☑	☐
2	The Precautions and Limitations applicable to the instructions are included. Caveats or exclusions that will be included in a future EC revision (e.g. future details, missing documentation, vendor outputs, etc.) are identified.	☑	☐
3	Implementation instructions have been written to ensure that design requirements are achieved and maintained throughout implementation.	☑	☐
4	The installation instructions clearly identify ALL installation sketches to be used and, encompass the entire installation scope of the mod. For software components, installation instructions are provided.	☑	☐
5	For concurrent modifications, the requirements of EGR-NGGC-0005, Attachment 3 have been met.	☐	☑
6	For temporary changes, requirements for temporary change tagging have been developed and documented.	☐	☑
7	For temporary changes, an expiration date has been established and specific removal requirements have been considered and documented.	☐	☑
8	The EC Parts List includes the necessary parts for the design, including software components.	☑	☐
9	The "Use" column of the EC Parts List is filled in correctly for the quality class of parts to be used in the design.	☑	☐
10	Elimination of inventory has been considered, including budget impact.	☐	☑
11	QC Holdpoints currently not included in existing procedures needed for implementation of the EC are identified. Refer to NUA-NGGC-1530.	☐	☑
12	For ECs requiring turnover, a request for the planner to initiate an AD type Work Order Task has been included in the instructions [BNP only]	☐	☑
13	A Turnover/Closeout Summary is included that identifies: • (for Master ECs) Scope of Child ECs including identification of affected SSCs and boundaries • Known activities to be verified in the turnover process, specifically, required Operations and Maintenance training	☑	☐

Implementation Section		Y	NA
	• Identification of post-turnover testing requirements • Justification if no turnover is required • Identification of known exceptions and caveats for turnover • Identification of closure activities and schedule • Identification of any tracking mechanisms for turnover or closeout activities • Spare parts are identified and M&CS notified		

Testing Considerations		Y	NA
1	It has been verified that the test will demonstrate satisfaction of all performance criteria, including software functions, of the modification in addition to verifying the operability of the affected components and systems.	☑	☐
2	It has been verified that the modification will be tested in all its operating configurations. It has been verified that the test determines the modification has not adversely affected the unmodified portions of the component or system.	☑	☐
3	A.1.2. It has been verified that the proposed test demonstrates proper functioning of the component or systems over its entire range of operation and can be performed under both current and anticipated plant conditions.	☐	☑
4	The test should verify that any substituted components or equivalency engineering was accurate and complete.	☐	☑
5	It has been verified that modifications to redundant equipment and components are tested identically and that subsequent testing receive the same level of review, verification, and validation as the initial test.	☐	☑
6	If the proposed test will cause plant parameters to change, it has been verified that all administrative and operating requirements are met for the anticipated changes.	☐	☑
7	Responsibility and authority to intervene or terminate the test if problems are encountered during testing have been established and communicated.	☑	☐
8	The test termination criteria are specified. It has been verified that the test termination criteria do not conflict with guidance contained in normal, off-normal, or emergency operating procedures. Methods for resolving discrepancies have been identified.	☑	☐
9	It has been verified and documented that any procedure or document referenced by the test procedure is the most current revision.	☑	☐
10	Consideration has been giving to whether or not this test is an infrequently performed test or evolution or requires heightened level of awareness procedures. The basis for this determination has been developed and documented. [BNP - 0PLP-017, CR3 – AI-550, HNP – PLP-100, RNP – PLP-037]	☐	☑
11	If senior managers are required to be present during the test, the appropriate managers and their responsibilities have been identified.	☐	☑
12	It has been verified that station personnel required to conduct the test are trained and qualified to perform the test.	☑	☐
13	Post modification testing includes plant mode required for testing and any special requirements.	☑	☐
14	Electrical and I&C post modification testing is specified per EGR-NGGC-0155.	☐	☑
15	If an SSC has been disturbed and then returned to original state, appropriate testing is specified.	☑	☐
16	If separate testing is performed on different portions of the affected SSCs (e.g., an electrical circuit), the overall test plan ensures that no portions of affected SSCs that are required to be tested are omitted.	☐	☑
17	Plant digital SSC-related testing has been implemented per criteria in EGR-NGGC-0157. Software functionality has been validated prior to installation using test systems, simulations, or mockups.	☐	☑
18	A special procedure has been developed for PMT if an adequate procedure does not currently exist.	☐	☑

	Testing Considerations	Y	NA
19	Post modification testing includes design parameter/function to be tested and acceptance criteria.	☑	☐
20	Failure modes and effects analysis results are used as input to modification test planning and software validations.	☐	☑

TECHNICAL GUIDELINES

Prepared by the International Concrete Repair Institute January 1997

Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays

Guideline No. 03732

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INTERNATIONAL CONCRETE REPAIR INSTITUTE

About ICRI guidelines

The International Concrete Repair Institute (ICRI) was founded to improve the durability of concrete repair and enhance its value for structure owners. The identification, development, and promotion of the most promising methods and materials are primary vehicles for accelerating advances in repair technology. ICRI members working through a variety of forums have the opportunity to address these issues and to directly contribute to improving the practice of concrete repair.

A principal component of this effort is to make carefully selected information on critical subjects readily accessible to decision makers. During the past several decades, much has been reported in the literature on concrete repair methods and materials as they have been developed and refined. Nevertheless, it has been difficult to find critically reviewed information on the state of the art condensed into easy to use formats.

To that end, ICRI guidelines are prepared by sanctioned task groups and approved by the ICRI Technical Activities Committee. Each guideline is designed to address a specific area of practice recognized as essential to the achievement of durable repairs. All ICRI guideline documents are subject to continual review by the membership and may be revised as approved by the Technical Activities Committee.

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INTERNATIONAL CONCRETE REPAIR INSTITUTE

Contents

This document is intended as a voluntary guideline for the owner, design professional and concrete repair contractor. It is not intended to relieve the professional engineer or designer of any responsibility for the specification of concrete repair methods, materials or practices. While we believe the information contained herein represents the proper means to achieve quality results, the International Concrete Repair Institute must disclaim any liability or responsibility to those who may choose to rely on all or any part of this guideline.

INTERNATIONAL CONCRETE REPAIR INSTITUTE

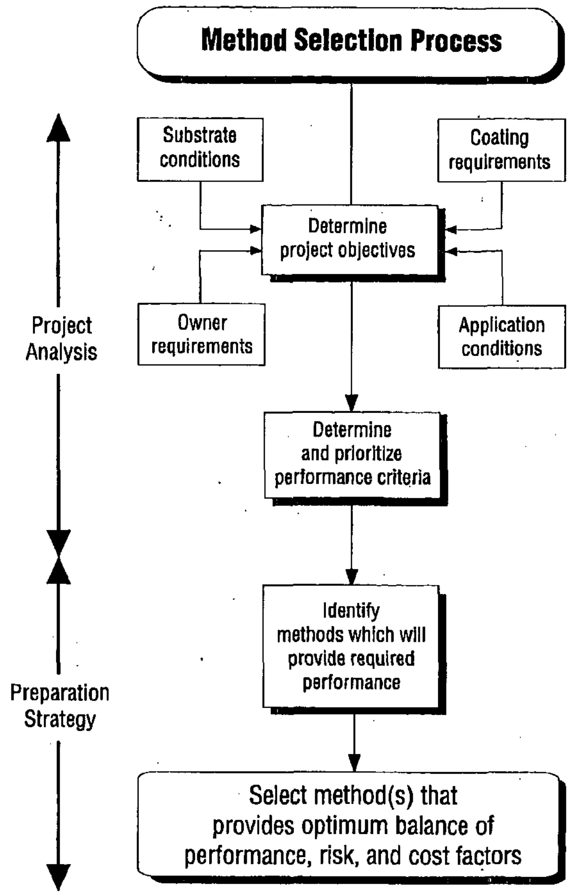
About this guideline

This guide provides designers, specifiers, contractors, and manufacturers with the tools needed to select and specify the methods for preparing concrete surfaces prior to the application of sealer, coating and polymer overlay systems. For the purposes of this guideline, surface preparation is the process by which sound, clean, and suitably roughened surfaces are produced on concrete substrates. This process includes the removal of unsound concrete and bond-inhibiting films, strength verification, opening the pore structure, and establishing profiles suitable for the application of the specified protective system.

Although many of the method summaries included in this document contain data on removal capabilities, a full discussion of methods for the removal of encrustations, stains, embedded contaminants, or existing coatings is beyond the scope of this guideline.

Guideline tools

1. **Method Selection Process:** A workbook designed to organize and prioritize information needed for good selection decisions is located in *Appendix A*. Sample checklists and examples are included.
2. **Method selector:** This chart identifies methods capable of producing the profile(s) typically recommended for each coating type.
3. **Method summaries:** Capabilities, limitations, operating requirements, environmental factors, and safety considerations for each method are presented.
4. **Surface profile chips:** These replicas of typical surfaces produced by one or more of the methods provide a visual standard for purposes of specification, execution, and verification.



Selecting surface preparation methods

Determine project objectives & requirements

Most coating or sealing projects will have unique conditions and special requirements that must be evaluated to determine which method(s) will best meet the engineers' and owners' objectives. The sample checklists may be used to gather data needed to identify and prioritize performance requirements (pages 34 – 36). They will help ensure that important issues will be resolved at the optimum time—before the project is underway.

1. **Substrate condition:** The strength of the substrate, and the presence of unsound or bond-inhibiting materials help define the nature and volume of preparation needed.
2. **Owner requirements:** Noise, vibration, dust, and water are effects generated by various preparation methods. The owner's need for uninterrupted use of the structure, concerns about operating environment or property damage potential will limit the choices.
3. **Material requirements:** Surface preparation requirements will vary with the protective coating system selected. The properties and application requirements of the selected system should be determined before or during this phase.
4. **Application conditions**
Generation of dust, slurries, or water may require containment and safe disposal. Mechanical ventilation, available power sources, the size of door openings, and minimum clearance will affect surface preparation decisions.

Establish performance priorities

Performance criteria which best satisfy project objectives and requirements are developed and prioritized (*see Appendix A, p. 37*).

Example: Deck coating installation

A parking structure providing 240 spaces for hospital employees is to be protected by a traffic bearing membrane. Surface preparation will remove all deteriorated concrete, bond-inhibiting contaminants, and achieve a profile of CSP 3 – 4. Structure has a common shear wall with patient rooms for two of its four levels. The hospital requires that 85% of parking capacity remain in service throughout project.

Priorities: (ranked in order of importance)

1 Dust-free preparation to prevent finish damage to parked vehicles
2 Low noise/vibration to minimize patient discomfort
3 Achieve profile CSP 3 or 4 to provide optimum surface for bonding
4 Fast turnaround to minimize inconvenience

Evaluate surface preparation methods

Selecting the method(s) which optimize project objectives requires a good knowledge of the available options. The method selector chart may be used to make a preliminary identification of the methods capable of producing the required surface profiles. The method summaries compare data on the capabilities, limitations, operating requirements, and environmental considerations for each surface preparation method.

Select and specify surface preparation methods

Final selection is based on the relationship between cost, project objectives, and risk. The selection process workbook (*Appendix A*) provides a systematic framework for organizing project data and assessing method suitability. More than one method may be capable of producing the desired results. Further, more than one method may be required to produce those results economically. Unacceptably rough profiles on existing or prepared surfaces may be reduced through additional passes using properly selected surface preparation equipment. On occasion, the application of a resurfacing mortar may be required to achieve the profile and appearance desired. The nine concrete surface profile chips provide benchmark profiles to aid in achieving the desired result.

Mechanics of concrete removal

In addition to project-specific requirements, method selection must also be guided by the following principles of sound practice:

1 The structure to be coated should not be damaged.
2 The reinforcing steel should not be damaged nor its bond with the concrete loosened.
3 Vibration, impact, or thermal loads applied should not weaken the concrete.

This section describes the cutting mechanisms used by the methods summarized herein. This information will help users assess the relative potential of each preparation method to damage or weaken the substrate.

Two methods, low-pressure water cleaning and detergent scrubbing, do not remove sound concrete and do not noticeably alter the profile of concrete surfaces. Cleaning is accomplished through one or a combination of the following: the surfactant effect of detergents, the solvent effect of water, and the shearing force of brushes or high velocity water. A third method, acid etching, chemically dissolves calcium hydroxide, $Ca(OH)_2$ crystals and calcium silicate hydrate (C–S–H) which make up the hydrated solids in cement paste. The dissolution of these reaction products causes a slight loss of cement paste, to produce a very light profile on the exposed surface. The remaining nine methods summarized in this guideline will utilize one or a combination of the following cutting actions.

Erosion

Erosion causes the wearing away or progressive disintegration of concrete surfaces. Abrasive force applied through grinding with stones, abrasive discs, or blocks with embedded diamonds wears away the cement paste, fines, and coarse aggregate at a uniform rate to produce a nearly flat surface having little or no profile (*Figure 1*).

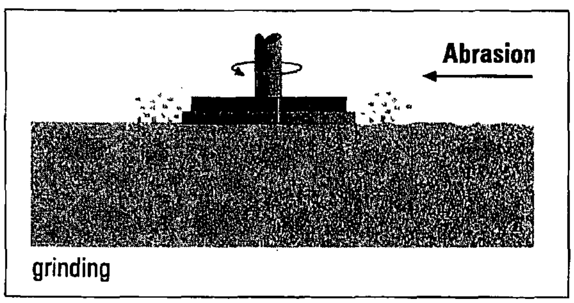


Figure 1

A stream of water projected onto the surface under high pressure is another form of erosion in which cavitation and the friction generated by water velocity combine to wear away the cement paste. Unlike grinding, water jetting will not produce a smooth, uniform surface. As exposure to water jetting increases, so will the profile as the softer paste and embedded fines erode leaving behind "islands" of the harder coarse aggregate. Under prolonged exposure to water jetting, coarse aggregate will be undercut and washed away (*figure 2*). **Applicable Methods:** grinding, high and ultra high-pressure water jetting.

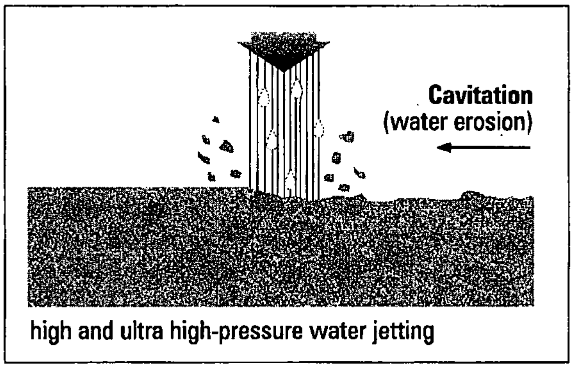


Figure 2

Impact

Several preparation methods strike the surface repeatedly with hardened points to produce momentary mechanical loads which, at the points of impact, exceed the tensile and compressive strength of the concrete, causing it to yield. The force of the impact pulverizes and fractures the structure of both cement paste and aggregate at and adjacent to the point of contact (*figure 3*). Some of the cracks and loosened aggregate may remain leaving a "bruised" layer at the surface. **Applicable methods:** scarifying, scabbling, milling/rotomilling, needle scaling.

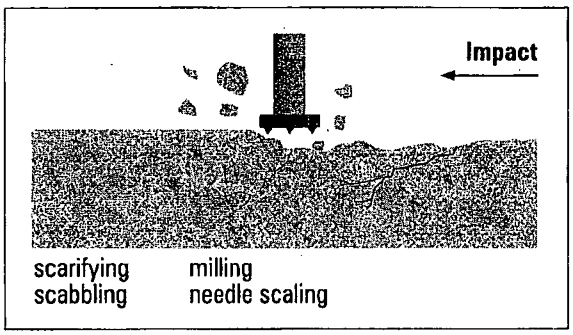


Figure 3

Pulverization

The cutting effect is derived from the collision of small particles traveling at a high velocity with the concrete surface (*figure 4*). Because the mass of the particles is comparatively small, their impact is not known to produce bruising. Hard, sharp-edged media can produce fast cutting rates. As with water jetting, the cement paste is reduced at a faster rate than is the coarse aggregate. This difference in cutting rate has the effect of exposing and undercutting the coarse aggregate to produce a surface that will become highly profiled as exposure time is increased. **Applicable methods:** steel shotblasting, abrasive blasting.

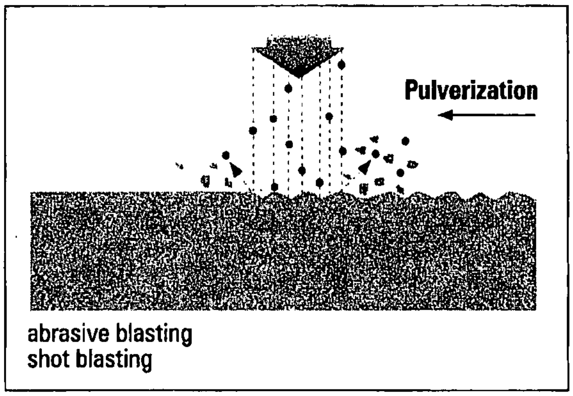


Figure 4

Expansive pressure

Two forms of expansive pressure are used to modify concrete surfaces: steam and water.

Steam: Energy from a high-temperature heat source rapidly heats the capillary and adsorbed water present in the cement paste to produce steam. This sudden increase in vapor pressure generates tensile stresses near the surface fracturing both matrix and aggregate, causing concrete material to scale or pop off in thin, flake-like chips (*figure 5*). Because the water heats more rapidly than the surrounding concrete phases, concrete temperatures in the top 2 mm typically do not exceed 250° C at recommended travel rates. At this exposure level, substrate temperatures at a depth of 7 mm do not rise above 70° C. Best results are achieved when surfaces to be prepared are soaked with ponded water for several hours prior to flame scaling.

Although the mechanical properties of cement paste in compression are not significantly altered at temperatures below 300° C, the fracturing produced by this

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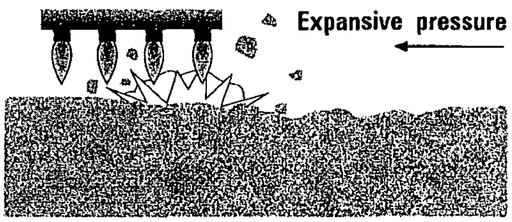
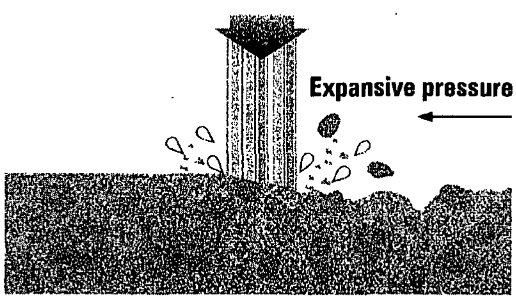


flame blasting

Figure 5

method of cutting may introduce additional micro-cracking near the free surface of the substrate to cause some reduction in tensile strengths. The limited test data available on the effects of this preparation method on the mechanical and durability properties of concrete are inconclusive. Further investigation into the condition of substrates prepared using this technique is needed. **Applicable methods:** flame blasting (flame scaling)

Water: Working at higher pressures, 15,000 – 45,000 psi (100 – 300 MPa), water jetting can produce a cutting effect similar to that of steam. An initial pass over horizontal concrete surfaces to be prepared using this method is sometimes taken with milling or scarifying equipment to remove ¼ to ½ inch (6 – 13 mm) of the original surface. The purpose is to introduce the cracks and micro-cracks needed to create numerous avenues of entry beneath the surface. The expansive pressure generated by water subsequently penetrating the fissures at high velocity will cause tensile failure along these planes of weakness *(figure 6)*. **Applicable methods:** high and ultra high-pressure water jetting



high and ultra high-pressure water jetting

Figure 6

Bruising

Several of the preparation methods described are likely to reduce the tensile strength of the prepared substrate. Field studies have shown that bond strengths achieved on surfaces prepared using high-impact mechanical methods are frequently lower than those on surfaces prepared using non-impact methods. This reduction in bond strength is caused by fracturing of the cement paste and loosening of aggregate without fully separating from the surface. This creates a weakened or "bruised" surface layer of interconnecting micro-cracks typically extending to a depth of ⅛ – ⅜ inch (3 – 10 mm). Under microscopy, the cracks are frequently seen to initiate at the surface at approximately a 45° angle and propagate horizontally to produce a weakened plane *(figure 3)*. It is generally accepted that the extent of the damage increases with the weight and power of the equipment used. However, the use of sharp, fine toothed cutters contacting the surface at a shallow angle may reduce or prevent the development of bruising. The relative risk of introducing bruising or micro-cracking into the substrate is indicated for each method *(figure 7)*.

Risk of Introducing Micro-Cracking

○ very low ◑ moderate ● high

Abrasive (sand) blasting	○
Steel shotblasting	○
Scarifying	◑
Needle scaling	◑
High and ultra high-pressure water jetting	○
Scabbling	●
Milling/rotomilling	●
Flame blasting	◑

Figure 7

Specifying concrete surface profiles (CSP)

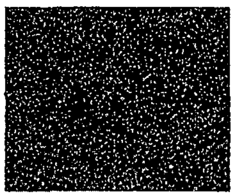
Several of the methods summarized are capable of producing a range of profiles on concrete surfaces. Communication of project requirements may be improved by using CSP profiles to define surface roughness.

ICRI has identified nine distinct profile configurations which may be produced by the methods summarized herein. As a set, these profiles replicate degrees of roughness considered to be suitable for the application of one or more of the sealer, coating, or polymer overlay systems, up to a thickness of ¼ inch (*see Appendix B*). Each profile carries a CSP number ranging from a base line of CSP 1 (nearly flat) through CSP 9 (very rough). The profile capabilities for each preparation method are identified by CSP number in the "Profile" section of the method summaries. Molded replicas of these profiles are included with this guideline to provide clear visual standards for purposes of specification, execution and verification. These benchmark profiles may be referenced in specifications, material data sheets, application guidelines, and contract documents to effectively communicate surface preparation requirements. When these profiles are used in conjunction with specifications for thicker coating and overlay systems, it is probable that more than one profile will produce acceptable results. When applicable, the range of suitable profiles should be specified.

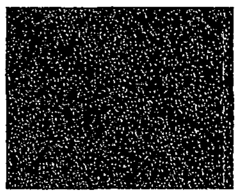
The concrete surfaces shown below were produced using a variety of preparation methods. Although each numbered CSP plaque bears the characteristic pattern and texture of the specific preparation method used, each plaque is representative of the profile height obtainable with all methods identified with the same CSP number.

Caution! The texture and appearance of the profile obtained will vary depending on strength, the size and type of aggregate and finish of the concrete surface. On sound substrates the range of variation can be sufficiently controlled to closely resemble the referenced CSP standard. As the depth of removal increases the profile of the prepared substrate will be increasingly dominated by the course aggregate.

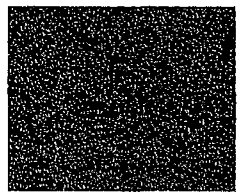
Images generated using video density imaging techniques are courtesy of David Lange, Department of Civil Engineering, University of Illinois at Urbana-Champaign.



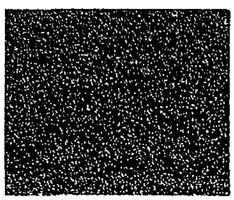
CSP 1
(acid etched)



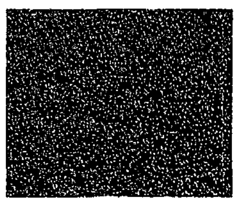
CSP 2
(grinding)



CSP 3
(light shotblast)

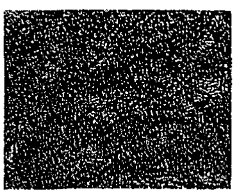


CSP 4
(light scarification)

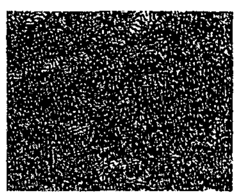


CSP 5
(medium shotblast)

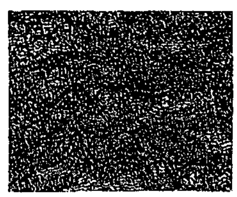
CSP 6
(medium scarification)



CSP 7
(heavy abrasive blast)



CSP 8
(scabbled)



CSP 9
(heavy scarification)

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Method selector

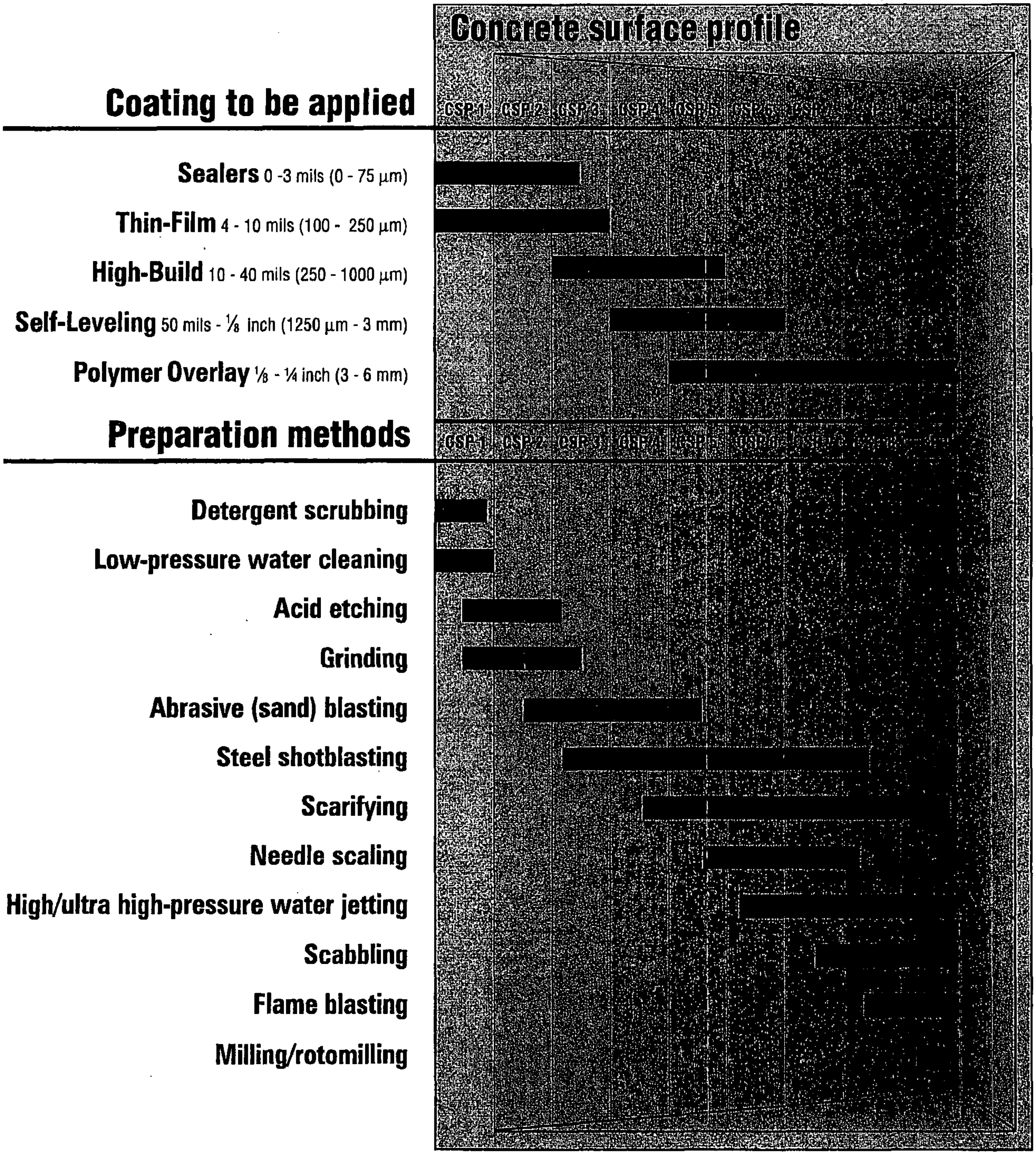

Photo: Tennant Company

Detergent Scrubbing

Chemical removal of oil, grease, and other deposits on concrete surfaces by scrubbing with a detergent solution.

Method summary

This method can be used indoors or outdoors on horizontal concrete surfaces to remove dirt, oil, and grease. Corner and edge cleaning can be detailed manually. The scrubbing process should produce clean surfaces, devoid of dirt, oil, grease, and loose debris without altering surface texture.

Purpose. Detergent scrubbing is frequently used to prepare concrete for acid etching. It may also prepare concrete surfaces for the application of sealers or surface hardeners, or for adhesive bonding.

Limitations. This method is limited to the removal of water-soluble or detergent-emulsifiable contaminants. (Debris which is readily loosened may be removed by light mechanical action by the scrubbers).

Removal. Suitable for superficial removal of oil, grease, organic or inorganic residues, some acrylic, wax, or rubber membranes, rust, and other oxidation deposits from concrete surfaces. Absorbed fluids such as oils and grease may require several treatments to achieve acceptable results. Bugholes and open pores at the surface may be scrubbed to a depth of 6-10 mils (150-250 µm).

Pattern. Detergent scrubbing will not produce any noticeable pattern effect on sound concrete surfaces.

Profile. ICRI CSP 1

A clean surface devoid of oil, grease, buildup, and loose debris. The scrubbing process should not alter surface texture.

Accessibility. With the variety of portable and maneuverable equipment available, most surfaces are accessible. Access to corners, recesses, and between penetrations is restricted by the reach and arc of the brushes. These areas may be addressed manually.

Environmental factors. Moderate to heavy contamination may produce significant amounts of sludge or other debris. Some debris may be considered hazardous or otherwise unqualified for discharge into sewer systems.

Debris produced by detergent scrubbing will contain particles of material or contaminants being removed. Any special requirements for containment and disposal will depend on the specific materials or contaminant being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment.

Suitable measures for the containment, collection, and proper disposal of debris and rinse water should be considered. Though nontoxic, some citric acid-based cleaning solutions have a pervasive odor.

Execution

- Apply chemical detergent solution.
- Scrub in chemical solution with stiff-bristled broom or scrubbing machine.
- Collect and dispose of solution.
- Repeat process as needed to achieve acceptable results.

Equipment

Manual method:

- mop
- stiff broom
- pressure washer
- squeegee
- wet/dry vacuum

Mechanical method:

- Automatic scrubbing machine (walk-behind or self-propelled). Available in gas, electric, propane, or diesel-powered models. Brush rotation speeds up to 300 rpm.
- Brushes (disc or cylindrical pad). Nylon bristle brushes are relatively soft. Polyethylene bristles are stiffer, more aggressive. Polyethylene/abrasive composite bristles will provide the most aggressive mechanical cleaning. Sizes range from 18 – 60 inch (0.5 – 1.5 m) brush path.
- Solution tanks range from 3 – 365 gallons (11 – 1,380 L) with recovery tanks to hold scrubbing residue.

Materials

- Industrial detergent rated to remove heavy oil and grease
- Water source

Labor. Low skill for manual scrubbing method. Medium skill to operate automatic scrubber and mix chemical solutions.

Down time. (The time considerations which follow are applicable to automatic scrubber machines). Mixing chemicals, filling tanks, and removing soilage from recovery tanks will involve some down time. For example, a 100 gallon (380 L) tank may take 20 – 30 minutes to fill. Changing brushes is quick and infrequent. Replacement frequency for pickup squeegees will depend on wear factors.

Cleanup. Scrubbing manually with brooms or mechanically with electric single disc machines will generate a liquid residue which must be removed by squeegee and vacuum to obtain a clean surface. Automatic scrubbers have an internal squeegee/vacuum system to remove the liquid residue immediately behind the scrubbing brushes.

Production rates. The following rates are approximate. Actual rates will vary considerably with the severity of soil, size of machine, and effectiveness of chemical solution being used.

- Manual with wet/dry vacuum recovery: 500 ft^2 (50 m^2) per hour.
- Manual with electric disc machine with wet/dry vacuum recovery: 1,000 ft^2/hr (100 m^2/hr)
- Small walk behind scrubber: 5,000 ft^2/hr (500 m^2/hr)
- Medium or large riding scrubber: 50,000 ft^2/hr (5,000 m^2/hr)

Standards & specifications

As required by the specifications of the manufacturer or customer.

Surfaces scrubbed in preparation for etching must be clean enough to allow chemical etching solutions to bite into cement paste. Inspection may consist of one or a combination of the following methods:

- Visual inspection should show no dirt, oil, grease, or debris on the surface.
- The prepared surface should be free of bond-inhibiting barriers and demonstrate sufficient strength for the proposed application.
- Gloss meter, slip tester/traction recorder.
- A solution hand scrubbed across area to be tested. Recovered solution should be clear.

ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41).

Safety

- Eye protection: Required.
- Personal protective equipment: Latex gloves, boot protection.
- Respiratory protection: Not required.
- Hearing protection: Recommended if automatic scrubbers are used.

Photo: Buildings Consulting Group, Inc.

Low-Pressure Water Cleaning

Water is sprayed at pressures less than 5,000 psi to remove dirt and loose, friable material. This method does not remove any significant amount of concrete.

Method summary

This method may be used outdoors to remove dust, friable materials, debris, or water-soluble contaminants from concrete surfaces and surface cavities. It may be used in interior spaces where mist, noise, and severe puddling can be tolerated. The method is suitable for horizontal, vertical, and overhead applications. This method does not produce any significant texture, profile, or pattern. For surface preparation applications, low pressure water cleaning should supplement other methods.

Purpose. Low-pressure water cleaning is used to rinse away dirt, dust, loose scale or debris generated by more aggressive surface preparation methods.

Limitations. This method is not suitable for the removal of sealers, coatings, curing membranes, or any significant volume of concrete.

Removal. Low-pressure water cleaning will not produce any measurable removal of sound concrete.

Pattern. Low-pressure water cleaning will not introduce any noticeable pattern effect on sound concrete surfaces.

Profile. ICRI CSP 1

Accessibility. With the wide variety of portable and maneuverable equipment available, most surfaces are easily accessible. Tight spaces can be accessed with a hose and hand-held lance. Presence of goods or equipment that cannot be adequately protected from mist or spray may restrict use of this method.

Environmental factors. This process produces loud noise similar to sandblasting. Mist and a large volume of water will be introduced into the work area.

Debris produced by low-pressure water cleaning will contain particles of material or contaminants being removed. Any special requirements for containment and disposal will depend on the specific materials or contaminant being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment.

Environmental regulations may require containment and regulated disposal of the liquid waste generated.

Execution

- A water jet is methodically moved back and forth over the surface until the desired results are achieved. If automated equipment is used, the operator typically makes parallel passes. If hand-held lances are used, the process will be slower, but similar.
- Standing water may need to be pumped, vacuumed, or squeegeed off the surface.
- Solid debris and water residue are disposed of as required by local regulations or project restrictions.

Equipment

- Booster pump (to increase pressure)
- Pressure rated hoses
- Water jet: wheeled equipment for horizontal surfaces; hand-held lance for vertical and overhead applications, corners, or other difficult-to-reach locations
- Suitable nozzle tip
- Runoff protection to catch debris flowing off site or toward drains

Materials. Water source may be provided by tanker, hydrant connection, industrial spigot, or pump.

Labor. Generally requires a two or three-person crew. Work may be performed with unskilled labor. Skilled supervision may be needed if complex equipment is used.

Down time. Setup time is typically two to four hours to protect surfaces and install runoff protection to catch loosened materials. Production may shut down periodically if water must be transported to the work area.

Cleanup. Several hundred gallons of water per hour may need to be drained away. The volume of debris trapped by collectors is usually small.

Production rates. The rates below are approximate. Actual rates will vary with the efficiency of equipment employed and preparation objectives.

- 1,000 – 2,000 ft^2/hr (100 – 200 m^2/hr) for flat surface.
- 250 – 1,000 ft^2/hr (25 – 100 m^2/hr) for hand-held equipment on vertical surfaces.

Standards & specifications

Visual inspection should find no obvious dirt, laitance, or debris on the surface. The prepared surface should be free of bond-inhibiting barriers and demonstrate sufficient strength for the proposed application. Beads of water indicate a surface contaminant that may need to be removed by other means. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41).

Safety

- Eye protection: Anti-fog goggles or face shield.
- Personal protective equipment: Rugged rubber or plastic gloves, steel-toed boots, and waterproof outerlayers.
- Respiratory protection: Not required.
- Hearing protection: Recommended.

Photo: Tennant Company

Acid Etching

Chemical removal of cement paste to clean and condition concrete surfaces prior to application of thin-film sealers or coatings.

Method summary

Acid etch is a mixture of water-soluble solvents, surface-active agents, and suitable acids designed to remove (etch) cement paste from the surface and pores of concrete. It also aids in dislodging slight traces of oils, grease, or fats remaining after detergent scrubbing. Etching produces a clean, lightly-profiled concrete surface to promote penetration and adhesion of sealers and coatings. The process will almost always be used to prepare concrete surfaces for the application of thin-film coatings. The process can be used inside or outside on most concrete, quarry tile, or stone surfaces.

Purpose. Etching is used to remove weak cement paste and to slightly profile the surface by exposing fine aggregate. This process is used to prepare concrete surfaces for the application of concrete sealers or thin-film epoxy, urethane, acrylic, and alkyd coatings.

Limitations

- Not suitable preparation for systems greater than 10 mils.
- Thorough removal of etching debris requires the use of vacuuming equipment.
- Solution is highly corrosive. Electronic equipment, machines and other metal components should be protected or removed.
- Thorough removal of etching debris requires large quantities of rinse water, mechanical scrubbing, and vacuum removal. (Incomplete removal will leave bond-inhibiting contaminants on the surface.)
- Hydrochloric acid may not be used on metallic hardened surfaces.
- Oils, grease, and other surface deposits must be removed prior to etching
- Not recommended for use on green concretes. Minimum age is six weeks.
- The etching process will saturate the substrate. When used in preparation for moisture-sensitive coatings, time restrictions may not allow for sufficient drying.
- Environmental considerations may require full containment and recovery of spent acid and rinse water.

Removal. The acid in the etching solution attacks the $Ca(OH)_2$ and C–S–H in the cement paste causing rapid deterioration at the surface. The concentration and volume of solution applied are controlled to limit the depth of chemical attack. Typical depth of removal is 4 to 10 mils (100-250 μm).

Pattern. Etching should not introduce any noticeable pattern effect on sound concrete surfaces.

Profile. ICRI CSP 1 – 3

Surface should feel like fine sandpaper with no residue or grit. Surface should have a dull, even appearance. If surface is still smooth or glossy, repeat procedure.

Accessibility. The equipment used for this method is portable and maneuverable. Access may be restricted by the presence of non-portable machinery or equipment subject to damage from corrosive mist or splash.

Environmental factors. Applied as an acid wash, the mixture may corrode metals on contact. Debris produced by acid etching will contain particles of material or contaminants being removed. Any special requirements for containment and disposal will depend on the specific materials or contaminant being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. Spent acid and rinse water should be disposed of as required by local regulations or project restrictions. Careful control of the etching process can produce a residue solution having a slightly alkaline pH of 8 or 9.

Execution

- Dilute acid mixture according to floor type and strength of concentrate. For standard concrete, use manufacturer's ratio. The usual concentration is approximately 10%. Dense or chemically-hardened floors may require higher concentrations and/or multiple passes.
- Thoroughly wet concrete surfaces. Any standing water must be removed prior to application of acid.
- Apply mixed solution uniformly at an approximate rate of 100 square feet (9 m^2) per gallon.
- Agitate acid solution with stiff bristle broom or power brush for five to ten minutes. Do not allow surface to dry. Vacuum residue.
- Thoroughly scrub with an alkaline detergent and vacuum residue. Repeat as necessary to completely remove etching debris.
- Rinse with clean water, scrub and vacuum dry.
- Allow floor to dry for a minimum of 12 – 16 hours.

Equipment

- Container to mix etching solution
- Applicator: Low pressure sprayer, plastic sprinkling can, or mop
- Floor scrubber or disc machine equipped with an abrasive bristle brush
- Power washer or hose to apply rinse water
- Vacuum system or scrubber for recovery

The use of automatic scrubbing equipment to apply acid etching solution is not generally recommended. However, this equipment is often used to recover etching solution after it has been diluted with rinse water. Consult equipment manufacturer to determine suitability.

Materials

- Acid etch solution. Typical solutions include muriatic (hydrochloric), sulfamic, phosphoric, and citric acids.
- Alkaline detergent for cleanup scrub
- Water source
- Plastic sheeting for machine protection

Labor. Medium to above medium skill level required to safely handle and mix hazardous materials and to operate equipment.

Down time. Minimal. Chemical mixing requires only a short period of time. Filling and emptying scrubber and wet-vac tanks should take ten to twenty minutes. Additional time required to remove portable machinery from etch area and to place plastic sheeting on non-portable machinery for protection.

Cleanup. While the surface is still wet, squeegee and vacuum acid solution and slurry debris. Immediately flood surface with alkaline detergent solution, scrub and vacuum. Some acid etching solutions produce a white residue which helps identify locations requiring additional scrubbing, rinsing, and removal. Flood etched surface with clear rinse water, scrub, and vacuum dry.

Production rates. The rates shown below are approximate. Actual rates will vary with the method used, density of surface, dilution ratio, and size of machines.

- Manual with wet/dry vacuum recovery: 1,600 ft^2/hr (150 m^2/hr).
- Medium scrubber: 8,000 ft^2/hr (740 m^2/hr).

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection should show a fine-grained surface profile with no white residue, dirt or debris remaining on surface. Dry surface check using a moisture meter. The prepared surface should be free of bond-inhibiting barriers and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41).

Safety

- Eye protection: Splash shield recommended.
- Personal protective equipment: Gloves, aprons, and boot protection required. Recommended materials for these items are neoprene or rubber.
- Respiratory protection: Use of respirators equipped with acid-gases canister is recommended for acid etching in poorly ventilated or confined space.
- Hearing protection: Required if automatic scrubbers are used for cleanup.
- Alkaline detergent can be used to neutralize concentrated acid spills.

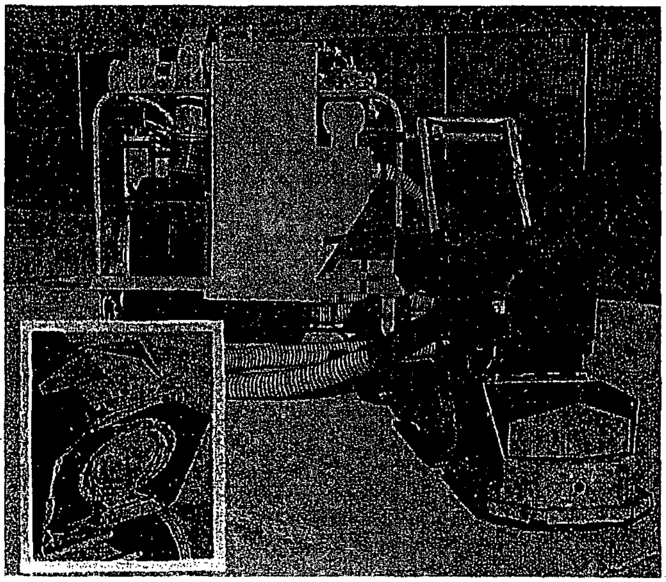

Photo: Equipment Development Co., Inc.

Grinding

The rotation of one or more abrading stones or discs applied under pressure at right angles to the concrete surface.

Method summary

This method may be used on horizontal, vertical and overhead surfaces to remove deposits or coatings, and to reduce or smooth surface profile. The grinding stone or disc is applied under pressure and moved across the surface until the desired effect is achieved. Grinding may be used on almost any substrate and is suitable for both interior or exterior applications. Efficiency considerations may limit coating removal applications to film thicknesses less than 6 mils (150 µm).

Purpose. Grinding is used on concrete surfaces to reduce or smooth slight surface irregularities and to remove mineral deposits and thin coatings.

Limitations. Grinding is not recommended for the following applications:

- Preparation of previously sealed or coated surfaces for recoating—unless followed by acid etching or shotblast.
- Surface profile is required.
- Removal of chlorinated rubber, acrylic, or other soft coatings or finishes.
- Removal of tile or carpet adhesives.
- Occupied work space (unless rigorous dust control methods are used).
- Surfaces of unknown composition.

Removal. Removal is practically restricted to surface protrusions and coatings less than 6 mils (150 µm) thick. May be used to remove noncombustible or non-heat degenerating coatings. Method will successfully remove rigid epoxy, polyurethane, and methacrylate coatings. Grinding may also be used to remove efflorescence, rust, and other oxidized deposits.

Pattern. Small hand-held grinders are likely to produce gouging and a circular, grooved pattern. Large walk-behind units fitted with aggressive media should eliminate gouging, but are likely to impart a circular pattern. Larger units using fine stones should not produce any detectable pattern.

Profile. ICRI CSP 1–3
Grinding produces a smooth surface. Other methods may be used in conjunction with grinding to produce required profile.

Accessibility. Most surfaces, including edges, are accessible. Portable equipment ranges from small hand-held grinders to walk-behind units with multiple discs. Access to corners and tight configurations is restricted by the arc of the grinding disc.

Environmental Factors. Dry grinding will produce a fine airborne dust which may be minimized with dust control attachments. Debris generated by this method will contain fine particles of any material or contaminant being removed. Materials likely to require special protective measures and handling include tile mastics, which may contain asbestos; lead-based paints; and PCB's which may have been absorbed by concrete in the vicinity of electrical equipment. Wet grinding, which may be selected to eliminate airborne dust, will produce a slurry residue. Slurry constituents from some materials may be considered toxic. Plans to collect and properly dispose of slurry and rinse water must be considered. Grinding soft, easily charred materials will generate smoke which may be considered hazardous.

Preparation should include plans to adequately protect occupants and workers. Noise and vibration levels are considered to be low.

Execution

Equipment. Appropriate selection of a grinder depends on the location and size of the area, specific removal requirements, and accessibility. They are available in electric, pneumatic, or gas-driven models. Sizes range from hand-held grinders to walk-behind machines. Rotation speeds vary from 1,000 to 9,000 rpm.

Materials. The grinding medium (stone or disc) is the consumed material, and will vary with job specific application requirements:

- Size: diameter ranges from 4 – 18 inches (100 – 450 mm).
- Composition: varies from very fine polishing media to aggressive cutting media with wet or dry diamonds.
- Shape: flat, cone-shaped, or cup disc.

Labor. Low to medium skill required.

Down time. Minimal. Setup requires very little time unless dust protection includes draping and taping. Changing stones or discs is quick. Frequency of replacement will depend on the composition of the stone or disc, substrate, and material being removed.

Cleanup. Grinding will leave a fine powdered residue of the removed material. The residue generated can be swept, rinsed with water, or vacuumed.

Production rates. Productivity will vary depending on grinding media selected and the type of material being removed. Estimated rates are:

- Hand-held units: 20 ft^2/hr (2 m^2/hr)
- Walk-behind units: 800 ft^2/hr (75 m^2/hr)

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile objectives. The prepared surface should be free of bond-inhibiting barriers and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41).

Safety

- Eye protection: Required.
- Personal protective equipment: Heavy gloves, steel-toed boots. Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin reaction.
- Respiratory protection: Required. Process will generate airborne dust. Mask should be approved for silica and other airborne dusts, and fit tightly to contours of face. If material being ground contains toxic substances, additional protection may be required.
- Hearing protection: Recommended.

Photo: Buildings Consulting Group, Inc.

Abrasive (Sand) Blasting

This method uses compressed air intermixed with an abrasive medium to clean concrete or steel surfaces. The air stream is channeled through a nozzle directly at the surface.

Method summary

Abrasive blasting is used to clean and profile concrete surfaces in preparation for the application of sealers, coatings, and polymer overlays. The process can provide a light cleaning profile, often referred to as a "brush blast," or it can be used to achieve a much heavier surface lineation for deep cleaning and profiling. It may also be used to remove surface contaminants and thin, brittle coatings, or adhesive films. Water may be introduced into the blast process to reduce airborne dust. Vacuum recovery systems may also be used with abrasive blast units to reduce dust and cleanup. This method may be used on horizontal, vertical, and overhead surfaces, and is suitable for both interior and exterior applications.

Purpose. Abrasive blasting is a highly flexible process capable of producing a range of profiles suitable for the application of the following systems:

- sealers: 0 – 4 mils (0 – 100 μm)
- thin-film coatings: 4 – 10 mils (100 – 250 μm)
- high-build coatings: 10 – 30 mils (250 – 750 μm)
- broadcast systems: 30 mils – ¼ inch (750 μm – 6 mm)
- monolithic toppings: ⅛ – ¼ inch (3 – 6 mm)

Limitations. Abrasive blasting typically generates a large volume of airborne dust. Increased profiles may become visible through concrete sealers and thin or clear coatings, producing an unsightly finish.

Abrasive blast is not recommended for the following applications:

- Removal of resilient coatings, uncured coatings or adhesives, and tar-based materials.
- It should not be used when occupied space, goods, or equipment cannot be adequately protected from dust infiltration.
- High volume concrete removal.

Removal. Removal is accomplished by the eroding effect of the blast media impacting the surface at high velocity. Depth of removal may range from a minimum of 1 – 2 mils (25 – 50 μm) to a practical maximum of 30 mils (750 μm).

Pattern. Abrasive blasting should not introduce any noticeable pattern effect.

Profile. ICRI CSP 2 – 4
Profile achieved is dependent upon duration of exposure to blast stream and size and cutting efficiency of blast media used.

Accessibility. The small size and portability of hose and blast nozzle provide virtually unrestricted access to all surfaces including edges, corners, and recessed spaces.

Environmental Factors. Abrasive blasting will produce airborne dust containing silica, concrete constituents and particles of any material being removed. Special provisions are often needed to protect people, property, and the environment. Blast curtains and containment areas may be used to isolate the blast process. Blast media substitutes such as sodium bicarbonate are sometimes used to reduce the dust hazard or volume of debris.

Any special requirements for containment and disposal will depend on the specific contaminants or materials being removed. Materials likely to require special han-

Abrasive (Sand) Blasting

dling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. Noise levels are likely to exceed 85 dB.

Execution

The blast media stream is directed at the surface using a controlled sweeping motion. The duration of exposure to the blast stream depends on the strength of substrate and the degree of cleaning and profiling required.

Equipment

- Air compressor of sufficient capacity to drive the equipment and blast media selected
- Blast media hopper (meters the media into the air stream passing through the hose and nozzle)
- Moisture and oil separators to insure clean, dry air supply
- Blast nozzle and hose

Materials. The blast medium, e.g. silica sand, slag (black beauty), etc. is the consumed material.

Labor. Medium to above-medium skill level required. Special training in safe operation and related environmental issues is recommended for crew members. Two workers per blast unit is standard—one to operate the blast nozzle, the other to support the blast media hopper and compressor and to manage the hoses.

Down time. Hours needed for set up and removal of work area protection may be significant. Time required for mobilization, setup, and maintenance of blast equipment and compressor is minimal.

Cleanup. Dust, fine particles of concrete or other pulverized materials, and a relatively large volume of expended blast media are generated by the abrasive blast process. Water soluble blast media, which can be flushed into conventional drainage systems, may substantially reduce the volume of debris to be collected and removed.

Production rates. Productivity is highly variable and is dependent upon the strength of the concrete, any surfacing materials or contaminants, accessibility, capacity of blast media hopper and compressor, and type of blast media used.

Production rate estimates range from 1,000 – 6,000 square feet (100 – 600 m^2) per eight hour shift per unit.

Standards & Specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

- Eye protection: Required.
- Personal protective equipment: Helmet, hood, and heavy gloves, boots and clothing are recommended for blast nozzle operator. Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin response.
- Respiratory protection: Required. Supplied air system is routinely used for blast nozzle operator.
- Hearing protection: Required.
- Safety devices: Blast nozzle must be equipped with an automatic shut-off device.

Photo: Blastrac Division, Wheelabrator Corp.

Steel Shotblasting

Steel shot is centrifugally propelled at high velocity onto the surface. This process is confined in an enclosed blast chamber which recovers and separates dust and reusable shot.

Method summary

Shotblasting is principally used to roughen horizontal surfaces in preparation for the application of sealers, coatings, or polymer overlays. This method is also used to remove some existing coatings, adhesives, and surface contaminants. Hand-held machines are available for use on vertical surfaces. Shotblasting is suitable for use in both interior and exterior applications.

Purpose. Cleaning and profiling concrete surfaces by removing dirt, laitance, curing compounds, sealers, or other superficial contaminants in preparation for the application of protective materials.

Shotblasting is suitable for the removal of polyurethane coatings up to 10 mils (250 μm) thick, tile mastics, and brittle coatings such as epoxy or methyl methacrylate systems up to ⅛ inch (3 mm) thick. Removal of thicker materials may require multiple passes.

Limitations. This method is generally not suitable for removing uncured resin systems, resilient coatings, adhesives, and tar-based materials. The pattern and profile of shotblasted surfaces may be visible through concrete sealers and thin or clear coatings.

Removal. Removal is accomplished by the pulverizing effect of steel shot impacting the surface at high velocity. Depth of removal is controlled by shot size, machine setup, and rate of travel. Generally, the maximum recommended depth of removal for a single pass is ¼ inch (6 mm).

Pattern. The "double exposure" that occurs at the point of overlap between successive passes produces a parallel striping effect at intervals determined by the width of cut. Skilled operation of equipment can minimize striping effect.

Profile. ICRI CSP 2 – 8
As the depth of cut increases, the profile will be increasingly dominated by the size and shape of the coarse aggregate.

Accessibility. Shotblasting equipment is available in a range of sizes to provide ready access to most surfaces. Edges and corners may be detailed to within ¼ inch (6 mm) of the vertical surfaces with specialty edging machines or hand-held units. Access to tight configurations, such as around and in between pipes, is restricted by the width of the machine used.

Environmental Factors. Shotblast systems produce very little airborne dust or contamination. Most models can be fitted with a filter to further lower the level of airborne dust produced.

Debris produced by shotblasting will contain particles of material or contaminants being removed. Any special requirements for containment and disposal will depend on the specific materials or contaminant being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment.

Special ventilation provisions may be required when operating gasoline, diesel, or propane-powered units indoors.

With the exception of some large machines, noise levels will usually be below 85 dB. Vibration is not considered to be a factor.

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Steel Shotblasting

Execution

The machine is steered in a straight line across the surface. At end of each pass, the machine is turned around and steered parallel to the previous path with minimum overlap. Some overlap is required to prevent the development of unprepared strips between passes.

Equipment

- Shotblasting machine: available in gasoline, diesel, propane, or electrically-powered units
- Power source: requirements for electric powered units will vary from 110/120 V @ 26 A to 460 V @ 60 A
- Brooms and shovels
- Spare parts for blaster maintenance
- Magnets or magnetic broom to retrieve fugitive steel shot

Materials. Steel shot is the consumed material. Consumption ranges from 10 to 20 lbs/hr. Commonly used sizes of steel shot are shown below:

Type	Diameter	Profile
S-170[1]	0.017 in. (0.43 mm)	CSP 3[2]
S-230	0.023 in. (0.58 mm)	CSP 3
S-280	0.028 in. (0.71 mm)	CSP 3
S-330	0.033 in. (0.84 mm)	CSP 5
S-390	0.039 in. (1.0 mm)	CSP 5
S-460	0.046 in. (1.17 mm)	CSP 7
S-550[1]	0.055 in. (1.40 mm)	CSP 7

1 Use of this size is not recommended by all manufacturers.

2 Association of profile with shot size is not precise as profile obtained is also influenced by machine set up and rate of travel.

Labor. Experienced or well-trained personnel to operate equipment is recommended. One worker with intermediate mechanical skills can operate and maintain most shotblast systems. Large, electrically-powered machines require connection to a three-phase, high-voltage power source which may require a licensed electrician.

Down time. Surfaces must be dry and broom cleaned prior to shotblasting. A test area is required to insure that media size and machine adjustment will achieve desired performance. Replacement of worn blasting wheels and liners is required every 20 to 40 hours and will take 20 to 45 minutes. Equipment is shut down every 30 to 60 minutes to remove debris from collection system.

Cleanup. Steel media may remain on the surface, in edges or corners, or trapped in cracks. It may be recovered by using magnets, magnetic broom, air blast, vacuum, or stiff bristle broom.

Production rates. The following rates are approximate and assume sound, 5,000 psi (35 MPa) concrete. Actual production rates will vary considerably and will depend on the strength of the concrete, the type of material being removed, preparation objectives, operator skill, and efficiency of equipment employed.

Small units: 150 – 250 ft^2/hr (14 – 23 m^2/hr)

Medium units: 350 – 1,500 ft^2/hr (33 – 140 m^2/hr)

Large units: 2,000 – 4,500+ ft^2/hr (190 – 420+ m^2/hr)

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

Eye protection: Required.

Personal protective equipment: Skin protection may be required during removal of hazardous materials and handling of debris.

Respiratory protection: May be required during removal of hazardous materials and handling of debris.

Hearing protection: Recommended.

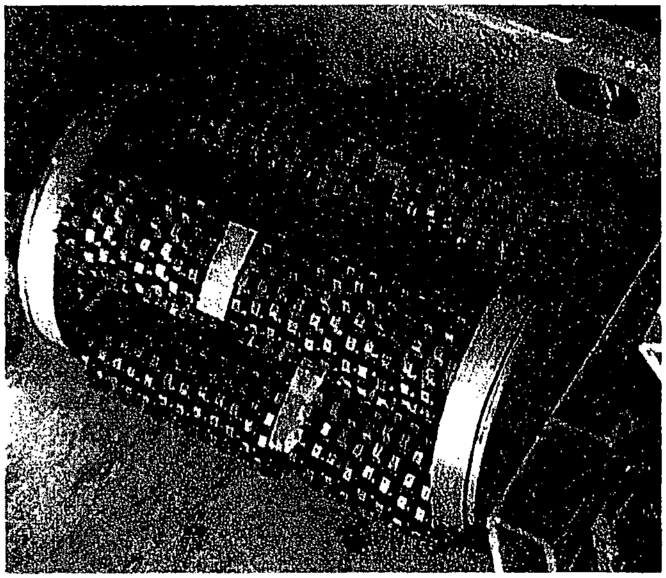

Photo: Restruction Corporation

Scarifying

The rotary action of the cutters (toothed washers) impacts the surface at a right angle to fracture or pulverize the concrete. The cutters are assembled on tempered steel rods mounted at the perimeter of a drum which rotates at high speeds.

Method summary

Scarification is used primarily on horizontal surfaces for the removal of concrete or brittle coatings up to ⅛ inch (3 mm) thick. It may also be used to profile concrete surfaces. Hand-held units are available for vertical, and overhead applications. Scarifying may be used on almost any substrate and is suitable for both interior or exterior applications. This method is also known as concrete planing.

Purpose

- The removal of brittle coatings such as epoxy, polyurethane, or methyl methacrylate systems up to ⅛ inch (3 mm) in preparation for the application of replacement coatings.
- Removal of deteriorated or contaminated concrete to depths ranging from ⅛ to ¾ inch (3 – 19 mm) depending on the strength of the substrate, cutter configuration, and size and power of the machine.
- Removal of high spots in order to level slabs.
- Profiling of concrete surfaces in preparation for the application of high-build coatings greater than 15 mils (375 μm), self-leveling systems, broadcast, thin overlays or placement of other repair materials.
- Removal of adhesives may be accomplished by the adjustment of spacers and the selection of appropriate cutters.

Limitations. Scarification is not recommended for surface preparation for sealers or coatings less than 15 mils (375 μm) or the removal of heavy elastomeric membranes.

This method may cause micro-cracking in substrate. (It has been demonstrated that micro-cracking will reduce the strength of the bond between the substrate and materials placed over it.) The deleterious effects of micro-cracking may be reduced or eliminated by following initial removal with steel shotblasting, abrasive blasting, or high and ultra high-pressure water jetting. The use of sharp, fine-toothed cutters may prevent the development of micro-cracking.

Removal. Removal depth may economically range from light surface profiling to ¼ inch (6 mm) for smaller equipment, and ½ – ¾ inch (13 – 19 mm) for larger equipment. Removal depth greater than ⅛ inch (3 mm) is accomplished in multiple passes.

Pattern. Scarifying will produce a parallel, striated pattern. The deepest striations will be produced at surface high points.

Profile. ICRI CSP 4 – 9

Accessibility. With portable equipment ranging in size from small hand-held scarifiers to large self-propelled units most surfaces are accessible to within ¼ inch (6 mm) of the edge. Access to corners and tight configurations such as around and in between pipes is restricted by the dimensions of the drum housing. The smaller walk-behind machines are able to pass through standard door openings.

Environmental factors. Scarifying will produce airborne dust containing concrete constituents and particles of the material being removed. Any special requirements for containment and disposal of dust and debris will depend on the specific contaminants being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment.

Noise levels are likely to exceed 85 dB. Vibration levels are moderate. Special ventilation arrangements will be required when operating gasoline or diesel-powered units indoors.

Execution

With the exception of hand-held units, most scarifiers are operated by pushing the machine forward over the surface, advancing at a slow walk. The depth and rate of cutting are adjusted by raising or lowering the drum to increase or decrease the impact of the cutters. Several passes may be required to achieve the desired profile. Debris must be removed after each pass.

Equipment

- Scarifier: available in electric, pneumatic, or gasoline powered models in sizes ranging from hand-held to self-propelled ride-on units. Path widths range from 4 – 36 inches (100 – 900 mm)
- Replacement drums: plan on four drums per machine for each eight hours of continuous operation
- Air compressor or other air supply (pneumatic models only)
- Industrial vacuum cleaner to be used with vacuum adapter attachments to limit airborne dust

Materials. The cutters are the consumed material. Rate of consumption depends on the following:

- Cutter configuration
- Cutter composition (hardened steel, tungsten carbide)
- Substrate hardness
- Composition of materials to be removed

Labor. Low to medium skill required.

Down time. Minimal. Setup requires very little time unless dust protection includes draping and taping.

Drum changes will take approximately five minutes. (See "materials" and "equipment" above to assist in estimating frequency of drum change). Rebuilding drums is usually an off-site activity.

Cleanup. Scarifying will generate dust and larger debris. While most scarifiers are not equipped to pick up debris, many units have adapters which may be used with industrial vacuum cleaners to contain dust. Sweeping and removal of the rough debris will be required.

Production rates. The rates shown below are estimates. Productivity will vary considerably depending on equipment size, depth of removal, and the type of material being removed.

- Hand held units: 20 ft^2/hr (2 m^2/hr)
- Walk-behind units: 800 ft^2/hr (75 m^2/hr)

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

- Eye protection: Required.
- Personal protective equipment: Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin reaction.
- Respiratory protection: Mask should be approved for silica and other airborne dusts, and fit tightly to contours of face. If materials being removed contain toxic substances, additional protection may be required.
- Hearing protection: Recommended.

Photo: Equipment Development Co., Inc.

Needle Scaling

Impacting the surface with pointed tips of a bundle of steel rods contained by a steel tube and pulsed by compressed air.

Method summary

This method can be used on concrete surfaces indoors, outdoors, or underwater, to remove efflorescence, brittle encrustations, and rigid coating systems. It is frequently used for work on edges and other tight spaces which cannot be accessed by larger, more automated equipment. It may be used underwater to remove barnacles and other marine shell fish attached to submerged surfaces. It is suitable for use on horizontal, vertical, and overhead surfaces.

Purpose. Needle scaling is used to remove coatings or brittle encrustations in preparation for the application of protective coatings or other repair work. It is an excellent method for detailing corners, edges, and most recessed areas. It is suitable for preparing concrete surfaces for high-build coatings, self-leveling and broadcast applications, and thin overlays.

Limitations. Needle scaling is not recommended for the following applications:

- Preparation for coatings less than 15 mils (375 μm)
- Removal of thick, resilient coatings
- Preparation of large surface areas
- Removal of sound concrete

Removal. Removal is accomplished by the superficial fracture and pulverization of concrete surfaces to which the unwanted material is adhered. Depth of concrete removal will typically be in the range of 1/16 to 1/8 inch (1.5 – 3 mm) and is dependent on aggregate size and composition.

Needle scaling is generally suitable for the following removal applications:

- Rigid coatings to 15 mils (375 μm)
- Soft or flexible coatings to 30 mils (750 μm)
- Brittle deposits to ¼ inch (6 mm)

Pattern. Needle scaling will produce random, evenly distributed impact craters around larger aggregate, imparting a heavy "orange peel" texture to the surface.

Profile. ICRI CSP 5 – 8

Accessibility. Hand-held needle scalers are available in several sizes providing virtually unrestricted accessibility.

Environmental factors. Debris produced by needle scaling will contain particles of any material or contaminants being removed. Any special requirements for containment and disposal will depend on the specific contaminants being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. Noise and vibration levels are low to medium.

Execution

Rod (needle) points are held against the surface with light to medium pressure. The pneumatically driven rods are activated by a trigger located in the unit's handle.

Equipment

- Needle gun: several sizes of pneumatic, hand-held units are available which vary in weight from 2½ – 15 lb. (1 – 7 kg). Size of rod bundle will vary from 12 to more than 30 rods.
- Replacement rod bundles: plan for six bundles per gun for each eight hours of continuous operation.
- Air hose

- Air compressor or other air supply producing 3 – 15 cfm @ 80 – 120 psi.

Materials. The hardened steel rods are the consumed material.

Labor. Low skill required.

Down time. Approximately five minutes per hour to change needle bundles. Rebuilding needle bundles is usually an off-site activity.

Cleanup. Needle scaling will generate dust, small granular particles or flakes. The tools are not equipped to collect debris, which may be vacuumed or swept up for proper disposal.

Production rates. Productivity will range from 10 – 50 ft^2/hr (1 – 5 m^2/hr). Rate is dependent on size of needle gun, number of needles per bundle, strength of substrate, and hardness of material being removed.

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, or bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

- Eye protection: Required.
- Personal protective equipment: Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin response.
- Respiratory protection: Process will generate airborne dust. Mask should be approved for silica and other airborne dusts, and fit tightly to contours of face. If materials being removed contain toxic substances, additional protection may be required.
- Hearing protection: Recommended.

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Photo: Allstate GeoTek, Inc.

High and Ultra High-Pressure Water Jetting

Water is sprayed at pressures between 5,000 and 45,000 psi (35 – 300 MPa) to remove heavy encrustations of dirt and loose, friable material. This method can also remove some coatings.

Method summary

This method may be used outdoors to remove heavy encrustations of efflorescence, scale, dirt, or water soluble contaminants from concrete surfaces and surface cavities. It may also be used in some interior spaces where heavy mist, spray, high noise levels, and severe puddling can be tolerated. Water jetting, at the higher pressures, effectively removes some coating systems. Suitable for horizontal, vertical, and overhead applications. This method is not economically suitable for the removal of sound concrete.

Purpose. High and ultra high pressure jetting may be used to remove laitance, efflorescence, scale, dirt, or other water-soluble contaminants. With suitable pressures and nozzle tips, high-strength epoxy, urethane, or methacrylate coating and thin overlay systems may be removed. It may also be used to remove carbonated, freeze/thaw damaged, or otherwise weakened material from concrete surfaces.

Limitations. High and ultra high-pressure water jetting is not recommended for the following applications:

- Removal of sound concrete.
- It should not be used where goods or equipment may be damaged by impact from water jets; or where they cannot be protected from heavy mist or flooding.

Removal. Unsound concrete may be removed to depths of ¼ – ¾ inch (6 – 19 mm) and is dependent on the depth of deterioration.

Pattern. Properly done, high and ultra high-pressure water jetting should not produce any noticeable pattern in durable concrete. However, poor operator technique or inappropriate selection of pressure and nozzle tips may severely etch sound concrete.

Profile. ICRI CSP 6 – 9

The surface profile of durable concrete may remain unaffected by this process. Pressure and nozzle tips may be adjusted to produce the desired profile. The use of high and ultra high-pressure water jetting on low-strength or deteriorated surfaces will produce a much more aggressive profile as surface defects are removed.

Accessibility. With the wide variety of portable and maneuverable equipment available, most surfaces are easily accessible. Tight spaces can be accessed with a hand-held lance.

The presence of goods or equipment that cannot be adequately protected from mist or spray may restrict use of this method.

Environmental factors. This process produces loud noise, similar to sandblasting. Heavy mist and a significant volume of water will be introduced into the work area. The volume of water introduced will range from 2 – 10 gallons per minute (3 – 38 liters per minute) and is determined by the requirements of the equipment selected. The possibility that environmental regulations may require containment and regulated disposal of the liquid waste generated should be considered.

Execution

The concrete surface is prepared by methodically moving the water jet back and forth over the surface until the desired results are achieved. If automated equipment is used, the operator typically makes parallel passes. If hand-held lances are used, the process will be slower, but similar. Standing water may need to be pumped or squeegeed off the surface. Units that clean and recycle jetting water are available. Dispose of solid debris, slurry, and water residue as required by local regulations or project restrictions.

Equipment

- Water pump with desired pressure capability
- Compressed air source producing a minimum of 85 cfm @ 120 psi
- High-pressure hoses
- Water jet: wheeled equipment for horizontal surfaces; hand-held lance for vertical and overhead applications, corners, or other difficult to reach locations. Robots may be used on horizontal and vertical surfaces.
- Suitable nozzle tip
- Runoff protection to catch debris flowing off site or toward drains

Materials

- Water source: Potable water is recommended and may be provided by tanker, hydrant connection, industrial spigot, or pump

Labor. Two or three person crew per machine. Medium to above medium skill level with appropriate training required. Must be able to assemble high pressure components and safely operate equipment capable of causing sudden, severe injury. Skilled supervision may be needed if complex equipment is used.

Down time. Setup time is variable depending on the size of the work area and specific protective measures required. Time to cover and protect surfaces and install runoff protection to catch debris may be estimated at 6 to 10 man-hours for typical applications.

Cleanup. Large volumes of water may need to be drained away. The volume of debris trapped by collectors is usually small. High and ultra high-pressure jetting of deteriorated surfaces may produce much more debris.

Production rates. The rates shown below are approximate and assume sound, 5,000 psi (35 MPa) concrete. Actual production rates will vary considerably and will depend on the strength of the concrete, hardness and bond strength of any coating being removed, preparation objectives, operator skill, and efficiency of equipment employed.

- Horizontal surfaces: 125 – 300 ft^2/hr (12 – 28 m^2/hr)
- Vertical surfaces: 50 – 250 ft^2/hr (5 – 23 m^2/hr)

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection should show no dirt, laitance or debris on the surface. The prepared surface should be free of bond-inhibiting barriers and demonstrate sufficient strength for the proposed application. Beads of water indicate a surface contaminant that may require increased depth of removal to achieve suitably clean surfaces. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

The operator must be protected from high velocity rebound. Hands and feet require additional protection as they might inadvertently contact the water jet.

- Eye protection: Anti-fog goggles meeting ANSI requirements for high impact, and face shield.
- Personal protective equipment: Metal-mesh gloves are strongly recommended, steel-toed boots, metatarsal guards, helmet, and waterproof outer-layers.
- Respiratory protection: May be required in areas where high impact could cause an accidental release of toxic substances.
- Hearing protection: Process will generate noise levels in excess of 85 dB. Earmuff type protectors strongly recommended.

Photo: Equipment Development Co., Inc.

Scabbling

Impacting the substrate at right angle with piston-driven cutting heads to create a chipping and powdering action. The driving mechanism is compressed air.

Method summary

Scabbling is used primarily on horizontal surfaces to remove concrete or brittle coatings up to 1/4 inch (6 mm) thick. It may also be used to deeply profile concrete surfaces. Hand-held units, some of which are commonly known as "bush hammers," are available for light service on vertical and overhead surfaces. This method is suitable for use in interior and exterior applications.

Purpose

- The removal of brittle coatings such as epoxy, polyurethane, or methyl methacrylate systems up to ¼ inch (6 mm) in preparation for overlays over ⅛ inch (3 mm) thick.
- Removal of deteriorated or contaminated concrete to depths ranging from ⅛ to ¾ inch (3 – 19 mm) depending upon the strength of the substrate, size and power of the machine, and bit configuration.
- Deep profiling of concrete surfaces in preparation for placement of overlays or other repair materials.

Limitations

- Scabbling frequently causes micro-cracking in concrete substrates. (It has been demonstrated that micro-cracking will reduce the strength of the bond between the substrate and most materials placed over it.) The deleterious effects of micro-cracking may be reduced or eliminated by following initial removal with steel shotblasting, abrasive blasting, or high and ultra high-pressure water jetting.
- Scabbling is not recommended for the removal of elastomeric membranes or gummy materials such as tile or carpet adhesives.

Removal. Depth of economical concrete removal is dependent on aggregate size and strength of the substrate and may range from ⅛ to ¾ inch (3 – 19 mm).

Pattern. Scabbling will produce a very irregular surface dominated by fractured coarse aggregate. There should be no discernible tool pattern.

Profile. ICRI CSP 7 – 9

Accessibility. With portable equipment ranging in size from small hand-held to large walk-behind units, most surfaces are accessible to the edges. Corners, recesses, and tight configurations are generally accessible with properly-sized bits fitted to hand held, single piston units. Care should be taken to avoid damage to adjacent walls or equipment.

Walk-behind units will pass through standard door openings and will require a minimum vertical clearance of 4 feet (1.2 m).

Environmental factors. Scabbling will produce airborne dust containing concrete constituents and particles of any other materials being removed. Any special requirements for containment and disposal of dust and debris will depend on the specific materials or contaminants being removed. Materials likely to require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. Noise levels are likely to exceed 85 dB. Vibration levels are moderate to severe. Work area enclosures and special ventilation provisions may be required indoors to prevent dust intrusion into nearby occupied work space.

Scabbling

Execution

Scabblers are operated by manually pushing the units across the surface in a back and forth motion at slow speed. The area being scabbled will require continuous sweeping to allow the operator to see the removal progress.

Equipment

- Scabbler: manually-operated machines range from single-head, hand-held units to walk-behind units having up to twelve heads
- Air compressor or other air source producing a minimum of 180 cfm @ 120 psi. Cfm requirements are likely to increase with larger equipment and multiple heads. (Disregard air requirements if hydraulic scabblers are used.)
- Air hose: ½ – 2 inches (13 – 50 mm) I.D.

Materials. Impact bits are the consumed material. These are available in varying configurations of tungsten carbide inserts.

Labor. Operator skill requirements are considered low.

Down time. Minimal. Setup requires very little time, unless dust protection includes draping and taping. Setup of air hoses and changing bits is required once per day. Bit changes will take anywhere from 10 minutes for single-head units to as much as 35 minutes for large, multi-head units. Scabbler machines require little maintenance.

Cleanup. Dust and larger particles up to ½ inches (13 mm) in diameter will be generated from the impact of the bits. Scabblers are rarely equipped to pick up this debris. Sweeping and vacuuming will be continuously required to remove the rough debris and fines.

Production rates. Productivity will vary considerably depending on size of machine, strength of substrate, depth of removal, and the type of material being removed. For heavy removal, estimated rates range from 20 ft^2/hr (2 m^2/hr) to 100 ft^2/hr (9 m^2/hr).

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, or bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41).

Safety

- Eye protection: Required.
- Personal protective equipment: Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin response.
- Respiratory protection: Required. Mask should be approved for silica and other airborne dusts, and fit tightly to contours of face. If materials being removed contain toxic substances, additional protection may be required.
- Hearing protection: Recommended.

Photo: Concrete Cleaning Inc.

Flame Blasting

The combination of oxygen and acetylene to produce a flame which is passed at a given height and rate over the substrate.

Method summary

Flame blasting is used on horizontal, vertical, and overhead surfaces to remove contaminated concrete, mastics, or other high-build coatings. The applicability of this method is restricted by the presence of a 3,200° C (5,800° F) open flame, and the generation of toxic fumes which may accompany the removal of some materials. This process does not generate dust and is suitable for interior and exterior applications.

Purpose. To remove elastomeric membranes, paints, coatings up to ¼ inch (6 mm) in preparation for the application of overlays over ⅛ inch (3 mm) thick. Flame blasting may also be used to remove grease and oil contaminants.

Limitations. This method may not be used in the vicinity of flammable or combustible materials. It will generate a heavy volume of smoke and fumes when used to remove membranes, coatings, and other hydrocarbons from the substrate. Flame blasting may produce micro-cracking. Although some bond strength testing suggests that the process does not cause micro-cracking, the data are insufficient to be conclusive. (It has been demonstrated that micro-cracking will reduce the strength of the bond between the substrate and most materials placed over it.) The deleterious effects of micro-cracking may be reduced or eliminated by following initial removal with steel shotblasting, abrasive blasting, or high and ultra high-pressure water jetting.

Removal. Removal is accomplished by the superficial fracturing of the substrate induced by the expansive force of superheated pore water. Depth of removal ranges from ⅛ – ¼ inch (3 – 6 mm) per pass.

Pattern. Flame blasting will produce an irregular, chipped surface with no discernible pattern.

Profile. ICRI CSP 8 and higher

Sharp angular surface with a profile amplitude ranging from ⅛ – ¼ inch (3 – 6 mm).

Accessibility. The equipment is relatively small and highly maneuverable. A hand-held torch connected to the fuel source with flexible hoses provides unrestricted access to include edges, corners, and recessed spaces. However, access may be restricted by the presence of combustible adjacent surfaces, or non-portable machinery or equipment.

Environmental factors. Flame blasting will generate hot, flying debris capable of igniting combustible materials in the vicinity of the process. The acetylene-oxygen combustion products are not hazardous. However, the heat of the flame may generate smoke and fumes which may be respiratory irritants or toxic, depending upon contaminants present in the substrate or materials being removed. Materials likely to pose a respiratory hazard and require special handling include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. It is probable that the risk factors posed by the vaporization of contaminants or materials being removed cannot be reliably accessed in every instance. In these circumstances, the prudence and utility of using this method would need to be very carefully considered.

Execution

Concrete surfaces to be cleaned and profiled by this method must be presoaked for one to two hours to produce saturated, surface dry conditions. This step is required to insure that the substrate contains enough moisture to generate the expansive force required to fracture the surface.

Equipment

- Specialized equipment designed to shape the flame, positively control fuel sources, and project the flame onto the substrate is required
- Sufficient hose to transport fuel from the storage location to the work area

Materials. Acetylene and oxygen are the consumed materials. These industrial gases must be available in appropriate containers.

Labor. Operators must be trained by the manufacturer of the equipment and skilled and knowledgeable in the handling of oxygen-acetylene mixtures. Operators must know when and how to use high temperature open flames and which materials are hazardous when they burn or decompose under heat.

Down time. Minimal. Some time is required for setup and changing tanks.

Cleanup. Flame blasting produces debris consisting of concrete chips. If the substrate was protected by a coating or other barrier system, the chips may be covered with a charred polymer residue. Debris may be removed with oil-free air blast or by mechanical or manual sweeping with stiff-bristled brushes.

Production rates. Rates depend on the thickness and composition of the materials being removed, the number of flames, and the rate of travel. Estimated rates range from 50 – 600 ft^2/hr (5 – 55 m^2/hr).

Standards & specifications

As required by the specifications of the manufacturer or customer.

Visual inspection to verify profile. The prepared surface should be free of dust, debris, bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

Flame blasting will induce the explosive fracture of aggregate which may propel hot, airborne fragments as far as 20 feet (6 m).

- Eye protection: Goggles and face shield meeting ANSI requirements for high impact resistance are required. Radiant energy shading as recommended by flame equipment manufacturers.
- Personal protective equipment: Helmet and heavy, heat resistant insulating gloves are required. Skin should be protected by heavy, noncombustible clothing and steel-toed boots.
- Respiratory protection: May be required depending upon the composition of materials being removed. It is probable that, at a minimum, the use of masks fitted with organic vapor canisters will be required during the removal of materials containing polyurethane, methacrylate or epoxy compounds.
- Hearing protection: Recommended.

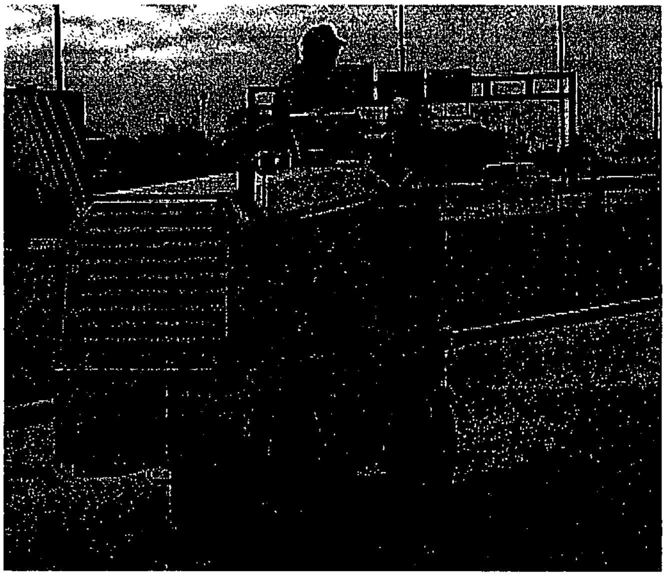


Photo: Lanford Brothers Company, Inc.

Milling/Rotomilling

An aggressive method for removing the upper level of a concrete substrate by "clawing" or grooving using a large machine with cutting teeth attached to a rotating drum.

Method summary

Milling is used on horizontal surfaces to remove unsound concrete, mastics or other high-build coatings, and asphaltic overlays. It may also be used to deeply profile concrete substrates. This method is suitable for use in interior and exterior applications.

Purpose. Heavy-duty removal of deteriorated concrete and virtually any overlay, coating, or mastic materials in preparation for the placement of protective overlays.

Limitations. Slabs must be structurally able to support large, heavy equipment. This method will produce high levels of noise, dust, and severe vibration.

Milling operations will probably cause micro-cracking. (It has been demonstrated that micro-cracking will reduce the strength of the bond between the substrate and most materials placed over it.) The deleterious effects of micro-cracking may be reduced or eliminated by following initial removal with steel shotblasting, abrasive blasting, or high and ultra high-pressure water jetting.

Removal. The cutting teeth strike the surface with great force, fracturing material into chips and dust. Depth of concrete removal ranges from ¼ – 4 inches (6 – 100 mm). Removal depth is determined by the number and size of teeth. Smaller teeth in greater numbers are used when shallow removal depths are desired. Most machines are equipped with depth gauges which allow the operator to limit the depth of cut.

Pattern. Milling will produce a very irregular surface dominated by fractured coarse aggregate. A tool pattern will range from linear striations to deep grooving.

Profile. ICRI CSP 9

Extremely rough, chipped surface with a profile amplitude ranging from ¼ – ½ inches (6 – 13 mm). Profile obtained is determined by the number and size of teeth.

Accessibility. Most milling equipment will reach to within 6 inches (150 mm) of walls, and 12 inches (300 mm) of corners. A vertical clearance of approximately 6 feet 8 inches (2 m) is required. Turning radii will need to be plotted to determine if there is sufficient space for maneuver around columns, wall, and corners. Shoring of supported levels may be required.

Environmental factors. Milling will produce airborne dust containing concrete constituents and particles of any other materials or contaminants being removed. Any special requirements for containment and disposal of dust and debris will depend on the specific materials or contaminants being removed. Materials likely to require special handling and disposal include tile mastics, which may contain asbestos; lead-based paint; and PCBs which may have been absorbed by concrete in the vicinity of electrical equipment. Work area enclosures to prevent dust intrusion into occupied work space may be needed. Special ventilation provisions may be required when operating gasoline or diesel powered units indoors.

If water is used to control dust or clean the substrate, the run off will have a high pH and may contain regulated substances. Filtration systems or settlement tanks may be needed in conjunction with drainage systems to meet environmental requirements.

Noise levels will exceed 85 dB. Vibration levels are severe.

Execution

- Milling equipment is driven in a straight path.
- Depth is controlled by observing depth gauge. Multiple passes may be required.
- Each pass must overlap the adjacent pass.
- Debris is removed from the site.

Equipment

- Milling machine (transported by tractor and low-bed trailer with ramp)
- Debris removal equipment may include dump trucks, loader, conveyor system, shovels and brooms
- Shoring devices may be required to support machine weight on elevated slabs

Materials. Milling heads or "teeth."

Labor. Experienced, trained machine operators are needed to operate equipment and perform periodic maintenance or replacement of cutting heads. Additional workers with appropriate skills are needed to operate the support equipment such as conveyors, dump trucks, and for general clean up.

Down time

- Job site must be prepared to receive equipment. Electrical hazards, structural capacity analysis, environmental requirements, and safety issues must be addressed prior to machine operation.
- Mobilization of the equipment onto the surface, installation and adjustment of cutting heads, and dust/debris control equipment.
- Smaller work areas may require equipment to be shut down at 30 minute intervals for debris removal.
- Periodic inspection, adjustment, or replacement of cutting heads or drive train components is required to maintain specified cutting depth and profile. Replacement of cutting heads is generally needed every 20 hours of operating time.

Cleanup. Chips and dust may be removed with water, air, brooms, or shovels. Self-propelled sweepers are commonly used.

Production rates. Estimated rates are listed below:

- 1000 ft^2/hr (90 m^2/hr) for small machines
- 3000 – 4000 ft^2/hr (280 – 370 m^2/hr) for mid-range machines
- 15,000 ft^2/hr (1400 m^2/hr) for large highway machines

Standards & specifications

Milled substrates are visually inspected to confirm compliance with specifications for profile and depth of removal. The prepared surface should be free of dust, debris, bond-inhibiting barriers, and demonstrate sufficient strength for the proposed application. ACI 515.1R describes methods and criteria for judging surface cleanliness and strength (see ref. page 41). Laboratory testing may be required to verify complete removal of specified contaminants.

Safety

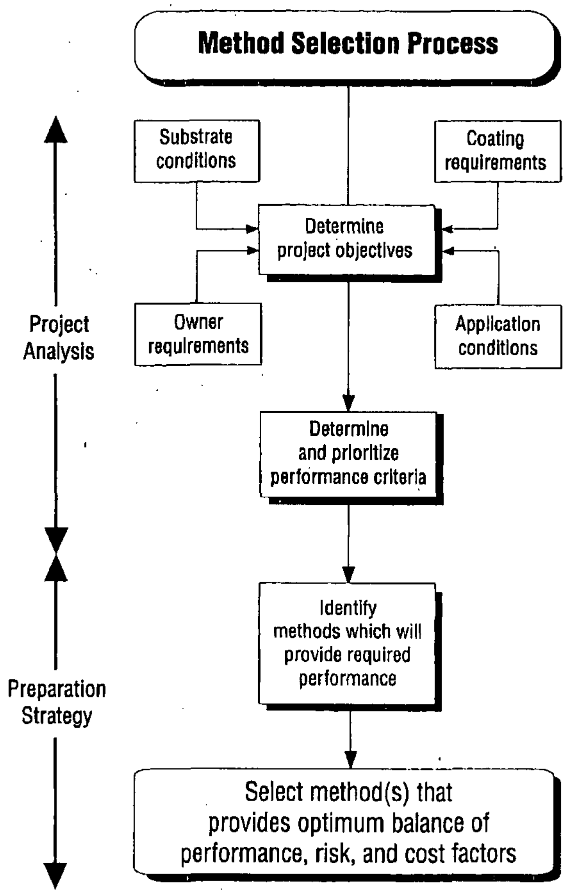
- Eye protection: Required.
- Personal protective equipment: Skin should be protected by clothing and barrier creams. Dust may produce alkali burns or allergic skin response.
- Respiratory protection: Required. Process will generate airborne dust. Mask should be approved for silica and other airborne dusts, and fit tightly to contours of face. If materials being removed contain toxic substances, additional protection may be required.
- Hearing protection: Required.

Appendix A

The Method Selection Process

The initial step in the selection process is to determine project objectives and requirements. Consistently good preparation decisions cannot be achieved without a thorough understanding of the material requirements, substrate conditions, and the owner's objectives and operating needs. Because the surface preparation method(s) used will determine the substrate profile, consideration of methods should be deferred until after the coating system has been selected and film thickness requirements are known. It is only after performance requirements have been identified and prioritized, and selection criteria have been defined, that the selection of specific methods of surface preparation can be made.

The checklists which follow in *Section 1* help ensure that critical information is identified and considered on every project. The data generated in the evaluation phase are analyzed to identify project priorities and to develop criteria for the selection of surface preparation methods. This phase is discussed in *Section 2*. Examples of need prioritization are included to underscore the fact that selection decisions will be driven by a series of tradeoffs. Once project requirements, priorities and selection criteria have been determined, the Method Summaries and Method Selector (pages 7 – 31) may be used to identify the method, or combination of methods, most likely to produce the desired results for that project. The Method Selector may be used to quickly match typical coating system requirements and methods capable of producing the required profile. The factors which should shape the selection decision are reviewed in *Section 3*.



Appendix A

Section 1

Determine project objectives and requirements

The information gathered in this phase is needed to develop specific criteria for determining which method or combination of methods will best meet the engineer's and owner's objectives. Checklists on the following pages provide examples of the data needed to identify and prioritize performance requirements.

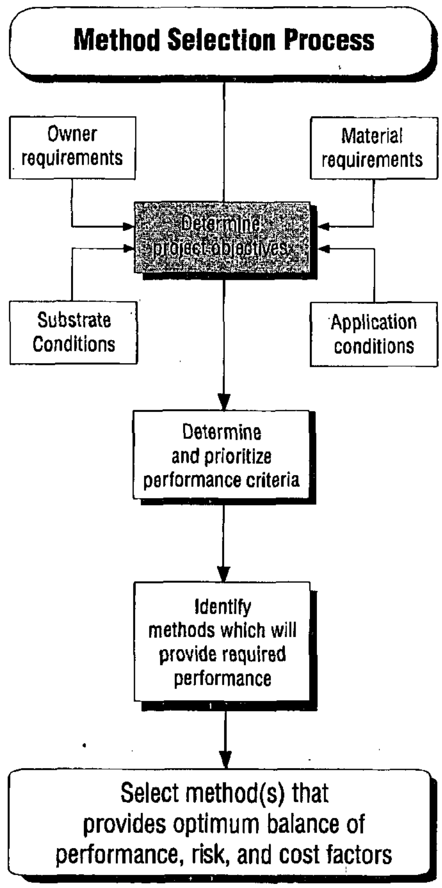
1 **Substrate condition:** The strength of the substrate and the presence of unsound or bond-inhibiting materials help define the nature and volume of preparation needed. Although a discussion of the various techniques and test methods used to evaluate the condition of concrete is beyond the scope of this guideline, the checklists provide examples of the types of information which should be considered.

2 **Owner requirements:** Noise, vibration, dust, and water are among the possible effects generated by various preparation methods. These can disrupt routine use of the structure or damage its contents. The owner's need for uninterrupted use of the structure, concerns about the operating environment, or property damage potential will often limit the choices.

3 **Material requirements:** Good decisions about surface preparation cannot be made without knowing the properties and application requirements of the selected material. Surface preparation, and profile requirements in particular, will vary with the protective system selected. Ideally, the protective coating system to be applied should be selected before or during this phase. The short description of these broad coating categories provided in *Appendix B* help illustrate the effect substrate profile may have on the performance and appearance of these systems.

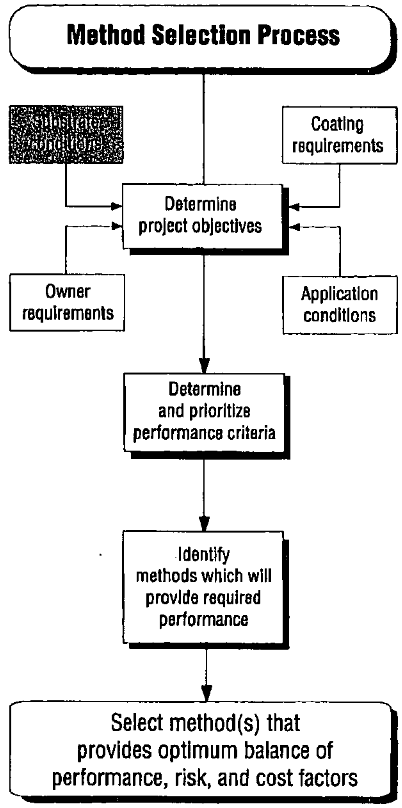
4 **Application conditions**
The generation of dust, slurries, or large volumes of water may introduce requirements for their containment and safe disposal. The type and capacity of mechanical ventilation and available power sources, the size of door openings and minimum vertical clearance are all examples of application conditions which will affect surface preparation decisions.

The checklists will help ensure that the most important issues will be considered and resolved at the optimum time—before the project is underway.



Appendix A

Substrate Condition



Surface

Soil/Efflorescence/Encrustation

Type ____________________

Thickness ____________________

Bond strength ____________________

Surface imperfections

❒ laitance ❒ bugholes ❒ ridges ❒ exposed aggregate ❒ abrasion

❒ other ____________________

Bond-breaking contaminants

❒ oil ❒ membranes ❒ coatings ❒ curing films ❒ latex modifiers

❒ other ____________________

Soundness

Deteriorated concrete depth ____________________

Cause ____________________

Pull-off test results ____________________

Chloride content ____________________

Hazardous materials present

❒ PCB ❒ asbestos mastic ❒ pesticides ❒ chemicals

❒ heavy metals ❒ other ____________________

Special containment or disposal required ____________________

____

General observations

Permeability (inhibit penetration) ____________________

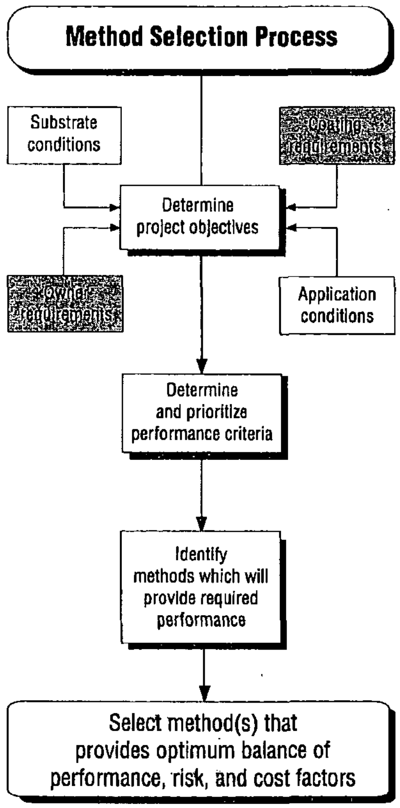
Section thickness ____________________

Required depth of removal ____________________

Moisture content ____________________

Appendix A

Owner Requirements



Project objectives

____

____

____

____

____

____

Appearance of applied system

Texture: ❒ smooth ❒ slip-resistant ❒ reflect substrate contours

Opacity: ❒ clear ❒ translucent ❒ solid color

Structure utilization needs

Work period

hours ____________________ duration ____________________

Negative effects

noise ____________________ water/slurry ____________________

dust ____________________ smoke & fumes ____________________

vibration ____________________ flying debris ____________________

Material Requirements

Substrate

Tensile strength (ICRI No. 3735 ACI 503 Appendix A)

____

Surface profile
acceptable range (CSP numbers) ____________________

Material

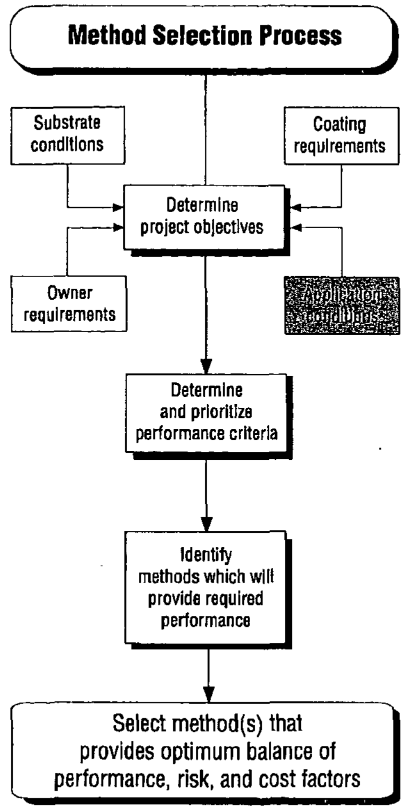
Film thickness wet: ____________________ dry: ____________________

Moisture tolerance ____________________

Alkali tolerance ____________________

Appendix A

Application Conditions



Accessibility

Surface orientation

❒ horizontal ❒ vertical ❒ overhead

turning radius _____ door openings ______ min. vertical clearance ______

load-bearing capacity ______________________________

non-portable equipment/machinery ______________________

notes ______________________________

Environmental considerations

containment of airborne debris ______________________

containment and disposal of liquid/slurry debris ______________

drainage system ______________________

restrictions on use ______________________

containment and disposal of solid debris ______________

hazardous waste containment and disposal ______________

Mechanical data

Electricity types available ______________________

locations ______________________

Air maximum pressure ______________________

available cfm ______________________

locations ______________________

Ventilation natural ______________________

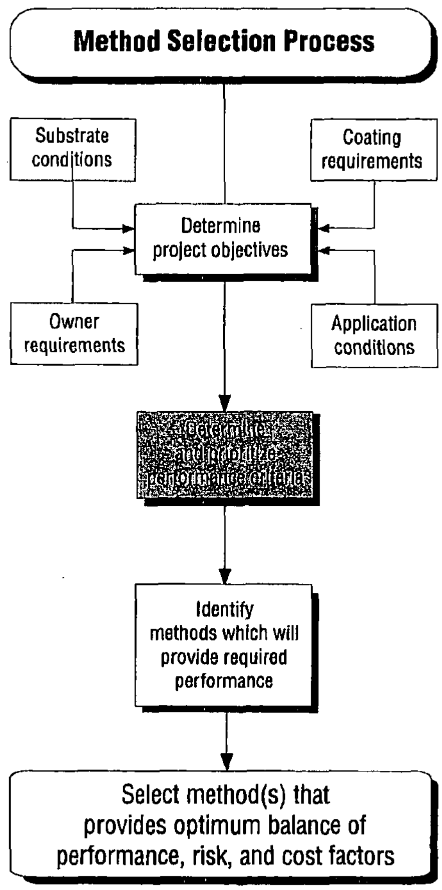
mechanical ______________________

Appendix A

Section 2

Establish performance priorities

Surface preparation methods should not be specified until the performance criteria which best satisfy project objectives are identified. Information on existing conditions, requirements, and project objectives collected in the evaluation phase is used to develop performance criteria, which are then prioritized. These should be ranked in descending order of importance. Objectives and requirements that are not essential should not be listed. This process allows competing demands to be carefully weighed to ensure that the performance criteria most critical to the success of the project become the selection criteria. Two sample lists are shown below:



Example 1: Interior floor replacement

A 30 x 70 foot (9 x 22 m) room in a large production facility is to be converted from shipping into an electronic components assembly area. The existing $^1/_8$ inch (3 mm) aggregate-filled MMA floor is to be replaced with an epoxy, antistatic conductive floor coating. The conductive floor will be installed during a 96 hour facility shut down. Dust must not circulate in the climate-controlled building. A surface profile of CSP 2 – 3 is required to ensure fiber continuity in the base coat.

Priorities: (ranked in order of importance)

1 Achieve CSP 3 or lower to meet floor system requirement to ensure conductive function

2 Dust-free preparation in order to preclude product quality problems

3 Fast turn-around to complete project within shut down window

4 Low vibration to maintain calibration of sensitive instrumentation

Example 2 Deck coating installation

A 240 stall structure providing employee parking for general hospital is to be protected by a traffic bearing membrane. Surface preparation must remove all deteriorated concrete, bond-inhibiting contaminants, and leave deck surfaces with a profile within a range defined by CSP 3 – 4. The parking structure has a common shear wall with patient rooms for two of its four levels. The hospital requires that 85% of parking capacity remain in service throughout project.

Priorities: (ranked in order of importance)

1 Dust-free preparation to prevent finish damage to parked vehicles

2 Low noise/vibration to minimize patient discomfort

3 Achieve profile CSP 3 or 4 to provide optimum surface for bonding

4 Fast turn around to minimize employee inconvenience

Appendix A

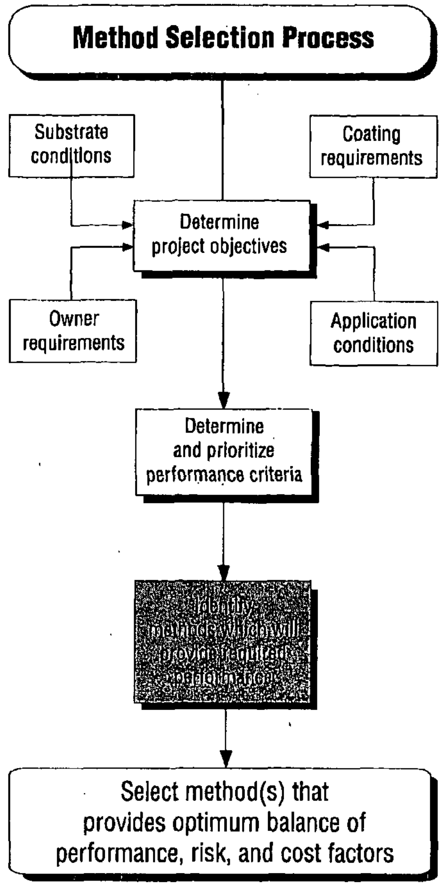
Section 3

Selecting and specifying methods of surface preparation

Most coating or sealing projects will have unique conditions and special requirements that must be carefully evaluated before the selection criteria can be established. Selecting the method(s) which optimize project objectives requires a good knowledge of the available options. The Method Summaries and Method Selector contained in this guideline (pages 7 – 31) allow users to readily compare data on the capabilities, limitations, operating requirements, and environmental considerations for each surface preparation method. Using the performance criteria developed earlier (*Sections 1 and 2*), the number of suitable methods is likely to be quickly narrowed to 1 – 3 potential selections. The Method Selector (page 7) may be used make a preliminary identification of the methods capable of producing the required surface profiles. In some cases, however, specific project conditions may preclude the use of the methods suggested.

Careful evaluation of competing priorities will be required to determine the best selection. Selection criteria provide a systematic framework for assessing method suitability and guide decisions when compromise is needed to ensure achievement of the most important project objectives.

In some instances, more than one method may be needed to produce the desired results. For example, high impact mechanical methods which produce surface "bruising" may sometimes provide the most efficient means of achieving the required degree of cleaning. In these circumstances, subsequent treatment with shot or abrasive blasting, fine scarification or high and ultra high-pressure water jetting may be used to restore substrate soundness. In another example, the most cost effective approach to surface preparation may include the use of a method which produces a high profile in the substrate. Material consumption on prepared concrete surfaces is influenced by several factors including substrate surface area, porosity, waste, uniformity of film thickness, and the volume of material needed to fill in surface depressions caused by profiling. If necessary, unacceptably high or rough profiles on existing or prepared surfaces may be reduced by means of additional passes using properly selected surface preparation equipment. On occasion, the application of a resurfacing mortar or leveling film of a coating material compatible with the system to be applied may be required to achieve the profile and appearance desired.



Final selection is based on the relationship between cost, project objectives, and risk.

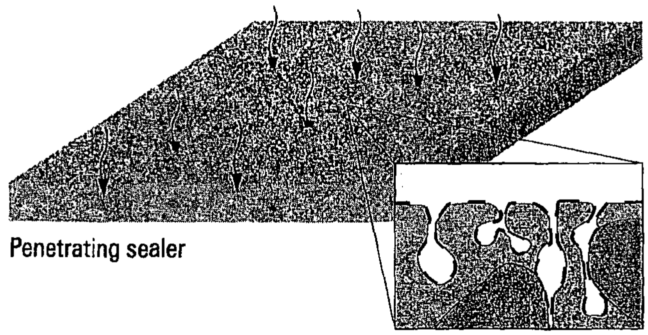
Appendix B

Sealers and coatings

Concrete sealers

0 – 3 mils (0 – 75 µm) dry

Penetrating sealers such as silanes or siloxanes will have little or no effect on the appearance of the treated surfaces. Any surface defects, contaminants, or profile will be visible. Film-forming sealers such as epoxies, urethanes, and acrylics, in unpigmented formulations may substantially darken concrete and impart a sheen. Lack of hiding power is comparable to that of the penetrating sealers. Pigmented formulations may hide stains and impart a degree of light reflectivity; however, surface irregularities and profile will not be altered.

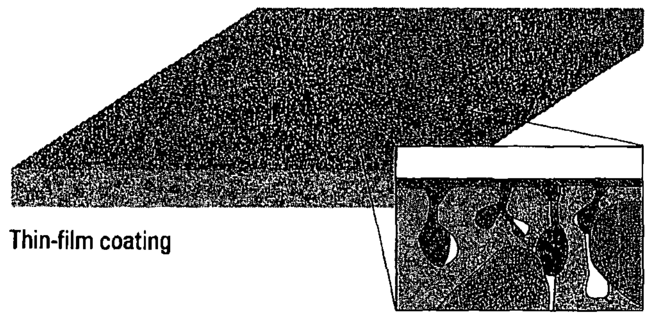


Penetrating sealer

Thin-film coatings

4 – 10 mils (100 – 250 µm) dry

These products may be formulated to achieve high hiding power. However, even relatively minor surface imperfections and all but the lowest of profiles produced by surface preparation equipment will show through.

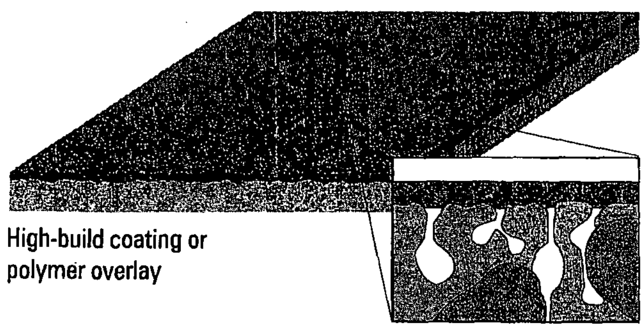


Thin-film coating

High-build coatings, self-leveling coatings, and polymer overlays

10 mils – ¼ inch (250 µm – 6 mm) dry

The selection of these materials for application provides the specifier with many more preparation options. These materials will have both high hiding power and some ability to fill in irregularities and level prepared surfaces. The contractor's ability to produce a smooth finish over higher profiles improves with increasing thickness of the applied coating system.



High-build coating or polymer overlay

Appendix C

Safety

Safety implications anticipated for each method are included in the Safety section of the method summaries. The information is intended only to alert users to the nature and magnitude of the safety issues associated with the method described.

Referenced OSHA regulations apply to typical hazards that may reasonably accompany a selected method of surface preparation. Additional regulations may apply depending on the work area conditions and jurisdiction. Consult a safety professional or OSHA about applicable regulations.

For further information, refer to the OSHA regulations that pertain to each of the protection categories referenced in the method summaries. Included therein are detailed references to safety protocols, equipment standards, personnel training, and documentation needed to meet OSHA requirements.

OSHA Regulations

Eye Protection
29 CFR 1910.133 (General Industry)
1926.102 (Construction)

Personal Protective Equipment
29 CFR 1910.132 (General Industry)
1926.28 (Construction)

Respiratory Protection
29 CFR 1910.134 (General Industry)
1926.103 (Construction)

Hearing Protection
29 CFR 1910.95 (General Industry)
1926.101 (Construction)

Hazard Communication
29 CFR 1910.1200 (General Industry)
1926.59 (Construction)

Appendix D

References and Related Material

American Concrete Institute. Annual. *Manual of Concrete Practice*, Five Parts, Detroit, MI, "Guide to the use of Waterproofing, Damp-proofing, Protective, and Decorative Barrier Systems for Concrete," ACI 515.IR, Chapter 3, Concrete Conditioning and Surface Preparation. (note in particular: Section 3.5 "Tests for surface quality prior to application")

ASTM American Society for Testing and Materials. Annual. *Annual Book of ASTM Standards*, Philadelphia, PA. Note: Use the latest available issue of each ASTM standard.

ASTM D 4258 Standard Practice for Surface Cleaning Concrete for Coating This practice defines methods of cleaning concrete to remove grease, dirt, and loose material prior to the application of coatings. The procedures outlined in the standard include: broom cleaning, vacuum cleaning, air blast cleaning, water cleaning, detergent water cleaning, and steam cleaning of concrete surface for applying coatings for light duty service. ***Broom cleaning:*** is to remove most surface dust and other loosely adherent solid contaminants. ***Vacuum cleaning:*** removes dust and other debris by the use of a heavy duty industrial vacuum. ***Air blast cleaning:*** uses compressed air and abrasive at 80 to 100 psi through a blast nozzle held approximately 2 feet from the substrate. ***Water cleaning:*** uses a stream of clean potable water of sufficient pressure to remove debris. Hand scrubbing with stiff-bristled brush may also be required. ***Detergent water cleaning:*** the removal of water-soluble surface contaminants, oils, grease, and other emulsifiable materials using a detergent or non-solvent emulsifier and stiff-bristled brush. ***Steam cleaning:*** uses a jet of high-pressure steam to remove contaminants. Detergents or non-solvent emulsifying agents may be added to aid in removal. Areas where detergents or non-solvent emulsifying agents are used must be flushed with potable water to meet an acceptable criteria for pH. An acceptable surface after cleaning of concrete by one or more of these methods shall be a substrate free of oil, grease, loosely adhering concrete, and other contamination.

ASTM D 4259 Standard Practice for Abrading Concrete This is a standard practice to provide a clean and roughened surface that is free of laitance, form release agents, curing agent, oil, grease, and other penetrating contaminants. The surface shall be free of fins, projections and loosely adhering concrete, dirt, and dust particles. Suitable methods include: using rotary impact, vertical impact, and circular grinding equipment; ***Water blast cleaning:*** using a high pressure water blasting unit and fresh potable water; ***Abrasive blast cleaning:*** including wet or dry open-blast cleaning with nozzles and self-contained recirculating blast-cleaning apparatus.

ASTM D 4260 Standard Practice for Acid Etching Concrete The intent of this practice is to prepare concrete surfaces prior to the application of coatings by altering the surface profile and removing foreign materials, such as weak surface laitance. All grease, oil and other penetrating contaminants should be removed prior to acid etching. Fins and protruding surface irregularities are to be removed by mechanical means. Typical acid solutions covered by this method include: muriatic (hydrochloric), sulfamic, phosphoric and citric acids. ***Note:*** Hydrochloric acid shall not be used where chlorides are prohibited. The acid solutions are applied to a surface that has been pre-wetted with potable water. After scrubbing with a stiff-bristle brush, the surface is flushed with fresh potable water to remove reaction products.

ASTM D 4262 Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces This test method is used when chemical cleaning or acid etching has been employed to prepare concrete surfaces for coating. The acidity or alkalinity of the final rinse water is measured using pH test paper with a minimum range of from 1 to 11 pH. Measurement of at least two areas in each 500 square feet at random locations is required. The final pH reading shall not be more than 1.0 lower or 2.0 points higher than the original pH of the rinse water unless otherwise specified.

ASTM D 4263 Standard Test Method For Indicating Moisture in Concrete by the Plastic Sheet Method This test method indicates the presence of capillary moisture in concrete by taping a plastic sheet 18 inches square to the surface to be coated. The test should be conducted when the ambient conditions and surface temperature are within the established parameters for application of the specified coating system. The plastic is to remain on the substrate for a minimum of 16 hours. Upon removal, the area is inspected for the presence (or absence) of moisture.

ASTM D 4285 Standard Test Method for Indicating Oil or Water in Compressed Air This test method uses either an absorbent or nonabsorbent collector that is positioned 24 inches in front of the discharge air after any in-line oil and water separators. After a period of not less than 1 minute, the collector is inspected for indications of oil discoloration or water.

TECHNICAL

GUIDELINES

Prepared by the International Concrete Repair Institute (reissued March 1995) October 1989

Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

Guideline No. 03730

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Introduction

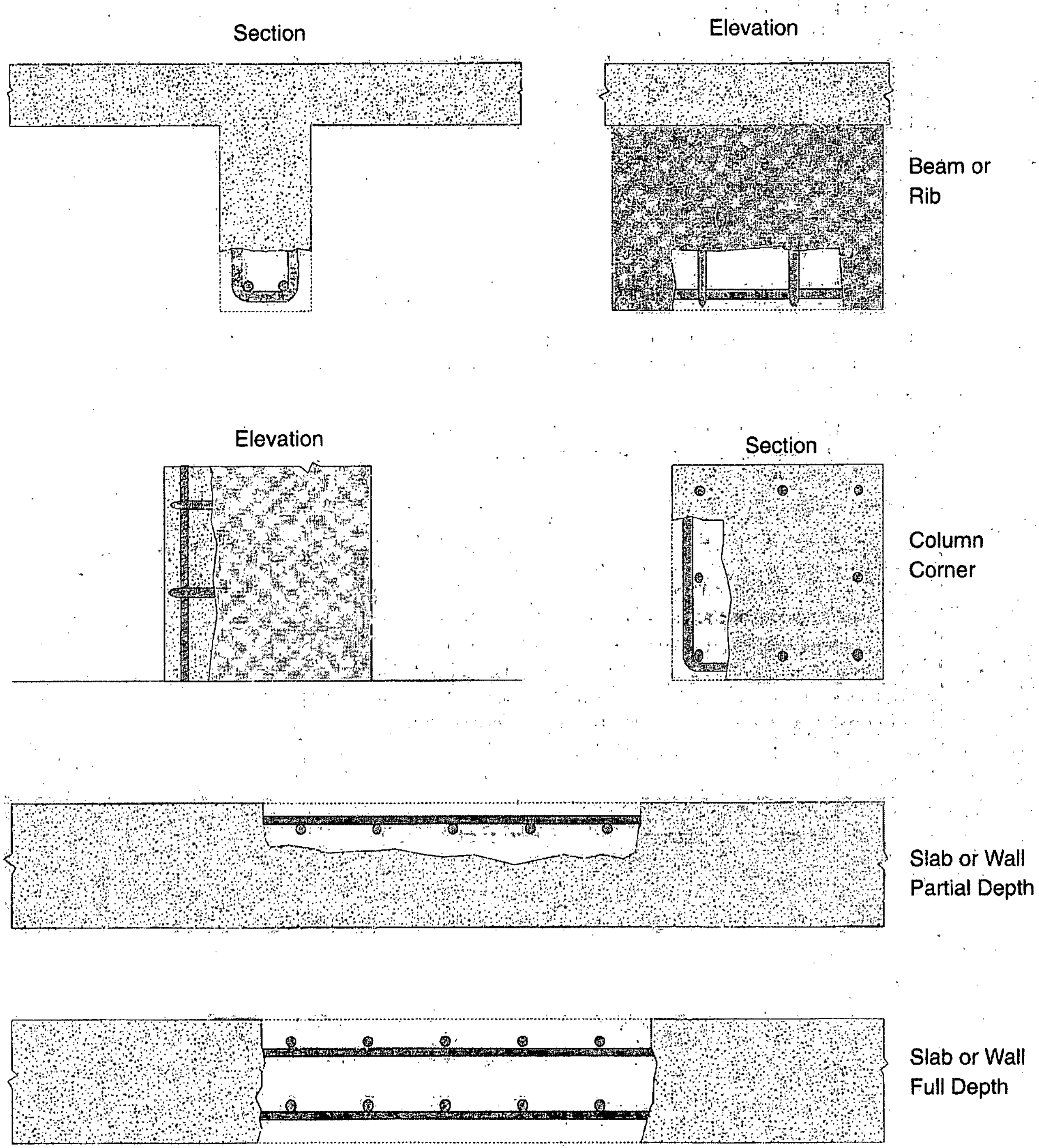
This document is the result of a process of distribution, commentary, and revision by the Technical Guidelines Committee and the membership of the International Concrete Repair Institute. It was submitted to the voting members of the Association for approval on August 1, 1989, and approved by over 95% of the respondents.

Several of the comments of the voting members, both from those who voted for approval and those who voted against approval, are worth noting and are reprinted below.

- Even though a guideline exists for determining the amount of allowable corrosion before replacing or supplementing a reinforcing bar, it is always wise to consult a structural engineer if any corrosion exists.
- Special caution should be taken to locate and avoid **buried electrical conduits** or **prestressing** or **post-tensioning tendons** when performing removals. Cutting into either can be a life threatening situation.
- Undercutting the reinforcing bar should not be counted on to secure the repair structurally in lieu of proper methods of bonding a repair to the existing substrate.
- A sawcut can and, possibly should, be greater than the 1/2 in. (13 mm) noted, as long as the reinforcing steel is not cut into.

Removal Geometry

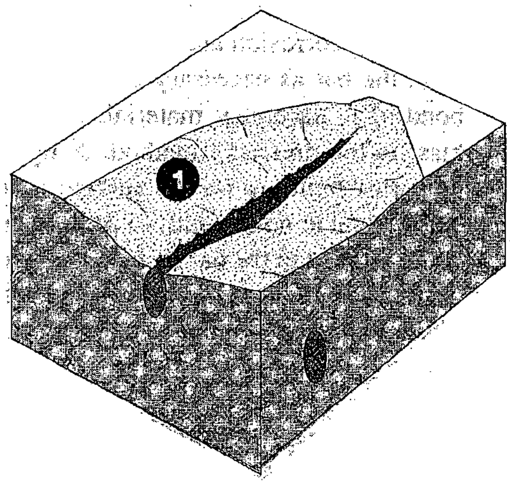
Caution! Before starting removals, review effect of removals on structural integrity. Provide shoring of member as necessary. Particular care shall be exercised at slab/beam connections to columns.

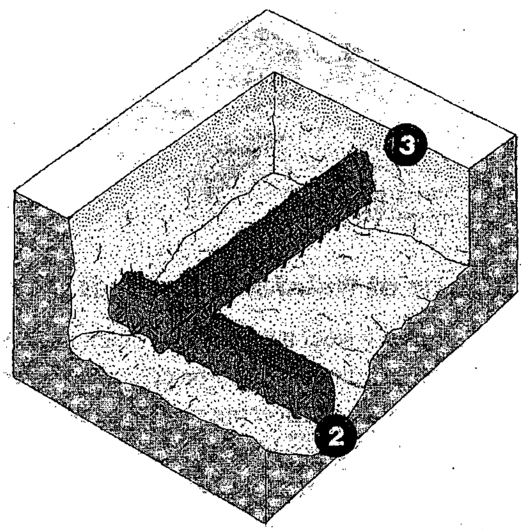


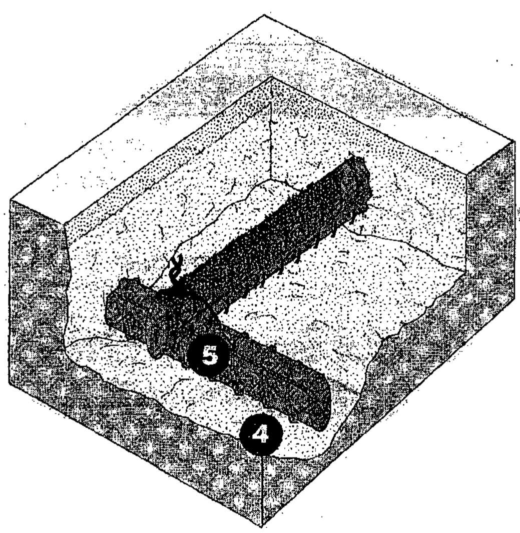
Exposing and Undercutting of Reinforcing Steel

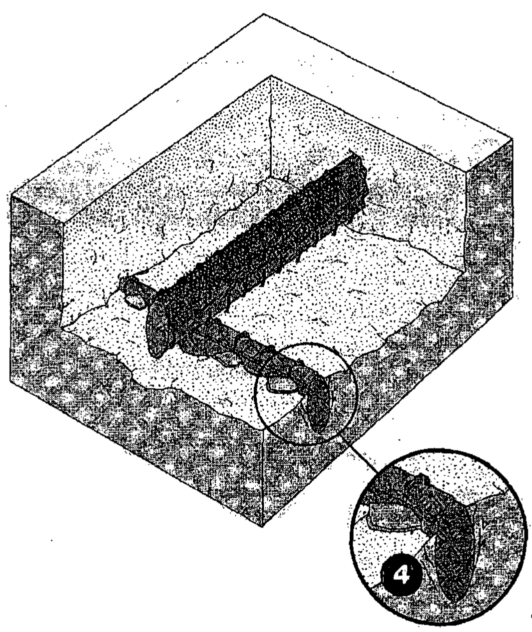
These details are applicable to horizontal, vertical, and overhead locations. They are also applicable to removal by hydro-demolition, hydro-milling, and electric, pneumatic or hydraulic impact breakers.

1. Remove loose or delaminated concrete above corroded reinforcing steel.
2. Once initial removals are made, proceed with the undercutting of all exposed corroded bars. Undercutting will provide clearance for under bar cleaning and full bar circumference bonding to surrounding concrete, and will secure the repair structurally. Provide minimum $^3/_4$ inch (19 mm) clearance between exposed rebars and surrounding concrete or $^1/_4$ inch (6 mm) larger than largest aggregate in repair material, whichever is greater.
3. Concrete removals shall extend along the bars to locations along the bar free of bond inhibiting corrosion, and where the bar is well bonded to surrounding concrete.
4. If non-corroded reinforcing steel is exposed during the undercutting process, care shall be taken not to damage the bar's bond to surrounding concrete. If bond between bar and concrete is broken, undercutting of the bar shall be required.
5. Any reinforcement which is loose shall be secured in place by tying to other secured bars or by other approved methods.





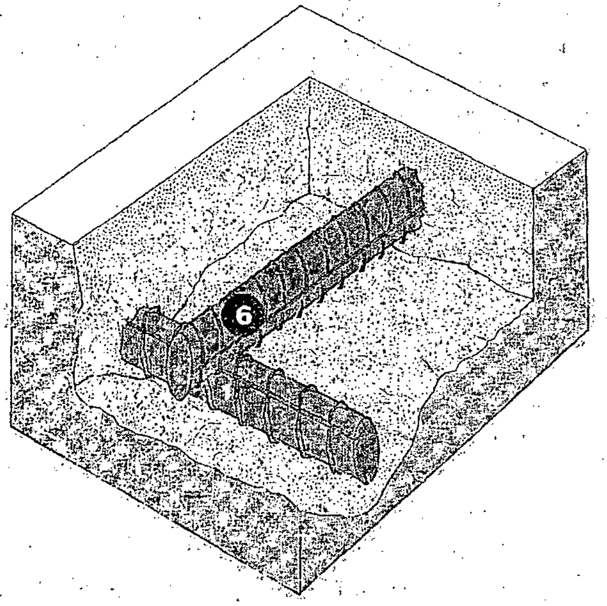


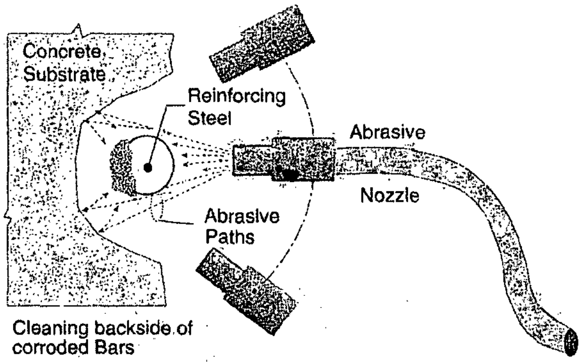


Cleaning and Repair of Reinforcing Steel

Cleaning of Reinforcing Steel

❻ All heavy corrosion and scale should be removed from the bar as necessary to promote maximum bond of replacement material. Oil free abrasive blast is the preferred method. A tightly bonded light rust build-up on the surface is usually not detrimental to bond, unless a protective coating is being applied to the bar surface, in which case the coating manufacturer's recommendations for surface preparation should be followed.





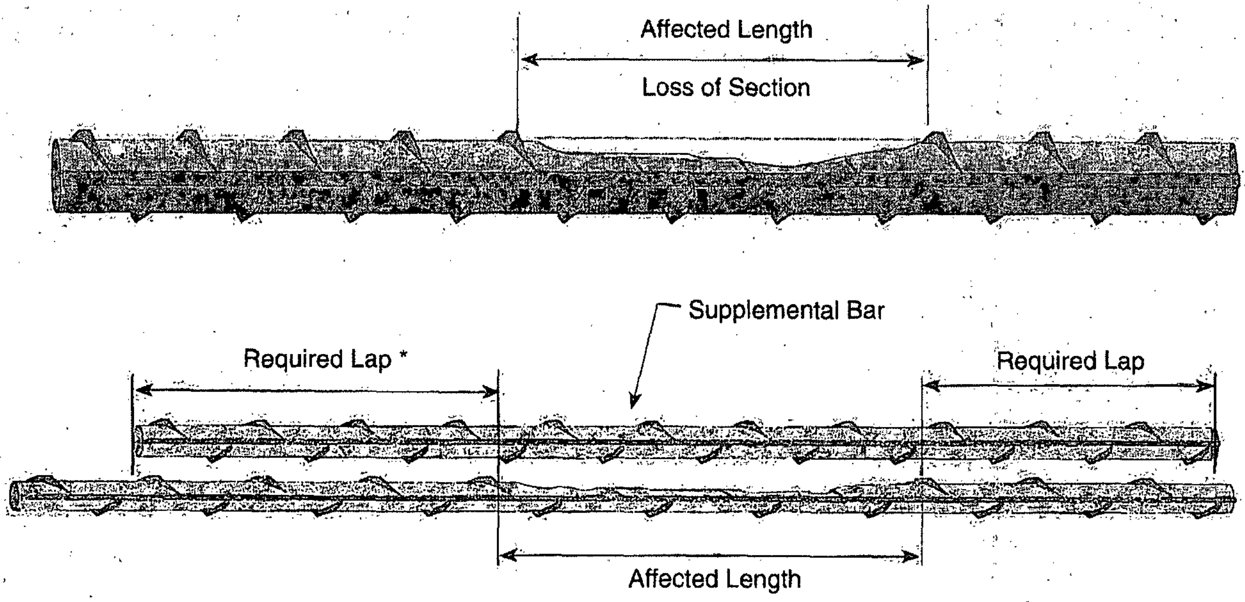
Cleaning backside of corroded Bars

Repair of Reinforcing Steel Due to Loss of Section

If reinforcing steel has lost significant cross section, a structural engineer should be consulted. If repairs are required to the reinforcing steel, one of the following repair methods should be used:

- Complete bar replacement, **or**
- Addition of supplemental bar over affected section.

New bars may be mechanically spliced to old bars **or** placed parallel to and approximately $^3/_4$ in. (19 mm) from existing bars. Lap lengths shall be determined in accordance with ACI 318; also refer to CRSI and AASHTO manual.



Edge and Surface Conditioning of Concrete

These details are applicable to horizontal, vertical, and overhead locations. They are also applicable to removal by hydro-demolition, hydromilling, and electric, pneumatic or hydraulic impact breakers.

Do not use these details for shotcrete applications—for shotcrete repairs refer to ACI 506 Edge Preparation Guidelines.

7 Remove delaminated concrete, undercut reinforcing steel (refer to "Exposing and Undercutting of Reinforcing Steel" on page 3), remove additional concrete as required to provide minimum required thickness of repair material.

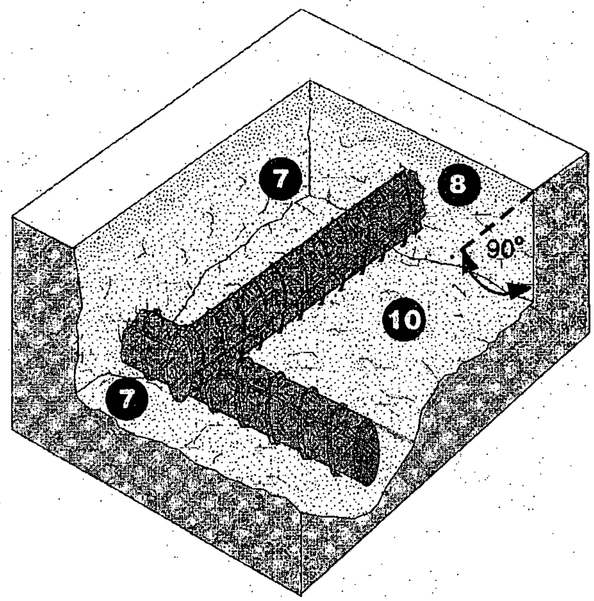
8 At edge locations, provide right angle cuts to the concrete surface with either of the following methods:

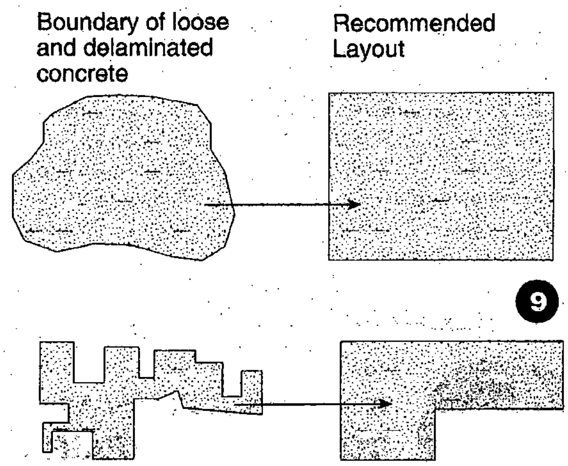
- Sawcut 1/2" (13 mm) or less as required to avoid cutting reinforcing steel.
- Use power equipment such as hydrodemolition or impact breakers. **Avoid feather edges.**

9 Repair configurations should be kept as simple as possible, preferably with squared corners.

10 After removals and edge conditioning are complete, remove bond inhibiting materials (dirt, concrete slurry, loosely bonded aggregates) by abrasive blasting or high pressure waterblasting with or without abrasive. Check the concrete surfaces after cleaning to insure that surface is free from additional loose aggregate, or that additional delaminations are not present.

11 If hydrodemolition is used, cement and particulate slurry must be removed from the prepared surfaces before slurry hardens.





Designation: D 4580 – 03

Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding[1]

This standard is issued under the fixed designation D 4580; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for surveying concrete bridge decks by sounding to determine delaminations in the concrete. It is not intended that the procedures described herein are to be used on bridge decks that have been overlaid with bituminous mixtures. The procedures may be used on bridge decks that have been overlaid with portland cement concrete mixtures; however, areas indicated to be delaminated may have a lack of bond between the overlay and the underlying bridge deck (Note 1).

NOTE 1—The influence of variable field conditions such as traffic noise, vibration, moisture content of the concrete, and the like, are not completely known and additional investigation may be needed. It is generally agreed that the practice should not be used on frozen concrete.

1.2 The following three procedures are covered in this practice:

1.2.1 *Procedure A, Electro-Mechanical Sounding Device*—This procedure uses an electric powered tapping device, sonic receiver, and recorder mounted on a cart. The cart is pushed across the bridge deck and delaminations are recorded on the recorder.

1.2.2 *Procedure B, Chain Drag*—This procedure consists of dragging a chain over the bridge deck surface. The detection of delaminations is accomplished by the operator noting dull or hollow sounds. Tapping the bridge deck surface with a steel rod or hammer may be substituted for the chain drag.

1.2.3 *Procedure C, Rotary Percussion*[2]—This procedure consists of rolling a dual-wheel, multi-toothed apparatus attached to an extension pole over the bridge deck surface. The percussive force caused by the tapping wheels will create either a dull or hollow sound indicating any delamination.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 This practice may be used in conjunction with other methods in determining the general condition of concrete bridge decks.

2.2 This practice may be used in determining specific areas of delamination requiring repair.

PROCEDURE A—ELECTRO-MECHANICAL SOUNDING DEVICE

3. Summary of Procedure

3.1 Longitudinal lines at a predetermined spacing are established on the bridge deck.

3.2 After calibration, the sounding device is pushed along the established lines. Electrically powered tapping wheels emit vibrations into the deck that are sensed by sonic receivers. Areas of delamination are indicated by deflections on a strip chart recorder.

3.3 All portions on the strip chart indicating delaminations are plotted on a scaled map of the bridge deck. An outline is made showing the areas of delamination.

4. Apparatus

NOTE 2—The apparatus described here has been found suitable and is the most common type commercially available. Other apparatuses that do not exactly conform to these requirements such as sounding device, tapping rate, or sonic receivers may also be accepted.

4.1 *Electro-Mechanical Sounding Device*—A small, three-wheeled cart upon which is mounted a 12-V battery, two tapping wheels, two sonic receivers, a two-channel-strip recorder, and associated connectors and cables.

4.1.1 *Tapping Wheels*—Two rigid-steel-tapping wheels capable of tapping the bridge deck surface at the rate of 33 times/s. The tapping wheels shall be located approximately 6 in. (152 mm) apart.

[1] This practice is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.32 on Bridges and Structures.

Current edition approved July 10, 2003. Published September 2003. Originally approved in 1986. Last previous edition approved in 2002 as D 4580 – 02.

[2] The rotary sound detecting device for concrete and procedure are patent pending in the US Patent and Trademark Office by Philip K. Clark Company, Inc., 503 Central Drive, Suite 102, Virginia Beach, VA 23454. Interested parties are invited to submit information regarding the identification of an alternative(s) to this patent pending item to ASTM International Headquarters, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. Your comments will receive careful consideration at a meeting of the responsible technical subcommittee,[1] which you may attend.

4.1.2 *Sonic Receivers*— Two sonic receivers consisting of oil-filled soft tires, inside each of which a receiving transducer is mounted in nonrotating proximity to the concrete surface. The transducers shall be piezo-electric hydrophones that are coupled to the concrete surface through the soft tires and the oil within the wheels. Each receiving wheel shall be located approximately 3 in. (76 mm) outside of and parallel to its corresponding tapping wheel.

4.1.3 *Strip Chart Recorder*—A two-channel-strip chart recorder shall be capable of receiving the signals from the sonic receivers. The electronics unit shall accept only those portions of the signal that occur during the first 3 ms after the occurrence of a tap and further limit the recorder to respond only to those frequency components of the signal that lies in the range of 300 to 1200 Hz. The processed signals shall be rectified and integrated to produce a visual record on the respective channels of the record chart. The chart shall be driven in proportion to the distance traveled so that the length of the record represents a predetermined length of travel. The recording pen on one channel shall be capable of acting as an event marker.

4.1.4 *Cables and Connectors*—There shall be sufficient cables and connectors for connection of the left-tapping wheel sonic-receiver system to the left channel of the strip chart recorder and the right-tapping wheel sonic-receiver system to the right channel of the strip chart recorder.

4.2 *Measuring Tape, Markers, Stringline*—A measuring tape, markers, and stringline shall be provided for establishing lines on the bridge deck that will serve to keep the sounding device positioned properly while making the survey.

4.3 *Calibrator*—A solid aluminum bar capable of checking the operational system of the sounding device.

5. Calibration

5.1 Place the device on the calibrator bar in the on position with the chart drive operating. This will establish the electrical zero line.

5.2 With the calibration switch in the calibrate position, turn on the power, transmitter, and chart drive switches. Each of the recorder pens should trace a rather erratic line approximately half way between the maximum pen movement and the electrical zero line. This line may vary one or two major divisions due to normal variations in the response of the system to the aluminum bar. If the response line does not fall as described, then each channel shall be adjusted with the appropriate calibration adjustment control.

6. Bridge Deck Layout

6.1 Any accumulation of debris on the deck must be removed.

6.2 Beginning at a curb face, mark each end of the bridge at the interval chosen for making the survey.

NOTE 3—Various spacing intervals such as 15 in. (38.1 cm), 18 in. (45.7 cm), and 3 ft (91.4 cm) have been used. The closer spacings are recommended for an in-depth analysis of the bridge deck. The wider spacing intervals are suitable for general-condition surveys of bridge decks.

7. Test Procedure

7.1 Stretch the stringline between corresponding marks on each end of the bridge.

7.2 With the switch in the operate position and the power and transmitter switches on, push the sounding device at a normal walking speed over the bridge deck. The device must be centered over the stringline. Continue in this manner until the entire deck has been surveyed.

7.3 Mark the ends of the bridge, expansion devices, and so forth, by activating the event marker.

8. Data Interpretation and Plotting

8.1 Construct a scaled map of the deck surface.

8.2 Plot the limits of all portions of each trace indicating a delamination. A delamination is considered a trace deflection of four or more minor chart divisions above the normal background response.

8.3 Connect the limits of these plots and outline the individual delaminated areas.

8.4 Determine the total area contained in the individual delaminated areas.

8.5 Divide the total delaminated area by the total bridge deck area and multiply times 100 to yield the percent of deck area delaminated.

PROCEDURE B—CHAIN DRAG

9. Summary of Procedure

9.1 A grid system is laid out on the bridge deck.

9.2 Chains are dragged over the deck surface. Delaminated areas are those where a dull or hollow sound from the chain dragging operation is apparent.

9.3 Delaminated areas are outlined on the deck surface. A map is prepared indicating the location of delaminations with respect to the grid lines.

10. Apparatus

10.1 *Chains, Steel Rods, or Hammers*—Acceptable sizes and configurations of chains, steel rods, or hammers are those that produce a clear ringing sound when dragged or tapped over nondelaminated concrete and a dull or hollow sound over delaminated concrete. A common chain drag configuration consists of four or five segments of 1-in. (25-mm) link chain of ¼-in. (6-mm) diameter steel approximately 18 in. (45.7 cm) long, attached to a 2-ft (61-cm) piece of aluminum or copper tube to which a 2- to 3-ft (61- to 91.4-cm) piece of tubing, for the handle, is attached to the midpoint, forming a T. Steel rods ⅝ in. by 4 ft (16 mm by 121.9 cm), or larger, have been found to produce satisfactory results.

NOTE 4—Heavier chains have generally been shown to produce a more definitive sound under heavy traffic conditions.

10.2 *Measuring Tape, Markers, and Stringline*—A measuring tape, markers, and stringline shall be provided for establishing a grid system on the bridge deck. Markers such as spray paint or lumber crayon shall be used to outline delaminated areas on the deck surface.

11. Bridge Deck Layout

11.1 Any accumulation of debris on the deck must be removed.

11.2 Construct a grid system on the deck surface with a lumber crayon so that delaminated areas marked on the deck can be plotted easily on a map by referencing the areas to the grid.

12. Test Procedure

12.1 Survey the entire bridge deck by dragging the chains or tapping with the steel rod or hammer over the entire surface. On nondelaminated concrete, a clear ringing sound will be heard. A dull or hollow sound is emitted when delaminated concrete is encountered.

12.2 Mark the areas of delamination on the deck surface with the spray paint or lumber crayon.

13. Plotting

13.1 Construct a scaled map of the deck surface.

13.2 By referencing to the established grid system on the deck, plot the areas of delamination on the map.

13.3 Determine the total area contained in the individual delaminated areas.

13.4 Divide the total delaminated area by the total bridge deck area and multiply by 100 to yield the percent of deck area delaminated.

PROCEDURE C—ROTARY PERCUSSION

14. Summary of Procedure

14.1 A grid system is laid out on the bridge deck, vertical structural support or the underside of the bridge structure.

14.2 A rotary percussive device is rolled over the bridge deck, vertical structural member or the underside of the bridge deck. Delaminated areas are those areas where a dull or hollow sound is created from the rotary percussion units striking the surface.

14.3 Delaminated areas are outlined on the bridge deck's surface, vertical structural surface or on the underside of the bridge deck surface. A map (or field schematic) is prepared indicating the locations of the delaminations with respect to the grid lines or with respect to their proximity to permanent structural elements.

15. Apparatus

15.1 *Rotary Percussion Sounding Device*—A "T" shaped device with two rotary percussion units, which spin when rolled over a concrete surface. The device is either hand-held or attached to an extension pole to reach the overhead surfaces of structural members or the underside of the bridge deck surface. As the rotary percussion sounding device is rolled over the surface, the two percussion units strike the surface with sufficient force to create either a clear ringing sound when passing over solid concrete or a dull or hollow sound when passing over delaminated concrete.

15.2 *Rotary Percussion Units*—Two hardedened steel, 15-point percussion units are fit onto an axle and are capable of being rolled over the surface to be tested to sufficiently strike the concrete surface to generate the hollow sound indicative of delaminated concrete.

15.3 *Extension Pole*—The rotary percussion device is attached to a telescoping extension pole to reach the surface to be tested, either the top slab deck or an overhead structural member.

15.4 *Measuring Wheel, Markers, and String Line*—A measuring wheel adapted to fit a telescoping extension pole. Lumber crayons, spray paint markers, and string line shall be used to establish a grid system so that the delaminated areas can be accurately recorded.

16. Bridge Deck Layout

16.1 Any accumulation of debris on the deck must be removed.

16.2 Construct a grid system on the deck surface, vertical structure member, or the underside of the bridge deck with chalk line, lumber crayon, or by the test area's proximity to fixed structural components. Plot the areas on the field sheet.

17. Test Procedure

17.1 Survey the entire deck surface or overhead structural member by rolling the rotary percussion device over the entire surface. On non-delaminated concrete, a clear ringing sound will be heard. A dull or hollow sound will indicate delaminated concrete.

17.2 Mark the areas of delamination on the deck surface with spray paint or lumber crayon. Mark the areas of delamination on the vertical structureal members or the underside of the deck structure with an up-spraying spray paint device or lumber crayon.

18. Plotting

18.1 Construct a scale map of the surface to be tested.

18.2 By referencing the established grid system on the deck or overhead surface, plot the areas of delamination on the map.

18.3 Determine the total delaminated area within the grid system.

18.4 Divide the total delaminated area by the total bridge deck area (or overhead structural element) and multiply by 100 to yield the percent of deck area or overhead structural element found to be delaminated.

19. Report

19.1 The report shall include the following information:

19.1.1 Bridge location and description,

19.1.2 Survey method used,

19.1.3 Date of test,

19.1.4 Spacing of interval if Procedure A is used,

19.1.5 Percent of deck delaminated, and

19.1.6 Remarks.

20. Precision and Bias

20.1 The nature of the methods do not allow for a round-robin testing program. Practices do not provide test results, therefore, no precision and bias statement has been made.

NOTE 5—Available data suggests that the chain drag procedure is more precise in locating delaminations than is the electromagnetic sounding device.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

ACI 503R-93
Reapproved 2008

USE OF EPOXY COMPOUNDS WITH CONCRETE

Reported by Committee 503

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Epoxy compounds have found a wide variety of uses in the concrete industry as coatings, grouts, binders, sealants, bonding agents, patching materials, and general adhesives.

Properties, uses, preparations, mixtures, application, and handling requirements of epoxy resin systems when applied to and used with concrete and mortar are presented. The adhesiveness of epoxy and its chemical, thermal, and physical properties are given. The modification of the foregoing properties to accommodate given situations is reviewed.

Problems encountered in surface preparation are reviewed and procedures and techniques given to insure successful bonding of the epoxy to the other materials. Temperature conditioning of the base material and epoxy compound are outlined. The cleaning and maintaining of equipment is reviewed. Procedures to be followed in the application of epoxy compounds in the several use situations are given. The important factors which insure that the epoxy compound will harden (cure) and therefore perform its function are discussed together with alterations of the hardening rate. The allergenic and toxic nature of epoxies and the chemicals used with them in the industry create a hazard and precautions are detailed throughout the report.

Keywords: **abrasion resistant coatings**; abrasive blasting; acid treatment (concrete); adhesion; adhesives; aggregates; bonding; bridge decks; **chemical analysis**; chemical attack; cleaning coatings: compressive strength; concrete construction; concrete finishes (hardened concrete); concrete pavements; concretes; cracking (fracturing); electrical properties; **epoxy resins**; flexural strength; floor toppings; fresh concretes; grout; grouting; history; joints (junctions); metals; mix proportioning; mixing; mortars (material); patching; **plastics**; **polymers and resins**; popouts; repair; resurfacing; shrinkage; skid resistance; stairways; **temperature**; tensile strength; underwater construction; waterproof coating; wood.

CONTENTS

ACI 503R-93 supersedes ACI 503R-89 and became effective July 1, 1993.

CHAPTER 1 -- INTRODUCTION

1.1 -- Background

1.1.1 -- There are many characteristics of epoxies and their uses which make them a desirable adhesive for use with concrete. Some of these advantages are:

1.1.1.1 *Adhesion* -- Epoxy resins have excellent adhesive qualities and will bond to nearly all construction materials. A few of the nonpolar thermoplastics such as polyethylene, present adhesion problems and are exceptions.

1.1.1.2 *Versatility* -- The wide range of available physical and chemical properties of epoxy resin systems makes their consideration requisite in any situation involving repair, overlay, coating, or adverse environment, of concrete. The variety of curing agents, extenders, diluents, fillers and other modifiers available to the formulator permit the attainment of special characteristics for any particular application.

1.1.1.3 *Chemical resistance* -- Epoxies are resistant to the attack of acids, oils, alkalies, and solvents.

1.1.1.4 *Low shrinkage* -- Compared to other thermosetting resins, epoxies have low autogenous shrinkage. Formulations are available in which effective linear shrinkage is as low as 0.001 percent.

1.1.1.5 *Rapid hardening* -- At normal ambient temperatures it is possible for a mixed resin and hardener system to go from a liquid to a solid state in a matter of several minutes, or the time can be extended several hours by changing the system.

1.1.1.6 *Moisture resistance* -- A thin coating of an appropriate epoxy system can provide a high degree of impermeability even when continuously inundated in water. Some, though not all, epoxy materials absorb significant amounts of water in a moist environment. Select and use epoxy products (adhesives, coatings, mortars) that have low water absorption. Water absorption will not be a problem if the material has less than 1 percent absorption as measured by ASTM D 570 and specified by ASTM C 881.

1.1.2 -- The benefits of using epoxy resins are noteworthy but caution must also be exercised. The following discussion briefly summarizes some of the precautions necessary:

1.1.2.1 *Strain compatibility*

1.1.2.1.1 Epoxy bonds very rapidly to a concrete surface and within a short time may be considered as monolithic. The autogenous shrinkage strains which take place in some epoxy formulations during curing can cause severe strains at the bond line and when combined with thermal strains contribute significantly to delamination, generally by failure in the top ¼ in. (6 mm) of concrete interface.

1.1.2.1.2 There is a wide difference in the coefficients of thermal expansion between concrete and the cured epoxy. Even normal temperature variations can be the cause of delamination. Filling the epoxy system with fillers such as silica reduces the difference in thermal expansion in proportion to the amount used. The use of a flexible epoxy compound will allow the system to adjust for the difference in thermal coefficient of expansion.

1.1.2.2 *Thermosetting plastic* -- The components which make up the epoxy system must be mixed thoroughly and close control of temperature must be exercised before and during mixing and curing. Selection of the epoxy formulation that will cure at a given substrate temperature is crucial to the cure. All epoxies will not cure on cold substrates. Proper selection is the best solution. ASTM C 881 specifies three temperature cure classes. Once cured the epoxy will not melt. However, many systems lose some of their elasticity at higher temperatures and become cheesy since their mechanical properties change significantly beyond their heat deflection temperature (HDT). The HDT is different for each formulation but for those systems used in construction, it generally ranges from 60 to 160 F (15 to 71 C).

1.1.2.3 *Slabs on grade* -- Slabs on grade can present unique bonding problems if there is moisture present in or under the slab during application and cure of an epoxy (or any other impervious polymer) material on the slab. Rising moisture in the slab caused by capillary action can exert forces on the epoxy material that will prevent an adequate bond from being achieved. Even if moisture is not present during application and cure these same forces can subsequently cause loss of a bond that was weak because of other factors such as inadequate surface preparation.

1.1.2.4 *Safety* -- Epoxy compounds are allergenic and safe handling practices must be exercised in each instance. Solvents used on the job to clean epoxied equipment often require more caution than the epoxy. Previous experience dictates that the user be thoroughly familiar with the information contained in Chapter 9, Handling Precautions.

1.1.3 -- The foregoing cautions can be satisfied by using the appropriate epoxy system, selected on the basis of a carefully prepared listing and evaluation of all job and application restrictions (those which bear on handling are noted in Chapter 9) and requirements involved. Epoxies have very selective properties and it is unwise to rely on a general specification or general performance criteria.

1.2 -- General

1.2.1 *Recommended references* -- The documents of the various standards producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures
503.1 Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and Other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive
503.2 Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive
503.3 Standard Specification for Producing a Skid-Resistant Surface on Concrete by the Use of a Multi-Component Epoxy System
503.4 Standard Specification for Repairing Concrete with Epoxy Mortars
504R Guide to Joint Sealants for Concrete Structures
515.1R A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete

ASTM

C881 Specification for Epoxy-Resin-Base Bonding Systems for Concrete
C884 Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay
D 570 Test Method for Water Absorption of Plastics
D 648 Test Method for Deflection Temperature of Plastics Under Flexible Load (1820 kPa/264 psi)

ANSI

Z 129.1 Precautionary Labeling of Hazardous Industrial Chemicals
K 68.1 Guide for Classifying and Labeling Epoxy Products According to their Hazardous Potentialities

Code of Federal Regulations

16 CFR 1500 Hazardous Substances and Articles; Administration and Enforcement Regulations
29 CFR 1910 Occupational Safety and Health Standards
49 CFR Transportation

The preceding publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

American National Standards, Inc.
1430 Broadway
New York, NY 10018

U.S. Office of the Federal Register
National Archives and Records Administration
Washington, D. C. 20408

1.2.2 -- This report is based on those known and most accepted field practices for the use of epoxy resins with concrete. It provides the user with an adequate guide for successful application and performance of epoxy resins to the extent of its coverage. However, the epoxy supplier should always be consulted concerning each new variable introduced by the user.

1.3 -- Scope

1.3.1 -- The rapid growth of the use of epoxy compounds in the concrete industry and the proliferation of available epoxy systems emphasizes the need of this committee report. The wide range of epoxies which can be used as adhesives on, in, or with concrete limits the detail which can be given herein. The result is an often brief coverage of any particular topic with constant referral of the user to the formulator for details of application and performance. Nevertheless, those problems which are generally encountered in the use of epoxies with concrete are noted and their solutions presented.

1.3.2 -- Emphasis is given to the preparation of surfaces to receive epoxy adhesive, details of compound preparation, use and application, with notes concerning rate of hardening of compound, and cautions to be exercised when using any epoxy. Ranges of physical properties are noted as well as possible uses of the material.

CHAPTER 2 -- HISTORY OF EPOXIES

2.1 -- Origin of epoxies

2.1.1 *General* -- The word "epoxy" is of Greek derivation. The Greek word "epi," which means "on the outside of," was combined with the word "oxygen" which describes the presence of the oxygen atom in the molecular structure. In short, the word is a Greek description of the chemical symbol for the family of epoxies (see Fig. 2.1).

2.1.2 *Discovery of epoxy applications* -- The first practical application of epoxy resin took place in Germany and Switzerland in the 1930s with concurrent experiments being conducted in the United States, although the basic chemistry had been known for several decades. The first known patent on epoxy was issued to Dr. Pierre Castan in Switzerland in 1936. Three years later, Dr. S.O. Greenlee of the United States explored and developed several basic epoxy systems, many of which we use today as adhesives and coatings.

2.2 -- Early attempts at using epoxies

2.2.1 *General* -- Limited production of epoxy resins started in the late 1940s and commercially produced epoxy resin adhesives became available in the early 1950s. Initial laboratory tests using epoxies on concrete also began in the late 1940s and were directed toward their use as coatings on floors and highways. Developments were limited to the laboratory until about 1953, as engineers and scientists attempted to identify the basic physical properties and probe potential uses of epoxy systems.

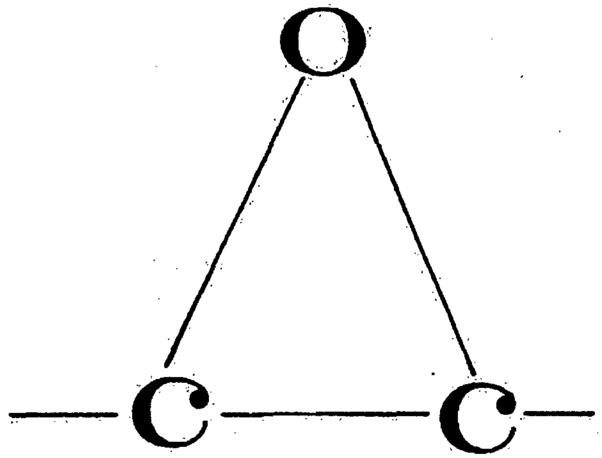


Fig. 2.1 -- Chemical symbol for the family of epoxies

2.2.2 *Early field tests for bonding*

2.2.2.1 First interest in the use of epoxy as an adhesive in the construction industry was in 1948 when it was used as a bond for two pieces of hardened concrete. Epoxy proved to be a satisfactory structural adhesive with the capability of being stronger than the concrete it bonded together.

2.2.2.2 In 1954 the California Highway Department became interested in epoxies as a bonding agent for raised traffic line markers on concrete highways. The successful utilization of an epoxy as a bonding agent encouraged the extension of research into the field of structural repair of concrete, and the eventual application of an epoxy-polysulfide polymer, as a bonding material for joining new concrete to old.

2.2.3 *Early field tests for surfacing materials* -- In 1953 the Shell Chemical Corp. initiated field tests to evaluate epoxy systems as surfacing materials on highways, following successful laboratory tests by the company. Favorable results encouraged the pursuit of this as a solution to an age-old problem of restoration of deteriorated concrete surfaces.

2.3 -- Development of epoxy applications with concrete

2.3.1 *General* -- Epoxy formulations developed until there were available systems with a combination of properties which made them uniquely suited for use as an adhesive with concrete. They had high bond strength, characteristics similar to other structural materials when cured and long-term resistance to aggressive environments, with easy application characteristics and low shrinkage during cure. These properties led to many different applications, some of which are discussed below.

2.3.2 *Epoxy for bonding* -- The ability of epoxy to bond two pieces of concrete generated interest in the possibility of bonding fresh concrete to existing concrete. Experiments with the latter situation met with limited success until the development of epoxy resin-polysulfide systems. Since that time efforts with these and other recently developed adhesive systems have extended their desirable properties and their general acceptance by the concrete industry until they are now widely used.

2.3.3 *Epoxy for grouting*

2.3.3.1 *Epoxy injection systems* -- Epoxy injection as a means of performing structural grouting and repair was first used in the late 1950s. The approach was to premix the epoxy and then pump the mixed epoxy system. The injection of epoxy into structural cracks permitted for the first time a positive technique for the restoration of the structural integrity of cracked concrete. In 1960 a system was developed utilizing pressure injection with a mixing head at the nozzle of the injection gun which expanded the applications of epoxy as a grouting adhesive in structural concrete.

2.3.3.2 *Epoxy bolt grout* -- The use of epoxy as a grout to bond bolts or dowels to hardened concrete was first attempted in the late 1950s. This application came about from the need to grout bolts in existing concrete slabs for mounting heavy machinery. Concurrently, epoxy grout was used to bond dowels into the ends of existing concrete slabs as a shear transfer mechanism for extension of existing slabs.

The use of an epoxy grout which could attain high early strength and which would not shrink significantly during curing solved an old problem for manufacturing plants, that of rapid installation of new equipment with minimum delay until full operation.

Epoxy grout has also been successfully used for installation of handrails, architectural metals, precast concrete panels, structural members (both concrete and steel), concrete railroad ties, and for numerous other applications.

2.3.4 *Epoxy coating materials*

2.3.4.1 *Epoxy seal coat*

2.3.4.1.1 Epoxy seal coating was first applied as test patches in industrial plants along the eastern coast in 1953 and on highways in 1954. Although there were varying degrees of success and failure with these applications, the initial results were encouraging to many observers. Large scale experimental applications were attempted in 1956 on the Wilbur Cross Parkway, the Triborough Bridge and the George Washington Bridge. The apparent success of these latter applications led to more elaborate testing all across the United States by 1958. Tests at that time were conducted primarily with coal tar epoxies applied as seal coats and then given a skid-resistant surface by broadcasting fine sand or emery aggregate across the surface. This procedure, while successful in many respects, was not as utopian as had been hoped. Then in 1962 a thin topping of asphaltic concrete on top of a coal tar epoxy seal coat was tried as an alternative solution on a bridge in New York City which moved quite successful. The method has since been extended using other epoxy systems.

2.3.4.1.2 Seal coats using epoxies of low viscosity have also been successfully applied on highway, industrial and commercial surfaces.

2.3.4.2 *Epoxy polymer concrete as a wearing course* -- Epoxy polymer concrete was first used as a wearing course in the repair of popouts and spalled areas on the surfaces of various concrete bridge decks in California in 1957, on the San Francisco-Oakland Bay Bridge, and in industrial plants and warehouses. The epoxy polymer concrete consisted primarily of the epoxy resin system and clean, dry well-graded sand By 1963, several bridges in various parts of the United States had been successfully resurfaced with epoxy polymer concrete.

2.2.4.3 *Epoxy resin specifications* -- The U.S. Army Corps of Engineers published the first Federal specification for an epoxy resin system in 1959 and ASTM specification C 881 was first published in 1978. The use of the epoxy systems has since expanded in many directions, because of requirements for solution of coating, patching and resurfacing problems.

2.4 -- Present status of epoxies

2.4.1 Epoxies are presently used with concrete in the form of coatings, repair materials, grouts, bonding agents, paints, adhesives, epoxy mortars and polymer concrete, seal coats, penetrating sealers, wearing surfaces, and as admixtures to portland cement concrete to make epoxy polymer modified concrete. Thus, the appeal for epoxies has been enhanced, both from an economy and performance standpoint.

CHAPTER 3 -- CHEMICAL AND PHYSICAL CHARACTERISTICS OF EPOXY RESINS

3.1 -- General

Epoxy compounds are generally formulated in two or more parts. Part A is most often the portion containing the epoxy resin and Part B is its hardener system. Almost without exception, epoxy systems must be formulated to make them suitable for specific end uses.

3.2 -- Adhesion properties

3.2.1 *General* -- Epoxies bond well (Fig. 3.1) to almost every material providing that an appropriate surface preparation has been given (see Chapter 5). Because the quality and surface condition of concrete is rarely completely known, tests for adhesion are advised (see Appendix A). There are many reasons why epoxies make good adhesives including, but not limited to, the following:

a) They can be in liquid form and yet contain no volatile solvent
b) They adhere to most materials used in construction
c) No by-products are generated during curing
d) Curing shrinkage is low

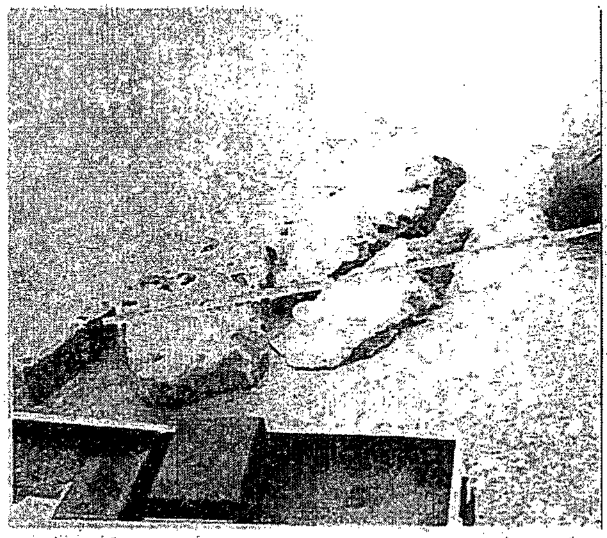


Fig. 3.1 -- Epoxy adhesive when properly applied can form a bond with greater strength than the concrete to which it is applied, as shown here (courtesy L. Mitchell, Consulting Engineer)

e) Long time dimensional stability is good

f) They have high tensile and compressive strengths

g) Appropriate formulations are resistant to the action of weathering, moisture, acids, alkalis and most other environmental factors

3.2.2 *Mechanical property comparisons of epoxies and concrete*

3.2.2.1 *Physical properties* -- In Table 3.1 epoxy strengths and tensile elongation are the values at time of rupture. However, even highly elongating epoxy binders may have negligible stretch when heavily filled.

Table 3.1 -- Comparative mechanical properties of epoxy system and concrete

	Flexural strength psi (MPa)	Tensile strength psi (MPa)	Compressive strength psi (MPa)	Tensile elongation percent
Structural concrete (typical)	500-1000 (3.4-6.9)	300-700 (2.1-4.8)	3000-10,000 (20.7-68.9)	001
Epoxy compounds (typical)	1500-5000 (10.3-34.1)	500-7000 (3.4-48.9)	500-12,000 (3.4-82.7)	0.2 to 150

3.2.2.2 *Temperature effects* -- Epoxy resins react upon combination to form a thermosetting plastic which thereafter does not melt. The properties of a cured epoxy system generally change very little with temperatures well below the Heat Deflection Temperature (HDT) as measured by ASTM D 648. Beginning in the region about 18 F (10 C) below the HDT rigidity, creep resistance and chemical resistance are adversely affected as temperature is increased. Above 572 F (300 C) most resins will char and generally volatilize. The resulting fumes may be toxic.

3.3 -- Susceptibility to chemical attack

3.3.1 -- Epoxies are considered as generally resistant to chemical attack. A general comparison with concrete is given in Table 3.2.

Table 3.2 -- Chemical properties of epoxy and concrete

	Epoxy	Concrete
Wet-dry cycling	Excellent	Excellent
Chloride deicing salts	Excellent	Fair
Muriatic acid (15 percent HCl)	Excellent	Poor
Foods acids (dilute)	Good	Poor
sugar solutions	Excellent	Fair
Gasoline	Excellent	Excellent
Oil	Excellent	Excellent
Detergent cleaning solutions	Excellent	Excellent
Alkalies	Excellent	Good
Sulfates	Excellent	Fair

Epoxy systems used to protect concrete from the effects of food spillage must be compounded for specific end uses. For example, a system resistant to acetic acid may not be resistant to all concentrations of acetic acid. This is because many organic acids have vapor pressures lower than water and, therefore, as spillage evaporates, the acid solution becomes more concentrated. Another note of caution relative to potential failures is that chemical resistance tests are often run at 77 F (25 C) whereas spillage may be much hotter. Food acid absorption by epoxy resins is a function of temperature. Acid absorption at 150 F (66.5 C) may be up to 100 times the absorption at 77 F (25 C). Furthermore, vegetable acid spillage usually contains plant sugars which form a series of organic acids when bio-oxidized. These acids, usually present in small amounts, also may become more concentrated as evaporation of spillage progresses. Therefore, proper selection of the epoxy formulation is important to the success of the substrate protection. Follow the recommendations of the epoxy manufacturer. A typical installation is shown in Fig. 3.2.

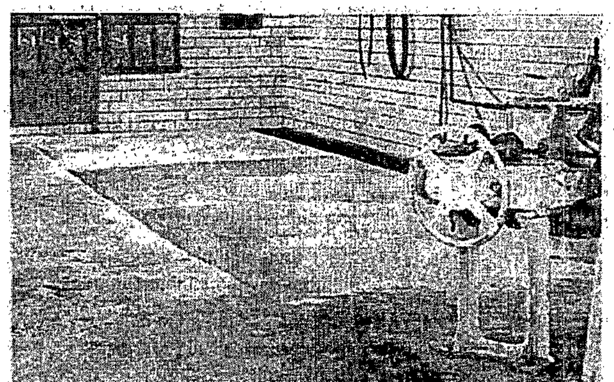


Fig. 3.2 -- Epoxy mortar floor topping in a food processing plant (courtesy Protex Industries)

3.3.2 -- Epoxies are widely used for industrial applications where chemical spillages are the normal environmental condition. Consult with the epoxy manufacturer to determine which formula should be considered.

3.4 -- Electrical properties

3.4.1 -- Epoxies are excellent electrical insulators.

3.4.2 -- Special techniques must be employed to enable an epoxy formulation to be a conductor or partial conductor of electricity. There are places where this is necessary, such as operating room floor surfacings in hospitals, clean rooms and manufacturing areas where static discharge cannot be tolerated. The reader is referred to the instructions from manufacturers specializing in such applications.

3.5 -- Abrasion resistance

3.5.1 -- Epoxies can be formulated to withstand severe abrasion, but conditions of use have to be understood before the best selection of materials can be made. For example, will the surface be dry or wet? Hot or cold? Will abrasion be from rubber wheels, steel wheels, waterborne rocks, etc.? For specific end uses, the epoxy compound manufacturer should be consulted and given a full description of service environmental conditions.

3.6 -- Resilience

3.6.1 -- Epoxies can undergo deformation, and yet recover and return to their original shape providing that their elastic limit has not been exceeded.

3.7 -- Creep

The amount of creep which will occur depends not only on the load but also on how close the service temperature is to the Heat Deflection Temperature (HDT), the amount of inorganic filler in the system, and the degree of confinement of the epoxy system as it is loaded.

3.8 -- Thermal expansion

3.8.1 -- A major difference between epoxy compounds and concrete lies in their coefficients of thermal expansion (see Fig. 3.6).

3.8.2 -- Steel and concrete usually have similar thermal expansions. Combined as reinforced concrete, the difference in their coefficients of thermal expansion does not usually become a problem either in design or use. On the other hand the considerable difference in coefficient of thermal expansion between epoxies and portland cement concrete does require careful consideration.

3.8.3 -- Consider the factors indicated in Fig. 3.3 where (a) is a slab of concrete surfaced with an epoxy (b). Due to the difference in coefficients of thermal expansion as the temperature rises (b) will attempt to grow larger than (a) and, if the concrete were as elastic as the epoxy, the result would be as shown in Fig. 3.4, obviously exaggerated. Conversely, if the temperature drops, (b) will shrink more than (a) and will produce the deformation

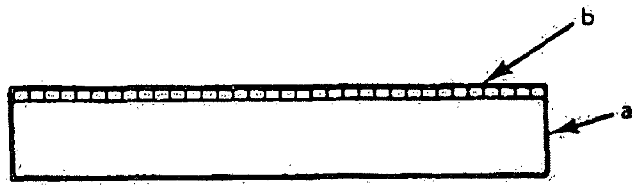


Fig. 3.3 -- A layer of epoxy (b) adhered to a thickness of concrete (a)

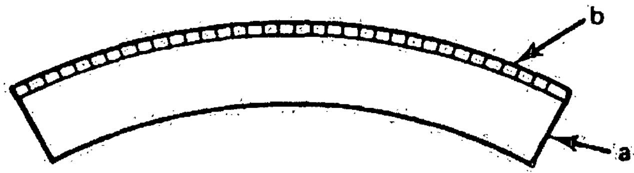


Fig 3.4 -- The effect of temperature increase in an epoxy-concrete system

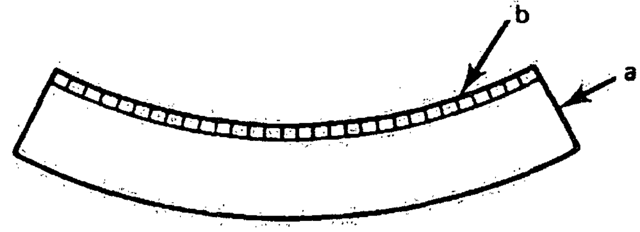


Fig. 3.5 -- Effect of temperature decrease in an epoxy-concrete system

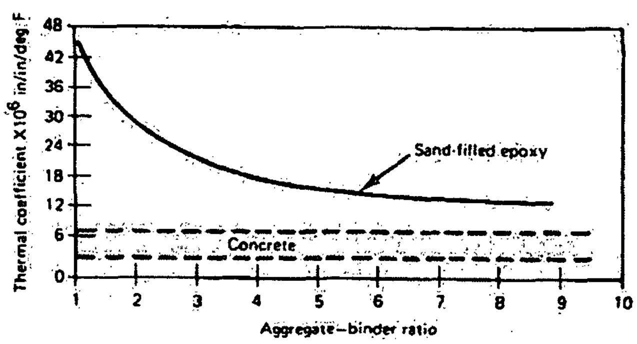


Fig. 3.6 -- The effect of changes in the sand aggregate-binder ratio on the thermal coefficient of an epoxy system

shown in Fig. 3.5.

3.8.4 -- The higher elastic modulus of concrete tends to restrain the movement of the epoxy, thereby causing severe stresses at the interface upon temperature changes. Epoxies yield under stress, and, if properly formulated, they will accommodate relatively larger dimensional changes resulting from thermal effects. Also, the coefficient of thermal expansion of the epoxy can be reduced by the addition of fillers, see Fig. 3.6, with an increase in modulus of elasticity typically resulting.

3.8.5 *Thermal coefficient of epoxy-aggregate systems* -- The thermal coefficient of an epoxy system will be reduced as the aggregate content of the system is increased as indicated in Fig. 3.6.

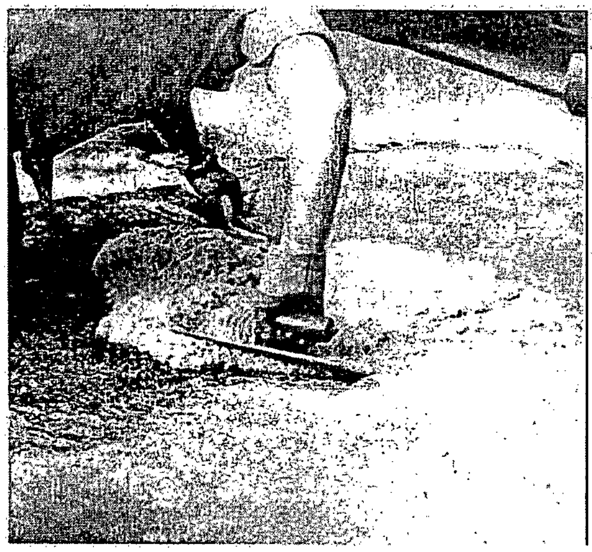


Fig. 4.1 -- Application of a thin epoxy mortar floor coating in an area subject to abrasion and chemical attack (courtesy Sika Chemical Corp.)

Fig. 4.2 -- An epoxy sealer and light reflector on the walls of a highway tunnel (courtesy Adhesives Engineering)

3.9 -- Exothermic reaction during cure

Epoxies develop heat during their cure. The temperature rise will depend on mass as well as formulation. To keep this temperature rise to a minimum, it is advisable to maintain a high surface area to volume during mixing and application, to add the maximum quantity of aggregate consistent with the intended application, or both.

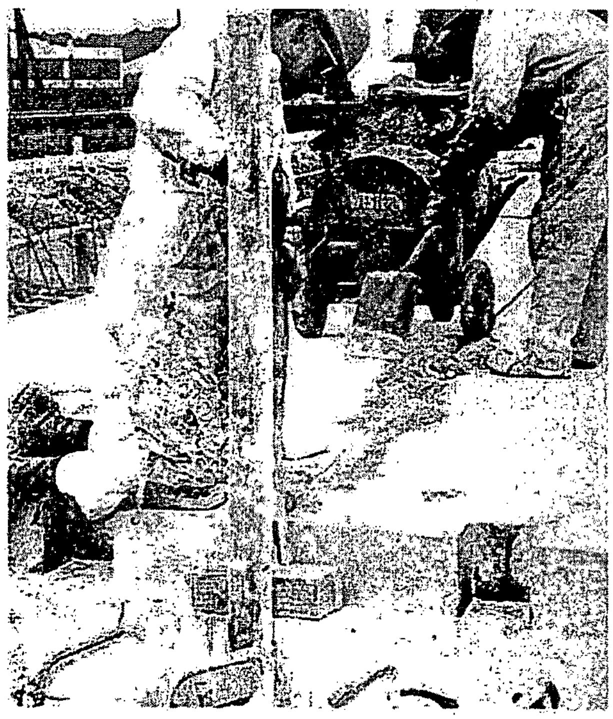


Fig. 4.3 -- Epoxy grouting of keyways in rapid transit bridge (courtesy Adhesives Engineering)

3.10 -- Curing and aging stresses

Curing and aging stresses are developed in epoxies. These stresses can be minimized by correct formulation.

3.11 -- Thermosetting properties

Epoxy resins are thermosetting plastics, i.e., in the process of hardening, they undergo chemical change and cannot be reliquified by heating.

CHAPTER 4 -- USES OF EPOXY RESINS

4.1 -- General

Epoxy resins, meeting ASTM C 881 have good adherence to concrete under all conditions whether wet or dry, and have been found useful for a wide variety of applications with concrete (Fig. 4.1-4.5). For the best performance under each condition of use, the properties of the epoxy resin system should be tailored to meet the specific needs of each type of application. Thus, it is unlikely that a system consisting only of an epoxy resin and pure hardening agent will find wide utility. It is for this reason that the epoxy resin systems sold commercially are generally the products of formulators who specialize in modifying the system with flexibilizers, extenders, diluents, and fillers to meet specific end-use requirements. It logically follows that it is important to adhere to the formulator's recommendations for use.

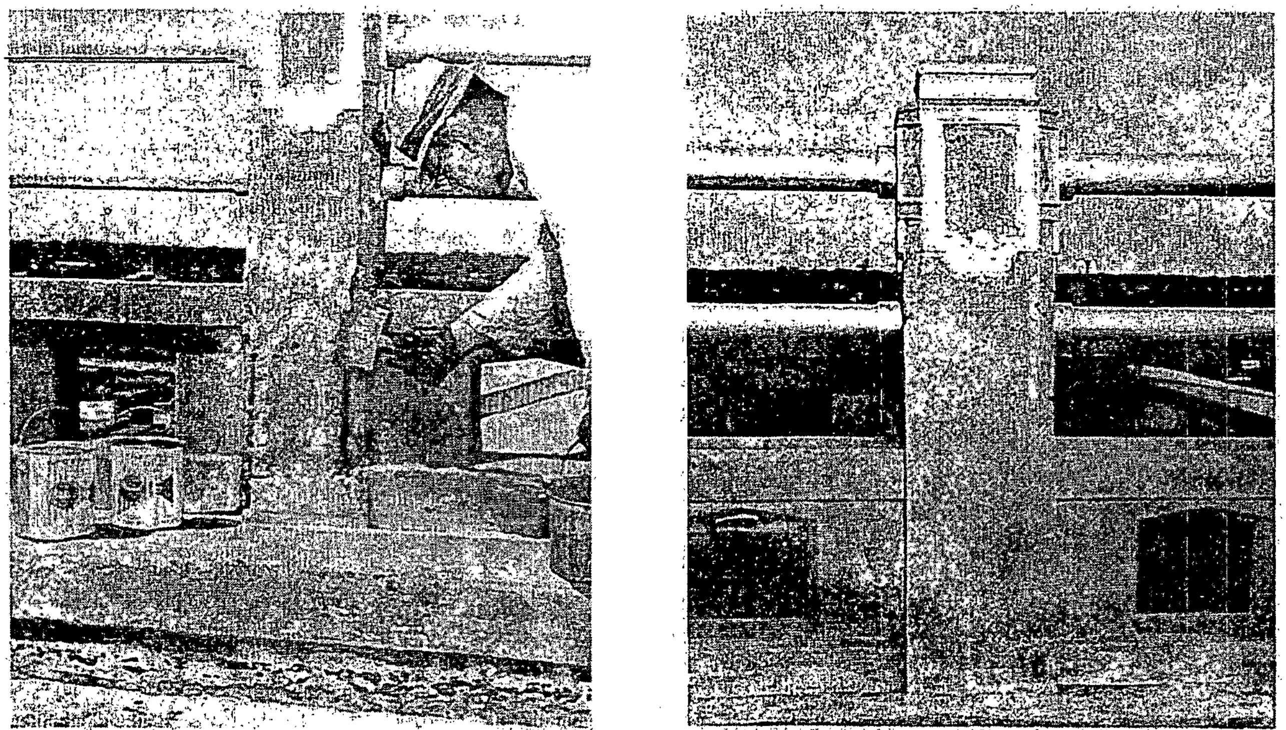


Fig. 4.4 -- Repair of a concrete bridge railing upright (courtesy Protex Industries)

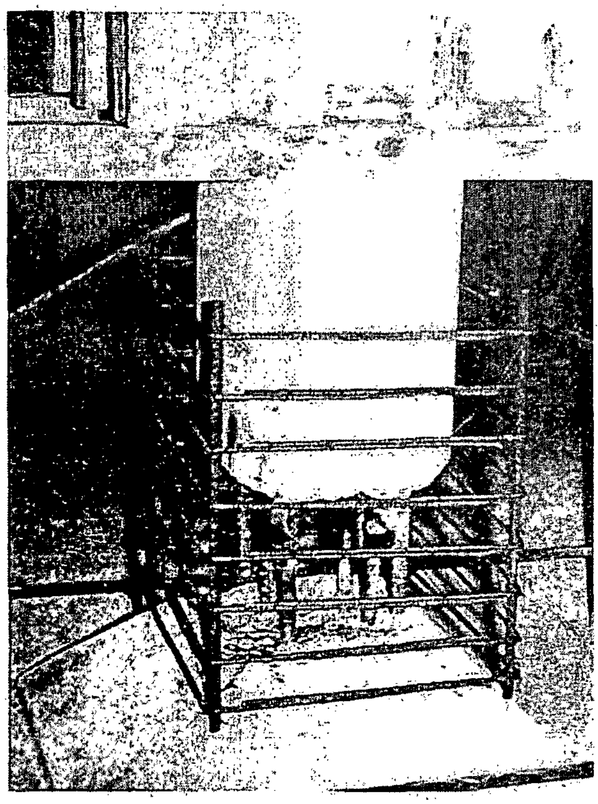


Fig. 4.5 -- Repair of a column-base connection. All exposed surfaces will be epoxy coated prior to casting new concrete (courtesy Protex Industries)

4.2 -- Protective coating

4.2.1 -- Because of their impermeability to water and their resistance to attack by most acids, alkalis, and many solvents, epoxy resin systems have been widely used as protective coatings for concrete. Such coatings may vary from sealers with thin films of 2 or 3 mil (0.05 or 0.08 mm) thickness to high-build coatings amounting to overlays. When used as a coating it is essential that the system be compounded so as to avoid or relieve excessive shrinkage and thermal stresses between the coating and concrete surface in order to prevent delamination of the coating through loss of bond or failure of the concrete.

4.2.2 -- Same of the most severe environments for the protective-coating type of applications are those of the highway bridge deck, industrial floor and parking deck surface for the purpose of preventing penetration of acid rain, chemicals, water and deicing solutions into the concrete. The coating may be used either as the wearing surface itself or may be covered by some type of asphaltic concrete overlay. In either case the coating should have mineral particles imbedded in the surface to provide adequate skid resistance for traffic when it is used as the wearing surface (see Section 4.4), and to provide bond when used beneath a bituminous overlay.

4.2.3 -- Many industrial environments involve exposure of concrete to acid, alkali, or solvents. Floors and walls located in such areas, as well as storage vats, can be made chemically resistant by the use of the epoxy resins.

4.3 -- Decorative coating

Epoxy resins serve exceptionally well as tile-like coatings; however, they surface chalk in outdoor exposure. In the case of wall surfaces, epoxy coatings present a hard, glossy surface and can withstand the abrasive and corrosive action of cleaning materials. Epoxy coatings are especially suitable for floors, car washing areas, and such outdoor locations as patios and porches, because of their good resistance to wear and moisture. In this connection, they make an appropriate coating for swimming pools, serving the additional function of sealing the concrete surface to the passage of water.

4.4 -- Skid-resistant coating

Concrete surfaces can be made highly skid resistant by the application of an epoxy coating into which mineral particles are embedded. Typical applications are treads of stairways, walkways in certain critical areas, and highway pavement surfaces near toll booths. As mentioned in Section 4.2.2, bridge decks are often given such a skid-resistant coating although the primary purpose for the treatment is often protection of the bridge deck itself.

4.5 -- Grout

Epoxy resins find wide application as grouting materials. The filling of cracks, either to seal them from the entrance of moisture or to restore the integrity of a structural member is one of the more frequent applications. Cracks of ¼ in. (6 mm) or less are most effectively filled with a pourable or pumpable epoxy compound, whereas an epoxy resin mortar should be used for wider cracks. Epoxy resins are useful as grouts for setting machine base plates and for grouting metal dowels, bolts, and posts into position in concrete.

4.6 -- Adhesive

4.6.1 -- Epoxy resin is a good adhesive for most materials used in construction, such as concrete, masonry units, wood, glass, and metals. However, many plastics, such as polyethylene, cannot be effectively bonded. Typical applications where epoxy resin has been used for cementing various materials to harden concrete are the joining of masonry units, precast concrete bridge deck girders, wood and metal signs, plastic traffic marker buttons, and the setting of dowels in preformed or drilled holes in concrete.

4.6.2 -- Epoxy resin is useful as the bonding medium between fresh and hardened concrete for such purposes as bonding a concrete overlay to an existing slab. For this purpose, it is essential that a formulation be used which will cure and bond properly under the moist conditions present in fresh concrete. Epoxy compounds can also be used as shear connectors for composite construction such as a metal beam and cast-in-place concrete slab.

4.7 -- Binder for epoxy mortar or concrete

Epoxy can be used as the sole binding material to form a resin mortar or polymer concrete. Such mixtures have been widely used for patching or repairing surface defects of many types of concrete structures, particularly highway bridges and pavements. Epoxy mortars and concretes are also especially adapted to repair of hydraulic structures where continued submersion lessens the problems of thermal expansion.

4.8 -- Underwater application

Epoxy resin formulations are now available which can be used to coat, overlay, patch or grout concrete and other construction materials in the splash zone or underwater in either brackish, fresh or salt water environments.

4.9 -- Epoxy-modified concrete

Most recently, epoxy resins when emulsified have found use as an additive to portland cement concrete and mortars to form "epoxy-modified concrete." These epoxy resin systems when added to concrete can increase adhesion of the concrete to concrete or to steel, increase strength, and reduce permeability. This use of epoxy resin is relatively new, but is growing.

CHAPTER 5 -- PREPARING SURFACES FOR EPOXY COMPOUND APPLICATION

5.1 - General

5.1.1 -- The preparation of surfaces to receive epoxy compound applications must be given careful attention as the bonding capability of a properly selected epoxy for a given application is primarily dependent on proper surface preparation. Concrete surfaces to which epoxies are to be applied must be newly exposed, clean concrete free of loose and unsound materials. All surfaces must be meticulously cleaned and be as dry as possible, and be at proper surface temperature at the time of epoxy application. When a substrate is still moist after the cleaning process, a moisture-insensitive epoxy formula should be used.

5.1.2 -- The method or combination of methods employed for satisfactory surface preparation will depend on the type, extent and location of the application. If preparation work involves the removal of concrete, such removal should be accomplished by well controlled mechanical means (see Section 5.3.2). Those surfaces or areas which do not require concrete removal in depth must be satisfactorily cleaned to remove all substances detrimental to bond of epoxy compounds. All equipment for supplying compressed air must be equipped with efficient oil and water traps to prevent surface contamination from the compressed air supply.

5.1.3 -- Prior to the application of epoxy resin compounds, it is generally considered necessary to field test the condition of the prepared concrete surface to receive the epoxy resin as well as the adhesion of the epoxy resin compound. Methods of field surface evaluation, determination of moisture percolation through the concrete, and of surface preparation are discussed hereinafter.

5.2 -- Concrete surface evaluation

5.2.1 *General*

5.2.1.1 Efforts to obtain good adhesion to a weak surface are futile since failure of the surface is likely to occur. Conversely, poor bonding can occur with perfectly sound surfaces if they are not properly prepared. Surfaces should be prepared according to ACI specifications ACI 503.1, 503.2, 503.3 and 503.4:

a) The surface must be strong, dense and sound.
b) The surface should be dry and clean, i.e., free from surface contaminants such as dust, laitance, oil, grease, and curing compounds.
c) The surface must be at the proper temperature to permit proper wetting by the epoxy application and to provide for prompt curing of the epoxy resin compound.
d) Moisture and water vapor may sometimes permeate through the concrete to the surface being treated, and must be recognized as a potential problem.

Evaluate moisture content or outgasing of the concrete by determining if moisture will collect at bond lines between old concrete and epoxy adhesive before epoxy has cured. This may be accomplished by taping a 4 x 4 ft (1 x 1 m) polyethylene sheet to concrete surface. If moisture collects on underside of polyethylene sheet before epoxy would cure, then allow concrete to dry sufficiently to prevent the possibility of a moisture barrier between old concrete and new epoxy.

5.2.1.2 To insure that the above conditions will be met, tensile test methods have been the principal means for field testing horizontal concrete surfaces. The same methods can be adapted for use on inclined or vertical surfaces. The tests serve either of two purposes:

a) To provide a convenient means for determining the bonding strength (adhesion) of the epoxy compound to a surface which has been prepared for bonding, or;
b) To detect a weakened concrete surface.

5.2.1.3 The test methods described in Appendix A are suggested as being suitable field tests.

5.2.2 *Evaluation of surface preparation*

5.2.2.1 Extensive use of the field test method described in Appendix A, Section A.1, has shown that where proper bonding has been obtained on properly prepared portland cement concrete surfaces, failure usually occurs in the concrete. Such failures indicate that the bond strength of the epoxy compound is greater than the tensile strength of portland cement concrete and satisfactory bonding of the epoxy compound has been demonstrated. At the same time, the magnitude of stress measured at failure of the concrete indicates whether the surface may be weak and requires further investigation. An evaluation of the quality of the concrete will be required to properly evaluate failures lower than 175 psi (1.2 MPa), recognizing that in some instances lower stress levels might be expected and acceptable.

5.2.2.2 The simplified field test method described in Appendix A, Section A.2, was originally developed to evaluate the sufficiency of surface preparation for an epoxy application and to detect relative differences in potential surface strength over the area to be repaired. This test method is also considered adequate to detect deficiencies in a prepared concrete surface. Although experience with the simplified method has not been as extensive as with the field test method (Section A.1) it is the simpler, less costly and less time consuming test of the two and, therefore, has the advantage of enabling more complete coverage of a surface area in a given length of time. Average values from the test method of Section A.2 can be used to assess the adequacy of the surface and the magnitude of stress measured at failure of the concrete indicates whether the concrete is sufficiently sound for the application. Failure of the portland cement concrete at stress levels be low 175 psi (1.2 MPa) generally indicates that the surface is suspiciously weak and further investigation of the surface may be necessary before full scale application of the epoxy compound.

5.3 -- Removal of concrete for repairs

5.3.1 -- The removal of the unsound or damaged concrete may be a part of rehabilitation work on structures involving epoxy applications (see Fig. 5.1). Such removal should be accomplished by well controlled mechanical means.

5.3.2 -- a first step in most concrete removal operations, it is generally recommended that the periphery of the required removal area be saw cut to a depth consistent with the type of repair. Saw cutting delineates the repair area and serves to essentially (if not totally) eliminate edge spalling and weaknesses that might be introduced by outlining the repair area with other types of equipment. It also serves to produce a shoulder against which repair material can be placed and smoothly finished, thus producing a neat appearing repair. The saw

Fig. 5.1 -- Removal operation of all unsound concrete in bridge deck down to top steel. Repair was made by bonding the fresh high early strength concrete patch to the old concrete using an epoxy adhesive at the interface (courtesy Adhesives Engineering)

cut line should be located several inches outside of the visual limit of the defect to insure that all defective concrete is removed and that the ultimate repair is bonded to sound concrete. The depth of saw cut should be at least ½ in. (13 mm) for epoxy-bonded portland cement concrete and mortar repairs; ¼ to ½ in. (6 to 13 mm) saw cuts are adequate for repairs employing epoxy mortars providing that removal of concrete within the repair area may be accomplished without spalling or otherwise damaging the concrete at the saw cut.

5.3.3 -- In preparing cutouts for popouts or small spalls wholly within a structural component (i.e., not involving joints, edges, or corners), very thin edges (sometimes referred to as feather-edging) may be permitted, but these should be at least ¼ in. (6 mm) deep thereby providing a shoulder of sufficient depth to permit a smooth finish. High frequency chipping hammers have been successfully used to make cutouts for this latter type of repair.

5.3.4 -- The concrete within the area delineated by the saw cut must be removed to a depth sufficient to expose sound concrete over the entire repair area. If doubt exists concerning the completeness of unsound concrete removal, it is best to remove the concrete to what may be a somewhat excessive depth to assure an eventually sound repair. Concrete removal should be accomplished mechanically with medium to lightweight air hammers equipped with appropriate cutting tools; or, for relatively large, horizontal areas, other equipment such as a mechanical scarifying machine may be appropriately and economically used.

5.3.5 -- Upon completion of the concrete removal operation, all newly exposed surfaces should be cleaned by an abrasive blasting method. When water is used as the abrasive blasting method the wet concrete should be allowed to dry (see 5.2.1.1). When forced drying is necessary, the surface may be dried with radiant heaters, or hot air blowers.

5.4 -- Surface preparation

5.4.1 *General* -- Proper preparation of any surface to receive an epoxy application is of primary importance no matter how carefully other phases of the application procedure have been performed. Bond failure can be expected if surface preparation is inadequate. Proper preparation of a given surface is an art and a science and must be given careful attention.

5.4.2 *Concrete surfaces*

5.4.2.1 *Recommended procedures* -- Those surfaces or parts of surfaces which do not require removal of concrete in depth must nevertheless be precleaned to remove all substances detrimental to bond of epoxy compounds, such as laitance, curing membranes, dust, dirt, grease, oils, fatty acids and other debris resulting from surface preparation operations. The cleaning method or combination of methods will typically include abrasive blasting techniques such as sandblasting, steel shot blasting, high pressure water blasting or flame blasting. Whatever preparations are used, the result should be a surface abraded to an extent that small aggregate particles are exposed but the surface should not be polished or be unnecessarily rough and it must be free of all surface contaminants. Care must be exercised to assure that any water used in cleaning is itself clean and also that no contaminants are present in any compressed air.

5.4.3 *Previously coated surfaces* -- Surfaces which have been previously treated with curing membranes, oils, silicones, paints, coatings (including epoxies) and other treatments may be encountered. Also, occasionally a bond or tack coat of an epoxy compound may harden before application of the top coat can take place. It is necessary to completely remove such materials and the best assurance of complete removal is by abrading methods. When there is doubt concerning selection of a cleaning method, it is considered good practice to make a small trial installation using one or more cleaning methods, applying the epoxy compound to be used in the work, and checking adhesion by one of the tensile test methods described in Appendix A.

5.4.4 *Metal surfaces*

5.4.4.1 *General* -- Metal surfaces must be cleaned and at the time of epoxy application be free of dust, dirt, oil, grease, rust, mill scale, weld splatter, and any other contaminant. Abrasive cleaning methods must be carefully considered. Adequate cleaning and surface profile are important factors in the abrasive cleaning selection. The method selected must be capable of cleaning the entire surface area, especially when vertical or overhead surfaces are to be cleaned. Precleaning is necessary if oil and grease deposits are on the surface. Mineral spirits, naphtha (100 F (38 C) minimum flash point) toluol (toluene) and xylol are satisfactory solvents for this purpose. Good ventilation and adequate safety precautions are necessary when solvents are used After precleaning and mechanical cleaning, any dust or debris created by the mechanical cleaning must be removed prior to epoxy application. A cleaned metal surface is very susceptible to corrosion, particularly in a humid atmosphere, so the work should be planned to permit the epoxy application as soon as possible after cleaning to prevent flash rusting which may occur within minutes.

5.4.4.2 *Test for adequacy of metal surface preparation* -- The sufficiency of preparation of a metal surface can be partially determined by use of the water-break-free test. The test is a check of the surface tension of the metal surface. Individual droplets of distilled water are applied to the surface with an eyedropper. Depending on the cleanliness of the surface the water will tend to remain in a hemispherical shape, or will immediately spread. If the surface is not clean, the water will not spread but will behave somewhat like a drop of water on wax paper or on a polyvinyl chloride sheet. If the surface is clean and the surface tension is low the water will spread into a thin film, wetting a relatively larger area. There are, of course, all degrees of wetting between the two extremes and anything less than apparent low surface tension should be suspect.

5.4.4.3 *Steel* -- Epoxy resins adhere well to steel. Steel surfaces should be abrasive blasted for good results and should be scrubbed thoroughly after abrading, washed well, and dried. Solvent precleaning is necessary if oil or grease is present. Adequate adhesion can often be attained using only solvent cleaning where there is bright metal with no mill scale. Surface adequacy should be checked by the water-break-free test.

5.4.4.4 *Galvanized metals* -- The surface treatment for galvanized metals is the same as that given for steel except that the surface need not be abrasive blasted unless there are signs of subsurface corrosion. The surface should be scrubbed thoroughly with a solvent (see Section 5.4.4.1), washed well with clean water, and dried. A good water-break-free condition should be obtained. Au improved bond can be obtained by etching with muriatic (hydrochloric) acid (20 parts by weight concentrated acid to 80 parts by weight water) for 3 or 4 min. After the etching treatment, the surface must be washed with clean water and dried.

5.4.4.5 *Aluminum* -- Adequate preparation of aluminum surfaces is difficult to achieve and care must be exercised to see that cleaning has truly been complete. The following procedures are designed for field use where abrasive blasting is not practical and for large surfaces that cannot be immersed in acid storage cylinders. The aluminum surface must be scrubbed with a nonchlorinated cleaner until a good water-break-free test is obtained and then etched with proprietary chromate treatment following manufacturer's directions and safety requirements. These treatments are generally plant operations.

5.4.4.6 *Copper and copper alloys* -- Copper and copper alloys are very difficult to bond, especially if high adhesive strength is desired, primarily because of rapid oxidation of the copper surfaces. Abrasive blasting is the preferred method of surface preparation, followed by thorough scrubbing with distilled water and drying. The following procedures are recommended as alternatives for field use.

5.4.4.6.1 Clean the surface with methyl ethyl ketone, then wash with acetone. Immerse the metal in or wash the surface with either: (a) 15 parts by weight ferric chloride, 30 parts by weight concentrated nitric acid, and 200 parts by weight clean water; or (b) 20 parts by weight ferric chloride, 50 parts by weight concentrated hydrochloric acid, and 30 parts by weight clean water. The surfaces should be washed or immersed in either of the above two solutions for 2 or 3 min, then rinsed thoroughly with clean water and dried. The cleaned prepared surface should be bonded or primed as soon as possible. The above concentrated acids should be handled with caution. They emit acrid fumes and can cause skin burns.

5.4.4.6.2 Copper is also readily cleaned with household ammonia (aqueous ammonia) which is more readily handled safely than are the foregoing acid compounds. The surface must be washed as before.

5.4.4.7 *Hazards* -- Many of the solvents and chemicals used for preparing metal surfaces are toxic, volatile, flammable or all three. Precautions associated with the particular materials used should be studied and carefully followed.

5.4.5 *Wood surfaces* -- Epoxy resin systems bond very well to wood surfaces. The surface of the wood should be free of sanding or filling dust. Such dust may be cleaned from the wood by wiping with an alcohol soaked rag or by an air jet.

In some woods and in some humid locations this degree of dryness may produce cracking of the wood and therefore be impractical. In such cases, tests should be made to determine the lowest acceptable moisture content to which the wood can be temporarily subjected and the epoxy formulator apprised of the existence of moisture in the application to obtain the best adhesive for the job. Before application, the wood surface should be filed with a rough file or rasp. Fine filing or sanding is not desirable since it will tend to fill the wood pores and inhibit thorough wetting by the epoxy. All filing residue must be removed before the application of bonding agents.

5.5 -- Temperature conditioning

5.5.1 -- The ease and effectiveness of epoxy application is greatly influenced by the temperature of surfaces on which the epoxy compound is applied. Epoxy compounds commonly in use today react most favorably when substrate temperatures are in the range of 0 to 140 F (-18 to 60 C). The conditions under which epoxy compounds are to be employed should be anticipated and provisions made for proper temperature conditioning of the epoxy.

5.5.2 -- When concrete and atmospheric temperatures exceed 90 F (32 C), difficulties may be experienced in application of the epoxy compound owing to acceleration of the reaction and hardening rates. If ambient temperatures are anticipated, work should be scheduled when the temperature is lower, such as in the early morning hours. At temperatures below 40 F (4 C), difficulties may occur due to deceleration of the reaction rates. The presence of frost or ice crystals may also be detrimental. If it is necessary to apply epoxy compounds at temperatures exceeding 90 F (32 C), the work should be supervised by a person experienced in applying epoxy at high temperatures. Epoxy systems formulated for elevated temperature are available.

CHAPTER 6 -- PREPARING EPOXY COMPOUND AND EPOXY MIXTURES FOR USE

6.1 -- General

Epoxy resins and their hardeners or curing agents are co-reactants in a chemical reaction. The proportioning of the resin and hardener is extremely important. The two must be combined in very specific ratios and they must be mixed very thoroughly to produce homogeneity within the mixed compound and insure complete reaction. Temperature of the components of the epoxy compound can greatly affect the mixing procedure and temperature conditioning may be required. An itemization of other handling precautions is given in Chapter 9.

6.2 – Temperature conditioning of material

In field work where low ambient temperatures exist it is helpful to raise the temperature of the components since both the epoxy resin and hardener exhibit a very marked lowering of viscosity as their temperatures rise. The lower viscosity makes mixing much easier and faster. A lower viscosity also reduces the tendency to whip air into the compound during mixing. Components that are above normal temperatures exhibit a shortened working life (pot life) of the mixed compound. In this case, precooling of the components before mixing may be desirable.

6.2.1 *Epoxy compound components*

6.2.1.1 *Heating* -- Several methods are available for heating the adhesive material to a temperature where effective mixing can take place. A simple method is to store the components indoors in a heated room or warehouse overnight prior to using and to remove them from the heated room shortly before use. When such storage space is not available, or a more rapid heating is required, ovens can be used or even simple heated field enclosures can be built. Still another method is to immerse the components in their containers in a hot water bath (see Fig. 6.1).

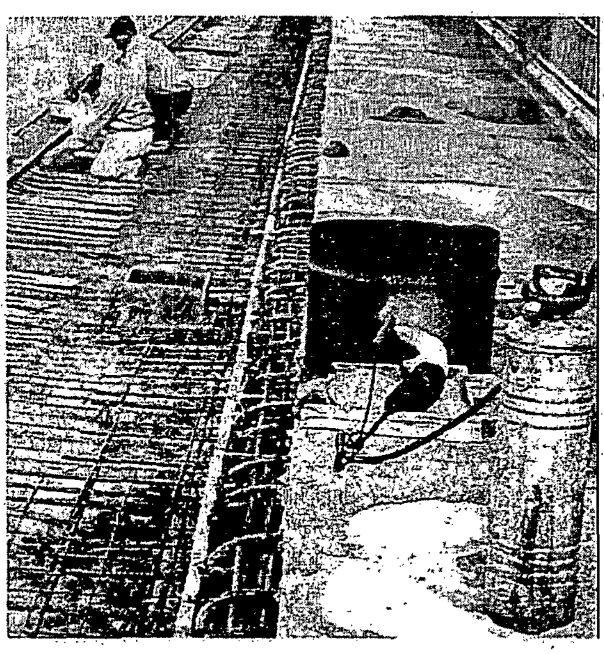


Fig. 6.1 -- Heating a water bath in which cans of epoxy resin and hardener can be temperature conditioned to facilitate use and proper hardening. In background workmen are brushing on an epoxy grout for bonding new plastic concrete to an old concrete section

When elevated temperature sources are used, care must be taken not to heat the components of the compound even locally to temperatures which might cause degradation of the material. The degradation temperature depends upon the specific compound. Epoxy component materials in general use in the construction industry will not be harmed by temperatures as high as 150 F (65 C). Care must be taken, however, not to shorten the working life too much by heating the material, since the temperature of the mixed compound significantly affects the working life or pot life of the materials.

6.2.1.2 *Cooling* -- When cooling is required to provide adequate working life, the following methods can be used: store in the shade, store in a refrigerator or refrigerated room, immerse containers in a bath of cold water.

In no case should the material be cooled to the extent that adequate mixing becomes difficult below about 60 F (15 C).

6.2.2 *Aggregate*

6.2.2.1 *Heating* -- Aggregates for epoxy mortars or concretes are often warmed before being added to the epoxy compound to make mixing easier, to help cure the epoxy mortar or concrete more quickly, or to drive off aggregate surface moisture. Aggregates, like the epoxy compound components, may be warmed by storing in a heated building, or by burners or radiation.

Care must be taken not to heat aggregates excessively because such heating can limit the working life of the epoxy mortar and change the characteristics of the cured epoxy compound The manufacturer's instructions for the specific epoxy compound should be followed; however, in general, aggregate temperatures over 120 F (49 C) should be avoided.

6.2.2.2 *Cooling* -- Aggregate which has been stored in the sun or has been dried may be considerably above normal ambient temperature and can substantially shorten the working life of epoxy mortar or epoxy concrete. Spreading the aggregate into thin layers and storing in the shade will accelerate cooling.

The aggregate should not be cooled to the extent that when combined with the epoxy mixing becomes difficult or that condensation of moisture from the air takes place.

6.3 -- Mixing and proportioning

6.3.1 *Components of epoxy* -- The required accuracy of proportioning varies with each epoxy compound. Some compounds can tolerate a wider variation but such variations should only be allowed if test data are available that demonstrate the complete effect of the variation on both mechanical and chemical resistance properties of the cured compound.

6.3.1.1 *Methods of proportioning* -- The most accurate method of proportioning is the use of preproportioned units supplied by the manufacturer so that the entire contents of both component containers are mixed together. If such packaging is not available, the components may be mixed together in the ratios specified by the manufacturer. These ratios may be expressed either by weight or volume.

6.3.1.2 *Automatic metering* -- Automatic metering equipment is available which is designed specifically for metering paste or liquid adhesive components. These metering devices are either "shot" type where successive specific quantities of each component are dispensed or the continuous type where the metering device regulates the flow rate of the epoxy components in the proper ratio.

6.3.2 *Epoxy mortar and epoxy concrete* -- Epoxy mortars are proportioned by adding the mixed epoxy compound to a specified amount of aggregate. This again can be done either by the use of premeasured packages or by weight or by volume.

6.4 -- Mixing

6.4.1 *General* -- Mixing of epoxy systems must produce a uniform and homogeneous mix.

6.4.2 *Components of epoxy* -- The components of the epoxy compound are first mixed in a manner which provides stirring or agitation which will effectively put them into a solution together.

6.4.2.1 *Batch mixing* -- The normal methods of providing the required agitation in small containers (one quart) (one liter) involve the use of spatulas, palette knives, or similar devices. For larger volumes, a mechanically driven tumbling type mixer is desirable (see Fig. 6.2). A paint mixing paddle driven by a low speed electric drill (see Fig. 6.3) may be used with the caution that paddle type mixers introduce air which can reduce adhesion and strength if cured with air still entrapped. Mixing should continue until the compound is homogeneous. This may take from 2 to 10 min, depending upon the viscosity, density and flow characteristics of the epoxy. Paste-like materials may also be mixed on flat surfaces with a trowel by repeated straight strokes which tend to drag one component through the other. Many compounds have their components distinctly pigmented so that mixing produces a third color. This is very helpful in determining when a complete mix has been achieved.

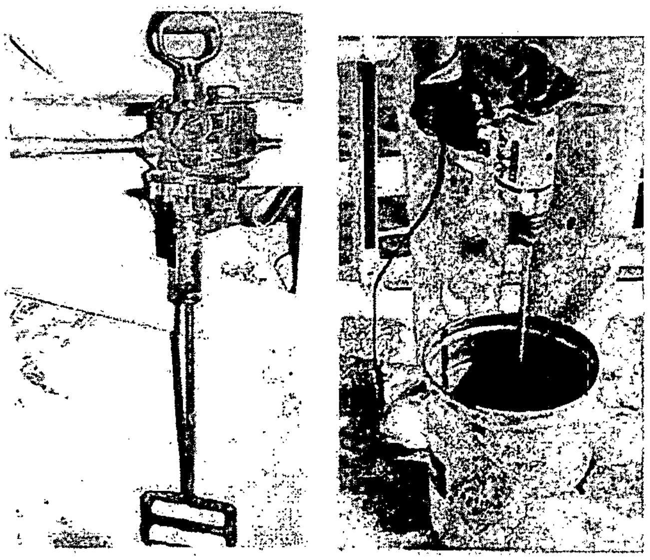
6.4.2.2 *Continuous mixing* -- Commercial equipment is available which will pump the epoxy compound components through a mixing head which forces the components to blend together (see Fig. 6.4). Mixing heads are frequently used with two component airless spray equipment for epoxy coatings and membranes.

6.4.3 *Epoxy mortar* -- The mixing of epoxy mortar requires that the epoxy binder thoroughly wet each and every one of the aggregate particles.

6.4.3.1 *Hand mixing* -- Although it is difficult to do, epoxy mortars can be hand mixed in small quantities using a spatula or trowel.

6.4.3.2 *Mechanical mixing* -- The most preferred method of mixing is by mechanical means. Larger quantities can be mixed in portland cement drum type mortar mixers or a mixing unit that blends the epoxy components and aggregate together into a homogenous mass.

Fig. 6.2 -- Rotating bucket mixing of epoxy compounds (courtesy Protex Industries)



(a) (b)

Fig. 6.3 -- Mixing of epoxy system components can be performed using a blade on a drill Shown here are (a) pneumatic and (b) electric drills (courtesy L. Mitchell, Consulting Engineer, and Sika Chemical Corp.)

6.4.4 *Epoxy (polymer) concrete*

6.4.4.1 *Order of addition* -- Epoxy polymer concretes are mixed in a similar manner to epoxy mortars with one exception. In relatively stiff mixes the finer aggregate should be added to the mixed epoxy binder before the larger aggregate. This order of addition will help prevent the tendency of the mix to "ball" by wetting out the finer aggregate that have more surface area. The finer aggregate should be added slowly.

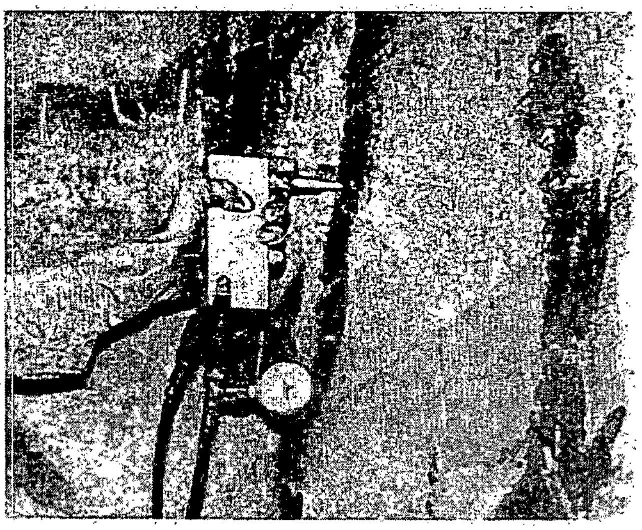


Fig. 6.4 -- A continuous mixing head gun being used for crack injection. Note that a thermoplastic surface seal was first applied, then through entry ports in the sealer the gun pumps the adhesive (courtesy Adhesives Engineering)

6.4.4.2 *Avoid segregation* -- Just as in portland cement concrete and asphaltic concrete mixes, care should be taken to avoid segregation of the aggregates prior to adding them to the binder material. If segregation does occur, the epoxy polymer concrete will not be uniform.

6.4.5 *Epoxy modified concrete*

6.4.5.1 *Order of addition* -- Mixing order and methods vary from one product to the next product. Each manufacturer's instructions should be carefully followed.

6.5 -- Cleaning of equipment

6.5.1 *General* -- Except in cases where disposable mixing equipment is used, special care should be taken to prevent the cured epoxy compound from bonding to mixers and containers. There are five general approaches which are used, either separately or in combination with one another.

6.5.2 *Solvents* -- The most widely used cleaning method is to immerse the tools and wash the containers prior to the epoxy compound gelling with strong semipolar solvents such as ketones and certain chlorinated solvents like methylene chloride. Mineral spirits or toluene may also be used, with greater safety, although not as efficient as the above solvents. In each case complete cleaning and drying are necessary before reuse. For emulsifiable epoxy systems, water can be substituted for solvents as a cleaning agent.

6.5.3 *Strippers* -- Once the epoxy compound has cured, commercial strippers may be used which will attack the cured epoxy compound. Some epoxy compounds are more readily attacked by strippers than others.

6.5.4 *Mechanical abrasion* -- Cured epoxy compounds can be abraded with the use of a grinding wheel, although the process is generally slow if the buildup of material is large.

6.5.5 *Burning* -- Most epoxy compounds will burn if their temperature is raised to about 500 F (260 C). Thus, metal tools and containers which might not be damaged by these temperatures can be cleaned in this manner. Because the products of combustion can be harmful if inhaled, ventilation must be provided.

6.5.6 *Preventing the bond* -- An alternative technique for maintaining equipment is to prevent a bond of the cured epoxy to the tools or containers in the first place. Release agents such as dry silicone sprays, spray-on films, and special wax emulsions are useful where excessive abrasion is not encountered. Care should be taken that the type of release agent used does not contaminate the epoxy compound and interfere with proper cure or bonding.

6.6 -- Caution on solvents and strippers

The common solvents and strippers may be highly toxic and flammable. The reader is referred to Chapter 9 for a discussion of precautions which must be taken in handling these chemicals.

CHAPTER 7 -- APPLYING EPOXY COMPOUNDS

7.1 -- General considerations

7.1.1 -- The applicator should be assured that the epoxy to be applied has the proper rate of hardening and viscosity for the job. Both are affected by the temperature at which the epoxy is applied (Section 6.2.1), and both can affect the ultimate thickness of the epoxy layer. The amount of sag and thickness that will be achieved in the adhesive layer also depends partly on whether it is applied to a vertical surface, to the top of a horizontal surface or the bottom and whether the surface is flat or irregular.

7.1.2 -- Highly porous concretes or concrete made of very absorptive aggregate may absorb enough epoxy to starve the glue line. Such concrete should be given a first seal coat of the same epoxy adhesive to penetrate into the absorptive aggregate. Allow the seal to become tack free and then apply the second coat. To assure adhesion most epoxy manufacturers recommend that subsequent coats be applied within 24 hrs. If a longer time is required before recoating, sandblast the last coat to remove the gloss and immediately apply the next coat.

7.1.3 -- Spray applications are suitable for many purposes, but they do not always establish a full, uniform contact as do brush and roller applications. The brush and roller methods of application are preferred. However, they require more time to apply and it is harder to maintain the desired thickness of the epoxy application on cold surfaces.

7.1.4 -- Intimate contact is essential for maximum effectiveness and all necessary measures should be taken to assure complete wetting. Thorough wetting by the epoxy may be more difficult to achieve with an epoxy mortar or concrete than with a plain binder.

7.2 -- Specific applications

7.2.1 *Skid-resistant protective aggregate broadcast overlays*

7.2.1.1 *General* -- The proper epoxy resin system should be selected for the expected application temperatures and in-service environmental conditions. The following aggregates are suitable to provide skid resistance: aluminum oxide, silicon carbide, silica sand, blast furnace slag, roofing granules, and trap rock.

7.2.1.2 *Application methods* -- Two acceptable ways to apply an aggregate broadcast overlay are in common use.

7.2.1.2.1 One method is to apply one coat of mixed resin first, using brushes, rollers, brooms, screeds, or spray equipment, then, within 1 to 10 mm, broadcasting the aggregate by hand or machine, taking care not to cause "shoving" of the resin from the impact (Fig. 7.1-7.3). The aggregate determines the final texture or smoothness and should be applied at about the rate of 1.5-14 lb/yd^2 (0.8-7.3 kg/m^2).

7.2.1.2.2 Another method is to apply two or three coats of resin where protective treatment is required against deicers or other aggressive agents. The aggregate is added to the second and third coat as in Section 7.2.1.2.1 above. When the epoxy is tack free the excess (loose) aggregate is removed and the next coat is applied over the remaining aggregate, encapsulating the aggregate. A three coat system provides better protection. This method is known as a "seeded system."

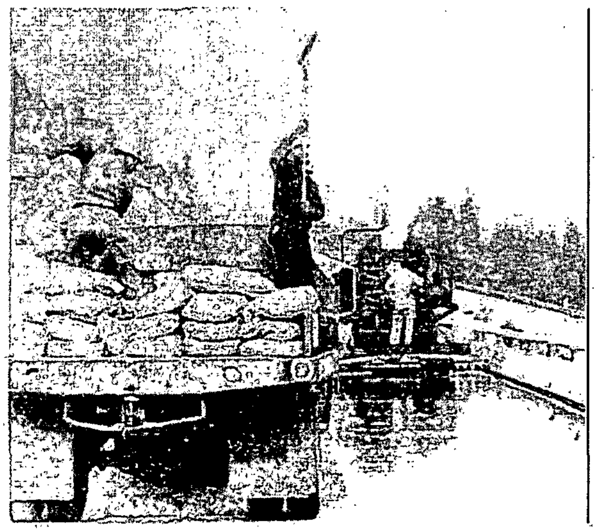


Fig. 7.1 -- Epoxy seal and skid resistance binder coat sprayed onto pavement by automatic mixing, metering and application machine followed by sand broadcasting (courtesy Adhesives Engineering)

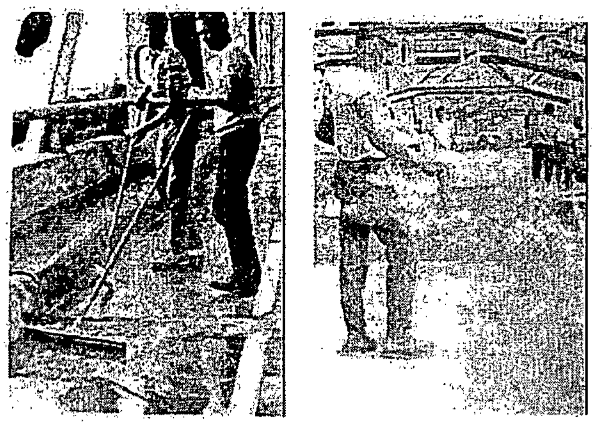


Fig. 7.2 -- Squeegee and roll on application of seal coat followed by skid resistant layer spread by a hand seeder (courtesy Sika Chemical Corp.)

Fig. 7.3 -- Skid resistant calcined bauxite being applied by an automatic seeder for improved uniformity of coverage (courtesy Adhesives Engineering)

7.2.1.3 *Bridges, parking decks and pavements*

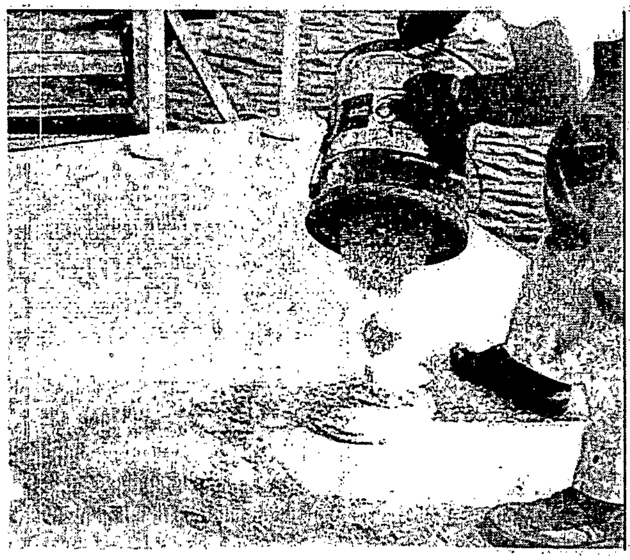
7.2.1.3.1 Bridge decks, parking decks, and pavements have been treated or surfaced with epoxy materials in many ways. These can be categorized as:

a) Aggregate broadcast overlays (covered in Section 7.2.1)

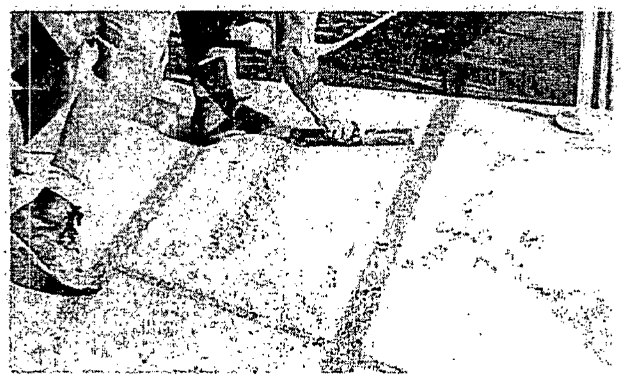
b) Epoxy polymer mortar overlays (covered in Section 7.2.2)

c) Surface and penetrating sealants (covered in Sections 7.2.2 and 7.2.3)

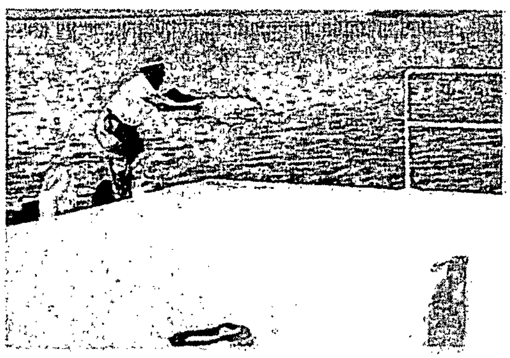
7.2.2 *Epoxy polymer mortar overlays* -- The general se-



(a)



(b)



(c)

Fig. 7.4 -- Mortar overlay sequence: (a) epoxy mortar is dumped onto primed surface, (b) mortar then troweled onto surface restoring deck to grade, (c) epoxy seal coat is squeegeed onto cured mortar surface and a skidproof finish of sand broadcast over fresh epoxy

quence for installing epoxy polymer mortar overlays is shown in Fig. 7.4.

7.2.2.1 Surface evaluation and preparation should follow the same procedures as set forth in Chapter 5. Joints and cracks should be evaluated and repaired as outlined in Section 7.2.5. In the case of working cracks or joints, a joint should be made in the epoxy overlay so that flexible joint sealants may be used. Generally speaking, deep holes should be filled with epoxy mortar and properly compacted and the patch brought within ¼ in. (6 mm) of the final grade before the epoxy mortar overlay is applied. The patching procedures in Section 7.2.4 should be followed. Since the epoxy mortar must adhere to any patching mortars used, the recommendations of the manufacturer of the patching mortar must be followed.

7.2.2.2 Polymer epoxy mortars used for overlays consist of a liquid binder filled with from 4 to 7 parts (by weight) of a graded aggregate to one part of binder. The amount of aggregate used depends on particle shape and void characteristics. A single gradation of fine aggregate has been used with some resin systems. Single gradation aggregate contain a larger volume of voids than graded aggregate. Therefore, to obtain a nonporous mortar when using single gradation aggregate, high resin contents are required. From a theoretical standpoint, just enough binder should be used to fill all the voids in the aggregate matrix. This amount produces optimum physical properties, lowest cost, and lowest shrinkage. The maximum amount of aggregate used is governed by the void content of the aggregate. For freeze-thaw durability and chemical resistance, the air voids in the finished mortar should be less than 12 percent.

The thermal coefficient of expansion of epoxy resins is much greater than that of concrete, but the thermal coefficient of aggregate is similar to that of concrete; consequently the maximum quantity of aggregate consistent with freeze-thaw durability and workability should be used to reduce the stresses that develop between epoxy mortar and concrete during changes in temperature.

ASTM C 884 can be used to anticipate problems caused by the differential thermal expansion and contraction of epoxy mortars and portland cement concrete.

7.2.2.3 The binder system itself consists of two or more liquid components that are combined and thoroughly mixed prior to incorporation of the aggregate. Once the components are mixed, chemical reactions start immediately and the application procedure must be followed to completion. Pot life and working time will vary considerably, depending on the system, the temperature, and the handling procedure. An applicator must therefore be thoroughly familiar with the particular system being used before attempting an application of any large size.

7.2.2.4 For any mortar system to perform, it must bond strongly and permanently to the concrete surface. To do this, it must completely wet the surface, leaving no voids or dry areas at the interface. To assure this complete wetting it is the usual practice to apply a prime coat of the clear binder system to the prepared surface just prior to application of the mortar. This thin primer may be applied with rollers, by spray equipment, or with squeegees if the surface is relatively smooth. Brooms and large brushes have also been used.

7.2.2.5 After the binder is mixed it should be added immediately to the aggregate in a mortar mixer. In most cases the aggregate specified will be a clean, dry, properly graded silica sand. A very workable sand has a small amount of fines passing the No. 100 (149-micron) sieve and usually has little or no material retained on the No. 8 (2.38 mm) sieve (see Section 7.2.4.1). The grading should be uniform between these limits. Formulators may supply special sands which they have found to be optimum for their systems.

7.2.2.6 It is important to control the temperature of the aggregate, both before mixing and during that part of the mixing cycle that precedes the addition of the binder. If the mix gets hot due to the sun, hot equipment, or frictional heat from mixing, the curing reactions will be accelerated and premature hardening may occur. In cool weather the aggregate is sometimes preheated in order to accelerate the cure. Once everything is in the mortar mixer, mixing should continue only long enough to get a completely wetted aggregate and a uniform mix. Extending the mixing time will develop heat and shorten the time available for spreading. Viscosity will also increase making the system less workable. As soon as mixing is complete the mortar should be dumped on the surface in the area where it will be applied and spread out into a relatively thin layer. This helps to dissipate exothermic reaction heat and extend work time.

7.2.2.7 After the mortar is placed on the uncured primed surface and spread out with rakes or hoes to the approximate thickness desired, a vibrating screed operating on rails set to give the desired thickness is passed over the mortar. For bridge and parking decks and highway pavements the resulting surface is usually satisfactory. Touchup can be done with trowels if necessary. The usual practice is to then broadcast a light layer of sand over the surface to eliminate any slick spots or resin-rich areas. This not only improves the appearance but assures uniform antiskid characteristics. Minimum thickness for an overlay applied in this manner is ¼ in. (6 mm). These guides can vary depending on requirements of the application and the system used.

7.2.2.8 In areas where it is impractical to use a screed or if a fine finish is desired, the mortar can be troweled either by hand or with power equipment. This technique approaches an art and the variations are specific for each formulation. The use of solvents, oils, or other troweling aids is prohibited, as these materials weaken the system and lead to early failure.

Prompt cleanup of all equipment and tools is a must (see Section 6.5). As epoxy systems cure, they become insoluble in practically all common solvents. If solvents are to be used, as recommended by the formulator, they must be used before the epoxy cures. If the epoxy cures on the equipment, cleaning must be performed with a hammer and chisel or with blowtorch and scraper. Caution in all aspects of cleanup is emphasized (see Chapter 9).

7.2.3 *Surface and penetrating sealers for waterproofing* -- The sealing of surfaces for waterproofing should conform to ACI 515.1R. Working joints should be sealed in accordance with ACI 504R. If there are cracks that require repair by epoxy compounds before sealing the surface, they should be repaired in accordance with appropriate provisions of Section 7.2.5.

7.2.4 *Patching*

7.2.4.1 Epoxy patches may be used either to repair an exposed surface or to prepare a surface to receive an epoxy overlay. For thin patches a sand should be added to the epoxy that has a gradation falling within the range given in Table 7.1. For patches of ¾ in. (19 mm) or greater thickness the sand should be combined with a coarse aggregate whose maximum size is one-third the thickness of the patch or less. The use of coarse aggregate reduces the coefficient of thermal expansion. The binder to aggregate ratio, parts by volume, is generally less than 1-5, depending on the grading of aggregate.

Table 7.1 -- Sand grading for thin epoxy patches

U.S. standard, sieve No.	Size of opening	Amount passing, percent
4	4.76 mm	100
8	2.38 mm	95-100
16	1.19 mm	60-80
30	595 μ	35-55
50	297 μ	15-50
100	149 μ	5-15
200	74 μ	0-4

7.2.4.2 The following steps should be followed:

7.2.4.2.1 Prepare patch areas following guidelines given in Chapter 5, extending the newly exposed abrasive blasted surface beyond the patch perimeter by 1 ft (300 mm).

7.2.4.2.2 Prime all newly chipped or abrasive-blasted concrete with the neat binder epoxy. Evenly apply the epoxy to wet all surfaces including the steep sides and the reinforcement steel. Do not allow the epoxy to puddle in the low areas of the hole. The epoxy mortar must be placed before the prime coat becomes tack free.

7.2.4.2.3 Place the mixed epoxy patching material in the hole. If the depth of the hole is greater than 6 in. (150 mm), place each lift no thicker than 6 in. (150 mm) and allow lift to cool before placing the next lift. Troweling of each lift is not necessary. On the final lift, place the epoxy mortar thicker than the surrounding concrete edges. Compact and screed the surface. For smoother surfaces, trowel the epoxy until the desired smoothness is obtained. Follow the epoxy manufacturer's recommendation for the maximum depth of lift and maximum time of application between lifts. If the maximum time is exceeded, then the surface of the previous lift may require mechanical abrasion.

7.2.4.2.4 All texturing of the epoxy surface should be accomplished by the screeding or troweling techniques, not by adding sand to the uncured epoxy mortar. Sprinkling sand on the surface of the patch to provide added skid properties often shows rubber build-up faster than the surrounding surfaces.

7.2.4.3 When a faster cured patching system is required, select a product that has the desired capabilities. Heating of the concrete surface of the newly placed epoxy mortar to shorten the cure time is often less than cost effective. Curing the epoxy below the manufacturer's recommended low cure temperature will probably result in failure. Follow the manufacturer's instructions for best results.

7.2.4.4 On vertical or overhead repairs, select an epoxy mortar that is capable of hanging in ¾ to 1 in. layers (19 to 25 mm). Carefully follow the epoxy manufacturer's recommendations for temperature controls and sand gradation.

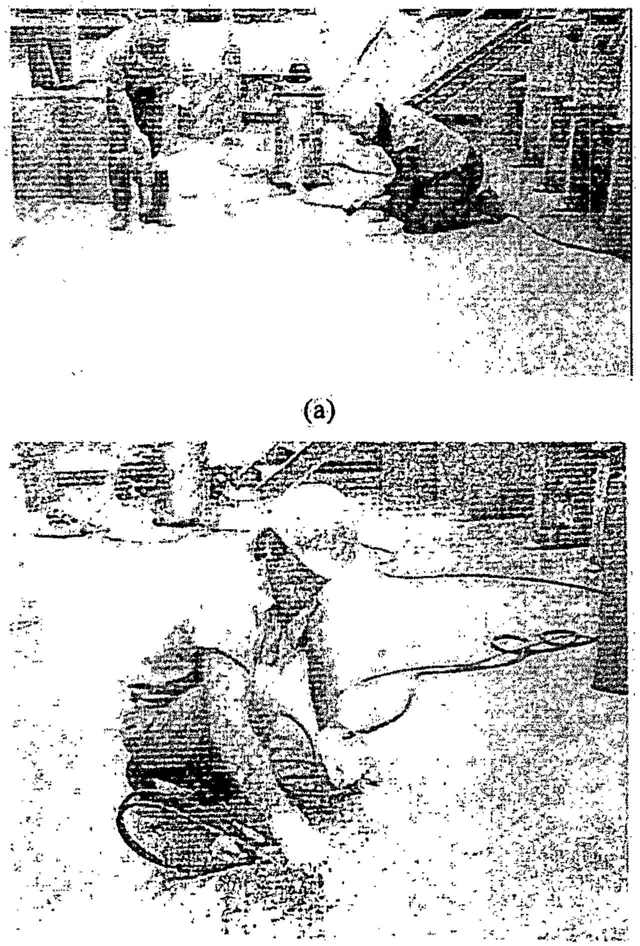
7.2.5 *Grouting and sealing cracks and joints* -- ACI 504R describes practices for sealing of joints, including joint design, material available, and methods of application. Fig. 7.5 shows one method for sealing cracks. Before grouting or sealing structural cracks it should be determined if the crack is active, and if so, what are the causes? ACI 224.1R discusses causes and evaluation of cracks in hardened concrete. Cracks that are active should be treated as described in 504R. However, most cracks are dormant and should be low pressure epoxy injected to fill the entire void and return the concrete, including the reinforcement steel, to its original monolithic design state.

7.2.5.1 *Surface seal* -- The first step in filling a crack by injecting liquid epoxy resin adhesive is to provide a surface seal on all faces of the crack so that the liquid resin will not leak and flow out of the crack prior to gelling and curing. If unexposed faces of the concrete cannot be reached, crack repair by pressure injection is extremely difficult unless special steps are taken. Where the crack face cannot be reached but where there is backfill or where a slab on grade is being repaired, the backfill material or subbase material is often an adequate seal in itself. There are two methods used to provide this seal:

7.2.5.1.1 *Routing* -- Creating a V-groove by routing is not required unless the surface concrete at the edge of the grade has deteriorated. Routing is then required to remove the deteriorated concrete down to a sound substrate. The crack is vacuumed to remove debris and dust. The surface ports are placed and the routed void is filled with epoxy mortar or a non-sag epoxy adhesive.

7.2.5.1.2 *Surface seal* -- A non-sagging epoxy adhesive is applied to the face of the crack completely bridging the crack. An epoxy adhesive that sets at the desired interval should be selected. Slow to rapid curing adhesives are available in clear or pigmented formulas. In some cases a thermoplastic adhesive is used where the sealing material is applied at an elevated temperature.

7.2.5.2 *Entry ports* -- To inject the adhesive material through the surface seal, entry ports must be provided. Three methods are in general use:



(a)

(b)

Fig. 7.5-(a) Prior to crack injection holes for entry ports are drilled into debris-filled cracks and vacuumed to remove contaminants, (b) injection of epoxy compound is then performed on each part (courtesy Adhesives Engineering)

7.2.5.2.1 *Vacuum drilled holes - entry ports inserted* -- A hole is drilled with a vacuum chuck or core bit over the crack to a depth of ½ to ¾ in. (13 to 19 mm). The hole diameter varies among entry port manufacturers. Most are typically about 5/8 in. (16 mm) in diameter. It is important to select a vacuum bit that is compatible in diameter size with the entry port diameter. The vacuum bit is attached to a vacuum chuck, which has an exit port to which a vacuum hose connecting to a wet-dry vacuum unit is attached. As the hole is being drilled, all dust and debris are removed from the hole during the drilling process, leaving a clean, uncontaminated open crack. After drilling, the entry port is placed into the hole and the entire exposed crack surface sealed and all entry ports are anchored with an epoxy adhesive.

7.2.5.2.2 *Bonded flush fitting* -- When the cracks are V-grooved or the concrete surface is wet, a method frequently used is to place an entry port called a tee over the crack. The tee is bonded to the concrete surface with the epoxy adhesive at the time of covering the entire crack with the surface sealer.

7.2.5.2.3 *Interruption in seal* -- Another system of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

7.2.5.3 *Mixing the surface seal and injection adhesives* -- This is done either by batch or continuous methods. In batch mixing the epoxy components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of epoxy that can be used before the material begins to gel. When the epoxy material begins to gel, its flow characteristics change and pressure injection becomes more and more difficult. In the continuous mixing system the two liquid epoxy components pass through positive displacement metering pumps, prior to passing through an automatic mixing head. This system allows the use of fast-setting adhesives that have a short pot life.

7.2.5.4 *Pumping the injection adhesive* -- To fully fill the crack with mixed injection adhesive, some means of providing pressure and flow is required. The following methods are typical.

7.2.5.4.1 *Pressure pot* -- A frequently used method is that of forcing the material with air pressure from a standard paint pressure pot through hoses into the entry port. The injection adhesive may be placed in a disposable container within the paint pot.

7.2.5.4.2 *Caulking gun, air or hand actuated* -- A common method is to use a caulking gun cartridge filled with mixed adhesives.

7.2.5.4.3 *Pumps* -- Another method is to pump the injection components separately through positive displacement pumps. The resin and curing agent can be either gravity-fed or force-fed to the pumps. The pumps force the individual epoxy components through the hoses to a hand-held mixing chamber that properly mixes the material into the finished curable adhesive. This method of pumping and mixing eliminates problems caused by short pot life.

7.2.5.5 *Injecting the adhesive* -- The mixed adhesive enters the injection port through a connection fitting appropriate to the type of port fitting which has been attached to the concrete. The adhesive is injected into the crack through successive adjacent ports. Care must be taken to inject the adhesive at such a rate that the pressure required to inject does not exceed that pressure which the surface seal can tolerate or which might damage the structure. Low pressure pumping, typically in the range of 14 to 21 psi (1 to 1½ MPa), is desirable to properly allow the entire fissure to be filled.

7.2.5.5.1 *Horizontal surfaces* -- In a horizontal member, such as a floor, injection proceeds from one end of the crack to the other through adjacent ports. When possible, the crack is injected from the bottom of the horizontal concrete member filling upward.

7.2.5.5.2 *Vertical surfaces* -- In vertical surfaces the injection takes place from the bottom up through adjacent ports. Care must be taken not to entrap air or water in the crack during the filling process.

7.2.5.6 *Making sure the crack is filled* -- During injection operations it is very difficult to be sure that the crack is completely filled. Personal experience of the applicator and low pressure pumping techniques are very important. Ultrasonic testing methods to determine whether the crack has been filled have been perfected but the limited dissemination of this technology restricts the availability of this control method. The only practical method widely available is by drilling concrete cores. One or the other of these methods is absolutely necessary when assurance of a sound structural bond is required.

7.2.5.6.1 *Order of injection* -- The crack must always be filled through successive ports starting with the lowest one. Injection must continue through one port until the epoxy adhesive starts flowing out of the adjacent port in a steady stream without air or water. At this point, the first port must be capped off and injection started on the port which has begun to show adhesive.

7.2.5.6.2 *Location of ports* -- Entry ports should be spaced far enough apart to assure that when the adhesive material shows at the adjacent port it has completely filed the crack to its full depth. Normally they would be spaced about as far apart as the depth of penetration desired

7.2.5.6.3 *Calculation of theoretical amount required* -- A useful technique in helping to indicate whether the crack is filled is to estimate the theoretical void by measuring the width of the crack and the dimensions of the concrete member. Injection proceeds until the theoretical amount has entered the crack plus an allowance (50 percent additional has proved suitable). If the theoretical amount cannot be injected, the cause should be determined. The possibility of undetected voids of undetermined size connecting with a crack must be recognized and the gross amount of material to be injected determined and limited.

7.2.5.6.4 *Maintaining pressure* -- If pumping pressure cannot be maintained in a crack that is otherwise apparently full, the reason should be determined. Inability to maintain pressure indicates that the adhesive material could be leaking out through a broken seal or vent hole, or could be draining into connected cracks, or passing through the member into voids on the other side.

7.2.5.7 *Removing the surface seal* -- After the injected adhesive has cured, the surface seal should be removed by grinding or whatever means are necessary. Fittings and holes at entry ports should be painted with an epoxy patching compound.

7.2.5.8 *Adhesive properties* -- Ideally, the adhesive used should be compounded for pressure injection into cracked concrete. It should be pumpable, be readily assimilated into small cracks by capillary action, and should have the capability of bonding to wet concrete above 33 F (1 C). On dry concrete surfaces it should also be capable of wetting out a layer of dust or concrete fines that might exist inside the crack. It should also be capable of maintaining a low viscosity when pumped into colder (0 F [-18 C]) concrete and fully cure at the lowest substrate temperature during the curing period. The best bond is obtained to dry crack surfaces.

7.2.5.9 *Contaminated cracks* -- Cracks which have been contaminated with oils, grease, food particles or chemicals present special problems. Unless the crack can be cleaned sufficiently, to allow adequate adhesive penetration and bond, pressure grouting will not be an effective repair procedure.

Dirt or fine particles of concrete also prevent penetration. They must be removed in larger cracks by flushing with water, followed by drying or blown out using compressed air.

7.2.6 *Bonding fresh concrete to hardened concrete*

7.2.6.1 *General*

7.2.6.1.1 -- Epoxy bond coats must be manufactured specifically for the purpose of bonding fresh portland cement concrete to existing hardened concrete. They should be thixotropic (to avoid pooling) and able to hold at least a 15 mil (0.4 mm) film without sagging. Although an epoxy bond coat will provide satisfactory adhesion prior to the time the film is tacky to the finger, it usually is desirable to delay placement of new concrete until some degree of tack has developed. (Note: When vibrators are used it is essential to allow the epoxy bond coat to reach an appreciable tack, since vibration can, by emulsifying a fluid epoxy bond coat, displace it from the existing concrete to the detriment of the bond.) If, inadvertently, the epoxy bond coat reaches a soft rubber-like stage (no tack) prior to the placement of the new portland cement concrete, a second application of the epoxy bond coat is required. Also a highly viscous bond coat may not adequately penetrate the base concrete and eventual bond strength will be reduced. The concrete should be a nonbleeding mix of not more than 2 in. (50 mm) slump for best results.

7.2.6.2 *Formed concrete* -- The concrete surface should be prepared as in Section 5.4. Forms suitable for placement of the new concrete should be made in a way that permits them to be assembled and put in place within the time limit imposed by the gel time of the epoxy bond coat. The epoxy should be mixed in the proportions recommended by the manufacturer, and applied with a stiff brush roller or spray equipment. Sufficient force should be used to assure thorough and complete wetting of the concrete and exposed aggregate. Coating of the reinforcing steel improves adhesion and provides added protection. The forms should then be placed, and filled with portland cement concrete in the usual manner, before the epoxy becomes tack-free.

7.2.7 *Bonding hardened concrete to hardened concrete*

7.2.7.1 Before bonding, both surfaces should be thoroughly cleaned and both should be dry (see Chapter 5). Epoxy compound should be applied to both surfaces. If the surfaces are vertical, thixotropic epoxy compound should be used. The compound should be worked into the surfaces thoroughly with a brush. For horizontal surfaces an epoxy should be used which is so formulated as to be absorbed to a greater depth. It can be applied by brush, roller, or spray.

7.2.7.2 The surfaces should be pushed firmly together, and clamped in place if there is any likelihood of movement in the first several hours. Provision should be made to prevent any leakage from the joint during the hardening period.

7.2.8 *Reflectorized traffic points* -- Some traffic paints are essentially pigmented adhesives for bonding glass beads or reflecting aggregate. These should be applied to clean, dry surfaces during a period when traffic can be kept off the pavement for a period sufficient for the epoxy to attain some strength -- usually a minimum of about 3 hr. The normal coverage should be about 100 ft^2/gal. (2.5 m^2/L). About 6 lb (2.7 kg) of glass beads should be evenly distributed over 100 ft^2 (9.3 m^2) of fresh paint.

7.2.9 *Coatings to prevent chemical attack* -- When epoxies are used as coating, they should be used in accordance with ACI 515.1R.

7.2.10 *Bonding concrete to steel* -- Before applying epoxy to steel, the steel must be prepared as detailed in Section 5.4. The epoxy should be applied to the steel if it is to be bonded to fresh concrete, and the concrete placed while the epoxy is still tacky, as in Section 7.2.6. If the steel is to be bonded to hardened concrete, the epoxy should be applied to both surfaces. The materials should be clamped or held together with just sufficient force to prevent movement during hardening. Excessive force should be avoided to prevent introduction of stresses when the clamps are removed. Provision should be made to prevent epoxy from running out of the joint.

7.2.11 *Bonding concrete to aluminum* -- Aluminum surfaces should be prepared as in Section 5.4.4. The same procedures are used as in bonding concrete to steel. It should be noted, however, that aluminum is susceptible to attack by the alkalies of concrete, as well as by calcium chloride if it is present. Such attack can be prevented in most circumstances by insuring a pinhole-free film on the aluminum surface. Two coats should first be applied to the aluminum and allowed to set before applying the coat that bonds it to the concrete. The second and third coatings should be applied while the previous one is still tacky. Uncoated aluminum must never be allowed to come into contact with reinforcing steel in concrete, because it sets up a galvanic couple that results in corrosion of metal followed by fracture of the concrete.

7.2.12 *Bonding concrete to other metals* -- Other metals to be bonded to concrete should be prepared as in Section 5.4.4. Precautions should be taken to prevent galvanic couples (Section 7.2.11). Epoxy should be applied intimately to the surface. Fresh concrete, or hardened concrete with a freshly applied epoxy coating, should be brought into contact with the prepared surface while the epoxy is still tacky. An example of bonding concrete to metal is shown in Fig. 7.6.

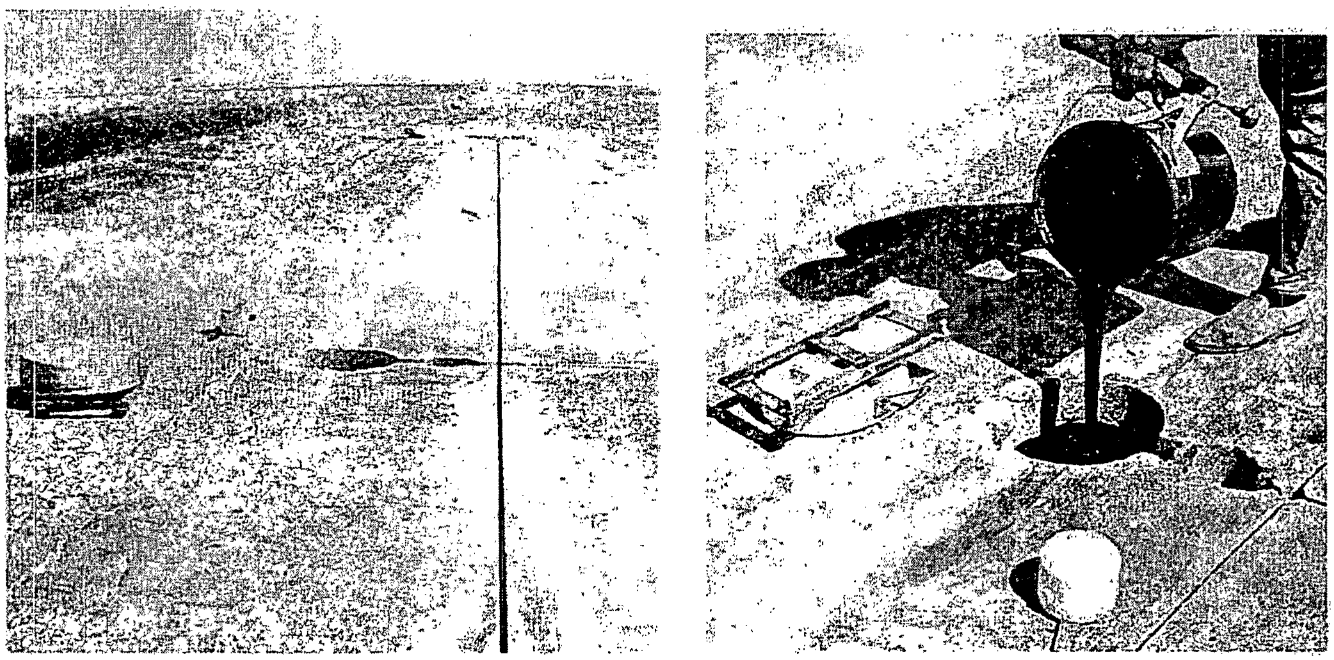


Fig. 7.6 -- Embedment of center line lighting in runway. Holes were cored, mixed epoxy poured therein and the light and junction boxes set and grouted (courtesy Adhesives Engineering)

7.2.13 *Bonding concrete to wood* -- For surface preparation, see Section 5.4.5. The epoxy should be applied to both the wood surface and the concrete surface if the wood is to be bonded to hardened concrete. If it is to be bonded to fresh concrete, the epoxy should be applied to the wood surface. The wood should be protected against absorption of moisture during the concreting operation so that no dimensional changes will occur in it at this time. Because of high volume changes on alternate cycles of wetting and drying some woods are not suitable for bonding to concrete.

7.2.14 *Bonding concrete to plastics* -- Bonding concrete to plastics presents special problems. Tests should be made to determine how bond can best be obtained, and consultations held with the manufacturers.

7.3 -- Underwater applications

With most formulations bonding can be achieved best under dry conditions. When dewatering and surface drying of the concrete is not possible, special epoxies should be chosen. Some can be applied directly to surfaces while they are underwater. Preparation should include trial applications by the user and subsequent testing of bond results since application techniques are critical in most cases.

CHAPTER 8 -- HARDENING

8.1 -- Rate of hardening

8.1.1 -- Epoxy compounds are available with a wide range of hardening rates, varying from a few minutes to several weeks. For use with portland cement concrete, the six following classes of epoxy compounds are designated in ASTM C 881.

Type I through V

Class A:	For use below 40 F (4.5 C)
Class B:	For use between 40 and 60 F (4.5 to 16 C)
Class c:	For use above 60 F (16 C)

Types VI and VII

Class D:	For use between 40 and 65 F (4.5 and 18 C)
Class E:	For use between 60 and 80 F (15.5 and 26.5 C)
Class F:	For use between 75 and 90 F (24.0 and 32.0 C)

The temperatures indicated for each class refer to the temperature of the concrete substrate. The use of these materials outside the designated temperature range is discussed in Section 8.2.

8.1.2 -- The most important factors influencing the rate of hardening, other than the composition of the compound, are temperature of the concrete substrate, the air temperature, and the temperature attained by the mixed compound. As soon as the epoxy resin and hardener are mixed together the hardening reaction begins. If the mixture is allowed to remain in a mass, the heat of reaction cannot escape and, consequently, the temperature of the mass increases, accelerating the reaction. As soon as the epoxy compound has been spread, it rapidly acquires the temperature of the surface onto which it was spread and is greatly influenced by the temperature of the air to which it is exposed.

8.13 -- To obtain the desired rate of reaction, it is important first to select the proper class of compound; second, to adequately mix the compound, while maintaining a minimum thickness of material by proper selection of a mixing container; third, to spread the mixed compound on a surface having a temperature within the desired range; and finally, to expose to air temperatures within the desired range.

8.2 -- Adjusting the hardening rate

8.2.1 -- Natural environmental conditions will not always be such that the concrete surfaces (to a depth of about 3 in. or 7.5 mm) and the air and epoxy temperatures are within the optimum range for the application. Preheating or cooling the surface to a satisfactory temperature, preheating or cooling the epoxy compound constituents before mixing, or both will then be necessary. Preheating the epoxy compound will increase its hardening rate thereby shortening the period available for application. Excessive preheating may shorten the application period to the extent that proper application cannot be accomplished thereby resulting in poor bond. Precooling the epoxy compound will increase its viscosity consistent with the amount of temperature reduction. The more viscous the material, the more difficult it is to properly apply. Excessive precooling can increase the viscosity to the extent that the mixed epoxy compound cannot completely wet the surface thereby resulting in poor bond. The formulator's recommended temperature range for mixing the epoxy compound should be followed for all field applications.

8.2.2 *Acceleration of hardening rate* -- An accelerated hardening rate will be needed when the concrete surface and air temperatures are unavoidably below the proper temperature range for the class of epoxy compounds chosen for the project. Many methods and combinations of methods can be devised, but most are impractical for large areas over thick concrete. The following are methods used for accelerating the hardening rate:

8.2.2.1 Infrared heaters to preheat the concrete surface and also to heat the epoxy compound after it is spread,

8.2.2.2 An inclosure heated by circulating warm air,

8.2.2.3 Clear polyethylene film placed over the completed job,

8.2.2.4 Heated aggregate mixed with the prepared compound in producing epoxy mortar or concrete.

In any event, uniform heating [not over 125 F (51 C)] is essential, and direct flame heating is prohibited.

8.2.3 *Deceleration of hardening rate* -- A decelerated hardening rate is needed when the concrete surface and air temperatures are inadvertently above the proper temperature range for the class of epoxy compounds chosen for the project. The following methods have been used to decelerate the hardening rate:

8.2.3.1 Protection of the application area from direct sunlight prior to, during, and after application of the mixed compound.

8.2.3.2 Use of ice bath to lower the temperature of the components before mixing.

8.2.3.3 Rapid spreading of the mixed compound in a thin film.

8.3 -- Opening the job to service

The strength requirements of the epoxy compound will differ with each end use. In many instances, the surface of the cured epoxy compound is not accessible for evaluation of the degree of hardness and strength attained. Therefore, it is necessary to rely on the supervisor's judgment and experience and on the manufacturer's data as to the anticipated strength. For some purposes, it is necessary for the epoxy compound to achieve almost full strength before opening the project to service, and the time required might be only a few hours at summer temperatures.

CHAPTER 9 -- HANDLING PRECAUTIONS

9.1 -- General hazards

9.1.1 -- Just as there are proper, safe practices for handling lime, acid, portland cement, etc., there are also precautions which should be observed when handling epoxy resins and materials used with them.

9.1.2 -- A number of different basic epoxy resins can be combined with an even greater number of curing agents, flexibilizers, fillers and other chemicals to produce several hundred different end products with various combinations of their unique properties. This versatility, which makes the epoxies so useful, also contributes to handling problems for the user (and, indeed, the manufacturers) of epoxy products. On the one hand, a few epoxy formulations are nonhazardous; on the other hand, there are a few formulations which are extremely hazardous; and in between are compounds with varying degrees of hazard.

9.1.3 -- Two typical health problems which may be encountered when epoxy materials are carelessly handled are:

9.1.3.1 Skin irritation, such as bums, rashes, and itches.

9.1.3.2 Skin sensitization, which is an allergic reaction similar to that caused in certain people by wool, strawberries, poison ivy, or other allergens.

9.1.4 -- It should be noted that sensitization reactions may sometimes occur immediately, but at other times they occur only after long periods of continual exposure. Workers should be aware of the possibility of delayed sensitization and not assume that they are immune.

9.1.5 -- The variety of the epoxy compounds marketed today make it essential that the labels and Material Safety Data (MSDS) sheets be read and understood by those people working with the products. Code of Federal Regulations (CFR) 16, Part 1500 regulates the labeling of hazardous substances including epoxy compounds.

ANSI standards: ANSI Z 129.1 and ANSI K 68.1 provide further guidance regarding classification and precautions.

9.1.6 -- Many epoxy resin formulations are classified as "corrosive" or "flammable" in 49 CFR Transportation Subchapter C "Hazardous Materials Regulations." Packaging, labeling, and shipping for such materials is controlled by 49 CFR Transportation.

9.2 -- Safe handling

Safe handling of epoxy materials can be accomplished by:

9.2.1 -- Working in a well-ventilated area. As with most chemicals, materials should be stored below eye level.

9.2.2 -- Disposable suits and gloves, available from many suppliers of work garments, are suitable for this use. Gloves should be tested for resistance to resins and solvents. Disposable rubber or plastic gloves are recommended and should be discarded after each use. Gloves should be tested for resistance to resins and solvents. Cotton gloves, if used, should never be reused if they have become soiled with epoxy compounds.

9.2.3 -- Careful attention to personal cleanliness and protection. Safety eye-glasses or goggles are strongly recommended both when handling epoxy compounds and acids. Involuntary habits such as face scratching or eyeglass adjustment should be avoided. For similar reasons, handling important tools, eating or smoking should not be done until the individual has washed up. When wearing soiled gloves, the workers should avoid touching door handles and other equipment which may subsequently be touched by a person not wearing gloves.

9.2.4 *Federal regulations* -- CFR 29, Part 1910 (OSHA Standards) regulate handling of hazardous substances including epoxy compounds.

9.3 -- What to do in case of direct contact

9.3.1 *To the clothing* -- Remove soiled clothing at once and change to clean garments. If the soiled garment cannot be thoroughly cleaned, it should be destroyed.

9.3.2 *To the body* -- Shower immediately with soap and water to remove spilled epoxy compounds from the body. Avoid contact with the genital areas until after the hands are carefully cleaned of all epoxy.

9.3.3 *To the eyes* -- Flush out with large amounts of water for at least 15 min, followed by immediate medical attention. (Safety goggles will usually prevent getting chemicals into eyes.)

9.3.4 *Other places* -- Do not use solvents other than soap and water or water soluble proprietary cleaners. Most solvents merely dilute the epoxy compounds, aiding them in penetrating the skin. At the same time, solvents tend to dry out the skin and any subsequent exposure is more likely to cause problems.

9.4 -- Use of solvents

9.4.1 *General* -- The epoxy compounds considered for concrete applications are usually solvent free. However, solvents may be used as a convenience for cleanup of equipment and areas on which epoxies might be spilled. The solvents used will require additional precautions depending on the characteristics of the type used. It is generally true that solvents should not be used to remove epoxy products from the skin. They tend to dry the skin and may themselves cause dermatitis. Additionally, they dissolve the epoxy compound and carry it into more intimate contact with the skin, thus aggravating the dermatitic problems which already exist due to skin contact with the epoxy compound. The following hazards might be encountered in the use of solvents and should be taken into consideration. It may be emphasized that when using a solvent, the combined hazards of both the solvent and the epoxy compound are encountered.

9.4.1.1 *Flammability and explosion hazard* -- Many solvents having low flash points are not recommended and should be avoided. Cleaning solvents such as ketones are red label materials and present a fire hazard. If used, adequate ventilation should be provided, equipment should be grounded and smoking or other fire initiating devices should be barred from the area of use. The chlorinated solvents, while not representing a fire hazard, will present a toxicological problem if a person smokes in their presence or if a fire occurs in the immediate area.

9.4.1.2 *Vapor hazard* -- Most solvents have some degree of volatility and the vapors can be toxic when inhaled Avoid using solvents which may be harmful.

9.4.1.3 *Contact hazard* -- Some cleanup solutions contain phenols or other very aggressive chemicals which can cause burns or other serious effects when contacting any part of the body directly or indirectly. Use such materials with great care following the recommendations of the supplier.

9.4.1.4 Dispose of spent solvents in accordance with local and federal regulations.

9.5 -- Education of personnel

No amount of equipment will substitute for worker education. Those involved in using epoxy materials should be thoroughly informed of the characteristics and hazards of the particular materials they must handle. Not only label instructions but also the manufacturer's literature and MSDS sheets should be reviewed and pertinent information passed on to each worker. The handling of epoxy materials is not a dangerous occupation as long as reasonable care is taken and personnel and equipment are kept clean. Instances of sensitization are rare but the possibility of a burn, a damaged eye, or other loss-of-time accidents makes knowledge and observance of safe handling practices absolutely essential. A sensitized person must not be allowed to continue working with epoxy materials.

APPENDIX A -- TEST METHODS

A.1 -- Field test for surface soundness and adhesion

A.1.1 -- Clean a portion of the area to which the epoxy compound is to be applied according to prescribed cleaning methods. The area selected for testing should represent the worst of surface conditions within the area to be repaired. The test area should be large enough so that the cleaning equipment and methods of cleaning to be employed in full scale operation may be used. This avoids the possibility of attaining a degree of cleanliness in a small test area which could not be matched later with the equipment to be used on a continuing basis. The surface must be thoroughly dry before undertaking Step A.1.2.

A.1.2 -- Mix materials and apply a test patch according to applicable procedures of Chapters 6 and 7 using the epoxy compound to be used in the work. The test patch should cover enough of the surface to include all the typical surface conditions found in the larger areas to be covered. For example, in a warehouse subjected to considerable forklift truck traffic, the test patch should span a line to include the wheel tracks where applied load and wear are most severe, and the center areas where deposition of oil and traffic soil is heaviest.

A.1.3 -- After the test patch has hardened, core drill through the coating and down barely into the subsurface by means of an electric drill fitted with a carbide-tipped or diamond core bit (Fig. A.1). The core bit should be of such size as to produce a cored disc 2 in. (5 cm) in diameter which will have the appearance of a small island of coated material (Fig. A.2).

A.1.4 -- Bond a standard 1½ in. (3.7 cm) diameter pipe cap, the bottom surface of which has been machined smooth and shoulder-cut to provide a 2 in. (5 cm) diameter surface (Fig. A.3), to the cored disc using nearly any commercially available room temperature rapid curing epoxy compound adhesive. Mix the epoxy components according to the supplier's recommendations just prior to use. A 2 oz (50 gm) portion of this material should have a working life of 20-25 min at 70-90 F (20-32 C). Apply a small amount of the mixed adhesive to the cored disc and to the bonding face of the pipe cap by spatula. Where desired, the bonding face may be heated to facilitate spreading of the adhesive. However, the cored disc should never be heated directly. Place the pipe cap on the cored disc. Direct a flame from a small gasoline blow-torch (an electric heat lamp or a portable gas radiant heater may be used as alternatives) into the interior of the pipe cap in such a way that no direct heat reaches the cored disc or the pavement bond line, and heat the pipe cap to about 160 F (70 C). (This temperature can readily be checked with a surface pyrometer.) Under these conditions the adhesive should harden in less than 1 minute. The bonded cap will be ready for testing as soon as it has cooled to air temperature.

A.1.5 -- After cooling the pipe cap and core, test the core by applying tension to it using a testing device similar to the one shown in Fig. A.4 and A.5. To prepare the testing device, screw the lower hook into the threaded pipe cap and attach to the loop on the lower portion of a Dillon dynamometer. Screw the upper hook, which has a threaded shaft, into the loading arm at the top of the rig, and attach to the loop on the upper portion of the dynamometer. When force is applied, the axis of the dynamometer must coincide with the axis of the pipe cap extended. Rotate the loading arm so that the threaded shaft and its connections are lifted, placing the pipe cap (and core) in tension. Tensile load should be applied at the approximate rate of 100 lb (45 kg) every 5 sec. The tensile load is indicated on the dynamometer gage. Record the load at which the pipe cap and connected core is separated from the concrete surface and convert to unit stress. Note the type of failure of which there are three possibilities or combinations thereof:

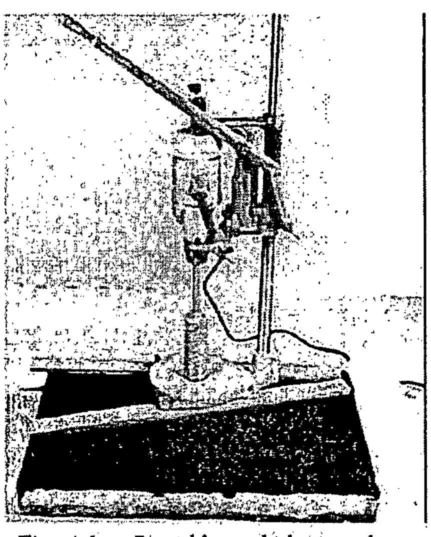


Fig. A.1 -- Portable carbide-tipped core drill in position for drilling

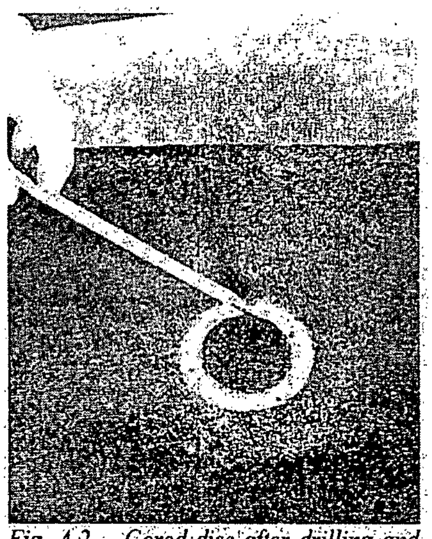


Fig. A.2 -- Cored disc after drilling and ready for the attachment of the pipe cap

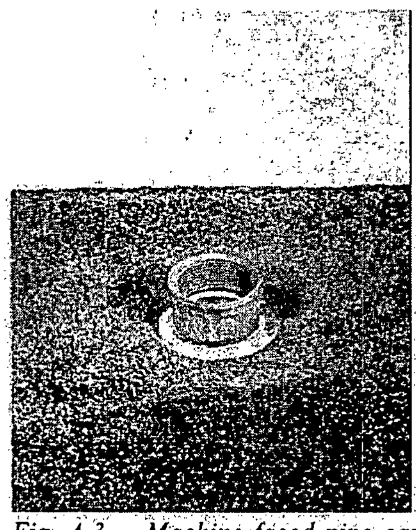


Fig. A.3 -- Machine faced pipe cap bonded to cored disc with epoxy compound

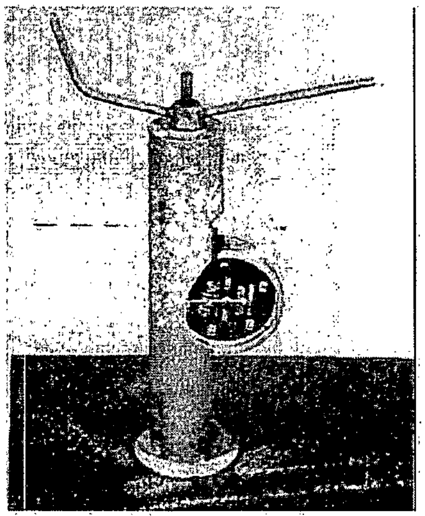


Fig. A.4 -- Mechanical testing device for pulling bonded pipe cap in tension

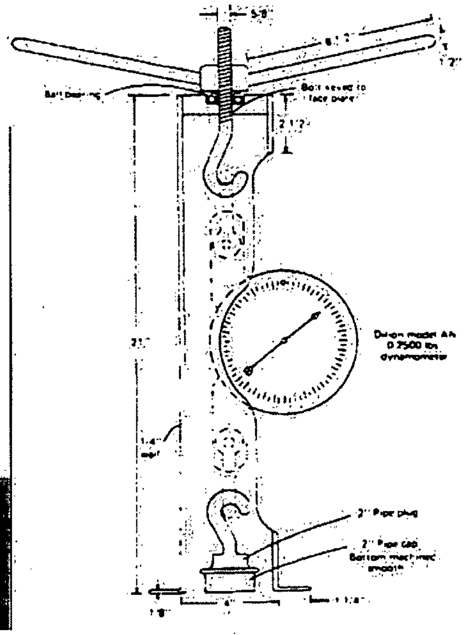


Fig. A.5 -- Functional sketch of mechanical testing device

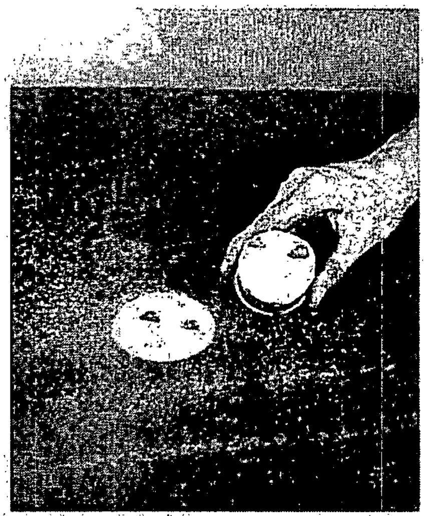


Fig. A.6 -- Typical failure in concrete; dark spots on cap and in aggregate indicate split aggregate

a) Failure in the concrete (cohesive concrete failure)
b) Separation of the epoxy compound from the concrete surface (adhesive failure)
c) Failure in the epoxy compound (cohesive resin failure)

Record the percent of each type of failure along with the load required to bring about the failure. A properly formulated epoxy compound applied to a properly prepared surface should result in a concrete failure as shown in Fig. A.6. When the pipe cap and core have been separated from the surface, the hole created by the test can easily be repaired using either an epoxy resin compound or the remaining epoxy adhesive if there is a surplus. When the strength of a concrete surface is to be tested alone, Steps A1.1 through A1.3 may be eliminated, except that a small area must be cleaned for bonding the pipe cap directly to the concrete surface. Tests should be performed in several areas which represent the worst conditions, and which give a statistical estimate of results to be expected.

A.2 -- Simplified field test for surface soundness

A.2.1 -- If this test is being employed to ascertain the need for surface preparation and detecting relative differences in potential surface strength over an area to be repaired, skip to Steps; A.2.2 and A.2.3. If the test is employed to ascertain adequacy of surface preparation, clean the area, or portions thereof if a large area, according to the prescribed cleaning methods. Portions of large areas to be test cleaned should be sufficient in number to be representative of the total area and each portion should be large enough so that the cleaning equipment intended for the full scale application can be used in a standard cleaning operation. Provision should be made for conducting the test at the rate of at least one test per 100 ft^2 (9.3 m^2) of area to be repaired The surface to be tested must be dry before proceeding with Step A2.2.

A.2.2 -- Cut 1 in. lengths of 1 in. aluminum T-section to provide a one in^2. bonding surface at the bottom of the flange. Drill a hole in the stem of each T-section for subsequent attachment of the testing device. Thoroughly clean the aluminum surface by abrading with crocus or emery cloth being careful to water wash and dry before using. Bond the aluminum T-section to the concrete surface using a fast setting epoxy compound mixed just prior to its use in accordance with the supplier's recommendations. This is accomplished by applying a small quantity of the epoxy compound to the concrete surface followed immediately by working the T-section into the epoxy in a manner to establish thorough contact between the epoxy, the concrete and the aluminum T-section. Upon completion of this operation, score around the perimeter of the T-section to remove excess epoxy which has squeezed out so that the bonded area will be the desired one square inch.

A.2.3 -- The following day, or as soon as the epoxy has set, attach a testing device similar to the one shown in Fig. A7 to the aluminum T-section or the mechanical device described in Step A.1.5. Apply tension at an uninterrupted, uniform rate. The tensile load is indicated on the dynamometer gage. Record the load at which each T-section is separated from the concrete surface and express it as unit stress. Note the type of failure, as in Step A.1.5.

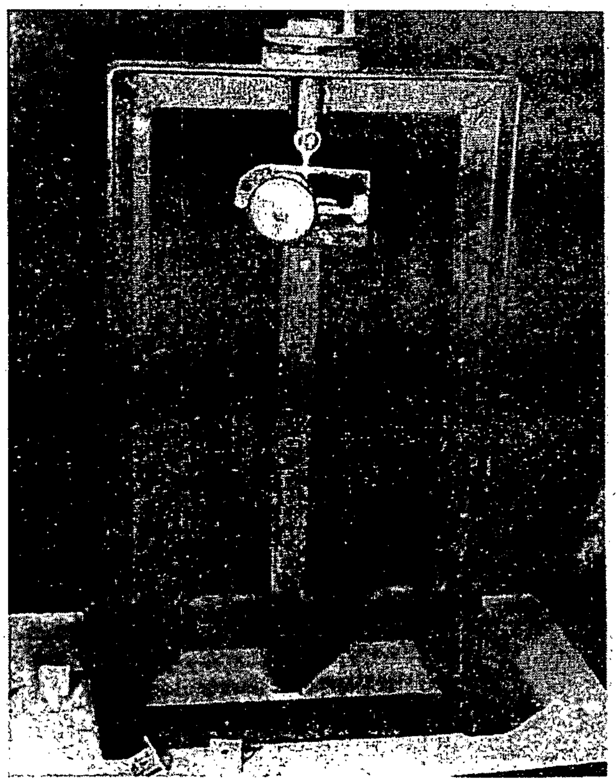


Fig A.7 -- Tension frame for pulling T-sections bonded to a surface (courtesy George W. Whitesides Co., Inc.)

APPENDIX B – TERMINOLOGY

Ambient: Usually used to describe temperature; meaning the same as the surroundings. Ambient usually, but not always, implies a temperature that is in the range of 60 to 90 F (15 to 32 C).

Broadcast: To toss granular material, such as sand over a horizontal surface so that a thin, uniform layer is obtained.

Delamination: Loss of adhesion and separation between coatings or between a coating and its substrate.

Diluent: A liquid ether which lowers the viscosity of epoxy formulations and which reacts chemically with them.

Epoxy concrete: A combination of epoxy resin and fine and coarse aggregate in a consistency similar to portland cement concrete.

Epoxy grout: A fluid epoxy compound used to fill cracks, set dowels, etc., in a manner similar to conventional grout.

Epoxy mortar: See resin mortar.

Extender: A nonreacting liquid substance added to epoxy compounds to extend pot life, increase flexibility, and lower the cost.

Flexibilizer: A substance which will react with epoxy compounds to impart flexibility.

Filler: A finely divided material, such as mica or talc, incorporated in an epoxy formulation to increase the hardness and lower the cost.

Hardener: A substance formulated so that when mixed with an epoxy resin it will cause the epoxy to solidify and harden.

Ionic: An adjective used to describe substances that dissolve to form ions. Upon dissolving, each molecule of the ionic substance splits into two or more ions. The ions always carry an electrical charge, either positive or negative. The positive and negative charges are always equal, so that the overall electrical charge is neutral.

Mil: One-thousandth of an inch.

Non-ionic: An adjective used to describe substances that dissolve without formation of ions. (See ionic)

Non-polar: Used to describe molecules characterized by a uniform distribution of electrons so that there is essentially no electrical charge, separation in the molecule. (see semi-polar)

Overlay: To apply a mortar to sufficient thickness, usually ¼ in. (6 mm) or more, to form a new surface. (see semi-polar)

Pot life: The period of time during which the epoxy compound is in a suitable condition for use.

Resin mortar: A combination of epoxy resin and fine aggregate in a consistency suitable for troweling.

Rout: To deepen and widen a crack to prepare it for patching or sealing.

Semi-polar: An adjective used to describe molecules that are intermediate between non-polar and polar types. Non-polar molecules are characterized by a uniform distribution of electrons such that there is essentially no electrical charge separation in the molecule. Polar molecules are characterized by a nonuniform distribution of electrons such that there is a difference in electrical potential from one end of the molecule to the other. Polar molecules tend to have higher solvent strength than non-polar molecules.

Stripper: A liquid compound formulated to remove coatings by chemical and/or solvent action.

Substrate: The uncoated surface upon which a coating is applied.

Thermoplastic plastic: A plastic that generally does not require curing agents and can be dissolved in a solvent or melted without permanent chemical change.

Thermosetting plastic: A plastic that, once cured, cannot be melted or dissolved in a solvent without undergoing drastic chemical change.

ACI 503R-93 was submitted to letter ballot of the committee and was approved according to Institute balloting procedures.

Attachment E – Bond Test Data

Test Number	Location	Bonding Adhesive	Debonding Force (lb)	Bond Stress (psi)	Comments

Use additional sheets as required.

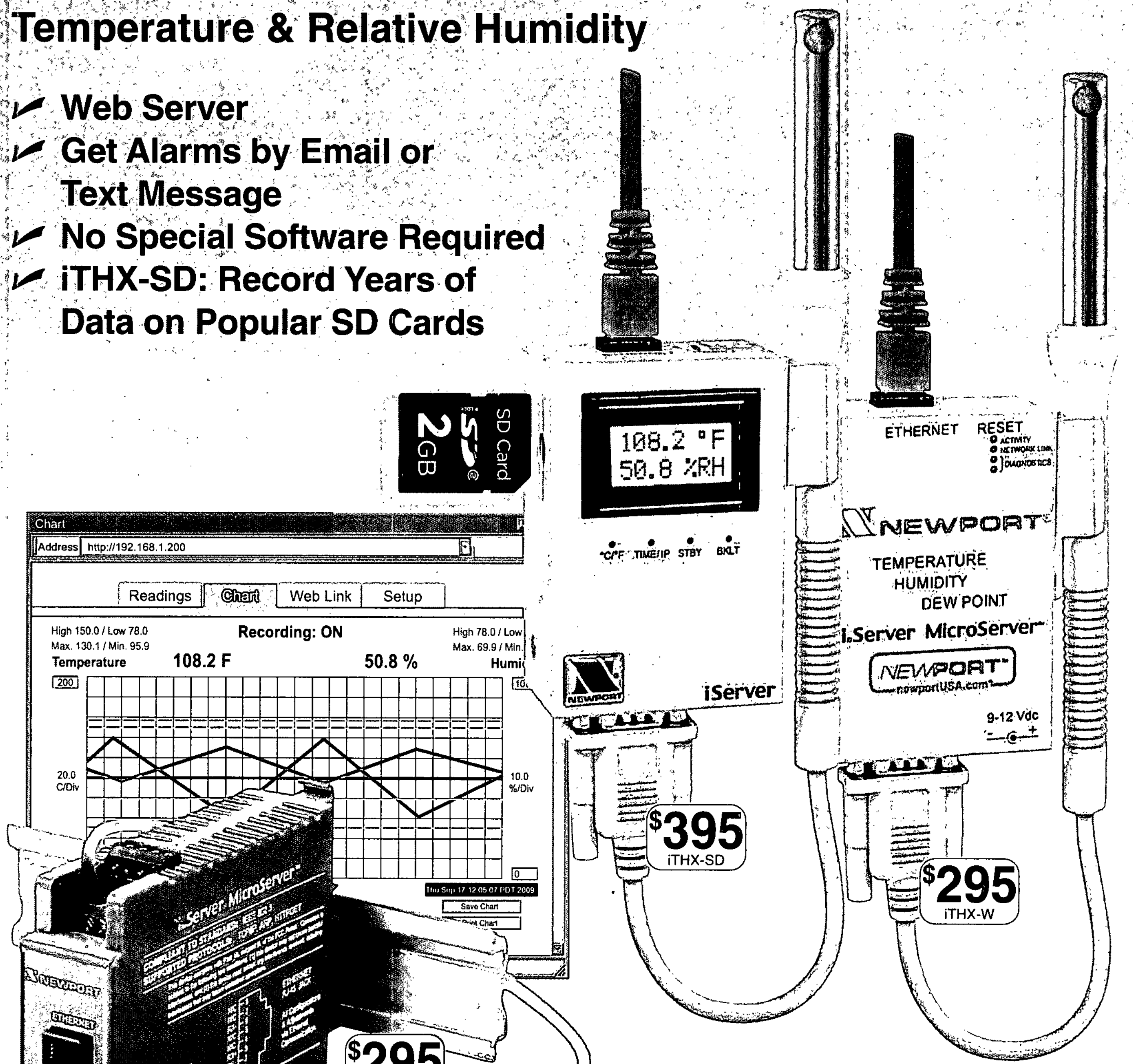
Intentionally Left Blank – Information was removed during final review of EC product.

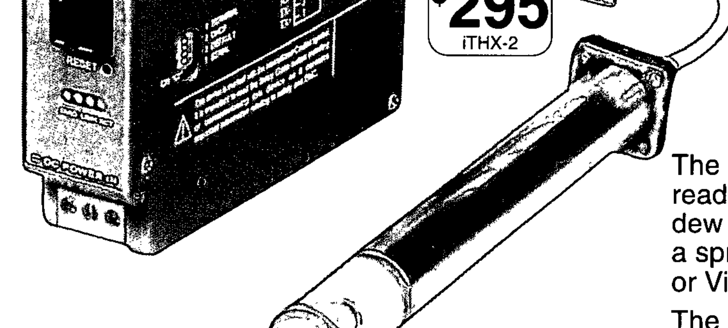
NEWPORT®

Virtual Chart Recorder

Temperature & Relative Humidity

- Web Server
- Get Alarms by Email or Text Message
- No Special Software Required
- iTHX-SD: Record Years of Data on Popular SD Cards





The **NEWPORT® iTHX** transmitter let's you monitor and record Temperature, Relative Humidity and Dew Point over an Ethernet network or the Internet with no special software except a Web Browser.

The iTHX serves Active Web Pages to display real time readings, display charts of temperature, humidity, and dew point or log data in standard data formats for use in a spreadsheet or data acquisition program such as Excel or Visual Basic.

The virtual chart viewed on the web page is a JAVA™ Applet that records a chart over the LAN or Internet in real time. With the iTHX, there is no need to invest time and money learning a proprietary software program to log or chart the data.

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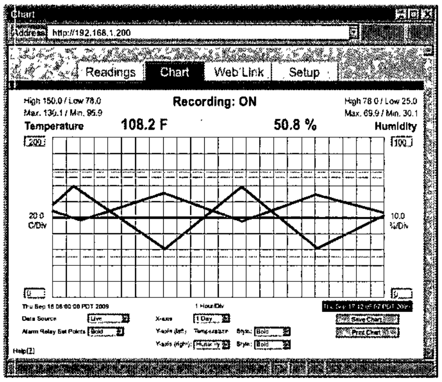
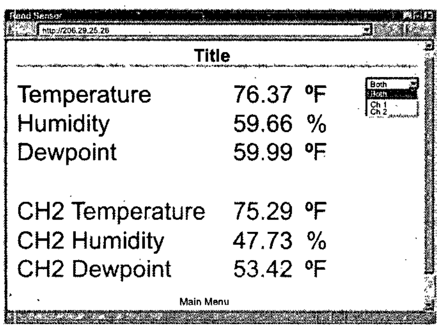
Adjustable Charts
Chart scales are fully adjustable on the fly. For example, the chart can display one minute, one hour, one day, one week, one month or one year. Temperature and humidity can be charted across the full span (-40 to 124°C, and 0 to 100% RH) or within any narrow range such as (20 to 30°C).
When a second sensor is added, users can select a chart that records channel 1, channel 2 or the difference of the two channels.



iTHX-SD Adjustable Chart

Display and Chart Two Channels
The iTHX transmitters come complete with a temperature and humidity probe for measurement of a single location. With the addition of a second probe, the iTHX transmitter can measure and display temperature, humidity and dew point in a second location up to ten feet away.



Reading 2 Sensors on iTHX-W

The transmitter can display and chart absolute measurements in both locations, or a differential measurement between the two locations. The second probe requires no change to the basic iTHX transmitter hardware.

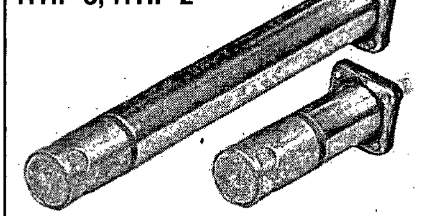
A second probe can be added at the time of purchase or in the future. NEWPORT offers a choice of industrial probes in 2" and 5" lengths, and a wand style for ambient indoor applications. A simple DB-9 "Y" connector is available for adding a second probe to model iTHX-W and iTHX-SD. No connector is required to add a second probe to the DIN rail mounted iTHX-2.

Award-winning Technology
The NEWPORT iTHX is simple to install and use, and features NEWPORT's award-winning **iServer** technology that requires no special software except a Web Browser.

The iTHX connects to an Ethernet Network with a standard RJ45 connector and sends data in standard TCP/IP packets. It is easily configured with a simple menu using a Web Browser and can be password protected.

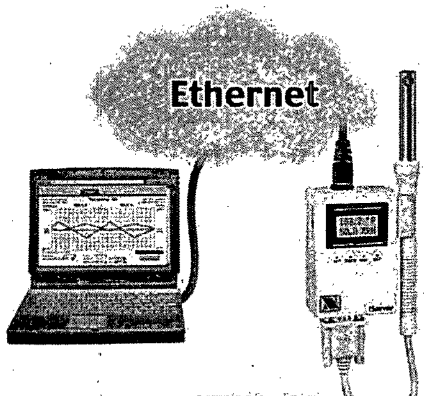
From within an Ethernet LAN or over the Internet, the user simply types its IP address or an easy to remember name such as "Cleanroom5" or "ServerRoom" in any Web Browser, and the iTHX serves a Web Page with the current readings.

Industrial Probes: iTHP-5, iTHP-2



Email Alarms
All NEWPORT iTHX models that are on a LAN that is connected to the Internet can trigger an alarm that can be sent by email to a user or a distribution list anywhere in the world, including text messages to cell phones and PDA's.

Typical Applications
The iTHX is great for monitoring temperature + humidity in applications such as: clean rooms, computer rooms, HVAC systems, pharmaceutical and food processing and storage, hospitals, laboratories, semiconductor fabs, electronic assembly, warehousing, museums, manufacturing, green-houses, farm animal shelters, and many more.



iTHX-SD

NEW iTHX-SD with SD Flash Memory Card and LCD Display
The NEWPORT model iTHX-SD with LCD display, adds several valuable features in addition to the backlit local display of temperature and humidity.

The iTHX-SD comes complete with a removable 2 GB SD Flash Memory card that can store up to seven years of readings taken at ten second intervals.

The data recorded on the SD card can be read with a standard card reader or remotely over an Ethernet network or the Internet.

With data being recorded on the SD card, a failure on the Ethernet network will not interrupt the data recording.

Alarm Relays
The iTHX-SD features two 1.5 Amp relays. With the easy Web-based setup page, the two relays can be programmed for any combination of temperature or humidity, and high or low set points. The relays can also be programmed to remain latched and require a manual reset if a limit is exceeded.

Battery Backup
The iTHX-SD comes with a universal 100 to 240 Vac power adapter.

A standard 9 Volt Alkaline battery (also included) allows the device to log data for up to 2 days without external ac power.

Temperature + Humidity

Sensor Specifications

Relative Humidity (RH)

Accuracy/Range: ±2% for 10 to 90%; ±3% for 5 to 10% and 90 to 95%; ±4% for 0 to 5% and 95 to 100%
Non-linearity: ±3%
Hysteresis: ±1%RH
Response Time: 8 seconds, tau 63%
Repeatability: ±0.1%
Resolution: 0.1%, 12 bit

Temperature (T)

Accuracy/Range*
Wand Probe: ±0.5°C (±1°F) for 5° to 45°C (41° to 113°F); ±0.5 to 1°C (±1° to 2°F) for 0° to 5°C and 45° to 70°C (32° to 41°F and 113° to 158°F)
Industrial Probe: ±0.5°C (±1°F) for 5° to 45°C (41 to 113°F); ±0.5° to 1.5°C (±1° to 2.7°F) for -40° to 5°C and 45° to 124°C (-40° to 41°F and 113° to 255°F)
***Note:** extended temperature range is for Ind. probe only, the iServer's operating temperature is 0 to 70°C
Response Time: 5 to 30 seconds, tau 63%
Repeatability: ±0.1°C
Resolution: 0.1°C, 14 bit

Probe Physical Dimensions

Wand Probe iTHP-W
Probe length: Ø19 mm x 198 mm (0.75" x 7.8")
Cable length 152mm (6") with DB9 Connector
Cable operating temp: 0°C to 80°C (32°F to 176°F)

Industrial Probe iTHP-5, iTHP-2:
Probe length: Ø16mm x 137mm *or* 51mm (0.63" x 5" *or* 2")
Housing material: SS316
Cable length 3m (10') or 0.9m (3')
Cable operating temperature: -40°C to 125°C (-40°F to 257°F)

iServer Specifications

Interfaces

Ethernet (RJ45): Fixed or auto-negotiating 10/100BASE-T, Auto MDI/MDIX: iTHX-SD; 10BASE-T: iTHX-W, iTHX-2
Sensor: Digital 4-wire (DB-9): iTHX-W, iTHX-SD; removable 8 position screw terminals: iTHX-2

Protocols

TCP, UDP, SNMP, SMTP, NTP, ARP, ICMP, DHCP, DNS, HTTP, and Telnet: iTHX-SD;
TCP, UDP, ARP, ICMP, DHCP, DNS, HTTP, and Telnet: iTHX-W, iTHX-2

LCD Display (iTHX-SD)

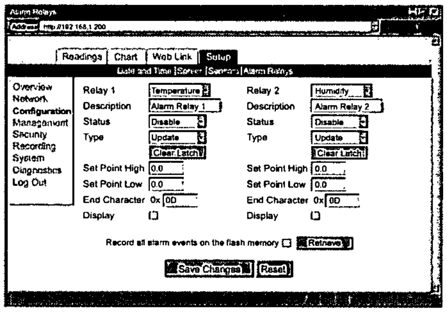
16 Digits 6mm (0.23")

SD Flash Memory Card (iTHX-SD)

2GB card: 8 months of data storage at 1 second recording intervals or 7 years at 10 second intervals

Relay Outputs (iTHX-SD)

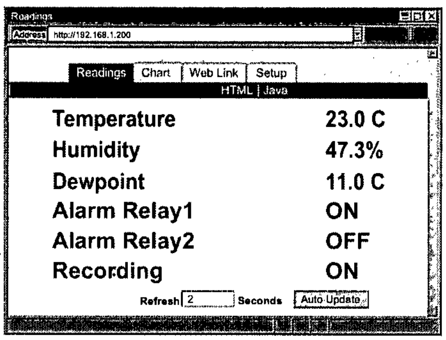
Two Relays 1.5A @ 30 Vdc



iTHX-SD Alarm Relays

Embedded WEB Server

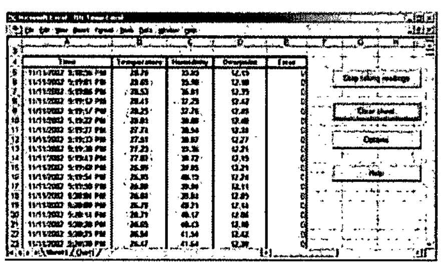
Serves WEB pages containing real-time data and live updated charts within definable time intervals



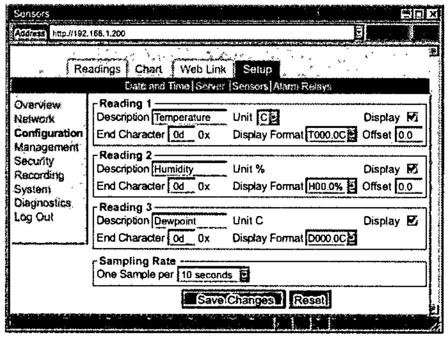
Readings on iTHX-SD

Software

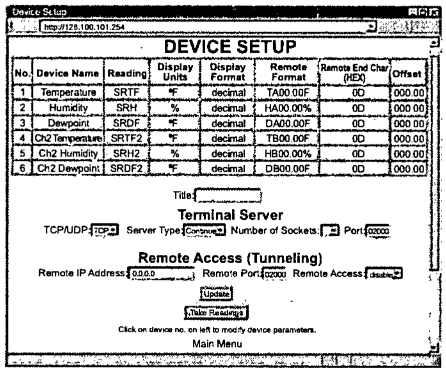
OPC Server; macro for datalogging in Excel program; compatible with Windows operating systems



Datalogging Spreadsheet



iTHX-SD Sensor Configuration



iTHX-W and iTHX-2 Configuration

Environmental

Operating Temperature:
Unit: 0 to 70°C (32 to 158°F)
Battery: -20 to 55°C (-4 to 131°F)
ac Adapter: 0 to 40°C (32 to 104°F)
Storage Temperature: -40 to 85°C (-40 to 185°F)

Power

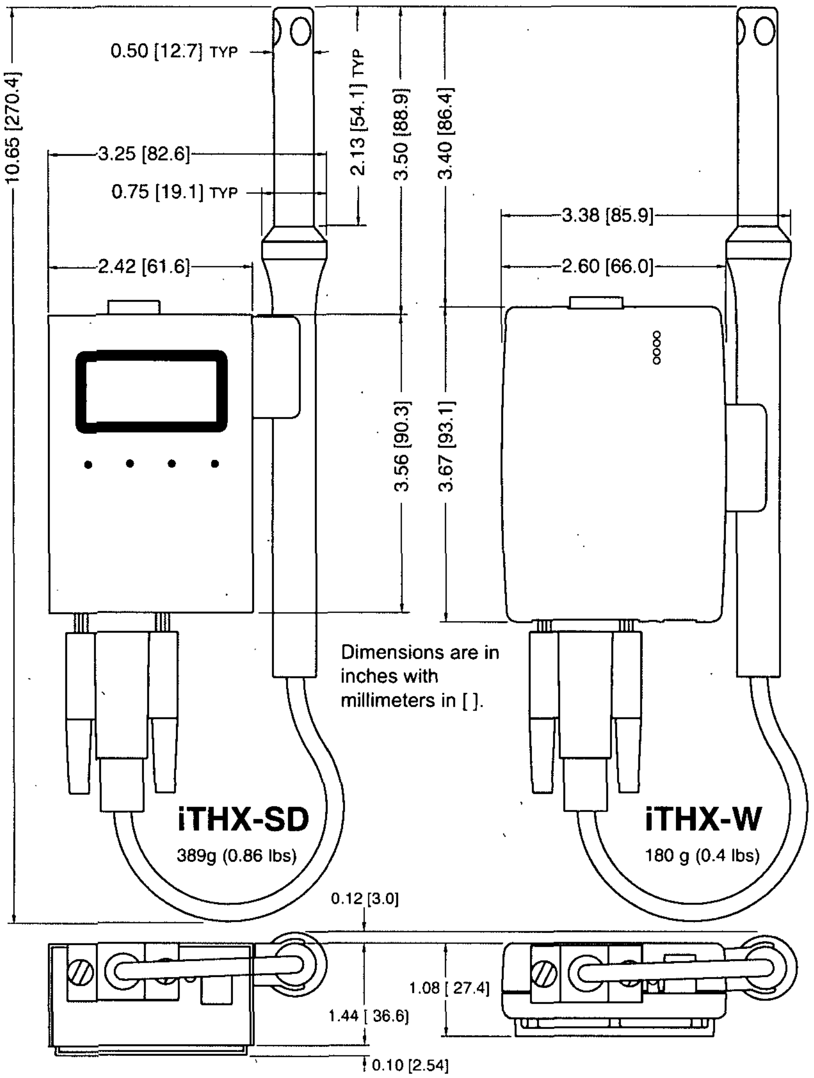
Input: 9 to12 Vdc: iTHX-W, iTHX-SD; 10 to 32 Vdc: iTHX-2
Safety Qualified ac power adapter:
Nominal Output: 9 Vdc @ 0.5A
Input: 100 to 240 Vac, 50/60Hz included: iTHX-W, iTHX-SD
Switching Power Supply sold separately: iTHX-2
Battery: 9Vdc, Alkaline iTHX-SD

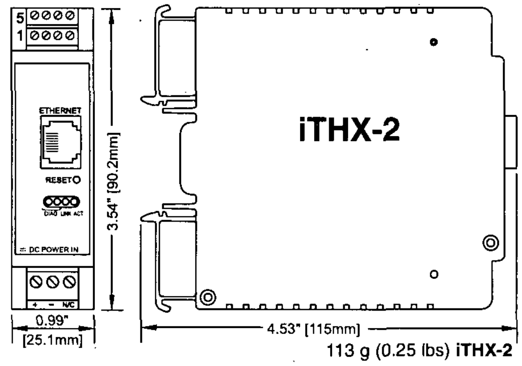
Packaging

Material: Steel metal case with wall mount bracket: iTHX-SD; Valox 364 PBT case with wall mount bracket: iTHX-W; Polycarbonate case with DIN Rail mount: iTHX-2

NIST Traceable Calibration Certificate available.
In compliance with ISO9001:2000, ISO10012-1.1992(E), ANSI/NCSL Z540-1.1994 and MIL-STD-45662A.

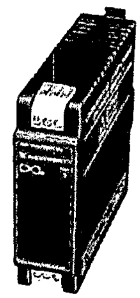
Mechanical Specifications



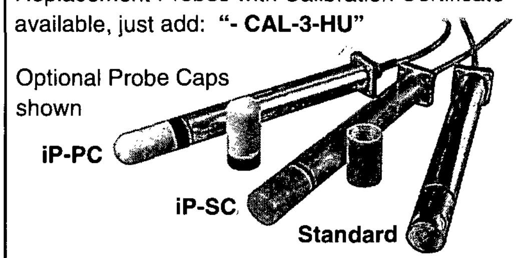


iDRN-PS-1000

- 24Vdc Supply
- Mounts to 35mm DIN rails
- Switching Power Supply powers up to 7 units



Replacement Probes with Calibration Certificate available, just add: **"- CAL-3-HU"**



No need to take your unit out of service to get re-calibrated, order a calibrated probe instead.

Model No.		Description	Price
iTHX-SD		iServer MicroServer™ for Temp + Humidity and Dew-point, LCD Display, 2GB SD Flash Memory Card, 2 Relay Alarm, Battery Back-up	395
iTHX-W		iServer MicroServer™ for Temperature + Humidity and Dew Point	295
	*	Standard 203 mm (8") Wand Probe, Cable 152 mm (6") with DB9 Connector. No Entry required	N/C
	-2	Industrial 51 mm (2") Probe, Cable 0.9 m (3 ft) with DB9 Connector. Substitution for Wand Probe	15
	-5	Industrial 137 mm (5") Probe, Cable 3 m (10 ft) with DB9 Connector. Substitution for Wand Probe	25
Accessories			
iTHP-W-6		Replacement 203mm (8") Wand Probe, Cable 152mm (6") with DB9 Connector	100
iTHP-2-DB9		Industrial 51 mm (2") Probe, Cable 0.9 m (3 ft) with DB9 Connector*1	115
iTHP-5-DB9		Industrial 137 mm (5") Probe, Cable 3 m (10 ft) with DB9 Connector*1	125
DB9-Y		DB9 "Y" Connector Adapter for 2 Probes with DB9 Connector	25
DB9-CA-3		Extension Cable, 0.9 m (3 ft) with DB9 Connector	15

Model No.		Description	Price
iTHX-2		iServer MicroServer™ for Temperature + Humidity and Dew Point	295
	*	Standard Industrial Probe 137mm (5"), Cable 3 m (10 ft), Stripped Wire Leads. No Entry required	N/C
	-2	Industrial Probe 51mm (2"), Cable 0.9 m (3 ft) with Stripped Wire Leads. Substitution for 5" Probe	N/C
Accessories			
iTHP-2		Industrial Probe 51 mm (2"), Cable 0.9 m (3 ft) with Stripped Wire Leads. *1	115
iTHP-5		Industrial Probe 137 mm (5"), Cable 3 m (10 ft) with Stripped Wire Leads. *1	125
iDRN-PS-1000		Power Supply (switching), 95 to 240 Vac input, 24 Vdc output @ 850 mA (powers up to 7 units)	150
RAIL-35-2		2 m (6.5 ft) section of 35mm DIN rail	15

Common Accessories		Price
iP-PC	Polyethylene Probe Cap, for wet environments	N/C
iP-SC	Porous Stainless Steel Probe Cap, 5um porosity, for dusty and pressurized (< 35 psi) environments	25
CAL-3-HU	NIST Traceable Calibration Certificate. Three (3) Humidity Points of 25%, 50%, 75%, one temperature 25°C, for new units	150
CAL-3-DUAL	Same as CAL-3-HU, for new units with 2 probes	175
CT485B-CAL-KIT	Calibration Kit, 33% and 75% RH Standards	75

Ordering Examples for iTHX-SD with LCD display, SD card, 2 relay alarm, battery back-up and wand probe: **iTHX-SD = $395.**
For dual channel iTHX-2 with additional industrial 5" probe and 10' cable: **iTHX-2 + iTHP-5 + iDRN-PS-1000. $295 + 125 + 150 = $570.**
For Calibrated Replacement Probe, with Certificate: **iTHP-W-6-CAL-3-HU. $100 + 50 = $150.**
*1 Other lengths of cable (up to 40 ft) are available, please contact our Sales Department. * Volume discounts are available.

TECHNICAL
GUIDELINES

Prepared by the International Concrete Repair Institute March 2004

Guide to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials

Guideline No. 03739

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INTERNATIONAL CONCRETE REPAIR INSTITUTE

About ICRI Guidelines

The International Concrete Repair Institute (ICRI) was founded to improve the durability of concrete repair and enhance its value for structure owners. The identification, development, and promotion of the most promising methods and materials are primary vehicles for accelerating advances in repair technology. Working through a variety of forums, ICRI members have the opportunity to address these issues and to directly contribute to improving the practice of concrete repair.

A principal component of this effort is to make carefully selected information on important repair subjects readily accessible to decision makers. During the past several decades, much has been reported in the literature on concrete repair methods and materials as they have been developed and refined. Nevertheless, it has been difficult to find critically reviewed information on the state of the art condensed into easy-to-use formats.

To that end, ICRI guidelines are prepared by sanctioned task groups and approved by the ICRI Technical Activities Committee. Each guideline is designed to address a specific area of practice recognized as essential to the achievement of durable repairs. All ICRI guideline documents are subject to continual review by the membership and may be revised as approved by the Technical Activities Committee.

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Synopsis

This guide is intended to provide a recommended method of evaluating the tensile bond of cementitious and polymer concrete surface repairs using in-situ drilled core tensile pull-off tests. This guide outlines equipment and material requirements, the test procedure, reporting, and acceptance criteria. Appendixes discuss the importance of bond to successful surface repairs and summarize factors affecting bond tests.

Keywords

Acceptance criteria, bond, bond failure, cohesive failure, composite system, concrete substrate, failure mode, pull-off strength, pull-off test, repair composite, surface repair, tensile bond, tensile load, trial repair.

Contents

1.0 Purpose and Scope

This guide has been prepared to aid and assist the facility owner, concrete repair designer, contractor, and repair material manufacturer by providing a recommended method of evaluating the tensile bond of cementitious and polymer concrete surface repairs using in-situ drilled core tensile pull-off tests. Typical applications include, but are not limited to, a prepared concrete substrate, partial depth repairs, overlays, encasements, and composite systems.

The repair of concrete surfaces involves the construction of a composite system that will differ from the existing concrete substrate. The new composite system (Fig. 1) consists of the following elements:

- existing concrete substrate;
- bond interface between existing concrete substrate and repair material; and
- repair material.

Composite System

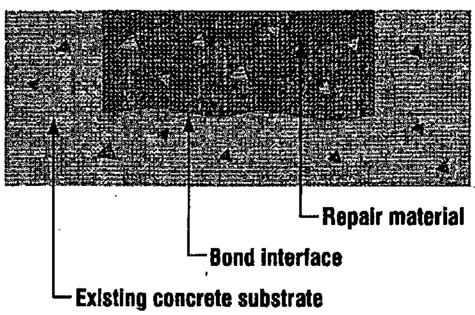

Fig. 1: Elements of a composite system

The recommended test method creates a tensile stress throughout the composite system that evaluates the soundness of the existing concrete substrate prepared for repair, and/or the bond strength of the repair material, and/or the tensile strength of the repair material. The test will also identify the location of failure and quantify the failure stress of the repaired concrete composite under a tensile load. The test method may also be used to evaluate the adhesive strength of bonding agents.

The recommended method of in-situ tensile pull-off tests involves hazardous materials, equipment, and operations (for example, core drilling to avoid embedded post-tensioning tendons, electrical conduit, etc.). This guide does not address the safety issues associated with the method. The user of this guide is responsible to determine appropriate safety and health practices prior to performance of the test.

2.0 Overview of Test Method

To perform the tensile pull-off test:

- the test site and surface are prepared;
- a core bit is used to drill through the prepared concrete substrate or the repair material/existing concrete substrate composite system;
- a rigid disc is attached to the top of the drilled core with a high-strength adhesive;
- the testing device applies a perpendicular tensile load to the core through the rigid disc; and
- tensile bond strength is reported as failure load divided by cross-sectional area of the core, and type of failure mode is also identified.

3.0 Equipment and Material Requirements

- *Coring Machine/Core Bit*—Coring machine shall be capable of coring perpendicular to the test surface without exerting any load onto the drilled core. Core bit shall be diamond-tipped.
- *Rigid Disc*—Disc shall be minimum 2.0 in. (50 mm) in diameter with adequate thickness to distribute the applied force without disc warping. For steel, a 2.0 in. (50 mm) diameter disc shall be a minimum of 0.8 in. (20 mm) thick; a 3.0 in. (75 mm) diameter disc shall be a minimum of 1.2 in. (30 mm) thick. For aluminum, a 2.0 in. (50 mm) diameter disc shall be a minimum of 1.0 in. (25 mm) thick; a 3.0 in. (75 mm) diameter disc shall be a minimum of 1.5 in. (38 mm) thick. Thickness of larger-diameter discs shall be increased sufficiently to prevent disc warping. The diameter of the drilled core shall match the disc diameter.
- *Adhesive*—For bonding a rigid disc to the drilled core, use a paste or gel adhesive that achieves a tensile bond strength to the test surface and disc that exceeds the tensile strength of the existing concrete substrate or repair composite.
- *Pull-Off Testing Device*—The minimum capacity of the device shall be at least twice the loading required to meet the acceptance

criteria (refer to Section 6). For a 2.0 in. (50 mm) diameter core, the required device typically has a capacity of at least 1500 lb (7500 N). The device shall be capable of applying a uniform force to the test specimen, which develops a stress of 5.8 ± 2.9 psi (0.04 ± 0.02 MPa) per s. The device shall be capable of recording the failure stress to the nearest 10 psi (0.07 MPa). The coupling used to connect the disc to the device should be designed to safely withstand the maximum tensile force, and to transmit the tensile force parallel to and in-line with the core axis without introducing bending, eccentricity, or rotational forces to the test specimen. The device shall be calibrated in accordance with manufacturer recommendations.

- *Other Equipment*—Thermometer, calipers, and measuring device.

4.0 Test Procedure

4.1 Test Site Selection/ Surface Preparation

4.1.1 Test Site Selection

- Location should be sound and free of delamination/debonding; and
- Location should avoid embedded items (for example, reinforcing steel, post-tensioning tendons, electrical conduits, etc.).

4.1.2 Test Surface Preparation

- Clean to remove all surface contaminants and loose or deteriorated concrete; and
- Prepare the test surface in accordance with project requirements and equipment manufacturer recommendations. For irregular test surfaces, preparation methods must provide a surface that allows firm and uniform seating of the testing device in a proper orientation to the test specimen. Note that some manufacturers recommend grinding or planing of concrete surfaces prior to testing. While this operation can optimize proper seating of the testing device and may be desirable for repair composites, it prevents meaningful results when testing a prepared concrete substrate (because the prepared surface has been removed).

4.1.3 Rigid Disc Attachment

Refer to Paragraph 4.2.4 for attachment of rigid disc to the test surface prior to coring.

4.2 Test Specimen Preparation

4.2.1 Coring

- *Prepared Concrete Substrate*—Drill a circular cut perpendicular to the surface and into the prepared concrete substrate to a minimum depth of 1.0 in. (25 mm) or one-half the core diameter, whichever is greater. For a 2.0 in. (50 mm) diameter core, the minimum depth shall be 1.0 in. (25 mm), and a 3.0 in. (75 mm) diameter core shall be 1.5 in. (38 mm). The core is left intact.
- *Repair Composite*—Drill a circular cut perpendicular to the surface, through the repair material, and into the existing substrate. The cut should extend to a minimum depth of 1.0 in. (25 mm) or one-half the core diameter, whichever is greater, into the existing substrate. For a 2.0 in. (50 mm) diameter core, the minimum depth into the existing substrate shall be 1.0 in. (25 mm), and a 3.0 in. (75 mm) diameter core shall be 1.5 in. (38 mm). The core is left intact.

4.2.2 Test Speciman Cleaning

Remove all standing water. Clean the test surface of any debris from the drilling operation and allow to dry.

4.2.3 Rigid Disc Attachment After Coring

Attach the rigid disc to the top of the drilled core using an adhesive (refer to Section 3, Equipment and Material Requirements). The surface must be clean and the disc centered over the drilled core. Cure the adhesive per the manufacturer's instructions. Do not allow the adhesive to run down the side of the drilled core into the annular ring. If this occurs, discard the test specimen and prepare another. At temperatures below 68 °F (20 °C), it is permitted to gently heat the disc to no more than 120 °F (50 °C) to facilitate the spreading and curing of the adhesive. Do not heat the disc/core with a direct flame. A hairdryer is often used. Allow sufficient time for the adhesive to cure.

4.2.4 Rigid Disc Attachment Prior to Coring

As an option, the rigid disc may be attached to the test surface in Paragraph 4.1 prior to coring in Paragraph 4.2, as long as coring will not adversely

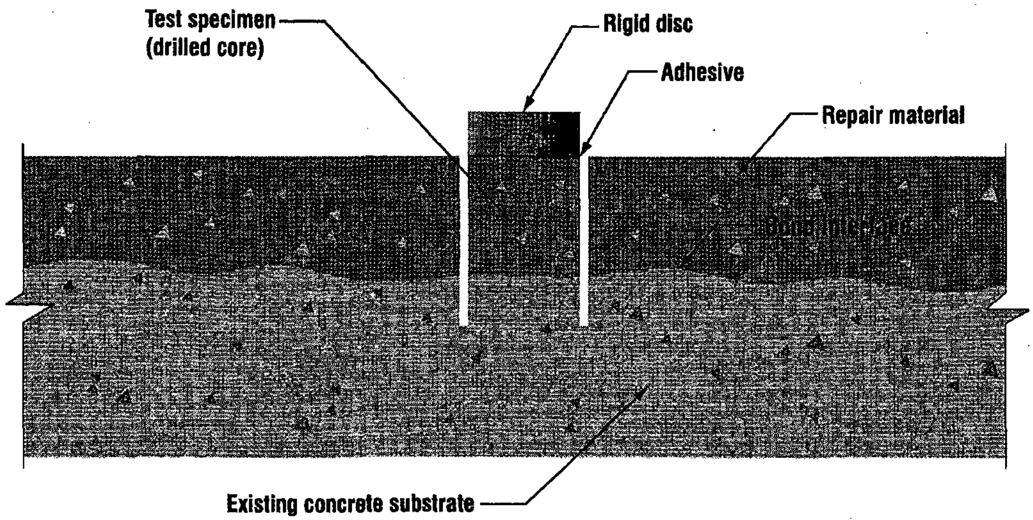

Fig. 2: Test specimen preparation (composite system)

affect or damage rigid disc installation. Refer to Paragraph 4.2.3 for attachment of the rigid disc.

Refer to Fig. 2 for schematic of test specimen preparation.

4.3 Loading and Testing

- Attach the pull-off testing device to the rigid disc. The reaction frame of the testing device must bear uniformly on the test surface to produce a perpendicular tensile load (that is, without eccentricity);
- Apply a tensile load at a constant rate of 5.8 ± 2.9 psi (0.04 ± 0.02 MPa) per second to the test specimen in a direction perpendicular to the concrete surface and parallel to the axis of the drilled core (Fig. 3);

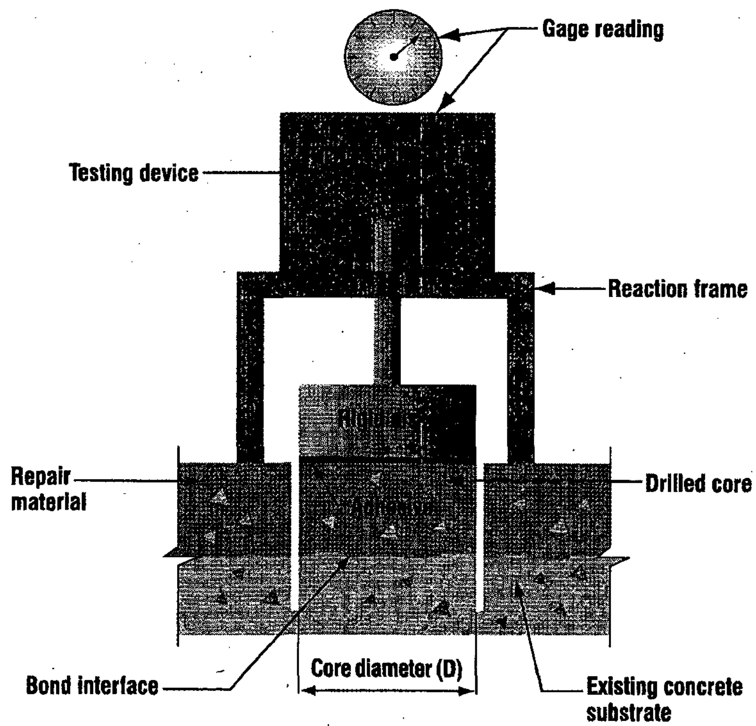

Fig. 3: Test setup (composite system)

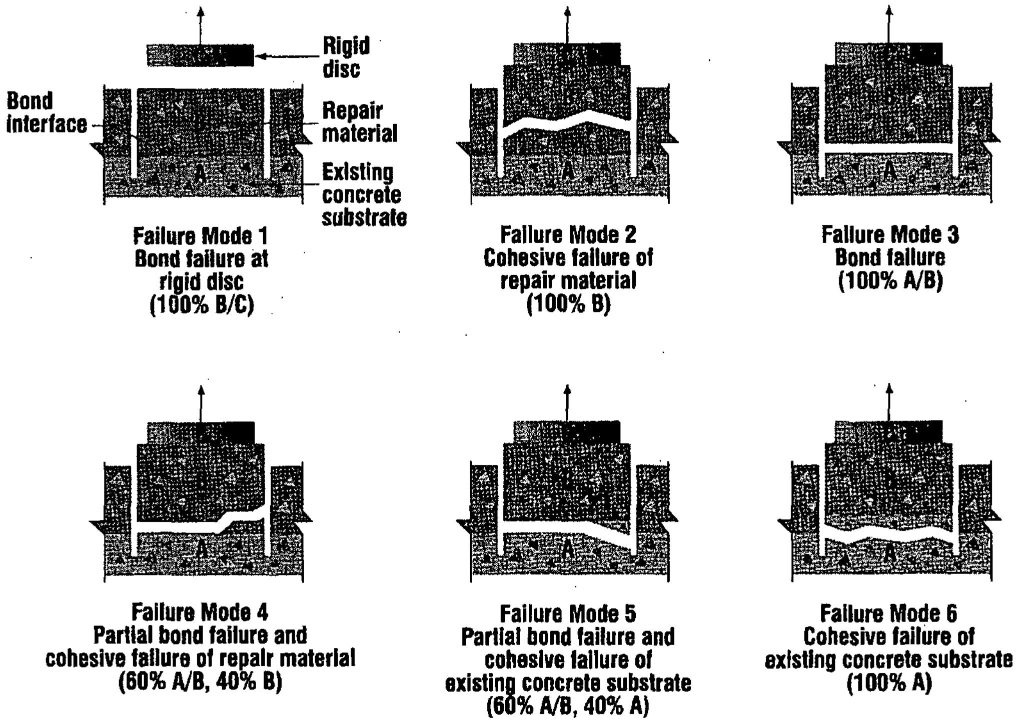

Fig. 4: Pull-off failure modes (composite system)

- Record the failure load and the mode of the failure (Fig. 4). Record the failure mode as:
  Mode 1: Adhesive bond failure of disc to the prepared substrate (without repair material) or repair material (composite system).
  Mode 2: Cohesive failure within repair material.
  Mode 3: Bond failure of repair material to the existing substrate.
  Mode 4: Partial bond failure of repair material to the existing substrate and partial cohesive failure within the repair material.
  Mode 5: Partial bond failure of repair material to the existing substrate and partial cohesive failure within the existing substrate.
  Mode 6: Cohesive failure within the existing substrate.
- Calculate area of the drilled core by measuring the diameter of the core along two perpendicular axes to the nearest 0.01 in. (0.25 mm) and averaging the two readings; and
- Calculate bond or tensile strength in psi (MPa) as tensile load/area of drilled core (Fig. 5).

TBS = Tensile Bond Strength
P = Pull-off force at failure = 1150 lb.
D = Diameter of core = 3.0 in.
A = Area of core

$$A = \frac{\pi D^2}{4} = \frac{3.14 \times (3.0)^2}{4} = 7.06 \text{ in.}^2$$

$$TBS = \frac{P}{A} = \frac{1150}{7.06} = 165 \text{ psi}$$

Fig. 5: Sample tensile bond strength calculation

5.0 Test Report

The test report should contain the following:

- project information;
- equipment and materials used, including type of pull-off testing device and type/size of core/rigid disc;
- age and conditions of existing substrate and repair material;
- location of test, weather conditions, and concrete surface temperatures;
- failure load or stress to the nearest 10 psi (0.07 MPa);
- calculated bond or tensile strength to the nearest 5 psi (0.035 MPa); and
- mode of failure.
  Refer to Fig. 6 for sample test report.

In-Situ Tensile Pull-Off Test Results

Project no.: ______________________ Weather: ______________________

Project name: ______________________ Temperature: ______________________

Project address: ______________________ Testing device: ______________________

Structure type: ______________________ Core/rigid disc size: ______________________

Owner: ______________________ Surface preparation method: ______________________

Engineer: ______________________ Repair material type: ______________________

Contractor: ______________________ Age of repair material: ______________________

Date	Test no.	Gage reading	Applied force (P)	Core dia. (D)	Core area (A)	Tensile bond strength (P/A)	Failure mode	Remarks

Fig. 6: Sample test report

6.0 Acceptance Criteria

6.1 Establishing Required Pull-Off Strength Prior to Repairs

6.1.1 Trial Repairs

6.1.1.1 Time and Frequency of Tests

Significant variance exists between the abilities of concretes of different composition and quality to resist pull-off stresses. It is recommended that trial repairs be made to evaluate the capacity of the existing concrete substrate and the repair materials to resist pull-off stresses. If the trials demonstrate that the strength of the existing concrete substrate and repair are not adequate, the advisability of making the repair should be re-evaluated. If possible, the amount and location of tests should be shown on the repair drawings or described in project specifications whenever pull-off testing is used as a basis for assessing surface repairs.

Trial sample repairs should be undertaken for each type of designated repair far enough before the related work is scheduled to allow curing of the repair materials and completion of evaluation tests. Pull-off tests should not be performed until at least 3 days after repair placement for polymer-based materials and 7 days or more after repair placement for cementitious materials. Pull-off tests may be performed at earlier ages if the design strength of the repair material has been met. Testing at later ages may be desired for slower strength gain repair materials and when curing occurs in cold weather, but not later than 28 days after repair placement. Pull-off tests should be performed at ages consistent with anticipated project schedule requirements. Trial sample repairs should be carried out using the same concrete removal and surface preparation methods, and the same material formulation and application methods as those to be used in the work. New trial sample repairs should be carried out if any changes in materials and equipment occur during the course of the work.

Trial sample repair areas should be chosen, to the extent reasonably possible, to encompass the majority of the positions and orientations of the surfaces to be repaired.

During the trial repairs, perform testing of a minimum of three test specimens for each trial repair area.

6.1.1.2 Required Pull-Off Strength Based on Trials

Requirements for the pull-off strength established by the trials should be based on achieving an average of 90% of the average trial speciman test results. Perform an additional speciman test to replace any specimen test with a result less than 75% of the average pull-off strength of the trial specimen test results.

The required pull-off strength should not exceed the tensile strength of the existing substrate or repair material, whichever is lower.

6.1.1.3 Revision of Pull-Off Strength Requirements

If unexpected job conditions are encountered, including lower/higher strength of the existing concrete substrate to be repaired, acceptance criteria may have to be adjusted to meet specific project conditions.

6.1.2 If Trial Repairs are not Possible

The requirement for trial repairs depends, to a certain extent, on the size of the project and the time available prior to repairs. If trial repairs are not possible, the following guidelines based on field experience may be helpful.

Structural performance of bonded repairs generally relies on the transfer of shear stresses across bond lines. These stresses may result from shrinkage of the repair material with respect to the existing substrate, differential thermal cycling between the repair and existing substrate, external loads applied to a structure, or other phenomena. While limited test data are available, there is no well-established correlation between tensile bond capacity and shear capacity of a bond line. Further, accurate calculation of bond line stresses under various loading conditions can be complex if all factors, including shrinkage and thermal volume changes, are considered. It should be recognized, therefore, that calculation of a precise tensile bond value necessary to satisfy structural requirements is not realistic. Consequently, acceptance criteria is typically developed based on an approximate calculation of shear demand, the assumption that shear capacity of the bond line will exceed tensile capacity, knowledge of bond values known to be achievable with specified methods and materials, and knowledge of performance of other similar repairs.

Experience demonstrates that bond strengths of 250 psi or greater can be achieved with available surface preparation and repair techniques in moderate to good quality concrete substrate materials. Test values of less than 250 psi that fail consistently within the existing concrete substrate may be an indication of an inferior or low-strength concrete substrate. Many specifiers use an acceptance criteria lower than 250 psi in recognition of surface preparation techniques that may be restricted in some manner, a repair application for which higher bond strength is perceived to be unnecessary, and possible data inaccuracies related to bond test procedures or equipment, etc. Legitimate test values (that is, those for which a high confidence in test methods and equipment is present) lower than 175 psi that fail at the bond line or superficially within the existing concrete substrate may indicate a partially damaged or contaminated bond surface. Where high bond strength is judged to be critical, investigation of the bond surface, assessment of existing concrete substrate strength, or selection of alternative surface preparation techniques should be performed. For repairs in which bond strength is perceived to be less critical, some specifiers allow acceptance of bond strengths for cementitious materials as low as 100 psi. A minimum pull-off strength of 200 psi is generally required for polymer materials.

6.2 Time and Frequency of Tests on Completed Repairs

Pull-off test should not be performed until at least 3 days after repair placement for polymer-based materials and at least 7 days or more after repair replacement for cementitious materials. Pull-off tests may be performed at earlier ages if the design strength of the repair material has been met. Testing at later ages may be desired for slower strength gain repair materials and when curing occurs in cold weather. Pull-off tests should be performed at ages consistent with trial repair testing.

For overlays and large repair areas, a minimum of three individual specimen tests should be performed for each 5000 ft^2 of repair. For smaller repair areas, a lesser frequency of testing may be more appropriate; however, a minimum of three specimen tests should be performed on the project. Additional guidance regarding frequency of sampling can be found in ASTM E 122, "Standard Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process." Test surfaces should be selected at random. Refer to ASTM D 3665, "Standard Practice for Random Sampling of Construction Materials," for guidance regarding random sampling criteria. At least one specimen test should be performed near a randomly selected perimeter edge or saw-cut joint.

6.3 Evaluation of Test Results on Completed Repairs

The acceptance criteria should be interpreted based on the analysis of failure modes (Fig. 4).

6.3.1 Acceptance of Test Results

For all modes of failure, accept pull-off test results if:

- For criteria developed by trial repairs:
  Average Strength: Average pull-off strength of the specimens is above the required pull-off strength (90% of average trial specimen test value).
  Minimum Strength: No specimen tests below 75% of the average trial specimen test value.
- For criteria developed without trial repairs:
  Average Strength: Average pull-off strength of the specimens is above the required pull-off strength.
  Minimum Strength: No specimen tests below 75% of the required strength.

6.3.2 Test Results Below Minimum Strength Requirements

For tests that fail to meet minimum strength requirements:

- test specimen may be faulty if the adhesive fails, adhesive does not completely fill the interface between the disc and the test surface, the disc is off-center, or the disc is not aligned in a plane perpendicular to the axis of the core;
- check for proper disc adhesion, positioning, and alignment;
- check alignment of testing device to assure that load is being applied parallel to axis of the core and axis of core is perpendicular to the test surface;
- retest specimens that did not meet minimum requirements;
- use values of acceptable specimens from original test with values derived from retest to determine adjusted average; and
- accept if adjusted average is above required pull-off strength and no specimen tests below the minimum required strength.

6.3.3 Test Results That Consistantly Do Not Meet Acceptance Criteria

When test results consistently fail to meet the acceptance criteria, a re-evaluation of project conditions should be performed. This assessment may include the re-evaluation of the required pull-off strength (average/minimum strength criteria), failure modes, repair/substrate materials, construction procedures, etc.

Appendix A

Importance of Bond to Successful Surface Repairs

The Composite System

Concrete surface repairs and overlays are composite systems. In composite systems, the bond between the individual components is critical for overall viability. The durability of the bond in such systems can be defined as a lasting, interfacial coexistence of new and existing phases. Assuming the properties of the components are good, any improvement of the bond will improve the properties of the composite system.

A Good and Lasting Bond

Achieving an adequate lasting bond between repair materials and existing concrete substrate is a critical requirement for durable surface repairs and overlays. The basic requirements for good bond are simple:

- absence of weak layers or contamination at the interface; and
- intimate contact between repair material and existing concrete substrate.

The bond at the interface between the repair material and existing concrete substrate, or phases, is likely to be subject to considerable stresses from internal forces (volume changes, freezing-and-thawing cycles, etc.), and external forces (force of gravity, impact, vibration, overall structural response, etc.). The stress conditions that develop at the bond line will vary considerably, depending on the type, use, and exposure of the structure. For example, the bond on a bridge deck overlay may be subject to shear stress in conjunction with tensile or compressive stress induced by shrinkage or thermal effects, and to compression and shear from service loads.

It is essential that the repair or overlay materials achieve a strong bond to the existing concrete substrate and that subsequent stresses not be severe enough to cause debonding. Repairs that have bond lines in direct tension have the greatest dependence on chemical bonding (adhesion). Repairs that are subject to shear stresses at the bond line are capable of stress resistance not only by chemical bonding mechanisms, but also by mechanical bonding (that is, aggregate interlock) mechanisms, which add greatly to shear bond capacity.

The key requirement of a successful repair is an adequate bond between the repair material and existing concrete substrate, which remains intact throughout its service life. At the present time, practical answers to the problems of bond may depend only on a short-term bond testing rather than long-term performance. An initially achieved adequate bond is only an indication of conformance with the specified parameters. There is no well-defined relationship between initial bond strength and the longevity of a repair. Longevity is influenced by many factors, including substrate surface preparation and texture, shrinkage of the repair material, and service conditions.

Factors Affecting Bond

Adherence between the repair material and existing concrete substrate in a composite system is a case of adhesion between solids, formed as a result of the setting and hardening of a semi-liquid substance (the repair material) placed on the surface of a second substance in solid state (the existing concrete substrate). Being semi-liquid, repair materials flow into the existing substrate surface irregularities of a solid, coming into intimate contact with the substrate and, as a result, interacting with its molecular forces. Factors that influence the formation of a bond and the degree of adhesion include: existing substrate properties, repair material properties, surface preparation methods, concrete placement and curing methods, and environmental exposure.

Differing Concrete Surfaces

The chemical and physical properties of existing concrete surfaces are complex, and a great deal of variability in these properties may occur throughout a repair or overlay area. Consideration of these properties is necessary to develop a recognition of methods and procedures that promote the development of good bond with repair materials.

Concrete surfaces are dissimilar in many properties, which include, but are not limited to:

- porosity;
- absorption;
- roughness/texture;
- degree of microcracking ("bruised" layer); and
- hardness.

Concrete surfaces can change with time as a result of:

- external mechanical forces such as those associated with concrete removal and surface preparation operations;

- interaction with the exterior environment. For instance, carbonation causes physical changes in porosity, water absorption, and hardness; and cracking can result from shrinkage and thermal effects; and
- interaction with the interior environment. For instance, moisture and chloride ingress causes electrochemical changes that may lead to corrosion of reinforcing steel.

A properly prepared concrete substrate facilitates the development of sufficient bond between the existing concrete substrate and repair material (refer to the ICRI Guideline No. 03732, "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays," and ICRI Guideline No. 03730, "Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion").

The most important characteristics of the prepared concrete surface with respect to achieving good bond are its roughness, soundness (that is, absence of contaminants and damaged paste or aggregate), cleanliness, and moisture condition prior to the application of the repair material. The most important factors during and after repair material placement are the selection of a suitable repair material and achieving proper installation, proper consolidation, and adequate curing. Each of these factors is mainly dependent on workmanship. The primary factor outside the control of a repair program is the quality of the existing concrete substrate intended to receive the repair, aside from issues related to damage that may be caused by concrete removals and surface preparation. Tensile pull-off testing has been found to be an effective tool in evaluating the integrity of the existing concrete substrate and the quality of workmanship exercised in the execution of a repair.

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Appendix B

Factors Affecting Bond Tests

Several test methods have been proposed to evaluate bond properties of composite repair and overlay systems. These include the following:

1. Tensile bond tests
   - Canadian Standard Association CSA A23.2-6B, "Method of Test to Determine Adhesion by Tensile Load;" and
   - British Standard BS 1881, 1992, "Recommendations for the Assessment of Concrete Strength by Near-to-Surface Tests," Part 207.
2. Slant-shear tests
   - BS 6319, *Testing of Resin Composites for Use in Construction,* Part 4: "Method of Measurement of Bond Strength (Slant-Shear Method)," British Standards Institute, London, 1984.
   - Kriegh, J. D., 1976, "Arizona Slant Shear Test: A Method to Determine Epoxy Bond Strength," ACI Journal, *Proceedings* V. 73, No. 7, July, pp. 372-373.
3. Twist-off shear test
   - Naderi, M.; Cleveland, D. J.; and Long, A. E., 1986, "Bond Strength of Patch Repair Mortars for Concrete," *Proceedings of the RMEM International Symposium on Adhesion between Polymers and Concrete,* Chapman & Hall, London, pp.707-718.

However, the most widely used field test has been the "pipe cap" pull-off test described in ACI 503R Appendix A and refinements of that test, such as the State of Virginia test method VTM-92 and commercial adaptations.

Pull-off tensile bond tests are gaining in popularity because of their relative simplicity and ability to meet most of the requirements for in-situ bond evaluation of concrete surface repairs.

The most important aspects of the tensile pull-off (bond) test are:

- load rate (that is, both the rate of load application and the uniformity of the rate of load application);
- load alignment (that is, axial with a core specimen to be tested and perpendicular to the surface to be tested);
- coring depth; and
- core/rigid disc size and rigid disc stiffness.

Load Rate: Load must be applied at a uniform rate. Abrupt starts and stops, such as those that occur by a series of discrete hand cranks in some test apparatus, are undesirable. Further, load application should be at a moderate rate that does not impart any impact effects nor creep effects.

Load Alignment: The objective of putting a bond plane into a uniform tensile stress state has been a challenge where the principal concern has been to minimize load eccentricity. Load eccentricity in a pull-off test depends on the normality of the core drilling (relative to the substrate) and accuracy in positioning the rigid disc on top of the core. For instance, if the eccentricity induced is 0.06 in. (1.5 mm) in a depth of 2.0 in. (50 mm), corresponding to an angle of 1.7 degrees, this leads to an increase in maximum stress at the core periphery of 20% (Austin, Robins, and Youguang 1995).

Coring Depth: Studies have shown (U.S. Army Corps of Engineers 1999) that a shallow coring depth beyond the bond line into the existing concrete substrate can cause significant stress concentrations at the periphery of the test specimen near the bond line. The greater the coring depth, the lesser impact on the test results. Based on available data, a minimum depth of 1.0 in. (25 mm) into the existing substrate (beyond the bond line) is recommended for 2.0 in. (50 mm) diameter cores, and 1.5 in. (38 mm) for 3.0 in. (75 mm) diameter cores.

Core/Rigid Disc Size and Rigid Disc Stiffness: In general, larger-diameter cores and discs provide a more representative sampling. While 2 in. (50 mm) diameter cores have been widely used for many years, some prefer larger, up to 3 in. (75 mm) diameter, cores. Larger core/rigid disc size may be more appropriate for thicker repairs and/or testing of concrete with larger size aggregates. In all cases, it is imperative that the rigid disc adhered to the surface of the test specimen have sufficient rigidity to distribute the applied load uniformly across the surface of the test specimen.

These factors must be controlled to minimize the variability of the test results and the influence of stress concentrations. Controlling these important factors can be challenging in field conditions. In particular, proper selection of a commercially available testing device has a significant impact of test results (U.S. Army Corps of Engineers 1999).