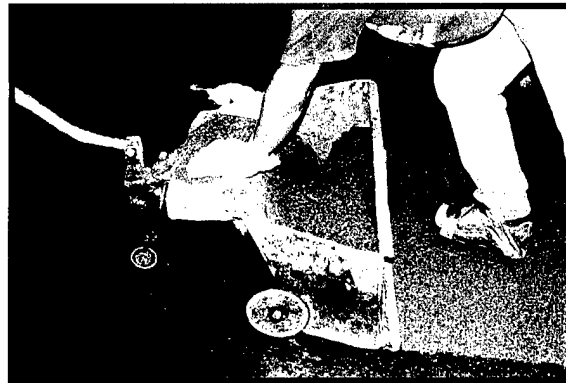
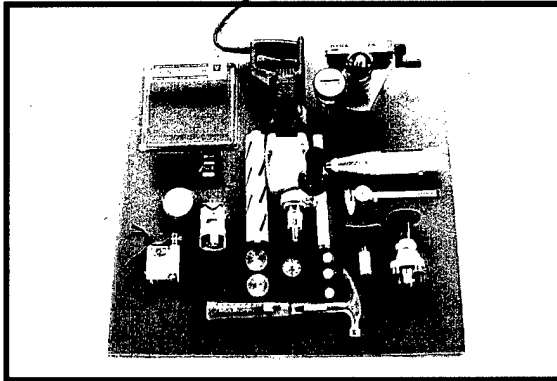




NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

Special Publication SP-2085-SHR

OVERVIEW OF INDUSTRY GUIDANCE ON CONCRETE CONDITION ASSESSMENT AND CONCRETE REPAIR FOR USE PRIOR TO COATING




by

C. Dave Gaughen
Joseph H. Brandon

20000818 170

June 2000

Approved for public release; distribution is unlimited.

 Printed on recycled paper

DTIC QUALITY INSPECTED 4

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-018

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 2000		3. REPORT TYPE AND DATES COVERED Not Final; June 2000	
4. TITLE AND SUBTITLE OVERVIEW OF INDUSTRY GUIDANCE ON CONCRETE CONDITION ASSESSMENT AND CONCRETE REPAIR FOR USE PRIOR TO COATING				5. FUNDING NUMBERS	
6. AUTHOR(S) C. Dave Gaughen and Joseph H. Brandon					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(S) Naval Facilities Engineering Service Center 1100 23rd Avenue Port Hueneme, CA 93043				8. PERFORMING ORGANIZATION REPORT NUMBER SP-2085-SHR	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES Naval Facilities Engineering Service Center 1100 23rd Avenue Port Hueneme, CA 93043				10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE A	
13. ABSTRACT (Maximum 200 words) <p>This Special Publication (SP) introduces a brief overview of concrete repair guidance offered by the American Concrete Institute (ACI) International, the International Concrete Repair Institute (ICRI), the American Concrete Pavement Association (ACPA), the Aberdeen Group, the Portland Cement Association (PCA), and work by authors considered experts in the field of concrete repair. The publication is divided into two parts: Part I, "Condition Assessment," and Part II, "Concrete Repair." Part I details condition survey, concrete evaluation, evaluation of structures, and additional surface evaluation; Part II introduces concrete removal, surface preparation, repair materials, placement methods, curing, quality control, and repair guidance.</p>					
14. SUBJECT TERMS Coating, paint, concrete, cement, materials, assessment, evaluation, repair, curing				15. NUMBER OF PAGES	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL		

EXECUTIVE SUMMARY

Prior to coating, concrete surfaces and structures may require repair. Repairs can range from the elementary, repair of a form-related defect, to the complex, rehabilitation of a load bearing structure. Even if the concrete was properly designed, placed, and cured, the combined effects of weathering, exposure to aggressive chemicals, physical attack, and service loads will eventually lead to concrete deterioration and distress. New concrete may also require repair and can develop an assortment of cracks, curling, honeycombing, and scaling. This effort is in response to the numerous field requests received by the Navy's Center of Expertise for Paints and Coatings and is intended to assist Naval activities in the process of concrete repair.

This Special Publication (SP) introduces a brief overview of concrete repair guidance offered by the American Concrete Institute (ACI) International, the International Concrete Repair Institute (ICRI), the American Concrete Pavement Association (ACPA), The Aberdeen Group, the Portland Cement Association (PCA), and work by authors considered experts in the field of concrete repair. The publication is divided into two parts: Part I, "Condition Assessment," and Part II, "Concrete Repair." Part I details condition survey, concrete evaluation, evaluation of structures, and additional surface evaluation; Part II introduces concrete removal, surface preparation, repair materials, placement methods, curing, quality control, and repair guidance.

Concrete repair may require a team effort to assess the concrete's condition, identify appropriate repair methods, recommend suitable repair materials, and specify correct installation procedures. The repair team can include a concrete inspector, engineer, architect, material manufacturer(s), contractor, and various other concrete specialists. When concrete surfaces and/or structures are properly repaired, repair durability is enhanced and coating performance is optimized.

TABLE OF CONTENETS

INTRODUCTION.....	1
PART 1: CONDITION ASSESSMENT.....	2
CONDITION SURVEY.....	2
CONCRETE EVALUATION.....	3
EVALUATION OF STRUCTURES.....	4
ADDITIONAL SURFACE EVALUATION.....	5
PART 2: CONCRETE REPAIR.....	6
CONCRETE REMOVAL.....	6
SURFACE PREPARATION.....	7
REPAIR MATERIALS.....	8
PLACEMENT METHODS.....	10
CURING.....	10
QUALITY CONTROL.....	11
REPAIR GUIDANCE.....	12
CONCLUSIONS.....	13
ACKNOWLEDGEMENTS.....	13
REFERENCES.....	14

INTRODUCTION

Prior to coating, concrete surfaces and structures may require repair. Repairs can range from the elementary, repair of a form-related defect, to the complex, rehabilitation of a load bearing structure. Even if the concrete was properly designed, placed, and cured, the combined effects of weathering, exposure to aggressive chemicals, physical attack, and service loads will eventually lead to concrete deterioration and distress. New concrete may also require repair and can develop an assortment of cracks, curling, honeycombing, and scaling. This effort is in response to the numerous field requests received by the Navy's Center of Expertise for Paints and Coatings and is intended to assist Naval activities in the process of concrete repair.

This report introduces a brief overview of concrete repair guidance offered by the American Concrete Institute (ACI) International¹, the International Concrete Repair Institute² (ICRI), the American Concrete Pavement Association³ (ACPA), The Aberdeen Group⁴, the Portland Cement Association⁵ (PCA), and work by authors considered experts in the field of concrete repair^{6,7}. The publication is divided into two parts: Part I, "Condition Assessment," and Part II, "Concrete Repair." Part I details condition survey, concrete evaluation, evaluation of structures, and additional surface evaluation; Part II introduces concrete removal, surface preparation, repair materials, placement methods, curing, quality control, and repair guidance. Each summary is presented sequentially and reflects the process of concrete repair. Examples of concrete structures and surfaces generally requiring repair are presented in Figures 1 - 6.

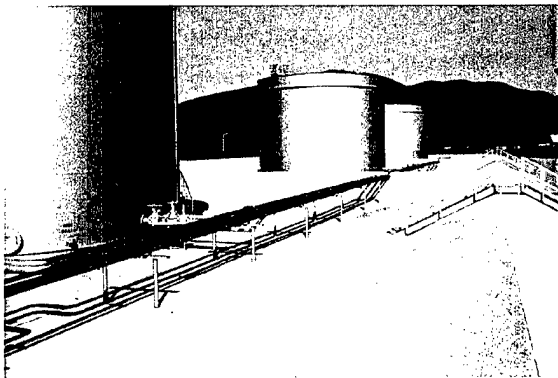


Fig. 1 - Secondary containment.



Fig. 2 - Architectural walls.



Fig. 3 - Formed wall, honeycombing.

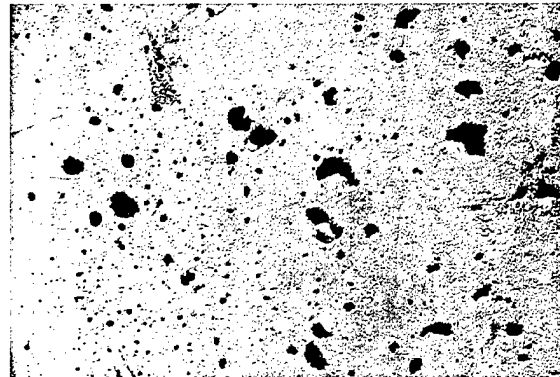


Fig. 4 - Standard wall, bugholes.

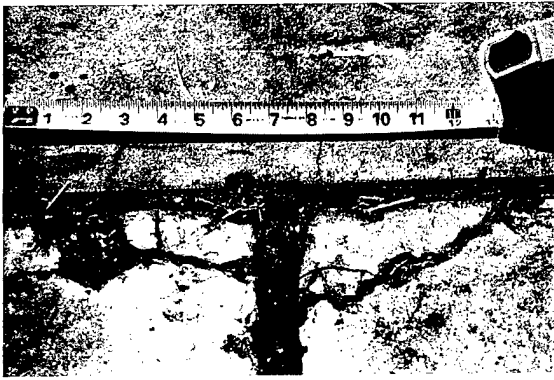


Fig. 5 – Industrial floor, corner spall.

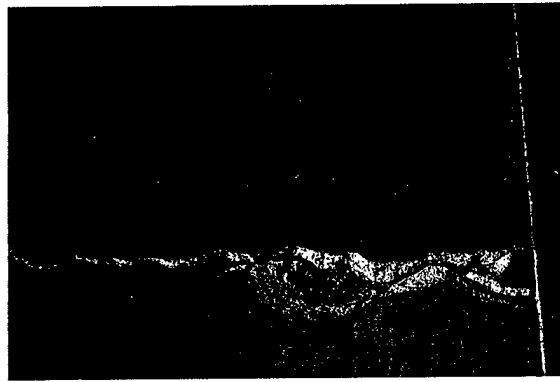


Fig. 6 – Hangar floor, spalled crack.

PART 1: CONDITION ASSESSMENT

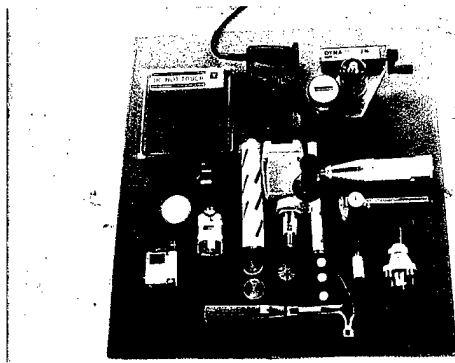


Fig. 7 – Various condition assessment tools.

CONDITION SURVEY

The purpose of a condition survey is to identify and document concrete defects, deterioration, and distress. The survey generally consists of a visual examination whereby problem areas are documented according to type, size, and location. The above Figure (Fig. 7) shows several tools typically used in the condition assessment process.

ACI 201.1R “Guide for Making a Condition Survey of Concrete in Service”

ACI 201.1R presents a systematic approach for surveying the condition of concrete in service. The guide defines ten types of cracking, thirty-one types of deterioration, seventeen types of surface defects, and contains forty-nine photographs of concrete distress manifestations. Definitions and photographs are presented as relative standards and are to be used with the guide’s “check list.” The guide is designed for use by experienced concrete field surveyors; however, it is written in a format that is easily understood and may be used by those who desire an introduction to the survey process.

The Aberdeen Group’s “A Troubleshooting Guide”

“A Troubleshooting Guide” compliments ACI 201.1R and is intended to show the variety of problems typically encountered in concrete construction. The publication contains fifty-six photographs representing over thirty types of concrete defects and deterioration.

Each identified problem is referenced directly to a past article published in The Aberdeen Group's "Concrete Construction" magazine.

ACI 224.1R "Causes, Evaluation and Repair of Cracks in Concrete Structures"

ACI 224.1R presents methods used to survey cracks and identifies eleven causes of cracking. Emphasis is placed on determining the extent and type of cracking using observation, nondestructive testing, and destructive testing.

PCA "Diagnosis and Control of Alkali-Aggregate Reactions in Concrete"

This document presents an overview of visual distress symptoms associated with Alkali-Aggregate Reactions (AAR). AAR distress symptoms may include map cracking, closed joints, spalled concrete, popouts, and color changes. The Alkali-Silica Reaction (ASR) is the most prevalent form of AAR and concrete becomes distressed when expansive reaction products are generated. To confirm the presence of AAR, either a petrographic examination or a uranyl-acetate fluorescent test method is recommended.

CONCRETE EVALUATION

The objective of a concrete evaluation is to quantify the degree of problems found during the condition survey.

Concrete Repair and Maintenance Illustrated⁸

This book contains fourteen sections on concrete evaluation and presents a simplified five-step approach for use in the typical evaluation: 1) Visual inspection, 2) Review of engineering data, 3) Condition survey, 4) Final evaluation, and 5) Condition survey report. In addition to concrete evaluation, seventy pages are dedicated to concrete behavior with discussions on metal corrosion, disintegration mechanisms, moisture effects, thermal effects, load effects, and faulty workmanship.

ACI 228.1R "In-Place Methods to Estimate Concrete Strength"

ACI 228.1R presents a review of methods used to estimate the strength of in-place concrete and establishes the relationship between methods and concrete compressive strength. Methods reviewed include Rebound Number, Penetration Resistance, Pullout Test, Break-Off Test, Ultrasonic Pulse Velocity, Maturity Method, and Cast-In-Place Cylinders. In-place strength methods apply to new and existing construction and are not intended to replace either core boring or laboratory testing. The report also discusses repeatability of results, interpretation and reporting of results, and in-place acceptance criteria. If used properly, the above methods may reduce the number of cores required to map a structure for in-place strength.

ACI 506.4R "Guide for the Evaluation of Shotcrete"

ACI 506.4R presents procedures that can be used to evaluate in-place shotcrete. Evaluation methods include Coring, Rebound and Indentation Tests, Penetration Tests, Pull-Out Tests, Sounding, Direct Tension, Sonic and Radar Methods, Infrared Thermography, and Radiography.

Petrographic Examination of Distressed Concrete⁹ (REMR TN CS-ES-1.7)

This document presents the capabilities and limitations of the science of concrete petrography. Concrete petrography is a laboratory evaluation and can be used to determine the following: 1) The current condition of concrete, 2) The causes of distress to concrete, 3) Whether the deterioration will continue, and 4) If deterioration is expected to continue and the amount of damage to be expected. Several examples of petrographic examinations are presented which illustrate the diversity of concrete petrography.

EVALUATION OF STRUCTURES

Concrete structures may require further evaluation for load bearing capacity, unique strength requirements, stability, structural safety, and other parameters.

Repair and Protection of Concrete Structures¹⁰

Chapter 8 titled "In Situ Evaluation of Concrete Structures" is presented sequentially and covers condition survey, methods of evaluation, equipment and methods of nondestructive testing, and the repair program. In addition to the evaluation process, Chapter 7 titled "Durability" (sixty pages) provides discussion on factors affecting durability and the modes of concrete deterioration.

ACI 364.1R "Guide for Evaluation of Concrete Structures Prior to Rehabilitation"

ACI 364.1R is a comprehensive document and is primarily for use in evaluating concrete structures for rehabilitation, aesthetic modifications, structural adequacy, degree of structural distress, and conformance to building codes. The guide covers preliminary investigation, detailed investigation, field inspection, condition survey, material sampling and testing, documentation, and reporting. Emphasis is placed on thirty combined evaluation procedures/methods for use in determining twenty-two properties of reinforcing steel, twenty-eight chemical and physical properties of concrete, and nineteen physical conditions of concrete. This document is ACI's foremost guide for evaluating concrete structures prior to rehabilitation.

ACI 437R "Strength Evaluation of Existing Concrete Buildings"

ACI 437R provides evaluation guidelines for use in establishing the loadings that can safely be sustained by the structural elements of a concrete building. The document covers preliminary investigation, condition survey, material evaluation, assessment of loading and environmental conditions, and analytical strength evaluation.

ACI 228.2R "Nondestructive Test Methods for Evaluation of Concrete in Structures"

ACI 228.2R presents nondestructive test methods for use in determining the condition of concrete and reinforcing steel in structures. Evaluation methods include Visual Inspection, Stress-Wave, Nuclear, Magnetic, Electrical, Infrared Thermography, and Ground Penetrating Radar. The document discusses the principles of each method and further describes the typical instrument. Within the report, nondestructive testing is defined as testing that causes no structurally significant damage to concrete.

ACI 318/318R “Building Code Requirements for Structural Concrete & Commentary”

This document supplements both ACI 364.1R and ACI 437R and serves as ACI’s basis for analytical evaluations involving strength.

ADDITIONAL SURFACE EVALUATION

To prevent coating failures, additional surface evaluation may be required to identify concrete with high moisture vapor emission, high levels of surface contamination, and low surface strength^{11,12}.

Moisture Vapor Emission

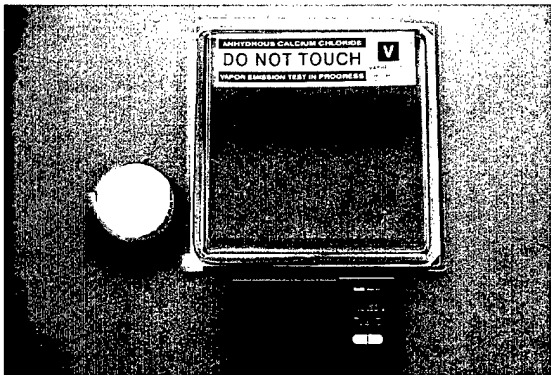


Fig. 8 – Moisture Vapor Emission Test Kit (MVETK) with scale: ASTM-F-1869¹³.

Vapor pressure sufficient to lift a coating system may be generated when coatings are applied to floor slab concrete with a high rate of moisture vapor emission^{14,15,16,17}. The concrete’s rate of moisture vapor emission can be quantified using calcium chloride Moisture Vapor Emission Test Kits (MVETK) (Fig. 8). In general, thin film epoxy flooring systems will withstand up to 3.0 lbs moisture/[24 hours, 1000 ft²] whereas epoxy mortar flooring systems will withstand up to 5.0 lbs moisture/[24 hours, 1000 ft²].

Surface Contamination

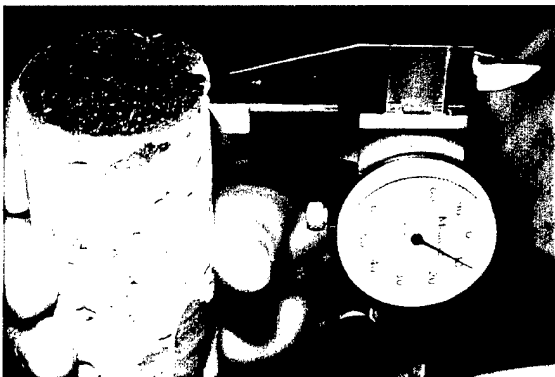


Fig. 9 – Depth of surface contamination.

Concrete cores can be extracted to quantify the depth of surface contamination and cores as small as 3/4” (diameter) by 2” (depth) are generally sufficient. On concrete with oil-

based contamination (grease, fuels, fats, etc.), a line can usually be seen which separates the dark-colored contamination from the uncontaminated concrete (Fig. 9). Surface concrete with less than 1/4" depth contamination is generally easily cleaned and successfully coated¹⁸. However, concrete surfaces with greater depth of surface contamination can require additional cleaning or, in extreme situations, concrete removal and replacement¹⁹.

Surface Strength

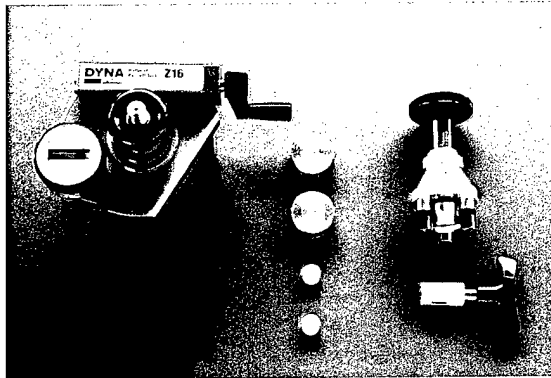


Fig. 10 – Portable adhesion testers with pull-off coupons: L) Dyna tester, R) Elcometer.

Concrete with weak surface strength can be quantified using a portable adhesion tester²⁰ (Fig. 10). In general, coatings may be successfully applied to architectural concrete walls with surface strength > 120 psi and floor slabs/containment structures with surface strength > 180 psi.

PART 2: CONCRETE REPAIR

CONCRETE REMOVAL

Concrete removal is the process of extracting deteriorated and distressed concrete identified as unsound. The below figures (Fig. 11 – 14) show equipment and procedures typically employed to remove unsound concrete.

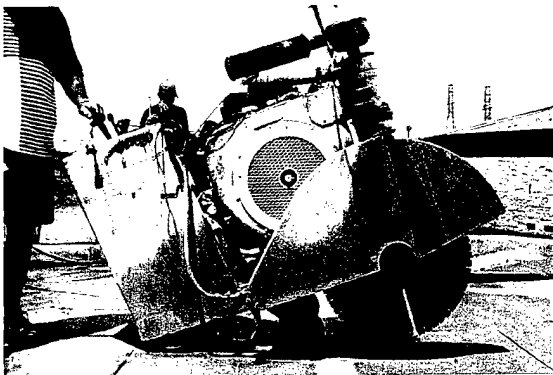


Fig. 11 – Water-cooled concrete saw.



Fig. 12 – Pneumatic chisel scaler.



Fig. 13 – Pneumatic chipping hammer.

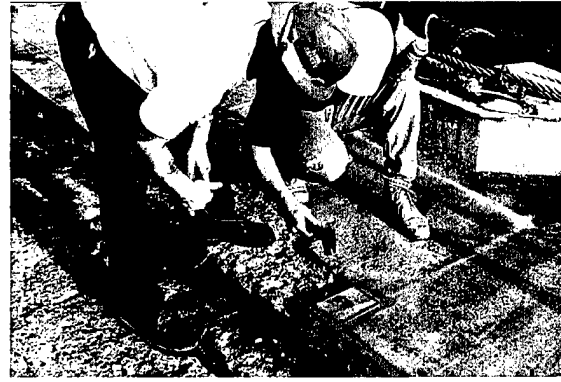


Fig. 14 – Sounding for delaminations.

ACI 546R “Concrete Repair Guide”

Chapter 2 of ACI 546R identifies and presents discussion on the various methods of concrete removal. Removal methods include Blasting, Cutting, Impacting, Milling, Hydrodemolition, Prospecting, and Abrading. Blasting is literally defined as explosive blasting and is used to remove concrete in large volume; however, it may leave distress fractures, bruising, and requires surface finishing by other methods. Cutting employs a variety of technologies such as High-Pressure Water Jetting, Saw Cutting, Diamond Wire Cutting, Mechanical Shearing, Stitch Drilling, and Thermal Cutting. Impact methods include Hand-Held Breakers, Boom-Mounted Breakers, and Scabblers. Milling is a grinding process that utilizes various sizes of scarification equipment. Hydrodemolition uses high-pressure water from 10,000 psi to 35,000 psi and can remove up to several inches of concrete. Prospecting methods induce a crack plane to assist in concrete removal and include Hydraulic Splitters, Water Pulse Splitter, and Expansive Agents. Abrading methods consist of Sandblasting, Shotblasting, and High-Pressure Water Jetting (with abrasives). In addition to concrete removal, this chapter briefly discusses concrete surface preparation.

Concrete Repair and Maintenance Illustrated²¹

This book contains several sections on concrete removal with emphasis on layout of surface repairs, removal geometry, and concrete removal methods. Procedures for partial depth concrete removal include Pneumatic Chipping Hammer, Hydro Removal, Pneumatic Scabbler, and Rotary Milling Machines. Full depth, concrete removal procedures include Hand Held Pneumatic Breakers, Pneumatic/Hydraulic Mounted Breakers, Splitters, and Hydro Demolition.

SURFACE PREPARATION

The objective of surface preparation is to further condition the concrete to properly receive the repair material. Surface preparation removes weak surface cement (laitance), rust deposits on reinforcing steel, and opens up the macro pores of concrete to enhance bonding. The below figures (Fig. 15 – 16) show two aspects of surface preparation.

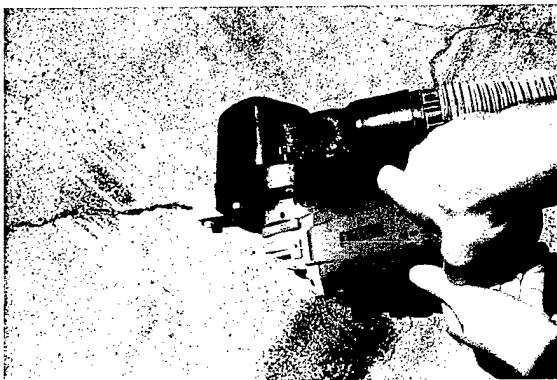


Fig. 15 – Chasing a crack.

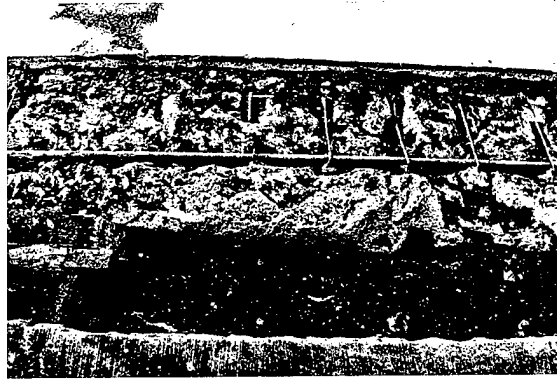


Fig. 16 – Grit blasted reinforcing steel.

ICRI No. 03732 “Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays”

ICRI No. 03732 is designed to facilitate the process of selecting and specifying the appropriate level of surface preparation prior to the application of a repair material. Surface preparation methods discussed are Detergent Scrubbing, Low-Pressure Water Cleaning, Acid Etching, Grinding, Abrasive Blasting, Shot Blasting, Scarifying, Needle Scaling, High-Pressure and Ultra High-Pressure Water Jetting, Scabbling, Flame Blasting, and Milling/Rotomilling. Discussions per surface preparation method include a method summary, purpose, limitations, removal, pattern, profile, accessibility, environmental factors, and execution. Rubber replica standards are available for use with this document and show nine variations of surface roughness.

ICRI No. 03730 “Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion”

ICRI No. 03730 details reinforcing steel corrosion and provides guidance on concrete removal geometry, exposing and undercutting of reinforcing steel, cleaning and repair of reinforcing steel, and surface/edge conditioning of concrete. Special notations are included which stress utilizing a structural engineer if rebar corrosion is encountered and extreme care when removing concrete surrounding electrical conduit, prestressing tendons, and post-tensioning tendons.

REPAIR MATERIALS

The selection of a concrete repair material can be a complex process and generally involves analyzing condition assessment results, predicting service conditions and environmental exposure, anticipating durability, constructibility, aesthetics, cost, and several other technical parameters.

ACI 546R “Concrete Repair Guide”

Chapter 3 of ACI 546R identifies various concrete repair materials and provides discussion on their advantages, limitations, application, and relevant standards. Repair materials identified include Conventional Concrete, Conventional Mortar, Dry Pack,

Ferrocement, Fiber-Reinforced Concrete, Cement Grout, Chemical Grouts, Magnesium Phosphate Concretes and Mortars, Preplaced-Aggregate Concrete, Rapid-Setting Cements, Shotcrete, Shrinkage-Compensating Concrete, Silica-Fume Concrete, Polymer-Impregnated Concrete, Polymer-Modified Concrete, and Polymer Concrete. The process of material selection is also presented with importance placed on the following repair material properties: coefficient of thermal expansion, shrinkage, permeability, modulus of elasticity, chemical, electrical, and color.

ICRI No. 03733 "Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces"

ICRI No. 03733 is an extensive guide for use in the selection of concrete repair materials. Repair material selection is defined as a process involving the evaluation of existing concrete and identifying project objectives, service and exposure conditions, and suitable repair material properties. Special attention is placed on determining the repair material's bond strength, dimensional behavior, durability, mechanical and constructibility properties. A table is also presented which summarizes the typical characteristics of ten repair materials. The guide's focus is to optimize the balance between repair material performance, risk, and cost.

Concrete Repair and Maintenance Illustrated²²

This book dedicates twenty-two pages to concrete repair material requirements, selection, and properties. Repair materials identified include Portland Cement Mortar, Portland Cement Concrete, Microsilica Modified Portland Cement Concrete, Latex Modified Portland Cement Concrete, Polymer Modified Portland Cement Mortar with Non-Sag Filler, Magnesium Phosphate Cement Concrete, Preplaced-Aggregate Concrete, Epoxy Mortar, Methylmethacrylate Concrete, and Shotcrete. Repair materials are further classified according to physical properties (compressive strength, elastic modulus, permeability, freeze thaw resistance, non-sag quality, exotherm during cure), application requirements, and ingredients.

ACI 503.5R "Guide for the Selection of Polymer Adhesives with Concrete"

ACI 503.5R identifies adhesives for use with concrete and provides discussion on type, application characteristics, properties during curing, properties of cured adhesive, and distinguishing characteristics. Adhesives identified include Epoxy, Polyester, Acrylic, Polysulfide, Polyurethane, Silicone, Polyvinyl Acetate, Vinyl Acetate Copolymers, Polyacrylic Esters, Acrylic Copolymers, and Styrene Butadiene Copolymers. These adhesives may be used in bonding hardened concrete to hardened concrete, plastic concrete to hardened concrete, repair of cracks, bonding inserts into concrete, and in bonding other materials to concrete.

Repair and Protection of Concrete Structures²³

This book contains one hundred twenty pages on materials used to repair concrete. Thorough discussions center on the science of polymeric building materials, material selection and handling, patching and resurfacing materials, sealing and waterproofing materials, chemical resistant masonry materials, and admixtures.

PLACEMENT METHODS

A placement method is the process used to deliver and/or apply the concrete repair material.

ICRI No. 03731 "Guide for Selecting Application Methods for the Repair of Concrete Surfaces"

ICRI No. 03731 present a summary of application methods used to place concrete repair materials. Methods discussed and graphically presented include Trowel Applied, Dry-Packing, Form and Cast-In-Place (partial and full depth replacement), Form and Pump, Preplaced Aggregate, Wet-Mix Shotcrete, and Dry-Mix Shotcrete. Four sequential steps are also provided to assist in the selection of a suitable application method.

ACI 304R "Guide for Measuring, Mixing, Transporting, and Placing Concrete"

Chapter 5 of ACI 304R covers the placement of concrete and discusses the following placement methods: Buckets and Hoppers, Manual or Motor Propelled Buggies, Chutes and Drop Chutes, Paving Equipment, and Slipforming. ACI 304R also presents discussion on Forms, Preplaced Aggregate, Concrete Placed Underwater, Pumping Concrete, Conveying Concrete, and Lightweight Structural Concrete.

CURING

Curing of a cementitious repair material is the process of maintaining a constant excess of moisture and/or water sufficient to complete hydration (curing of concrete). The rate at which a cementitious material cures is dependent upon material type, mix design, temperature, and humidity. If cementitious repair materials are used, liquid curing compounds typically decrease coating adhesion and should be avoided.

PCA "Design and Control of Concrete Mixtures"

Chapter 10 titled "Concrete Curing" covers the proper curing of concrete. Curing methods and materials reviewed include Ponding or Immersion, Spraying or Fogging, Wet Coverings, Impervious Paper, Plastic Sheets, Membrane-Forming Curing Compounds, Forms Left in Place, Steam Curing, Insulating Blankets or Coverings, and Specialty Curing (electrical, oil, infrared curing).

ACI 308 "Standard Practice for Curing Concrete"

ACI 308 provides a summary of practices used to cure concrete and presents discussion on Water Curing, Sealing Materials, and Additional Curing Procedures. Practices for Water Curing include Ponding or Immersion, Fog Spraying or Sprinkling, Burlap, Cotton Mats, Rugs, Earth Curing, Sand and Sawdust, and Straw or Hay. Sealing Materials consist of Plastic Films, Reinforcing Paper, and Liquid Membrane Forming Curing Compounds. Additional curing practices cover Cold Weather Protection and Curing, Hot Weather Curing, High Pressure Steam Curing, and Low-Pressure Steam Curing.

QUALITY CONTROL

From material selection to after repair placement, Quality Control (QC) consists of the actions used to evaluate the physical characteristics of the repair. Figure 17 shows the standard QC test for slump whereas the other figures (Fig. 18 – 20) depict stages of concrete repair where QC is generally required.



Fig. 17 – Slump test for consistency of concrete.



Fig. 18 – A simple rectangular repair geometry is preferred and not the above complicated geometry.



Fig. 19 – Finishing a repair.



Fig. 20 – Curing a repair. Placement of water saturated, plastic coated burlap over repair.

ACI 311.1R “Manual of Concrete Inspection”

ACI 311.1R presents inspection guidance on testing of materials, handling and storage of materials, concrete mixes, batching and mixing, inspection before concreting, concreting operations, curing, correction of defects, specific placement, and records and reporting. This manual is designed for use by concrete inspectors but may be useful to those interested in the field of concrete construction.

ACI “The Contractor’s Guide to Quality Concrete Construction”

This publication is written for those who order, form, place, consolidate, finish, and cure concrete. It covers QC issues associated with concrete mixes, concrete specifications, foundations, formwork, reinforcement in structures, joints and embedments in structures,

joints and reinforcements for slabs-on-grade, preparation for concreting, concrete placement and finishing, and field problems. A checklist of common field problems is also presented which includes the cause and future prevention.

PCA "Design and Control of Concrete Mixtures"

Chapter 14 titled "Control Tests for Quality Concrete" presents QC testing for aggregates (5 tests), freshly mixed concrete (12 tests), and hardened concrete (20 tests). Technical justification is provided for each control test identified.

ACI 311.4R "Guide for Concrete Inspection"

ACI 311.4R reviews general inspection guidelines and responsibilities for owners, engineers, contractors, and manufacturers. Additional inspection and testing guidance is provided for engineers on acceptance inspection, QC, implementation, and specialty work. Two appendices are also presented: I) Guide for Organizational Responsibilities, and II) Checklist for use with Inspection and Testing.

REPAIR GUIDANCE

In addition to the aforementioned publications, the below repair guidance can be used to assist in the repair of a variety of concrete defects, distress, and deterioration.

- ICRI/ACI "1999 Concrete Repair Manual"
- ICRI "High-Rise Facade Repairs"²⁴,
- ICRI "Facade Repair from a Contractor's Perspective"²⁵,
- ICRI "Precast Concrete Facade Repairs"²⁶,
- ICRI "Assessing the Durability of Repair Systems"²⁷,
- ICRI "Repair of Joints and Cracks in Industrial Floors"²⁸,
- ACI 224.1R "Causes, Evaluation and Repair of Cracks in Concrete Structures"
- ACI 503R "Use of Epoxy Compounds with Concrete"
- ACI 503.4 "Standard Specification for Repairing Concrete with Epoxy Mortars"
- ACI 503.6R "Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concretes"
- ACI 504R "Guide to Sealing Joints in Concrete Structures"
- ACI 506R "Guide to Shotcrete"
- ACI 506.2 "Specification for Shotcrete"
- ACI 546R "Concrete Repair Guide"
- ACI 548.5R "Guide for Polymer Concrete Overlays"
- ACI 548.1R "Guide for the Use of Polymers in Concrete"
- ACI 548.4 "Standard Specification for Latex-Modified Concrete (LMC) Overlays"
- ACI 549.1R "Guide for the Design, Construction, and Repair of Ferrocement"
- ACPA TB-002.02P "Concrete Paving Technology – Guidelines for Full-Depth Repair"
- ACPA TB-003.02P "Concrete Paving Technology – Guidelines for Partial-Depth Spall Repair"
- ACPA TB-005P "Technical Bulletin – Guidelines for Unbonded Concrete Overlays"

- ACPA TB-007P “Technical Bulletin – Guidelines for Bonded Concrete Overlays”
- The Aberdeen Group “Concrete Repair Vol. 1”
- The Aberdeen Group “Concrete Repair Vol. 2”
- The Aberdeen Group “Concrete Repair Vol. 3”
- “Guide to Concrete Repair²⁹”
- “Concrete Repair and Maintenance Illustrated³⁰”
- “Repair and Protection of Concrete Structures³¹”
- “Evaluation and Repair of Concrete Structures³²”
- “Foundation Behavior and Repair: Residential and Light Construction³³”
- “Bridge Inspection and Rehabilitation: A Practical Guide³⁴”
- “Epoxy Injection in Construction³⁵”

CONCLUSIONS

Prior to coating, concrete repair may require a team effort to assess the concrete’s condition, identify appropriate repair methods, recommend suitable repair materials, and specify correct installation procedures. The repair team can include a concrete inspector, engineer, architect, material manufacturer(s), contractor, and various other concrete specialists. When concrete surfaces and/or structures are properly repaired, repair durability is enhanced and coating performance is optimized. The above thirty-three summaries and thirty-two repair guidance references were presented to assist Naval activities in constructing lasting concrete repairs.

ACKNOWLEDGEMENTS

For technical review, the authors wish to thank Gregory D. Cline, P. E. (NFESC) and Douglas F. Burke, P. E. (NFESC).

REFERENCES

1. ACI International, P.O. Box 9094, Farmington Hills MI 48333-9094. www.aci-int.org
2. ICRI, 1323 Shepard Drive Suite D, Sterling VA 20164-4428. www.icri.org.
3. ACPA, 5420 Old Orchard Rd. Suite A100, Skokie IL 60077.
4. The Aberdeen Group, 426 South Westgate St., Addison IL 60101. www.wocnet.com.
5. PCA, 5420 Old Orchard Rd., Skokie IL 60077.
6. Peter H. Emmons. "Concrete Repair and Maintenance Illustrated." Construction Publishers & Consultants, 1993.
7. Noel P. Mailvaganam. "Repair and Protection of Concrete Structures." CRC Press, 1992.
8. Peter H. Emmons. "Concrete Repair and Maintenance Illustrated." Construction Publishers & Consultants, 1993.
9. ICRI. "1999 Concrete Repair Manual." (pp. 167).
10. Noel P. Mailvaganam. "Repair and Protection of Concrete Structures." CRC Press, 1992.
11. C. Dave Gaughen. "Concrete Floor Condition Assessment: UG-2038-SHR." Naval Facilities Engineering Service Center (NFESC). November 1999.
12. C. Dave Gaughen. "Sequential Approach to a Concrete Floor Condition Assessment: SP-2066-SHR." NFESC. March 2000.
13. American Society for Testing and Materials (ASTM). West Conshohocken, PA.
14. Robert Higgins. "Moisture Problems in Floor Slabs Do Cause Coating Failures." ICRI (video).
15. Robert Johnson. "Delamination of Polymer Coatings on Concrete Floor Slabs." ICRI (video).
16. Robert Gaul. "Moisture-Caused Coating Failures: Facts and Fiction." ICRI (video).
17. Frederick S. Gelfant and Frederick A. Pfaff. "Osmotic Blistering of Epoxy Coatings on Concrete." Journal of Protective Coatings and Linings (JPCL), December 1997.
18. Frederick S. Gelfant. "Cleaning Oil-Contaminated Concrete for Coating." JPCL, December 1996.
19. Patrick Watson. "Overlaying Oil-Soaked Industrial Floors." ICRI (video).
20. C. Dave Gaughen. "Quantifying Sound Coating Adhesion: SP-2067-SHR." NFESC. March 2000.
21. Peter H. Emmons. "Concrete Repair and Maintenance Illustrated." Construction Publishers & Consultants, 1993.
22. Ibid.
23. Noel P. Mailvaganam. "Repair and Protection of Concrete Structures." CRC Press, 1992.
24. Kevin Michols. "High-Rise Facade Repairs." ICRI (video).
25. Robert Joyce. "Facade Repair from a Contractor's Perspective." ICRI (video).
26. Predrag Popovic. "Precast Concrete Facade Repairs." ICRI (video).
27. Rick Montani. "Assessing the Durability of Repair Systems." ICRI (video).
28. Peter Craig. "Repair of Joints and Cracks in Industrial Floors." ICRI (video).

29. Bureau of Reclamation. "Guide to Concrete Repair." April 1997.
30. Peter H. Emmons. "Concrete Repair and Maintenance Illustrated." Construction Publishers & Consultants, 1993.
31. Noel P. Mailvaganam. "Repair and Protection of Concrete Structures." CRC Press, 1992.
32. U.S. Army Corps of Engineers. "Evaluation and Repair of Concrete Structures: EM 1110-2-2002." 1995.
33. Robert Wade Brown. "Foundation Behavior and Repair: Residential and Light Construction." McGraw-Hill, 1997.
34. Louis G. Silano. Bridge Inspection and Rehabilitation: A Practical Guide." John Wiley & Sons, Inc. 1993.
35. John Trout. "Epoxy Injection in Construction." The Aberdeen Group, 1997.