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Report on Evaluation and Repair of Existing Nuclear Safety-Related Concrete Structures

Reported by ACI Committee 349

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Reported by ACI Committee 349

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This report provides recommendations for the evaluation of existing nuclear safety-related concrete structures. The purpose of this report is to provide the owner, owner's engineering staff, consultants, and others with an appropriate procedure and background for examining concrete structural performance and taking appropriate actions based on observed conditions. Methods of examination, including visual inspection and testing techniques and their recommended applications, are cited. Guidance related to acceptance criteria for various forms of degradation and methods for repair are provided.

Keywords: corrosion; cracking; degradation; inspection; load test; nondestructive testing; nuclear plant; rehabilitation; reinforcement; repair; safety; serviceability; structural design; structural evaluation.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Recent structural challenges encountered from events such as the observed alkali-aggregate reactions (AARs)/cracking at Seabrook (U.S. Nuclear Regulatory Commission (U.S. NRC) 2011), cracking and chemical attack at Zion (Gregor and Hookham 1993), and the publicized reports of concrete degradation in domestic plants (Gregor and Hookham 1993; Electric Power Research Institute (EPRI) 1990; Ashar and Bagchi 1995) have highlighted the need for guidance on acceptable structural evaluation and repair methods from a code and regulatory viewpoint. These recommendations can be used to evaluate the condition of concrete structures at any point during their service life and following any imposed damage, aging, or loading event. For post-earthquake evaluations, supplemental guidelines and evaluation criteria, such as those discussed in EPRI TR 3002005284 (EPRI 2015a) and International Atomic Energy Agency (IAEA) Safety Reports Series No. 66 (IAEA 2011), should also be considered.

The evaluation process and techniques used in this report have been revised and updated to cover possible scenarios that could be encountered in nuclear safety-related concrete structures, with insights from the state-of-the-practice in the construction industry included as well. This report provides the user with relevant and more up-to-date information on evaluation and repair of nuclear structures with a focus on those that have been deemed nuclear safety-related. Note that this report provides recommendations for performing an evaluation. The responsible engineer and evaluation team should use engineering judgment in applying these recommendations. Visual inspection is the recommended primary evaluation tool for identification of degradation. A more exhaustive evaluation, using nondestructive examination (NDE) and invasive tests, could be warranted by observations subject to the responsible engineer's evaluation perspective.

1.2—Scope

Chapters 1 and 3 provide the introductory material and general methodology used, respectively. Chapters 4 through 7 and Chapter 9 include new information, expanded coverage, and relevant references for continued research. Chapter 8 provides guidance on the need for repair; use of proven methods, including those recently implemented in specific nuclear plants; and relevant industry references (ACI/ICRI 2013). To ensure that evaluations and any follow-up repairs are properly implemented, it is recommended that the responsible engineer remains in charge throughout the completion of all the tasks up to documentation, including evaluation reports and repair programs as defined herein.

This report supplements the ACI 349 code by presenting a framework for conducting an evaluation and developing any associated repair procedures for nuclear safety-related concrete structures. Before initiating this report, the scope of ACI 349 was self-limited to the design and inspection of newly constructed concrete nuclear structures. As the nuclear power plants in the United States grow older and become susceptible to the adverse effects of aging, their periodic inspection, proper evaluation, and repair have become more important issues. Recent U.S. NRC regulations 10 CFR50.65 and 10 CFR54 (U.S. NRC 2015a,b) require licensees to inspect and evaluate the condition of concrete nuclear structures that may have experienced age-related degradation. Also, following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami in Japan, the NRC established the Near Term Task Force (NTTF) to conduct a review of the NRC processes and regulations, and provide recommendations to the NRC regulatory process to enhance reactor safety. Subsequent to the NTTF findings, the NRC issued a letter under 10 CFR50.54 (U.S. NRC 2015a) on March 12, 2012, requiring owners of every U.S. nuclear power plant to perform seismic (Sezen et al. 2011) walkdowns to identify and address degraded, nonconforming, or unanalyzed conditions, and to verify the current plant configuration with respect to the current design basis and state of knowledge gained since such was prepared on seismic and flood hazards. The evaluation scope herein was tailored to support structural evaluations required by periodic regulatory requests and in support of hazard analyses. Documents including EPRI TR 3002005284 (EPRI 2015a) and NUREG/CR-5042 Supplement 2 (U.S. NRC 1989) should also be considered.

Effective maintenance, modification, and repair of any concrete structure begins with a comprehensive program of inspection and evaluation. This evaluation can include a visual review of previously accomplished repairs or maintenance, and performing condition surveys, testing, mainte-

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nance, and structural analysis. The term "concrete nuclear structure" denotes concrete structures used in a nuclear application, while the term "nuclear safety-related concrete structure" refers to a specific quality classification and a subset of concrete nuclear structures. Although this report was written to provide guidelines for completing an evaluation of nuclear safety-related structures, such guidance can also be used for other similar concrete structures in U.S. Department of Energy (DOE) nuclear facilities/laboratories, Independent Spent Fuel Storage Installations (ISFSIs) licensed under 10 CFR72 (U.S. NRC 2000), or any other applicable structures. The term "plant" is used interchangeably for "nuclear power plants," and "facilities" is used for DOE facilities and ISFSIs, which comply with the ACI 349 code (for example, Performance Category PC-3 or PC-4 and others defined per DOE Guide 420.1.2 [U.S. DOE 2000]) in the balance of this report.

Nuclear safety-related concrete structures are designed to resist the loads associated with plant operating conditions, postulated accidents, and severe environmental conditions. These structures provide protection for nuclear safety-related components from hazards internal and external to the structure, such as postulated missile impacts, impulsive loads, flooding, fire, earthquakes, and other severe environmental conditions. Additionally, the design for some of these structures can be controlled by the required thickness of concrete intended for shielding against radiation produced during the nuclear fission process. All nuclear safety-related structures share a common function: they are integrally designed with the various systems, equipment, and components they support, and protect to restrict the spread of radiation and radioactive contamination to the general public. An effective evaluation procedure provides a rational methodology to maintain the serviceability of nuclear safety-related structures. Each evaluation should make reference to and preserve the design basis, as defined by the updated final safety analysis report (UFSAR), technical specifications, codes and standards, calculations, drawings, and test records for the affected structure(s) in the disposition of findings and results. This includes qualification of any damage or degradation found, or necessity and suitability of various repair options.

Concrete nuclear structures, while unique in application, share many physical characteristics with other concrete structures. The four basic constituents of a concrete mixture are the same for nuclear or nonnuclear concrete structures: cement, fine aggregate, coarse aggregate, and water. Admixtures that enhance the constructability and durability of concrete are also permitted in nuclear structures, with certain limitations as defined in ACI 349. Nuclear safety-related structures can be similarly reinforced with normal reinforcing steel or prestressing steel, and can contain various structural steel embedments. Over time, operational and environmental conditions and loads can result in degradation of these steel elements and could affect the expected behavior of the structure. Whether the structure is considered nuclear safety-related or not, prudent engineering practices during material (concrete mixture) design and specification, structural design, and construction should be taken to minimize the potential for degradation during service. The success of such practices, however, is not ensured, given exposure to various events. Sound inspection programs in which the performance and condition of structures are periodically evaluated and monitored can be used to ensure that the structures continue to serve their intended function. Because of the many similarities between nuclear and nonnuclear concrete structures, practices and procedures used for their inspection and maintenance can be commonly used as defined herein.

The purpose and final scope of an evaluation procedure is defined by the owner, utility, holding company, governmental agency, or other organization. Development and implementation of an evaluation procedure for nuclear safety-related structures can serve many purposes, such as:

a) Provide documented evidence of continued performance and function by periodic evaluation

b) Identify and mitigate age-related degradation at early stages

c) Provide guidance for the development of an effective maintenance program

d) Support the application for an extended operating license

e) Provide baseline condition data for comparison following an earthquake, a short-term environmental load, or an accident condition

f) Provide baseline information regarding ongoing deterioration mechanisms so that any change can be identified and monitored

g) Provide guidance for walkdowns following an earthquake, flood, tsunami, or any other external event

h) Provide configuration and material property information for structural reanalysis, physical modification, or similar activity

This report identifies a procedure for the determination of critical structures, defines and characterizes the primary degradation mechanisms, provides insight on inspection techniques and frequencies, and provides guidance on the evaluation of inspection results and necessary repair. Herein, the word "repair" is intended to signify a goal to maintain the design basis and extend the service life of an affected structure in a nuclear plant, and encompasses rehabilitation, alteration, and repair actions. The design basis could have been changed since original design and construction in response to specific regulatory compliance requirements, so the most current design basis applies to evaluation and repair.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology." Definitions provided herein complement that resource.

BWR—boiling water reactor (BWR) is a type of light water nuclear reactor used for the generation of electrical power. In a BWR, the reactor core heats water, which turns to steam and then drives a steam turbine.

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degradation—effects resulting from internal material reactions, the external environment, and normal plant operations.

design basis—current licensing commitment for the safety-related concrete structure in question that is comprised of original design calculations, drawings, codes and standards, technical specification, safety analysis report requirements, and as-built construction documents.

drummy area—area where there is a hollow sound beneath a layer of concrete due to a delamination, poor consolidation, or void.

evaluation—an engineering review of an existing concrete nuclear structure with the purpose of determining physical condition and functionality of the structure.

function—the special purpose or activity for which a structure exists or is used.

passive cracks—cracks having an absence of recent growth and an absence of other degradation mechanisms at the crack.

PWR—pressurized water reactor (PWR) is a type of light water nuclear reactor used for the generation of electrical power. In a PWR, the reactor core heats water, which does not boil. This hot water then exchanges heat with a lower-pressure water system that turns to steam and drives the turbine.

rattle space gap—"seismic gaps," which are commonly referred to as "shake space," "rattle space," "construction joint systems," or "building joint systems," are part of the overall seismic design of the structure; their principal function is to allow different parts of the nuclear power plant to move independently during an operating-basis earthquake (OBE) or a design-basis earthquake (DBE).

repair—the reconstruction or renewal of concrete parts of an existing structure for the purpose of its maintenance or to correct deterioration, damage, or faulty construction of members or systems of a structure.

visual inspection—assessing the current condition of an accessible existing structure by observation.

CHAPTER 3—GENERAL METHODOLOGY AND EVALUATION PROCEDURE

3.1—General methodology

This report focuses on industry-accepted evaluation practices and recommends the application of those practices to the unique situations typically encountered in nuclear safety-related concrete structures. The objective is to develop a program of inspection and evaluation that recommends the most effective practices for inspection and evaluation of such structures. Through proper inspection and evaluation, the most likely locations for degradation and its causes within the nuclear safety-related structures can be identified. A thorough survey of these critical locations provides data to describe the current physical condition of the concrete, evaluate past structural performance, and form a basis for comparison during future inspections. The responsible engineer, who is the individual responsible for administering the evaluation procedure, can then review the information to evaluate the severity of the condition. The condition could be acceptable as-is or could require further in-depth examination and evaluation. The owner may opt to monitor the condition over a period of time to obtain more data. In more severe cases, the observed condition could require repair, rehabilitation, or replacement of the affected structure. In each case, the evaluation and ultimate corrective actions are based on interpretation of both qualitative and quantitative information regarding the structure in question.

Recommendations in this report use several established ACI reports on evaluation and repair that are developed for general concrete structures (Chapter 9). By implementing established recommendations in typical nuclear plant applications, an effective evaluation procedure can be developed for nuclear safety-related concrete structures. Use of general condition survey (visual inspection), supplemented by additional testing or analysis as required, is a recommended approach for most evaluations.

3.2—Scope

The evaluation of existing nuclear safety-related concrete structures could be required as a result of identified degradation or abnormal performance, in support of physical modifications, or for periodic validation of structural integrity. Comprehensive evaluation of all nuclear safety-related structures at periodic intervals is also desirable to monitor operational effects and possible degradation due to environmental conditions. This chapter describes the procedural steps that can be used to effectively monitor and maintain the nuclear safety-related concrete structures via prioritized evaluation.

An evaluation procedure document should be developed by the owner (3.5). The evaluation procedure should be comprehensive and include provisions for addressing the variety of potential uses, such as those cited in Chapter 1. The two procedural methods of evaluation that can be performed are selective (3.3) and periodic evaluations (3.4). These two methods use similar evaluation tools, such as visual inspections, but are different in terms of scope. The primary components of an evaluation procedure and guidelines for preparing the evaluation procedure document are further discussed in 3.5.

3.3—Selective evaluation

The selective evaluation method is used when an evaluation of a specific structure or structural component is required due to identified issues. The purpose of a selective evaluation is to provide information on a specific structure to serve as input for structural evaluation or subsequent design modification or repair of that structure. When the selective evaluation method is used, the structure in question and the acceptance criteria of the evaluation, such as the required in-place compressive strength and other properties, should be defined based on the design basis. The appropriate evaluation techniques, such as visual inspection and testing, that are used to support the selective evaluation should be defined in the evaluation procedure document. Selective evaluations are typically performed once for a specific purpose and are

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generally not repeated unless the initial evaluation indicates a need to monitor certain degradation mechanisms or structural performance over a defined period of operation.

3.4—Periodic evaluation

The periodic evaluation method can be used to demonstrate satisfactory performance of nuclear safety-related concrete structures, to identify the presence and activity of age-related degradation, or for other reasons as noted in Chapter 1. In contrast to selective evaluations, periodic evaluations are not intended to address a specific issue, but rather are employed to determine physical condition and functionality of nuclear safety-related structures with respect to the design basis. Periodic evaluations should be repeated at a certain frequency using a standardized procedure. Evaluation frequency is defined by the owner according to the licensing requirements and design basis in Table 6 of this report. This form of evaluation should provide an effective method for addressing the U.S. Nuclear Regulatory Commission (NRC)-mandated maintenance rule, or for technical justification in a license renewal application for the nuclear plant as a whole. The frequency of periodic evaluations should be established by considering the factors such as accessibility, physical condition, environmental exposure, and tolerance to anticipated degradation (Hookham 1991). This section discusses the basic criteria for prioritizing and selecting structures for periodic evaluation.

The intent of the prioritization process is to inspect a representative sample of the areas that are most likely to experience some form of degradation, as well as those areas where degradation can be critical to the structural integrity of nuclear safety-related structures. To verify that the selected sample areas are, in fact, representative of worst-case conditions, complementary sample area inspections should be made in areas where little or no degradation is expected. For example, structures primarily located below grade might not be readily accessible for evaluation, but could be exposed to an aggressive environment. Measures can be implemented that establish the condition of these structures through determination of soil and groundwater chemistry and local inspection during opportune soil excavations, such as during new equipment installation. While such efforts are indirect and not comprehensive, they can be used to characterize environmental exposure conditions and their effects to assist in prioritizing further evaluation efforts. Similarly, structures located underwater will not be accessible for evaluation with the same level of visual acuity as structures above water. Measures can be implemented that establish the condition of these structures using divers, dewatering, or remote underwater cameras. The condition of these structures through the inspection of exposed portions of the structures at the waterline and above can serve as a leading indicator of conditions underwater. While such efforts are indirect and not comprehensive, the results can be used to characterize environmental exposure conditions and their effects. The results can also be used to determine whether additional inspections are warranted and to prioritize any further inspection or evaluation efforts. For guidance on investigation and evaluation of underwater components, refer to ACI 546.2R and the *ASCE Manual of Practice* (MOP 101).

Three primary factors pertinent to each structure are common to the prioritization process in periodic evaluation: safety significance, accessibility, and exposure conditions. Safety significance is regulated by the requirements of 10 CFR50 (U.S. Nuclear Regulatory Commission (U.S. NRC 2015a) and 10 CFR100 (U.S. NRC 2015c)), from which the basic structural function and performance requirements are determined. Certain structures can provide multiple nuclear safety-related functions and are more important to the overall safety. Accessibility considerations dictate the degree to which the structure can be inspected under varying operating conditions and the need for special access requirements, such as excavation, divers and dewatering, and radiation protection. Exposure conditions are related to vulnerability of the structure to chemical, physical, and mechanical attacks due to natural and operating environments, and the microclimate to which each structure and structural component thereof is exposed. Prioritization decisions should be sensitive to any significant changes in these three factors, especially when variations such as multiple environmental exposures occur within the same structure. The following process can be used to prioritize the nuclear safety-related concrete structures for inspection (Hookham 1991):

a) List all primary nuclear safety-related structures

b) Categorize structures by location and accessibility; for example, exposed to external atmospheric conditions or indoors subjected to controlled environment, underwater, and subterranean, provided the surfaces of the structure can be accessed

c) Identify and list each structural component of each structure by function, such as wall, column, and slab

d) Identify and evaluate the safety significance of each structure and structural components within each structure and specify the extent of their boundaries, interfaces, and connectivity

e) Examine the aggressiveness of the operating and environmental exposure(s) and local conditions according to their propensity to promote various degradation mechanisms

f) Develop a prioritized listing of structures and their structural components for inspection; those most critical to the structural integrity and safety of the plant and those most likely to be exposed to severe degradation conditions should be given the highest priority

g) Assemble the design basis, including as-built drawings, specifications, design calculations, and other information addressing each structure on the prioritized listing

The number of structures included in a specific evaluation is dictated by the purpose of the evaluation. As an example, it might be necessary to consider the complete listing of structures to support a license-renewal application. For periodic evaluations, all nuclear safety-related structures should be considered in the selection process of the structural components list. Following prioritization and determination of an implementation schedule, the evaluation procedure is applied to the selected structures by the evaluation team. Chapter 7 addresses qualifications of the evaluation team.

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All repair activities associated with structural defects require the review and approval of the responsible engineer and LDP completing repair design.

Where the design basis does not provide guidance for specific tests critical to the performance of the repair, the division of responsibility in the contract documents should identify responsibilities for preparing a schedule of required testing and the acceptance criteria for such to assure compliance.

Issuance of the repair program document, defining the repair program, methodology, QA, and future needs for evaluation (frequency) under the responsible engineer's approval is the final QA action associated with a specific repair during design phase. Lessons learned, particularly relative to future repair of nonnuclear and nuclear safety-related concrete structures, should also be documented to maximize the likelihood of successful repair.

CHAPTER 9—REFERENCES

ACI Committee documents and documents published by other organizations are listed first by document number, full title, and year of publication, followed by authored documents listed alphabetically.

American Concrete Institute

ACI 201.1R-08—Guide for Conducting a Visual Inspection of Concrete in Service

ACI 201.2R-16—Guide to Durable Concrete

ACI 207.3R-94(08)—Practices for Evaluation of Concrete in Existing Massive Structures for Service Conditions

ACI 209R-92(08)—Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures

ACI 210R-93—Erosion of Concrete in Hydraulic Structures

ACI 215R-92(97)—Considerations for Design of Concrete Structures Subjected to Fatigue Loading

ACI 216.1-14—Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

ACI 221.1R-98(08)—Report on Alkali-Aggregate Reactivity

ACI 222R-01(10)—Protection of Metals in Concrete Against Corrosion

ACI 222.2R-14—Report on Corrosion of Prestressing Steels

ACI 224R-01(08)—Control of Cracking in Concrete Structures

ACI 224.1R-07—Causes, Evaluation, and Repair of Cracks in Concrete Structures

ACI 228.1R-03—In-Place Methods to Estimate Concrete Strength

ACI 228.2R-13—Report on Nondestructive Test Methods for Evaluation of Concrete in Structures

ACI 301-16—Specifications for Structural Concrete

ACI 307-08—Code Requirements for Reinforced Concrete Chimneys and Commentary

ACI 318-14—Building Code Requirements for Structural Concrete and Commentary

ACI 349-13—Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary

ACI 364.1R-07—Guide for Evaluation of Concrete Structures before Rehabilitation

ACI 365.1R-17—Report on Service Life Prediction

ACI 423.10R-16—Guide to Estimating Prestress Loss

ACI 437R-03—Strength Evaluation of Existing Concrete Buildings

ACI 503.4-92—Standard Specification for Repairing Concrete with Epoxy Mortars

ACI 503.5R-92(03)—Guide for the Selection of Polymer Adhesives with Concrete

ACI 515.2R-13—Guide to Selecting Protective Treatments for Concrete

ACI 546R-14—Guide to Concrete Repair

ACI 546.2R-10—Guide to Underwater Repair of Concrete

ACI 546.3R-14—Guide to Materials Selection for Concrete Repair

ACI 548.11R-12—Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concretes

ACI 562-16—Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary

American National Standards Institute

ANSI/AISC N690-12—Specification for Safety-Related Steel Structures for Nuclear Facilities

American Society of Civil Engineers

ASCE/SEI 11-99—Guideline for Structural Condition Assessment of Existing Buildings

ASCE MOP 101-01—Underwater Investigations: Standard Practice Manual

American Society of Mechanical Engineers

ASME BPVC-III-2017—Boiler and Pressure Vessel Code: Rules for Construction of Nuclear Power Plant Components

ASME BPVC-XI-2017—Boiler and Pressure Vessel Code: Rules for Inservice Inspection of Nuclear Power Plant Components

ASME NQA-1-2015—Quality Assurance Requirements for Nuclear Facility Applications

ASME RA-S-2008—Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications

ASTM International

ASTM C33/C33M-16—Standard Specification for Concrete Aggregates

ASTM C42/C42M-16—Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

ASTM C289-07—Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method) (withdrawn 2016)

ASTM C295/C295M-12—Standard Guide for Petrographic Examination of Aggregates for Concrete

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ASTM C457/C457M-16—Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

ASTM C666/C666M-15—Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C823/C823M-17—Standard Practice for Examination and Sampling of Hardened Concrete in Constructions

ASTM C856-17—Standard Practice for Petrographic Examination of Hardened Concrete

ASTM C876-15—Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete

ASTM C1077-17—Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Agency Evaluation

ASTM C1218/C1218M-17—Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

ASTM C1260-14—Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

ASTM C1293-08(2015)—Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

ASTM C1567-13—Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

ASTM C1583/C1583M-13—Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

ASTM D5144-08 (2016)—Standard Guide for Use of Protective Coating Standards in Nuclear Power Plants

ASTM E329-14—Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection

ASTM E543-15—Standard Specification for Agencies Performing Nondestructive Testing

International Concrete Repair Institute

ICRI 210.3R-2013—Using In-Situ Tensile Pulloff Tests to Evaluate Bond of Concrete Surface Materials

ICRI 210.4-2009—Nondestructive Evaluation Methods for Concrete Structures

ICRI 310.1R-2008—Surface Preparation: Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

ICRI 310.2R-2013—Guide for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair

ICRI 320.2R-2009—Selecting and Specifying Materials for Repair of Concrete Surfaces

ICRI 320.3R-2012—Guideline for Inorganic Repair Material Data Sheet Protocol

ICRI 320.4-2006—Developments in Repair and Retrofit of Post-Tensioned Structures

ICRI 320.6-2012—Evaluation and Repair of Unbonded Post-Tensioned Concrete Structures

ICRI 330.1-2006—Selection of Strengthening Systems for Concrete Structures

ICRI 340.1-2006—Selecting Grouts to Control Leakage in Concrete Structures

NACE International

NACE SP0390-2009—Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures

U.S. Army Corps of Engineers

EM 1110-2-2002—Evaluation and Repair of Concrete Structures

Authored documents

ACI/ICRI (American Concrete Institute and International Concrete Repair Institute), 2013, *Concrete Repair Manual*, fourth edition, V. 1 and V.2, American Concrete Institute, Farmington Hills, MI, 2363 pp.

Andisheh, K.; Scott, A.; and Palermo, A., 2014, "Preliminary Estimation of Reduction Factors in Mechanical Properties of Steel Reinforcement Due to Pitting Simulated Corrosion," NZSEE Conference, University of Canterbury, Department of Civil and Natural Resources Engineering, Christchurch, New Zealand, 10 pp.

Ashar, H., and Bagchi, G., 1995, "Assessment of Inservice Condition of Safety Related Nuclear Power Plant Structures," *Report* NUREG-1522, U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation, Rockville, MD.

Ashar, H.; Naus, D.; and Tan, C. P., 1994a, "Prestressed Concrete in U.S. Nuclear Power Plants—Part 1," *Concrete International*, V. 16, No. 5, May, pp. 30-34.

Ashar, H.; Tan, C. P.; and Naus, D. J., 1994b, "Prestressed Concrete in U.S. Nuclear Plants—Part 2," *Concrete International*, V. 16, No. 6, June, pp. 58-61.

ASTM International, 1990, "Manual on Maintenance Coatings for Nuclear Power Plants," *Manual* MNL 8, ASTM International, West Conshohocken, PA.

Bartlett, F. M., and Sexsmith, R. G., 1991, "Bayesian Technique for Evaluation of Material Strengths in Existing Bridges," *ACI Materials Journal*, V. 88, No. 2, Mar.-Apr., pp. 164-169.

Clifton, J. R., and Knab, L. I., 1989, "Service Life of Concrete," *Report* NUREG/CR-5466, National Institute of Standards and Technology, Government Publishing Office, Washington, DC, 86 pp.

Cowen, A., and Nichols, R. W., 1968, "Effect of Irradiation on Steels Used in Pressure Vessels," *Prestressed Concrete Pressure Vessels*, The Institute of Civil Engineers, London.

Electric Power Research Institute (EPRI), 1988, "Sourcebook for Microbiologically Influenced Corrosion in Nuclear Power Plants," *Report* NP-5580, 115 pp.

Electric Power Research Institute (EPRI), 1990, "Industry Report (IR) on Class I Structures," *EPRI Project* RP-2643-27, Bechtel Group, Inc., San Francisco, CA, 145 pp.

Electric Power Research Institute (EPRI), 2014, "Expected Condition of Reactor Cavity Concrete After 80 Years of Radiation Exposure," EPRI, Palo Alto, CA, Mar., 126 pp.

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Electric Power Research Institute (EPRI), 2015a, "Guidelines for Nuclear Plant Response to an Earthquake," TR 3002005284, EPRI, Palo Alto, CA, Oct., 90 pp.

Electric Power Research Institute (ERPI), 2015b, "Tools for Early Detection of ASR in Concrete Structures," *Report* TR-3002005389, EPRI, Palo Alto, CA, Sept., 116 pp.

Electric Power Research Institute (EPRI), 2016a, "Long-Term Operations: Impact of Radiation Heating on PWR Biological Shield Concrete," EPRI, Palo Alto, CA, Dec., 12 pp.

Electric Power Research Institute (EPRI), 2016b, "Structural Deformation as a Result of Expansion from Alkali-Silica Reaction," EPRI, Palo Alto, CA, Dec., 12 pp.

Electric Power Research Institute (EPRI), 2016c, "Structural Disposition of Neutron Radiation Exposure in BWR Vessel Support Pedestals," EPRI, Palo Alto, CA, June, 8 pp.

Field, K.; Remec, I.; and Le Pape, Y., 2015, "Radiation Effects in Concrete for Nuclear Power Plants—Part I: Quantification of Radiation Exposure and Radiation Effects," *Nuclear Engineering and Design*, V. 282, Oct., pp. 126-143. doi: 10.1016/j.nucengdes.2014.10.003

Frangopol, D.; Brühwiler, E.; Faber, M.; and Adey, B., 2004, "Life-Cycle Performance of Deteriorating Structures: Assessment, Design and Management," American Society of Civil Engineers, Reston, Mar., VA.

Gregor, F. E., and Hookham, C. J., 1993, "Remnant Life Preservation of LWR Plant Structures," *Proceedings of the 12th International Conference on Structural Mechanics in Reactor Technology (SMiRT)*, Elsevier Science Publishers, the Netherlands, 7 pp.

Harmathy, T. Z., and Stanzack, W. W., 1970, "Elevated Temperature Tensile and Creep Properties for Some Structural and Prestressing Steels," *STP 464*, ASTM International, West Conshohocken, PA.

Hookham, C. J., 1991, "Structural Aging Assessment Methodology for Concrete Structures in Nuclear Power Plants," *Report* ORNL/NRC/LTR-90/17, Oak Ridge National Laboratory, Oak Ridge, TN, Mar., 120 pp.

Hookham, C. J., 1995, "In-Service Inspection Guidelines for Concrete Structures in Nuclear Power Plants," *Report* ORNL/NRC/LTR-95/14, Oak Ridge National Laboratory, Oak Ridge, TN, Aug., 74 pp.

Institution of Structural Engineers (ISE), 2010, "Structural Effects of Alkali-Silica Reaction. Technical Guidance on the Appraisal of Existing Structures," The Institution of Structural Engineers (ISE), London, UK, Apr.

International Atomic Energy Agency, 2002, "Guidebook on Non-destructive Testing of Concrete Structures," *Training Course Series* No. 17, International Atomic Energy Agency (IAEA), Vienna, Austria, 231 pp.

International Atomic Energy Agency, 2011, "Earthquake Preparedness and Response for Nuclear Power Plants," *Safety Reports Series* No. 66, International Atomic Energy Agency (IAEA), Vienna, Austria, 204 pp.

Konecny, L.; Mukherjee, P. K.; and Frost, C. R., 1990, "Leaching of Concrete," *Conference on Advances in Cementitious Materials*, American Ceramic Society, 13 pp.

Krauss, P. D., 1994, "Repair Materials and Techniques for Concrete Structures in Nuclear Power Plants," *Report* ORNL/NRC/LTR-93/28, Oak Ridge National Laboratory, Oak Ridge, TN, National Technical Information System, Washington, DC.

Malhotra, V. M., 1976, "Testing Hardened Concrete: Nondestructive Methods," *American Concrete Institute Monograph* No. 9, American Concrete Institute, Farmington Hills, MI, 188 pp.

Malhotra, V. M., and Carino, N. J., 2003, *CRC Handbook on Nondestructive Testing of Concrete*, second edition, CRC Press, Boca Raton, FL, Dec., 384 pp.

Mori, Y., and Ellingwood, B., 1993, "Methodology for Reliability Based Condition Assessment; Application to Concrete Structures in Nuclear Plants," *Report* NUREG/CR-6052, National Technical Information Service, Springfield, VA, 149 pp.

National Institute for Standards and Technology, 2013, "Codes and Standards for the Repair of Nuclear Power Plant Concrete Structures: Recommendations for Future Development," National Institute of Standards and Technology, Boulder (NIST), American National Standards Institute (ANSI), 96 pp.

Naus, D. J., 1986, "Concrete Component Aging and Its Significance Relative to Life Extension of Nuclear Power Plants," *Report* NUREG/CR-4652, ORNL/TM-10059, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, 158 pp.

Naus, D. J., 2010, "A Compilation of Elevated Temperature Concrete Material Property Data and Information for use in Assessments of Nuclear Power Plant Reinforced Concrete Structures," *Report* NUREG/CR-7031, NRC, Washington, DC, Dec.

Naus, D., and Oland, B., 1998, "An Investigation of Tendon Sheathing Filler Migration into Concrete," *Report* NUREG/CR-6598, ORNL/TM-13554, Oak Ridge National Laboratory, Oak Ridge, TN. Mar., 85 pp.

Podolny Jr., W., and Melville, T., 1969, "Understanding the Relaxation in Prestressing," *PCI Journal*, V. 14, No. 4, p. 43 doi: 10.15554/pcij.08011969.43.54

Portland Cement Association (PCA), 2002, "Types and Causes of Concrete Deterioration," PCA, Skokie, IL, 17 pp.

Refai, T. M., and Lim, M. K., 1992, "In-Service Inspection and Structural Integrity Assessment Methods for Nuclear Power Plant Concrete Structures," *Report* ORNL/NRC/ LTR-90/29, Oak Ridge National Laboratory, Oak Ridge, TN.

Scollard, C. R., and Bartlett, F. M., 2004, "Rehabilitation Criteria for Post-Tensioned Voided-Slab Bridges," *Canadian Journal of Civil Engineering*, V. 31, No. 6, pp. 977-987. doi: 10.1139/l04-057

Seeberger, J., and Hilsdorf, H., 1982, "Einfluß von radioactiver Strahlung auf die Festogkeit and Struktur von Beton," *Technical Report* NR 2505, Institut für Massivbau and Baustofftechnologie, Universitat Karlsruhe.

Sezen, H.; Hookham, C.; Elwood, K.; Moore, M.; and Bartlett, M., 2011, "Core Testing Requirements for Seismic Evaluation of Existing Structures," *Concrete International*, V. 33, No. 11, Nov., pp. 43-48.

Soebbing, J.; Skabo, R.; Michel, H.; Guthikonda, G.; and Sharaf, A., 1996, "Rehabilitating Water and Waste

Water Treatment Plants," *Journal of Protective Coatings & Linings*, V. 13, May, pp. 54-64.

Stefanovie, V. M., and Milasin, N. L., 1971, "Correlation Between the Mechanical Properties and Microstructure of Irradiated Iron and Low-Carbon Steel," *STP 484*, ASTM International, West Conshohocken, PA.

Uddin, T., and Culver, C. G., 1975, "Effects of Elevated Temperature on Structural Materials," *Journal of the Structural Division*, V. 101, No. 7, Dec., pp. 1531-1549.

U.S. Army Corps of Engineers, 1995, "Evaluation and Repair of Concrete 2 Structures," *Engineer Manual EM 1110-2-2002*, 182 pp.

U.S. Department of Energy (DOE), 2000, "Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities," Guide 420.1.2, U.S. DOE, Washington, DC.

U.S. Department of Energy (DOE), 2011, "Nuclear Safety Management," *Code of Federal Regulations*, Part 830, U.S. DOE, Washington, DC.

U.S. Department of the Interior, 2012, "Best Practices for Repairing Concrete Surfaces Prior to Repairs and Overlays," *Report* Number MERL 12-17, Bureau of Reclamation, Washington, DC.

U.S. Nuclear Regulatory Commission (NRC), 1989, "Evaluation of External Hazards to Nuclear Power Plants in the United States: Other External Events," *Report* NUREG/CR-5042, Supplement 2.

U.S. Nuclear Regulatory Commission (NRC), 1990, "Determining Prestressing Forces for Inspection of Prestressed Concrete Containments," Regulatory Guide 1.35.1, U.S. NRC, Washington, DC.

U.S. Nuclear Regulatory Commission (NRC), 2000, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste," Title 10, *Code of Federal Regulations*, Part 72, U.S. NRC, Washington, DC.

U.S. Nuclear Regulatory Commission (NRC), 2010, "Generic Aging Lessons Learned (GALL)," *Report* NUREG-1801, Revision 2, U.S.NRC, Washington, DC.

U.S. Nuclear Regulatory Commission (NRC), 2011, "Concrete Degradation by Alkali Silica Reaction," *Information Notice (IN)*, ML 112241029.

U.S. Nuclear Regulatory Commission (NRC), 2012, Regulatory Guide 1.160, "Monitoring the Effectiveness of Maintenance at Nuclear Power Plant," Revision 3.

U.S. Nuclear Regulatory Commission (NRC), 2014, "Expanded Materials Degradation Assessment (EMDA), Volume 4: Aging of Concrete and Civil Structures," *Report* NUREG/CR-7153, Oak Ridge, TN.

U.S. Nuclear Regulatory Commission (NRC), 2015a, *Code of Federal Regulations*, Title 10, Part 50, Domestic Licensing of Production and Utilization Facilities, U.S. NRC, Washington D.C.

U.S. Nuclear Regulatory Commission (NRC), 2015b, *Code of Federal Regulations*, Title 10, Part 54, Requirements for Renewal of Operating Licenses for Nuclear Power Plants, U.S. NRC, Washington D.C.

U.S. Nuclear Regulatory Commission (NRC), 2015c, *Code of Federal Regulations*, Title 10, Part 100, Reactor Site Criteria, Appendix A, Seismic and Geologic Siting Criteria for Nuclear Power Plants, U.S. NRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC), 2017a, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR)," *Final Report* NUREG-2191.

U.S. Nuclear Regulatory Commission (NRC), 2017b, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," *Report* NUREG-0800, U.S. NRC, Washington, DC.

William, K.; Xi, Y.; and Naus, D. J., 2013, "A Review of the Effect of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants," *Report* NUREG/CR-7171, NRC, Washington, DC.

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