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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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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.

CONTENTS

ACI 349.3R-18 supersedes ACI 349.3R-02 and was adopted and published February 2018.

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-

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.