

ACI 349-13

**Code Requirements for Nuclear
Safety-Related Concrete Structures
(ACI 349-13) and Commentary**

An ACI Standard

Reported by ACI Committee 349



American Concrete Institute®

This is a preview. [Click here to purchase the full publication.](#)

Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at www.concrete.org/committees/errata.asp. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

ISBN: 978-0-87031-894-8

This is a preview. Click here to purchase the full publication.

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

An ACI Standard

Reported by ACI Committee 349

Herman L. Graves III, Chair
Adeola K. Adediran, Vice Chair

Partha S. Ghosal, Vice Chair
Lisa M. Anderson, Secretary

Omesh B. Abhat
Taha D. Al-Shawaf
Ranjit L. Bandyopadhyay*
Harry A. Chambers
Ronald A. Cook
Rolf Eligehausen
Farhad Farzam
Werner A. F. Fuchs
Stewart C. Gallocher
Branko Galunic
Orhan Gurbuz
James A. Hammell
Joseph Kendall Harrold
Gunnar A. Harstead
Christopher Heinz
Charles J. Hookham

Ronald J. Janowiak
Scott A. Jensen
Richard E. Klingner
Nam-Ho Lee
Javed Munshi
Dan J. Naus
Dragos A. Nuta
Richard S. Orr
Anton D. Pirtz
John F. Silva
Bozidar Stojadinovic
Barendra K. Talukdar
Donald T. Ward
Andrew S. Whittaker
Albert Y. C. Wong
Charles A. Zalesiak

Consulting Members
Hansraj G. Ashar
Peter J. Carrato
Mukti L. Das

The committee recognizes the following non-voting members for their contributions to the development of the code revision: Monzer M. Allam, Jorg NMI Asmus, Matthew Dominick D'Ambrosia, Chiara F. Ferraris, Ola Jovall, Angela McAlpin, Michael C. Mota, Nebojsa Orbovic, Debi Ramos, Madhumita Sircar, and J. Bret Turley.

*Ranjit L. Bandyopadhyay was a long-time member of ACI Committee 349 and the Committee Chair of ACI 349 at the time of his death in 2010. The committee expresses its appreciation for his friendship and leadership.

This standard covers the proper design and construction of concrete structures that form part of a nuclear power plant and that have nuclear safety-related functions, but does not cover concrete reactor vessels and concrete containment structures (as defined by Joint ACI-ASME Committee 359).

The structures covered by the Code include concrete structures inside and outside the containment system.

This Code may be referenced and applied subject to agreement between the owner and the Regulatory Authority.

All notation sections have been removed from the beginning of each chapter and consolidated into one list in Chapter 2.

The format of this Code is based on the "Building Code Requirements for Structural Concrete (ACI 318-08)" and incorporates recent revisions of that standard.

The commentary, which is presented after the Code, discusses some of the considerations of ACI Committee 349 in developing "Code Requirements for Nuclear Safety-Related Concrete

Structures (ACI 349-13)." This information is provided in the commentary because the Code is written as a legal document and therefore cannot present background details or suggestions for carrying out its requirements.

Keywords: anchorage; authority having jurisdiction (AHJ); beam-column frame; beams; building codes; columns; composite construction; concrete cover; cracking (fracturing); creep; curing; deep beams; deflection; earthquake-resistant structures; floors; folded plates; footings; formwork; inspection; joints; joists; load tests; loads; mixture proportioning; modulus of elasticity; nuclear power plants; nuclear reactor containments; nuclear reactor safety; nuclear reactors; precast concrete; prestressed concrete; quality control; reinforced concrete; safety; serviceability; shear strength; shearwalls; shells; slabs; specifications; splicing; structural analysis; structural design; temperature; torsion; walls.

ACI 349-13 supersedes ACI 349-06, was adopted August 15, 2013, and published June 2014.

Copyright © 2014, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is granted by the American Concrete Institute.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certification or equivalent.

This is a preview. Click here to purchase the full publication.

CONTENTS

INTRODUCTION, p. 7

CHAPTER 1—GENERAL REQUIREMENTS, p. 9

- 1.1—Scope, p. 9
- 1.2—Drawings and specifications, p. 10
- 1.3—Inspection, p. 11
- 1.4—Approval of special systems of design or construction, p. 12
- 1.5—Quality assurance program, p. 12
- References, Chapter 1, p. 12

CHAPTER 2—NOTATION AND DEFINITIONS, p. 14

- 2.1—Code notation, p. 14
- 2.2—Definitions, p. 22

CHAPTER 3—MATERIALS, p. 30

- 3.1—Tests of materials, p. 30
- 3.2—Cementitious materials, p. 30
- 3.3—Aggregates, p. 30
- 3.4—Water, p. 31
- 3.5—Steel reinforcement, p. 31
- 3.6—Admixtures, p. 33
- 3.7—Storage and identification of materials, p. 33
- 3.8—Referenced standards, p. 34
- References, Chapter 3, p. 36

CHAPTER 4—DURABILITY REQUIREMENTS, p. 37

- 4.1—General, p. 37
- 4.2—Exposure categories and classes, p. 37
- 4.3—Requirements for concrete mixtures, p. 37
- 4.4—Additional requirements for freezing-and-thawing exposure, p. 37
- 4.5—Alternative cementitious materials for sulfate exposure, p. 37

CHAPTER 5—CONCRETE QUALITY, MIXING, AND PLACING, p. 38

- 5.1—General, p. 38
- 5.2—Selection of concrete proportions, p. 38
- 5.3—Proportioning on the basis of field experience or trial mixtures, or both, p. 39
- 5.4—Proportioning without field experience or trial mixtures, p. 39
- 5.5—Average compressive strength reduction, p. 39
- 5.6—Evaluation and acceptance of concrete, p. 39
- 5.7—Preparation of equipment and place of deposit, p. 42
- 5.8—Mixing, p. 42
- 5.9—Conveying, p. 42
- 5.10—Depositing, p. 42
- 5.11—Curing, p. 43
- 5.12—Cold weather requirements, p. 44
- 5.13—Hot weather requirements, p. 44
- References, Chapter 5, p. 44

CHAPTER 6—FORMWORK, EMBEDMENTS, AND CONSTRUCTION JOINTS, p. 45

- 6.1—Design of formwork, p. 45
- 6.2—Removal of forms, shores, and reshoring, p. 45
- 6.3—Embedments in concrete, p. 45
- 6.4—Construction joints, p. 47
- Referenced standards Chapter 6, p. 47

CHAPTER 7—DETAILS OF REINFORCEMENT, p. 48

- 7.1—Standard hooks, p. 48
- 7.2—Minimum bend diameters, p. 48
- 7.3—Bending, p. 48
- 7.4—Surface conditions of reinforcement, p. 48
- 7.5—Placing reinforcement, p. 48
- 7.6—Spacing limits for reinforcement, p. 48
- 7.7—Concrete protection for reinforcement, p. 49
- 7.8—Special reinforcement details for columns, p. 49
- 7.9—Connections, p. 49
- 7.10—Lateral reinforcement for compression members, p. 49
- 7.11—Lateral reinforcement for flexural members, p. 49
- 7.12—Minimum reinforcement, p. 49
- 7.13—Requirements for structural integrity, p. 50
- References, Chapter 7, p. 50

CHAPTER 8—ANALYSIS AND DESIGN—GENERAL CONSIDERATIONS, p. 51

- 8.1—Design methods, p. 51
- 8.2—Loading, p. 51
- 8.3—Methods of analysis, p. 51
- 8.4—Redistribution of moments in continuous flexural members, p. 51
- 8.5—Modulus of elasticity, p. 51
- 8.6—Not used, p. 51
- 8.7—Stiffness, p. 51
- 8.8—Effective stiffness to determine lateral deflections, p. 52
- 8.9—Span length, p. 52
- 8.10—Columns, p. 52
- 8.11—Arrangement of live load, p. 52
- 8.12—T-beam construction, p. 52
- 8.13—Joist construction, p. 52
- 8.14—Separate floor finish, p. 52
- R8.14—Separate floor finish, p. 52

CHAPTER 9—STRENGTH AND SERVICEABILITY REQUIREMENTS, p. 53

- 9.1—General, p. 53
- 9.2—Required strength, p. 56
- 9.3—Design strength, p. 59
- 9.4—Design strength for reinforcement, p. 60
- 9.5—Control of deflections, p. 60
- References, Chapter 9, p. 65

CHAPTER 10—FLEXURE AND AXIAL LOADS, p. 67

- 10.1—Scope, p. 67
- 10.2—Design assumptions, p. 67
- 10.3—General principles and requirements, p. 67

- 10.4—Distance between lateral supports of flexural members, p. 67
- 10.5—Minimum reinforcement of flexural members, p. 67
- 10.6—Distribution of flexural reinforcement in beams and one-way slabs, p. 67
- 10.7—Deep beams, p. 67
- 10.8—Design dimensions for compression members, p. 67
- 10.9—Limits for reinforcement of compression members, p. 68
- 10.10—Slenderness effects in compression members, p. 68
- 10.11—Axially loaded members supporting slab system, p. 68
- 10.12—Transmission of column loads through floor system, p. 68
- 10.13—Composite compression members, p. 68
- 10.14—Bearing strength, p. 68

CHAPTER 11—SHEAR AND TORSION, p. 69

- 11.1—Shear strength, p. 69
- 11.2—Shear strength provided by concrete for nonprestressed members, p. 69
- 11.3—Shear strength provided by concrete for prestressed members, p. 69
- 11.4—Shear strength provided by shear reinforcement, p. 69
- 11.5—Design for torsion, p. 69
- 11.6—Shear-friction, p. 69
- 11.7—Deep beams, p. 69
- 11.8—Provisions for brackets and corbels, p. 69
- 11.9—Provisions for walls, p. 69
- 11.10—Transfer of moments to columns, p. 70
- 11.11—Provisions for slabs and footings, p. 70
- References, Chapter 11, p. 71

CHAPTER 12—DEVELOPMENT AND SPLICES OF REINFORCEMENT, p. 72

- 12.1—Development of reinforcement—General, p. 72
- 12.2—Development of deformed bars and deformed wire in tension, p. 72
- 12.3—Development of deformed bars and deformed wire in compression, p. 72
- 12.4—Development of bundled bars, p. 72
- 12.5—Development of standard hooks in tension, p. 72
- 12.6—Development of headed and mechanically anchored deformed bars in tension, p. 73
- 12.7—Development of welded deformed wire reinforcement in tension, p. 73
- 12.8—Development of welded plain wire reinforcement in tension, p. 73
- 12.9—Development of prestressing strand, p. 73
- 12.10—Development of flexural reinforcement—General, p. 73
- 12.11—Development of positive moment reinforcement, p. 73
- 12.12—Development of negative moment reinforcement, p. 73
- 12.13—Development of web reinforcement, p. 73

- 12.14—Splices of reinforcement—General, p. 73
- 12.15—Splices of deformed bars and deformed wire in tension, p. 74
- 12.16—Splices of deformed bars in compression, p. 75
- 12.17—Special splice requirements for columns, p. 75
- 12.18—Splices of welded deformed wire reinforcement in tension, p. 75
- 12.19—Splices of welded plain wire reinforcement in tension, p. 75

CHAPTER 13—TWO-WAY SLAB SYSTEMS, p. 76

- 13.1—Scope, p. 76
- 13.2—General, p. 76
- 13.3—Slab reinforcement, p. 76
- 13.4—Openings in slab systems, p. 76
- 13.5—Design procedures, p. 76
- 13.6—Direct design method, p. 76
- 13.7—Equivalent frame method, p. 76

CHAPTER 14—WALLS, p. 77

- 14.1—Scope, p. 77
- 14.2—General, p. 77
- 14.3—Minimum reinforcement, p. 77
- 14.4—Walls designed as compression members, p. 77
- 14.5—Empirical design method, p. 77
- 14.6—Nonbearing walls, p. 78
- 14.7—Walls as grade beams, p. 78
- 14.8—Alternative design of slender walls, p. 78

CHAPTER 15—FOOTINGS, p. 79

- 15.1—Scope, p. 79
- 15.2—Loads and reactions, p. 79
- 15.3—Footings supporting circular or regular polygon-shaped columns or pedestals, p. 79
- 15.4—Moment in footings, p. 79
- 15.5—Shear in footings, p. 79
- 15.6—Development of reinforcement in footings, p. 79
- 15.7—Minimum footing depth, p. 79
- 15.8—Transfer of force at base of column, wall, or reinforced pedestal, p. 79
- 15.9—Sloped or stepped footings, p. 79
- 15.10—Combined footings and mats, p. 79

CHAPTER 16—PRECAST CONCRETE, p. 80

- 16.1—Scope, p. 80
- 16.2—General, p. 80
- 16.3—Distribution of forces among members, p. 80
- 16.4—Member design, p. 80
- 16.5—Structural integrity, p. 80
- 16.6—Connection and bearing design, p. 80
- 16.7—Items embedded after concrete placement, p. 80
- 16.8—Marking and identification, p. 80
- 16.9—Handling, p. 80
- 16.10—Strength evaluation of precast construction, p. 80

CHAPTER 17—COMPOSITE CONCRETE FLEXURAL MEMBERS, p. 81

- 17.1—Scope, p. 81

- 17.2—General, p. 81
- 17.3—Shoring, p. 81
- 17.4—Vertical shear strength, p. 81
- 17.5—Horizontal shear strength, p. 81
- 17.6—Ties for horizontal shear, p. 81

CHAPTER 18—PRESTRESSED CONCRETE, p. 82

- 18.1—Scope, p. 82
- 18.2—General, p. 82
- 18.3—Design assumptions, p. 82
- 18.4—Serviceability requirements—Flexural members, p. 82
- 18.5—Permissible stresses in prestressing steel, p. 82
- 18.6—Loss of prestress, p. 82
- 18.7—Flexural strength, p. 82
- 18.8—Limits for reinforcement of flexural members, p. 82
- 18.9—Minimum bonded reinforcement, p. 82
- 18.10—Statically indeterminate structures, p. 82
- 18.11—Compression members—Combined flexure and axial loads, p. 82
- 18.12—Slab systems, p. 83
- 18.13—Post-tensioned tendon anchorage zones, p. 83
- 18.14—Intentionally left blank, p. 83
- 18.15—Intentionally left blank, p. 83
- 18.16—Corrosion protection for unbonded tendons, p. 83
- 18.17—Post-tensioning ducts, p. 83
- 18.18—Grout for bonded tendons, p. 83
- 18.19—Protection for prestressing steel, p. 83
- 18.20—Application and measurement of prestressing force, p. 83
- 18.21—Post-tensioning anchorages and couplers, p. 84
- 18.22—External post-tensioning, p. 84

CHAPTER 19—SHELLS, p. 85

- 19.1—Scope and definitions, p. 85
- 19.2—General, p. 85
- 19.3—Design strength of materials, p. 86
- 19.4—Section design and reinforcement requirements, p. 87
- 19.5—Construction, p. 87

CHAPTER 20—STRENGTH EVALUATION OF EXISTING STRUCTURES, p. 88

- 20.1—Strength evaluation—General, p. 88
- 20.2—Determination of required dimensions and material properties, p. 88
- 20.3—Load test procedure, p. 90
- 20.4—Loading criteria, p. 90
- 20.5—Acceptance criteria, p. 90
- 20.6—Provision for lower load rating, p. 91
- 20.7—Safety, p. 91
- References, Chapter 20, p. 92

CHAPTER 21—PROVISIONS FOR EARTHQUAKE-RESISTANT DESIGN, p. 93

- 21.1—General requirements, p. 93
- 21.2—Intentionally left blank, p. 96
- 21.3—Intentionally left blank, p. 96

- 21.4—Intentionally left blank, p. 96
- 21.5—Flexural members of moment frames, p. 96
- 21.6—Moment frame members subjected to bending and axial load, p. 102
- 21.7—Joints of moment frames, p. 106
- 21.8—Special moment frames constructed using precast concrete, p. 109
- 21.9—Special structural walls and coupling beams, p. 109
- 21.10—Special structural walls constructed using precast concrete, p. 117
- 21.11—Structural diaphragms, p. 118
- 21.12—Foundations, p. 122
- References, Chapter 21, p. 124

CHAPTER 22—STRUCTURAL PLAIN CONCRETE, p. 128

APPENDIX A—STRUT-AND-TIE MODELS, p. 129

- A.1—Definitions, p. 129
- A.2—Strut-and-tie model design procedure, p. 129
- A.3—Strength of struts, p. 129
- A.4—Strength of ties, p. 129
- A.5—Strength of nodal zones, p. 129

APPENDIX B—ALTERNATIVE PROVISIONS FOR REINFORCED AND PRESTRESSED CONCRETE FLEXURAL AND COMPRESSION MEMBERS, p. 130

APPENDIX C—ALTERNATIVE LOAD AND STRENGTH-REDUCTION FACTORS, p. 131

- C.9.1—Scope, p. 131
- C.9.2—Required strength, p. 131
- C.9.3—Design strength, p. 133

APPENDIX D—ANCHORING TO CONCRETE, p. 134

- D.1—Definitions, p. 134
- D.2—Scope, p. 136
- D.3—General requirements, p. 138
- D.4—General requirements for strength of anchors, p. 141
- D.5—Design requirements for tensile loading, p. 146
- D.6—Design requirements for shear loading, p. 155
- D.7—Interaction of tensile and shear forces, p. 164
- D.8—Required edge distances, spacings, and thicknesses to preclude splitting failure, p. 164
- D.9—Installation of anchors, p. 165
- D.10—Structural plates, shapes, and specialty inserts, p. 166
- D.11—Shear strength of embedded plates and shear lugs, p. 166
- D.12—Grouted embedments, p. 168
- References, Appendix D, p. 169

APPENDIX E—THERMAL CONSIDERATION, p. 171

- E.1—Scope, p. 171
- E.2—Definitions (moved to Chapter 2), p. 173
- E.3—General design requirements, p. 173
- E.4—Concrete temperatures, p. 175
- References, Appendix E, p. 176

**APPENDIX F—SPECIAL PROVISIONS FOR
IMPULSIVE AND IMPACTIVE EFFECTS, p. 177**

F.1—Scope, p. 177

F.2—Dynamic strength increase, p. 177

F.3—Deformation, p. 178

F.4—Requirements to assure ductility, p. 183

F.5—Shear strength, p. 184

F.6—Impulsive effects, p. 185

F.7—Impactive effects, p. 187

F.8—Impactive and impulsive loads, p. 188

References, Appendix F, p. 190

**SUMMARY OF CHANGES FOR ACI 349-06 CODE,
p. 192**

Page left intentionally blank.

CODE

INTRODUCTION

This Code covers the design and construction of concrete structures that form part of a nuclear facility and that have nuclear safety-related functions, but does not cover: i) Concrete reactor vessels and concrete containment structures, as defined by Joint ACI-ASME Committee 359; or ii) Steel-plate composite walls and steel-plate composite slabs, as defined by AISC-N690 Technical Committee 12.

The structures covered by this Code include concrete structures inside and outside the containment system.

This Code may be referenced and applied subject to agreement between the owner and the Regulatory Authority.

All notation sections have been removed from the beginning of each chapter and consolidated into one list in Chapter 2.

The format of this Code is such that it depends on the “Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary” and any applicable errata issued up to September 2011, and should be used in conjunction with that Code and applicable issued errata.

The Commentary, which is presented after the Code, discusses considerations of ACI Committee 349 in developing, “Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-13).” This information is provided in the Commentary because this Code is written as a legal document and, therefore, cannot present background details or suggestions for carrying out its requirements. For design of nuclear structures, in cases of conflict between this Code with other documents, except wherever this Code is in conflict with the specific requirements of the authority having jurisdiction (AHJ), ACI 349 shall govern.

The materials, processes, quality control measures, and inspections described in this Code should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certifications or equivalent.

COMMENTARY

INTRODUCTION

This Commentary discusses some of the considerations of Committee 349 in developing the provisions contained in “Code Requirements for Nuclear Safety-Related Concrete Structures (ACI 349-13)” hereinafter called the Code. The Code is based on “Building Code Requirements for Structural Concrete (ACI 318-08),” which is hereinafter called the Building Code. In preparing ACI 349-13, the committee has followed the text of the Building Code wherever appropriate.

Structural plain concrete, as described in Chapter 22 of ACI 318-08, is not endorsed for use in nuclear safety-related structures.

In the following commentary, all references to the Building Code and its commentary are to the 2008 revision unless specifically noted otherwise. Provisions of the commentary of ACI 318-08 apply except:

- The term “building official” is replaced with the term “licensed design professional”;
- λ , the modification factor for lightweight concrete, is not applicable for ACI 349-13 structures. The value of λ for ACI 349-13 structures is 1.0.

Page left intentionally blank.