

An ACI Standard
An ANSI Standard

Building Code Requirements
for Structural Concrete
Reinforced with Glass Fiber-
Reinforced Polymer (GFRP)
Bars—Code and Commentary

Reported by ACI Committee 440

ACI CODE-440.11-22



American Concrete Institute
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Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

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Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary

An ACI Standard

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This Code was developed via an ANSI-approved consensus process and addresses structural systems, members, and connections, including cast-in-place, precast, nonprestressed, and composite construction. The “Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars” (Code) provides minimum requirements for the materials, design, and detailing of structural concrete buildings and other applicable, nonbuilding structures reinforced with GFRP bars that conform to the requirements of ASTM D7957-22. Among the subjects covered are: design and construction for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; structural analysis methods; deflection limits; development and splicing of reinforcement; construction document information; field inspection and testing; and methods to evaluate the strength of existing structures.

Keywords: admixtures; aggregates; beam-column frame; beams (supports); cements; columns (supports); combined stress; composite construction (concrete to concrete); compressive strength; concrete; construction documents; continuity (structural); cover; curing; deflections; durability; flexural strength; floors; footings; formwork (construction); GFRP reinforcement; inspection; joints (junctions); joists; load tests (structural); loads (forces); mixture proportioning; modulus of elasticity; moments; piles; placing; precast concrete; quality control; reinforced concrete; roofs; serviceability; shear strength; spans; splicing; strength analysis; stresses; structural analysis; structural design; structural integrity; structural walls; T-beams; torsion; walls; water.

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CONTENTS

PREFACE, p. 5**CHAPTER 1—GENERAL, p. 7**

1.1—Scope of ACI CODE-440.11-22.....	7
1.2—General	7
1.3—Purpose	8
1.4—Applicability.....	8
1.5—Interpretation	9
1.6—Building official.....	10
1.7—Licensed design professional.....	10
1.8—Construction documents and design records.....	11
1.9—Testing and inspection	11
1.10—Approval of special systems of design, construction, or alternative construction materials.....	11

CHAPTER 2—NOTATION AND TERMINOLOGY, p. 13

2.1—Scope	13
2.2—Notation.....	13
2.3—Terminology	20

CHAPTER 3—REFERENCED STANDARDS, p. 30

3.1—Referenced standards.....	30
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CHAPTER 4—STRUCTURAL SYSTEM REQUIREMENTS, p. 32

4.1—Scope	32
4.2—Materials.....	32
4.3—Design loads	32
4.4—Structural system and load paths.....	32
4.5—Structural analysis	34
4.6—Strength	34
4.7—Serviceability.....	35
4.8—Durability	35
4.9—Sustainability.....	36
4.10—Structural integrity.....	36
4.11—Fire resistance and elevated service temperature.....	36
4.12—Requirements for specific types of construction.....	40
4.13—Construction and inspection.....	41
4.14—Strength evaluation of existing structures.....	41

CHAPTER 5—LOADS, p. 42

5.1—Scope	42
5.2—General	42
5.3—Load factors and combinations.....	42

CHAPTER 6—STRUCTURAL ANALYSIS, p. 47

6.1—Scope	47
6.2—General	47
6.3—Modeling assumptions.....	50
6.4—Arrangement of live load.....	52
6.5—Simplified method of analysis for continuous beams and one-way slabs	53
6.6—First-order analysis.....	54
6.7—Linear elastic second-order analysis.....	60
6.8—Inelastic analysis—Out of scope.....	61

6.9—Acceptability of finite element analysis	61
6.8—Inelastic analysis.....	61

CHAPTER 7—ONE-WAY SLABS, p. 63

7.1—Scope	63
7.2—General	63
7.3—Design limits	63
7.4—Required strength	64
7.5—Design strength.....	64
7.6—GFRP reinforcement limits.....	65
7.7—GFRP reinforcement detailing.....	66

CHAPTER 8—TWO-WAY SLABS, p. 69

8.1—Scope	69
8.2—General	69
8.3—Design limits	71
8.4—Required strength	72
8.5—Design strength.....	76
8.6—GFRP reinforcement limits.....	77
8.7—GFRP reinforcement detailing.....	78
8.8—Nonprestressed two-way joist systems—Out of scope.....	82
8.9—Lift-slab construction—Out of scope.....	82

CHAPTER 9—BEAMS, p. 83

9.1—Scope	83
9.2—General	83
9.3—Design limits	84
9.4—Required strength	85
9.5—Design strength.....	87
9.6—GFRP reinforcement limits.....	88
9.7—GFRP reinforcement detailing.....	91
9.8—One-way joist systems.....	100
9.9—Deep beams—Out of scope.....	101

CHAPTER 10—COLUMNS, p. 102

10.1—Scope	102
10.2—General	102
10.3—Design limits	102
10.4—Required strength	103
10.5—Design strength.....	104
10.6—GFRP reinforcement limits.....	105
10.7—GFRP reinforcement detailing.....	105

CHAPTER 11—WALLS, p. 110

11.1—Scope	110
11.2—General	110
11.3—Design limits.....	111
11.4—Required strength.....	111
11.5—Design strength.....	112
11.6—GFRP reinforcement limits.....	114
11.7—GFRP reinforcement detailing.....	115
11.8—Alternative method for out-of-plane slender wall analysis—Out of scope.....	116

CHAPTER 12—DIAPHRAGMS—NOT ADDRESSED, p. 117

CHAPTER 13—FOUNDATIONS, p. 118

13.1—Scope118
 13.2—General120
 13.3—Shallow foundations123
 13.4—Deep foundations125

CHAPTER 14—PLAIN CONCRETE—NOT APPLICABLE, p. 127

CHAPTER 15—BEAM-COLUMN AND SLAB-COLUMN JOINTS, p. 128

15.1—Scope128
 15.2—General128
 15.3—Transfer of column axial force through the floor system128
 15.4—Detailing of joints129

CHAPTER 16—CONNECTIONS BETWEEN MEMBERS, p. 131

16.1—Scope131
 16.2—Connections of precast members—Out of scope131
 16.3—Connections to foundations131
 16.4—Horizontal shear transfer in composite concrete flexural members133
 16.5—Brackets and corbels—Out of scope134

CHAPTER 17—ANCHORING TO CONCRETE—NOT ADDRESSED, p. 135

CHAPTER 18—EARTHQUAKE-RESISTANT STRUCTURES—NOT ADDRESSED, p. 135

CHAPTER 19—CONCRETE: DESIGN AND DURABILITY REQUIREMENTS, p. 137

19.1—Scope137
 19.2—Concrete design properties137
 19.3—Concrete durability requirements138
 19.4—Grout durability requirements—Out of scope...146

CHAPTER 20—GFRP REINFORCEMENT PROPERTIES, DURABILITY, AND EMBEDMENTS, p. 147

20.1—Scope147
 20.2—GFRP bars147
 20.3—Prestressing strands, wires, and bars—Out of scope149
 20.4—Headed shear stud reinforcement—Out of scope...149
 20.5—Provisions for durability of GFRP reinforcement ...149
 20.6—Embedments151

CHAPTER 21—STRENGTH REDUCTION FACTORS, p. 153

21.1—Scope153
 21.2—Strength reduction factors for structural concrete members and connections153

CHAPTER 22—SECTIONAL STRENGTH, p. 155

22.1—Scope155
 22.2—Design assumptions for moment and axial strength155
 22.3—Flexural strength157
 22.4—Axial strength or combined flexural and axial strength160
 22.5—One-way shear strength161
 22.6—Two-way shear strength168
 22.7—Torsional strength171
 22.8—Bearing178
 22.9—Shear friction—Out of scope180

CHAPTER 23—STRUCTURAL DESIGN METHOD—NOT ADDRESSED, p. 181

CHAPTER 24—SERVICEABILITY REQUIREMENTS, p. 182

24.1—Scope182
 24.2—Deflections due to service-level gravity loads...182
 24.3—Distribution of GFRP flexural reinforcement in one-way slabs and beams187
 24.4—GFRP shrinkage and temperature reinforcement ...189
 24.5—Permissible stresses in prestressed concrete flexural members—Out of scope190
 24.6—Permissible tensile stresses in GFRP reinforcement190

CHAPTER 25—GFRP REINFORCEMENT DETAILS, p. 192

25.1—Scope192
 25.2—Minimum spacing of GFRP reinforcement192
 25.3—Standard hooks, crossties, and minimum inside bend diameters192
 25.4—Development of GFRP reinforcement193
 25.5—Splices196
 25.6—Bundled reinforcement—Out of scope198
 25.7—GFRP transverse reinforcement198
 25.8—Post-tensioning anchorages and couplers—Out of scope205
 25.9—Anchorage zones for post-tensioned tendons—Out of scope205

CHAPTER 26—CONSTRUCTION DOCUMENTS AND INSPECTION, p. 206

26.1—Scope206
 26.2—Design criteria207
 26.3—Member information208
 26.4—Concrete materials and mixture requirements...208
 26.5—Concrete production and construction216

4 CODE REQUIREMENTS FOR STRUCTURAL CONCRETE REINFORCED W/ GFRP BARS (ACI CODE-440.11-22)

26.6—GFRP reinforcement materials and construction requirements221
26.7—Anchoring to concrete—Out of scope.....223
26.8—Embedments223
26.9—Additional requirements for precast concrete ...224
26.10—Additional requirements for prestressed concrete—Out of scope225
26.11—Formwork225
26.12—Evaluation and acceptance of hardened concrete 227
26.13—Inspection232

CHAPTER 27—STRENGTH EVALUATION OF EXISTING CONCRETE STRUCTURES, p. 235

27.1—Scope235

27.2—General235
27.3—Analytical strength evaluation.....236
27.4—Strength evaluation by load test237
27.5—Monotonic load test procedure238

APPENDIX—EQUIVALENCE BETWEEN SI-METRIC, MSK-METRIC, AND U.S. CUSTOMARY UNITS OF NONHOMOGENOUS EQUATIONS IN THE CODE, p. 241

COMMENTARY REFERENCES, p. 244

Authored documents.....245

PREFACE

This Code was developed by an ANSI-approved consensus process and addresses structural systems, members, and connections, including cast-in-place, precast, nonprestressed, and composite construction. The “Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars” (“Code”) provides minimum requirements for the materials, design, and detailing of structural concrete buildings and, where applicable, nonbuilding structures reinforced with GFRP bars that conform to the requirements of ASTM D7957-22, “Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement.” Among the subjects covered are: design and construction for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; structural analysis methods; deflection limits; development and splicing of reinforcement; construction document information; field inspection and testing; and methods to evaluate the strength of existing structures.

This Code covers the design of reinforced concrete members that are reinforced entirely with GFRP; the design of “hybrid” members with mixed types of reinforcement is outside the scope of this Code. However, this Code can be used for the design of GFRP-reinforced concrete members that are part of a structure that also includes members that are not reinforced with GFRP. In such a situation, this Code would cover the design of the GFRP-reinforced concrete members, and other applicable standards (such as ACI 318) would cover the design of other types of members in the structure. This Code covers the design of GFRP-reinforced concrete members in a structure assigned to Seismic Design Category (SDC) A. This Code also covers the design of GFRP-reinforced concrete members not designated as part of the seismic-force-resisting system in Seismic Design Categories B and C. This initial version of the Code, which has been developed from the body of GFRP-reinforced concrete research that has been published over the past 30 years, does not cover GFRP-reinforced concrete members in any structure assigned to Seismic Design Categories D, E, and F although subsequent editions of this Code are expected to incorporate additional SDCs as further research becomes available. Other topics that are not addressed in this version of the Code but are expected to be covered in subsequent editions include prestressed construction, lightweight concrete, shear connections of precast members, diaphragms, deep beams, drilled piers and caissons, brackets and corbels, methods for designing discontinuity regions using strut-and-tie theory where section-based methods do not apply, shear friction, and anchoring to concrete.

This Code is dependent on ACI 318-19 and adheres to the chapter and section numbering of ACI 318-19, with the exception of Chapter 15 in which language and numbering is dependent on ACI 318-14. This Code does not include several chapters that are addressed in ACI 318-19, specifically Chapter 12: Diaphragms, Chapter 17: Anchoring to Concrete, Chapter 18: Earthquake-Resistant Structures, and Chapter 23: Strut-and-Tie Method. These chapters have been identified as “Not Addressed” in this version of the Code, but are expected to be included in future versions of this Code as additional research becomes available. This Code also does not include Chapter 14: Plain Concrete from ACI 318-19 which has been identified as “Not Applicable” because it is not related to design with GFRP reinforcement and is not expected to be included in future versions of this Code, as ACI 318 is the applicable standard. Within chapters, the terms “out of scope” and “not applicable” are used for numbered section headings from ACI 318-19 that are not covered by this Code, while the term “intentionally left blank” is used as a place holder to maintain consistency with section numbering in situations where ACI 318-19 includes a numbered provision that is not also in this Code.

For ease of use, language in common with ACI 318 has been reproduced in this document. Provisions that are identical to ACI 318-19 are denoted with an equals sign (“=”). Accordingly, this Code follows the organizational philosophy of ACI 318, which is to present all design and detailing requirements for structural systems or for individual members in chapters devoted to those individual subjects, and to arrange the chapters in a manner that generally follows the process and chronology of design and construction. Information and procedures that are common to the design of multiple members are located in utility chapters.

Uses of the Code include adoption by reference in a general building code. The Code is written in a format that allows such reference without change to language. Therefore, background details or suggestions for carrying out the requirements or intent of the Code provisions cannot be included within the Code itself. The Commentary is provided for this purpose. This Code can supplement a current International Code Council (ICC) building code, supplement the codes governing new and existing structures of a local jurisdiction authority, or act as a stand-alone code in a locality that has not adopted an existing building code.

Some considerations of the committee in developing the Code are discussed in the Commentary, with emphasis given to the explanation of differences in design between GFRP-reinforced concrete and steel-reinforced concrete. For example, GFRP bars do not yield; rather, they are linear elastic until failure. Design procedures in this Code account for this difference from the traditional steel-reinforced concrete design procedures adopted in ACI 318, and approach design from the perspective of deformability (the ability of a member to undergo large displacements prior to failure) rather than from the steel-reinforced concrete design focus on ductility. Consequently, this Code permits GFRP-reinforced concrete flexural members to have either tension-controlled or compression-controlled failure modes.

Furthermore, GFRP bars possess high tensile strength only in the direction of the reinforcing fibers, which affects shear strength, dowel action, and bond performance; thus, design equations for shear strength and development length are necessarily different from the equations used for steel reinforcement in ACI 318, although the design procedures themselves are similar. Other significant differences from ACI 318 occur in serviceability design for deflection and crack control, as the stiffness of GFRP reinforcement can be as small as one-fourth that of steel reinforcement. Because the mechanical and bond properties of

6 CODE REQUIREMENTS FOR STRUCTURAL CONCRETE REINFORCED W/ GFRP BARS (ACI CODE-440.11-22)

GFRP bars are more negatively impacted at elevated temperatures than are steel bars, and reports from ASTM E119 fire tests on GFRP-reinforced concrete members are not yet available, this Code is only applicable where fire-resistance ratings are not required or where approved by the building official under the alternative means and methods provisions of 1.10.1. Recommendations for increasing the fire resistance of GFRP-reinforced concrete members have been included in the Commentary. Much of the research data referenced in the Commentary is cited for the user desiring greater detail on this subject. Other documents that provide suggestions for carrying out the requirements of the Code are also cited in the Commentary.

CODE

COMMENTARY

CHAPTER 1—GENERAL

CHAPTER R1—GENERAL

1.1—Scope of ACI CODE-440.11-22

- 1.1.1 This chapter addresses (a) through (h):
- (a) General requirements of this Code
 - (b) Purpose of this Code
 - (c) Applicability of this Code
 - (d) Interpretation of this Code
 - (e) Definition and role of the building official and the licensed design professional
 - (f) Construction documents
 - (g) Testing and inspection
 - (h) Approval of special systems of design, construction, or alternative construction materials

1.2—General

1.2.1 ACI CODE-440.11, “Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars,” is hereafter referred to as “this Code.”

1.2.2 In this Code, the general building code refers to the building code adopted in a jurisdiction. When adopted, this Code forms part of the general building code.

1.2.3 The official version of this Code is the English language version, using inch-pound units, published by the American Concrete Institute.

1.2.4 In case of conflict between the official version of this Code and other versions of this Code, the official version governs.

1.2.5 This Code provides minimum requirements for the materials, design, construction, and strength evaluation of GFRP-reinforced concrete members and systems in any structure designed and constructed under the requirements of the general building code.

1.2.6 Modifications to this Code that are adopted by a particular jurisdiction are part of the laws of that jurisdiction, but are not a part of this Code.

1.2.7 If no general building code is adopted, this Code provides minimum requirements for the materials, design,

R1.1—Scope of ACI CODE-440.11-22

R1.1.1 This Code includes provisions for the design of nonprestressed glass fiber-reinforced polymer (GFRP)-reinforced concrete used for structural purposes. This Code does not address concrete prestressed with GFRP. This Code does not cover any applications of steel reinforcement of concrete. The design of structural concrete reinforced with steel is governed by ACI 318. This Code covers the design of reinforced concrete members that are reinforced entirely with GFRP; the design of “hybrid” members with mixed types of reinforcement is outside the scope of this Code. However, this Code can be used for the design of GFRP-reinforced concrete members that are part of a structure that also includes members that are not reinforced with GFRP. Steel reinforcement may be present in GFRP-reinforced concrete members designed using this Code, but the steel reinforcement should not be considered as part of the reinforcement for that member for the purposes of strength or serviceability calculations.

This Code is a dependent code on ACI 318-19. This chapter includes a number of provisions that explain where this Code applies and how it is to be interpreted.

R1.2—General

R1.2.2 The American Concrete Institute recommends that this Code be adopted in its entirety.

R1.2.3 Committee 440 develops the Code in English, using inch-pound units. Based on that version, Committee 440 approved a version in English using SI units.

R1.2.5 This Code provides minimum requirements and exceeding these minimum requirements is not a violation of the Code.

The licensed design professional may specify project requirements that exceed the minimum requirements of this Code.