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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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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

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Lijuan Cheng	Kent A. Harries	Hayder A. Rasheed	

*Chair of Subcommittee responsible for developing this Code.
†Vice Chair of Subcommittee responsible for developing this Code.

Consulting Members

P. N. Balaguru	Koichi Kobayashi	Hajime Okamura	Luc R. Taerwe
Lawrence C. Bank	Howard S. Kliger	Mark A. Postma	Houssam A. Toutanji
C. J. Burgoyne	Ibrahim M. Mahfouz	Surendra P. Shah	Taketo Uomoto
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David M. Gale	Amir Mirmiran	Yasuhisa Sonobe	
Srinivasa L. Iyer	Antoine E. Naaman	Minoru Sugita	

The contributions of Peter H. Bischoff and Douglas G. Tomlinson to the development of this Code are acknowledged.

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. 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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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 suitable 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-friction 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 318M-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 equal 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 its 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

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

CHAPTER 1—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,

COMMENTARY

CHAPTER R1—GENERAL

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.