

Strengthening Structural Concrete with Fiber- Reinforced Polymer (FRP) Systems—Code Requirements and Commentary

Reported by ACI Committee 440S



American Concrete Institute
Always advancing



Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems— Code Requirements 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. Despite 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 <http://concrete.org/Publications/DocumentErrata.aspx>. 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 regarding 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.

ACI documents are written via a consensus-based process. The characteristics of ACI technical committee operations include:

- (a) Open committee membership
- (b) Balance/lack of dominance
- (c) Coordination and harmonization of information
- (d) Transparency of committee activities to public
- (e) Consideration of views and objections
- (f) Resolution through consensus process

The technical committee documents of the American Concrete Institute represent the consensus of the committee and ACI. Technical committee members are individuals who volunteer their services to ACI and specific technical committees.

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

Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems— Code Requirements and Commentary

An ACI Standard

Reported by ACI Committee 440S

Kent A. Harries, Chair

Maria Lopez de Murphy, Vice Chair

William J. Gold, Secretary

Tarek Alkhrdaji
Scott Arnold
Aniket Borwankar

Mahmut Ekenel
Ravi Kaniitkar
Michael W. Lee

Abheetha Peiris
J. Gustavo Tumialan
Erblina Vokshi

Consulting Member
Carl J. Larosche

ACI CODE-440.13 was developed to provide design professionals a code for the design of strengthening strategies for concrete structures using fiber-reinforced polymer (FRP) systems.

Keywords: buildings; carbon fiber; fiber-reinforced polymer; glass fiber; rehabilitation; repair; strengthening; structural design.

ACI CODE-440.13-24 was approved by the ACI Standards Board for publication June 5, 2024, and published September 2024.

Copyright © 2024, 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 obtained from the copyright proprietors.

CONTENTS

PREFACE, p. 4**CHAPTER 1—GENERAL, p. 5**

1.1—Scope	5
1.2—General	5
1.3—Purpose	5
1.4—Interpretation	6
1.5—Authority having jurisdiction	7
1.6—Licensed design professional.....	7
1.7—Inspector	7
1.8—Design and construction documents.....	7
1.9—Testing and inspection	8
1.10—Approval of special systems of design, construction, or alternative construction materials	8

CHAPTER 2—NOTATION AND DEFINITIONS, p. 9

2.1—Code notation	9
2.2—Definitions	12

CHAPTER 3—REFERENCED STANDARDS, p. 15

3.1—American Concrete Institute.....	15
3.2—American Society of Civil Engineers	15
3.3—ASTM International	15
3.4—Underwriters Laboratories.....	16

CHAPTER 4—FRP SYSTEM REQUIREMENTS, p. 17

4.1—General	17
4.2—Wet layup FRP systems	17
4.3—Precured carbon FRP systems	17
4.4—FRP near-surface-mounted bars	18

CHAPTER 5—CONCRETE SUBSTRATE REQUIREMENTS, p. 20

5.1—General	20
5.2—Bond critical externally bonded FRP systems.....	20
5.3—Contact critical externally bonded FRP systems	21
5.4—NSM FRP systems.....	21

CHAPTER 6—GENERAL DESIGN REQUIREMENTS, p. 22

6.1—General	22
6.2—Basis of design	22
6.3—Load factors and combinations.....	22
6.4—Design material properties.....	23
6.5—Maximum sustained loads	23
6.6—Maximum service temperature	24
6.7—Durability requirements.....	24

CHAPTER 7—DESIGN AND DETAILING FOR FLEXURAL STRENGTHENING, p. 25

7.1—General	25
7.2—Design strength.....	25
7.3—Design requirements.....	26
7.4—Nominal flexural strength.....	28
7.5—Moment redistribution for continuous reinforced concrete beams	31
7.6—Anchorage and development of externally bonded FRP.....	31
7.7—Development of near-surface-mounted FRP flexural strengthening	33

CHAPTER 8—DESIGN AND DETAILING FOR SHEAR STRENGTHENING, p. 35

8.1—General	35
8.2—Sectional requirements	35
8.3—FRP System wrapping schemes.....	35
8.4—Design strength.....	36
8.5—Nominal shear strength.....	36
8.6—FRP Contribution to shear strength.....	36
8.7—Anchorage for U-wraps	38
8.8—Details for FRP shear strengthening.....	41

CHAPTER 9—DESIGN AND DETAILING FOR AXIAL FORCE AND COMBINED AXIAL FORCE AND MOMENT STRENGTHENING, p. 42

9.1—General	42
9.2—Axial compression	42
9.3—Combined axial compression and bending.....	46

CHAPTER 10—FIRE RESISTANCE, p. 48

10.1—General	48
10.2—Fire resistance of FRP-strengthened members....	48

CHAPTER 11—FIELD INSPECTION, TESTING, AND EVALUATION, p. 50

11.1—General	50
11.2—Field inspection	50
11.3—Material testing.....	51
11.4—Evaluation and acceptance criteria	52
11.5—Inspection of coatings.....	52

COMMENTARY REFERENCES, p. 53

Authored documents.....	54
-------------------------	----

APPENDIX A—ADDITIONAL LOAD COMBINATIONS FOR FRP STRENGTHENING, p. 56

A.1—Appendix notation	56
A.2—Scope	56
A.3—Additional load combinations for FRP strengthening.....	56

PREFACE

This Code provides minimum design requirements for strengthening of existing concrete structural systems and members using externally bonded and near-surface-mounted (NSM) fiber-reinforced polymer (FRP) systems. Among the subjects covered are design and detailing for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; FRP anchorage to concrete; development and splicing of FRP reinforcement; field inspection; and testing. This Code was developed by a consensus process. This Code is written for use by licensed design professionals and authorities having jurisdiction. This Code provides minimum requirements for materials, design and construction, and quality control and assurance requirements for FRP strengthening systems. This Code is written in a format that allows adoption by reference in a repair code or a general building code. Background details or suggestions for carrying out the requirements or intent of this Code provisions are in the Commentary.



PAGE LEFT INTENTIONALLY BLANK

CODE

CHAPTER 1—GENERAL

1.1—Scope

1.1.1 ACI CODE-440.13, “Code Requirements for Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems—Code and Commentary,” is hereafter referred to as “this Code.” is presented in a side-by-side column format. These are two separate but coordinated documents, with Code text placed in the left column and the corresponding Commentary text aligned in the right column. Commentary section numbers are preceded by an “R” to further distinguish them from Code section numbers. The two documents are bound together solely for the user’s convenience. Each document carries a separate enforceable and distinct copyright.

1.1.2 This Code shall apply to the strengthening of existing concrete structures using only those unidirectional externally bonded and near-surface-mounted (NSM) fiber-reinforced polymer (FRP) systems permitted in **Chapter 4**.

1.1.3 This Code provides minimum requirements for the materials, design, and construction of FRP strengthening systems for concrete structures consistent with the requirements of **ACI CODE-562**.

1.1.4 This Code shall not be applied to the strengthening of masonry structures.

1.1.5 This Code provides minimum requirements for the strength evaluation, testing, and inspection of FRP strengthening systems for concrete structures consistent with the requirements of ACI CODE-562.

1.2—General

1.2.1 The requirements of this Code use strength design provisions for demands and capacities.

1.2.2 FRP strengthening is permitted for the following:

- (a) All members in structures assigned to Seismic Design Category (SDC) A in accordance with **ASCE/SEI 7**
- (b) Structural members not designated as part of the seismic-force-resisting system in all SDCs.

1.3—Purpose

1.3.1 The purpose of this Code is to provide for public health and safety by establishing minimum requirements for

COMMENTARY

CHAPTER R1—GENERAL

R1.1—Scope

R1.1.2 Throughout this Code, the term “structure” means an existing building, nonbuilding structure, member, or system.

R1.1.3 This Code focuses on concrete buildings and nonbuilding structures. For buildings or structures similar to buildings, members that are addressed by this Code include concrete portions of composite members, and precast and prestressed concrete members.

The licensed design professional can perform assessment, design, and quality assurance activities that exceed the minimum requirements of this Code. Requirements beyond the minimum stated in this Code, such as those for long-term durability, redundancy, or integrity, can be considered by the licensed design professional.

R1.1.4 Guidance for strengthening of masonry structures is provided in **ACI PRC-440.7**.

R1.2—General

R1.2.2 Seismic strengthening of members of the seismic-force-resisting systems in structures assigned to SDC B through F is outside the scope of this Code. Other standards, such as **ACI CODE-369.1** and **ASCE/SEI 41**, address repair and strengthening of seismic-force-resisting systems. **ACI PRC-440.2** provides guidance for the use of FRP systems for strengthening seismic-force-resisting systems.

R1.3—Purpose